

**AN INTEGRATED STUDY OF THE  
ISIPINGO RIVER AND ESTUARY: WATER AND  
SEDIMENT QUALITY, ESTUARY-NEARSHORE  
MATERIAL FLUXES, ANTHROPOGENIC IMPACTS  
AND MANAGEMENT**

RENELLE KAREN PILLAY

March 2013

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ANTHROPOGENIC IMPACTS AND MANAGEMENT**

By

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## ABSTRACT

The Isipingo River and Estuary system located in the province of KwaZulu-Natal, although relatively small, has been subjected to the impacts of intense development within the catchment. The catchment is characterized by informal and formal dwellings and intensive industrial activities in the lower catchment and in close proximity to the estuary. Significant modifications to the hydrology of the system has occurred as a result of the diversion of the Umlazi River (which previously merged with the Isipingo River at the estuary mouth), canalization of the lower portion of the Isipingo River flowing through the Prospecton Industrial Area and the development of the Diversion Works system (to regulate flows to the lower Isipingo River), removal of riparian vegetation, encroachment onto the river and estuarine floodplain, and land reclamation through the infilling of wetlands all of which has culminated in a deterioration of the functionality and health of this system. The main aspects of this study focus on water and sediment quality, material flux between the estuary and the sea and the management of the system. The water quality variables covered as part of this dissertation include physical, chemical (nutrients and heavy metals) and microbiological (faecal coliforms) components. The water quality of the river and estuary presents a risk to human health and the concentrations of heavy metals generally exceeded the South African Water Quality Guidelines that prescribes target levels, implying potential negative impacts to aquatic health. The Isipingo system exhibited signs of eutrophication with phosphorus concentrations in excess of the target level to prevent eutrophication. Excessive water hyacinth growth was visible during most of the field surveys. A geochemical assessment of heavy metals in surface sediments of the river and estuary was also undertaken. The results indicate that although the presence of several metals were undetectable at certain river sites, the concentrations of those heavy metals present increased in a longitudinal direction from the river to the estuary. The contamination factor analysis for all metals indicated low contamination except for selenium. The riverine sites yielded moderate enrichment by some heavy metals in both seasons. The degree of contamination for each site with the exclusion of selenium was low. The inclusion of selenium in the assessment raises the estuary to a considerably contaminated status in the wet season. The analysis suggests that the enrichment of the system by selenium is due to an anthropogenic source. The Geo-accumulation Index places the sediment in an overall unpolluted category. The study conducted on the net exchange of heavy metals and nutrients between the Isipingo Estuary and the adjacent marine environment (i.e. Indian Ocean) demonstrates that significant quantities of the suite of heavy metal analysed are exported on an annual basis while copper, nickel and zinc are imported into the estuary. Significant quantities of ammonia and nitrates are exported annually from the Isipingo Estuary while a net annual import of

phosphorous is observed. The variation in the quantity and concentration of nutrients exported during the seasons may be attributed to anthropogenic source. The import of nutrients from marine sources can accumulate in the estuary and contribute to eutrophication of the Isipingo Estuary. This study also demonstrated that although the ebb flow has a much longer duration than the flood flow, the flood velocities observed were generally greater than the ebb velocities. The final part of this research identifies other environmental problems experienced in the Isipingo catchment. The following issues are identified as directly or indirectly contributing to stress and deterioration of the water quality of the Isipingo system: reduction in water quantity, poor water quality, moderate enriched sediment, loss of habitat integrity, species diversity and invasive alien vegetation and uncontrolled solid waste. A Water Quality Management Plan including management objectives, strategies and action plans to address the direct and indirect factors influencing the system are proposed. A water quality monitoring program is also proposed for the Isipingo River and Estuary. The adoption and execution of the water quality management plan and monitoring program will assist in the prevention of further degradation of the system and will be a stepping stone toward improvement.

## **PREFACE**

The experimental work described in this dissertation was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Durban, from February 2010 to October 2012, under the supervision of Dr. S. Pillay.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any tertiary institution. Where use has been made of the work of others it is duly acknowledged in the text.

## DECLARATION: PLAGARISM

I, Renelle Karen Pillay, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs of other information unless specifically acknowledged as being sourced from other persons.
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As the candidate's supervisor I have/have not approved this dissertation/thesis for submission.

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## LIST OF ABBREVIATIONS

CF	Contamination Factor
$C_d$	Contamination degree
CSIR	Council for Scientific and Industrial Research
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Diversion Works System
EF	Enrichment Factor
ICMF	Isipingo Catchment Management Forum
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
Igeo	Geo-accumulation Index
KZN	KwaZulu-Natal
PCS	Prospecton Canal System
PIA	Prospecton Industrial Area
SAWQG	South African Water Quality Guidelines
SSI	Stewart Scott International
TWQR	Target Water Quality Range
WQMP	Water Quality Management Plan

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# CHAPTER ONE

## INTRODUCTION AND REGIONAL SETTING

### 1.1 Introduction

The modern era has set in motion the ever increasing demand for countries to further advance the economy and to pursue avenues to enhance social lifestyle. Social, political and economic activities are therefore the drivers inducing environmental change. Furthermore, the exponential increase in global population and the rapid expansion of human activities has placed enormous strain on the environment and the earth's natural resources such as freshwater resources (Fuggle and Rabie, 1994; CSIR, 2010a).

Water is an indispensable natural resource that is fundamental to life, the environment, industrial growth, development, food production, hygiene and sanitation as well as power generation (DWA, 2010). Despite the internationally recognized value of water as a precious commodity (DEAT, 2005), it is a resource that still suffers from pollution and over-exploitation. Currently, there is an increase in the global water demand coupled with a persistent drive towards effective management of freshwater resources around the world (WSP *et al.*, 2012). Ecosystems that serve a dual purpose of being reliant on water as well as enhancing water provision, purification and adaptive capacity to climate change are under threat (WSP *et al.*, 2012). Climate change is a phenomenon that has raised alarm bells on both an international and local front and, it has been projected that climate change will result in a decrease in the availability of freshwater in many parts of the world, including southern Africa (IPCC, 2007).

South Africa is a semi-arid country that receives an average rainfall of approximately 450 mm per year (DWAF, 2004a). There is a pattern of uneven distribution of rainfall across the country, with the southern and eastern regions receiving considerably more rainfall than the northern and western parts of the country (DEAT, 2006). Concomitant to this, South Africa, also experiences intermittent periods of droughts and floods (DWAF, 2004b). The uneven and variable distribution of precipitation and water availability in South Africa has necessitated the development of several inter-basin transfers to water deficient parts of the country (DWAF, 2004b).

In addition to the supply of water, river systems provide many goods and services upon which society depends (DWA, 2010). These include maintaining the habitat and integrity of aquatic organisms, transportation of sediment, serving as recreational and eco-tourism areas as well as disposal sites for effluent and solid waste.

Natural factors such as geology, vegetation, hydrology and geomorphology within a catchment influence the water quality of river systems (Dallas and Day, 2004). On a global level, river systems have been manipulated by people to increase land availability and to further economic growth and development (King *et al.*, 2003). The construction of dams and other impoundment structures, canalization of rivers and the diversion of river courses from their natural channels have resulted in the alteration of the bed, banks and riparian vegetation of river systems as well as the impedance of the flow of water along these systems (DWA, 2000). Land use activities occurring within a catchment are also responsible for the progressive degradation of the health and functioning of riverine and estuarine environments (Davies and Day, 1998; DEAT, 2005). Rivers transport sediment, water and other land derived material in a longitudinal direction culminating in the transport of this material to estuaries (Rowntree, 2006). Estuaries in turn have a prominent role serving as a source or sink of material, and in regulating material flux between land sea (Crossland *et al.*, 2005).

Estuaries are regarded as highly productive, dynamic and complex ecosystems (Scharler and Baird, 2005) that provide a variety of goods and services such as the provision of a habitat and nursery for aquatic organisms and other wildlife, biogeochemical cycling, flood attenuation, water purification, shoreline stabilization and recreational use (Dent and Breen, 2001). In South Africa, estuaries are popular areas for coastal development which has resulted in these systems being more heavily utilized (van Niekerk, 2007). River and estuarine systems are being placed under extreme pressure resulting in a steady decline in ecosystem integrity and health (DEAT, 2005; van Niekerk, 2007).

It has been documented that there has been an acceleration in the natural progression of changes to South African riverine and estuarine geomorphology (Allanson, 2001), which has been attributed to a broad spectrum of anthropogenic activities and these changes create the need for holistic study of riverine system including the estuarine environment and the interactions occurring between estuaries and marine environments.

### 1.1.1 Contextualization of the problem and rationale for the study

Water is a strategic resource for global development. Increasing pressure placed on aquatic systems as a result of development has resulted in a decline in water availability, quality and the ecological functioning of fluvial systems (King *et al.*, 2003; CSIR, 2010a). This has resulted in an international shift towards river and estuary protection and rehabilitation (DWA, 2010).

It is vital that as a water scarce country, South Africa's water resources are protected from both a quality and quantity perspective (DWA, 2010). However, the country is also considered to be a developing country, where water is regarded as a commodity which shapes the South African economic and social climate. Hence the potential for degradation of aquatic systems is great. Evidence that South Africa is rapidly approaching a water crisis of significant magnitude is mounting (CSIR, 2010a). This crisis encompasses all aspects of water management in both the demand and supply (WSP *et al.*, 2012). Apart from this, there has been a steady decline in the water quality of both surface and groundwater resources (Ashton *et al.*, 2008) with some scientists stating that poor water quality poses a far greater risk to South Africa's long term supply of freshwater than climate change (de Villiers and de Wit, 2010).

River systems have the ability to self purify (DWA, 2000). However, increased pollution arising from the disposal of effluent and other wastes concomitant with diminished flow attributed to increases in water abstraction and higher evaporation rates has further reduced the natural assimilative capacity of water resources (CSIR, 2010a). Contaminants present in the water column may be adsorbed onto fine textured bottom sediment (Callow, 1994). Sediment therefore act as sinks and temporary reservoirs for a variety of environmental contaminants and can therefore exhibit higher concentrations of these contaminants than the overlying water body (Milenkovic *et al.*, 2005).

In KwaZulu-Natal, many river systems and estuaries suffer from poor water quality and reduced river flows as a consequence of rapid development in recent years (Brijlal, 2005; Govender, 2009; Philip, 2010; Sukdeo *et al.*, 2011 and others). Whilst more research attention is generally focused on large river systems, smaller systems that have experienced extensive development within their catchments have become seriously impacted. In KwaZulu-Natal such systems include, amongst others, the Palmiet (Naidoo, 2005), Mdloti (Govender, 2009), Mvoti (Sukdeo *et al.*, 2011) and the Isipingo system (focus of this study).

The Isipingo catchment is located approximately 20 kilometers south of the Durban Central Business District, although a relatively small catchment, has been subjected to intensive changes in land uses such as industrial (light and heavy) and urban development (formal and informal housing). As such, the catchment has experienced alterations in hydrology and development encroachment onto the river system's floodplain. These changes have impacted severely on the health status of this aquatic system.

There have been a number of previous studies conducted on the Isipingo fluvial system. However, these have been largely confined to the Isipingo Estuary and have focused predominantly on general water quality, effects of development on the health of the estuary as well as the rehabilitation of the estuary (Begg, 1978; Ward, 1980; Begg 1984, Ramm *et al.*, 1985; Ramm, 1987; Furness, 1988; Umgeni Water, 1989; Kalicharran, 1990; Anderson, 1992; Grobler, 1992; Harrison *et al.*, 2000; Forbes and Demetriades, 2008; Moodley, 2010; Fernandes, 2011; Fernandes and Pillay, 2012). These studies have been fragmented, focusing on one or two health aspects of the system. In addition, there has been limited attention given to the heavy metal characterization of the river and estuary water. Furthermore, there have been no documented studies on heavy metal accumulation in the river and estuarine sediment, despite intense industrialization in the catchment and only Fernandes (2011) and, Fernandes and Pillay (2012) focused on the net exchange of material (nitrates) between the estuary and the near shore environment. Also, the Internal Strategic Perspective document for the Mvoti to Mzimkhulu Water Management Area highlighted the concern of faecal pollution in the Isipingo River (DWAF, 2004b). Thus far, no previous study has assessed the latter for the Isipingo River.

Finally, with regard to the development of a rehabilitation and management plan for the Isipingo system, the proposal for rehabilitation of the estuary by Kalicharran (1990) represented the first concerted effort of its kind but was based on fragmented legislation and divided jurisdiction. Whilst the eThekweni Municipality has developed an Estuarine Management Plan as part of the requirements of the National Environmental Management: Integrated Coastal Management Act, 2008 (Act 24 of 2008), this plan is confined largely to the estuary and its boundary and does not formulate a strategy to regulate and manage impacts associated with the entire Isipingo Catchment. The start of the democratic era in 1994 brought to the forefront principles such as co-operative governance and new holistic and integrated legislation which can aid the development of an improved rehabilitation and management plan for the Isipingo Catchment.

This study therefore addresses the issues identified in the above paragraphs related to previous research by adopting a more holistic study of the anthropogenic impacts on the Isipingo system and presents a proposal for the rehabilitation and management plan for the Isipingo catchment which can further assist with achieving the objectives of the Estuarine Management Plan.

## **1.2 Aim and objectives**

### **1.2.1 Aim**

The aim of this study is to holistically evaluate the water and sediment quality along the Isipingo River and estuary, to quantify the net material exchange (heavy metals and nutrients) between the Isipingo estuarine and marine environments and, to develop a water quality management plan for the Isipingo River and estuary.

### **1.2.2 Objectives**

The objectives of the study are:

- To identify historic land use changes that have occurred in the Isipingo catchment, in particular the lower reaches of the Isipingo River and estuary and to document how these changes have affected the catchment from a water quantity and quality perspective;
- To quantify and assess the present day chemical and microbiological water quality at selected sites along the Isipingo River and estuary;
- To quantify and assess heavy metal concentrations in sediment at selected sites along the Isipingo River and Estuary;
- To determine the amount of materials (heavy metals and nutrients) that are imported or exported through tidal interchange between the estuarine and marine environments; and
- To prescribe mitigation measures and management interventions for the Isipingo catchment.



### **1.3 Structure of the Dissertation**

This study comprises of six chapters. Chapter one introduces the research topic and presents the regional setting. Chapter two comprises of the theoretical framework. Chapter three documents the materials and methods employed in data collection, preparation and analysis.

Due to the considerable amount of water quality parameters analysed and the amount of data generated, Chapter four presents the results and discussion under specific subheadings.

The penultimate chapter identifies and summarizes the pressures placed and the impacts on the Isipingo system and proposes management strategies for the Isipingo Catchment Water Quality Management Plan. Chapter six presents the conclusion of the study and proposed recommendations.

### **1.4 Regional setting**

#### **1.4.1 Introduction**

This section identifies and describes the area of study. It firstly provides a description of the study area in terms of its regional location and general regional and catchment characteristics. The information that follows thereafter geographically contextualizes the study area in terms of its physiographic characteristics including the catchment size, topography, geology, soils, climate and drainage.

#### **1.4.2 Regional physiographical description**

The study area is the Isipingo catchment which is located along the east coast of South Africa within the province of KwaZulu-Natal (KZN) (Figure 1.1). Whilst the focus of the study is centered on the lower reaches of the Isipingo River, extending from the estuary mouth to approximately 500 meters upstream of the Isipingo Wastewater Treatment Works (WWTWs), it does take into consideration the land use impacts of the entire catchment. This is due to the fact that the middle to upper reaches of the catchment is largely dominated by dense residential development (both formal and informal) and the effects of this land use on water quality are represented by samples obtained downstream of this land use area.

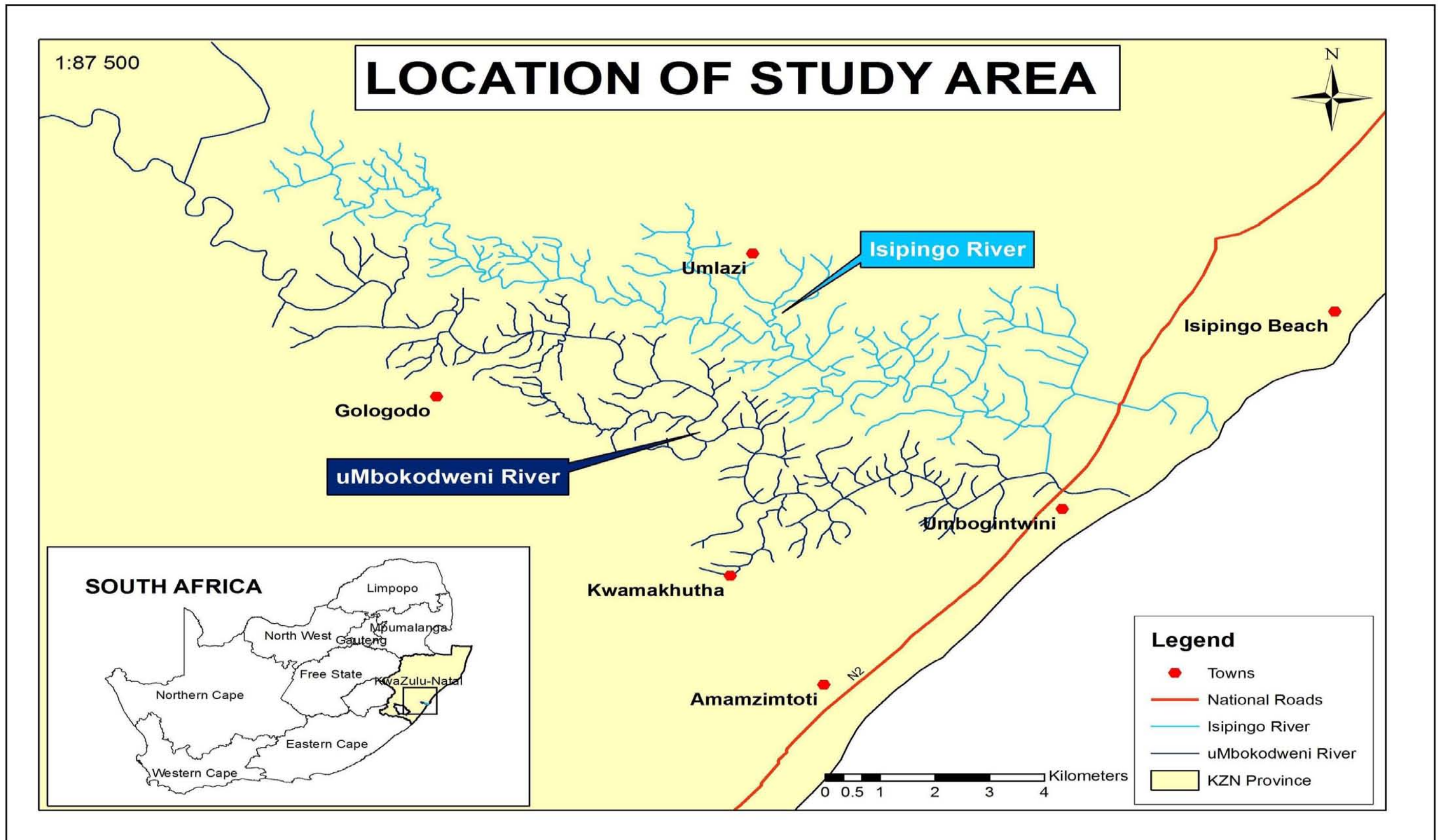


Figure 1.1: The Isipingo catchment. Inset: Location of study area in relation to the Province of KwaZulu-Natal and South Africa (after Pather, K., 2012)

#### **1.4.2.1 Topography of KwaZulu-Natal**

The general topography of KZN is characterized as an escarpment rising up to the Drakensberg Mountain range over a distance of approximately 250 km from the coastline as a consequence of post-Gondwana tectonism. The Drakensberg range has an approximate altitude of 3000 m and forms the natural western boundary of the province of KZN (Abed, 2009). Several events of erosion and upliftment succeeding the separation of Gondwana explain the landscape of KZN (Partridge and Maud, 1987). The upliftment on the eastern margin of Africa exceeded that of the western margin and, together with volcanic episodes gave rise to the Drakensberg Mountain Range (Partridge and Maud, 2000). The central region of the province comprises an undulating hilly plateau which rises towards the west (Cooper, 1993a). The KZN coastline is therefore characterised by a steep hinterland and small coastal plain (Cooper, 1993a) with the coastline being very narrow in the south but widening in the northern part of the province (DWAf, 2004b). The Drakensberg range forms the main watershed which gives rise to many fast flowing rivers which generate high sediment yields due to their high erosive potential (Cooper, 1993a). The sandy beaches located along the KZN coastline are sustained by the high fluvial sediment contribution (Cooper, 2001).

According to Pillay (1996), most of the rivers in KZN flow through incised valleys. There are 9 major perennial rivers, 10 secondary perennial rivers and 55 minor perennial rivers located in KZN which all drain to the Indian Ocean (Abed, 2009 as cited in Sukdeo, 2010), forming a number of estuaries and lagoons along the coast (Begg, 1978). Some rivers in the province are also seasonal (Cooper, 1993a). In South Africa, the total estuarine area is estimated at about 600km<sup>2</sup> (Turpie *et al.*, 2002) with a total of about 37 estuaries occupying an area of 400km<sup>2</sup> along the KZN coastline (Heydorn, 1985 as cited in Kalicharran, 1990).

#### **1.4.2.2 Hydrodynamics of KwaZulu-Natal coastline**

Tides along this coastline are semi-diurnal and the main wave approach is south-easterly which generates longshore drift currents responsible for northerly transport of sediments and material (Fernandes and Pillay, 2012). Nearshore cell circulation and morphodynamics can create a periodic reversal of longshore currents (Fernandes, 2011). The mean spring and mean neap tidal ranges are 2.72 m and 0.5 m respectively (Cooper, 1993a). The mean tidal range equates to approximately 2 m (Cooper, 2001). The warm Agulhas current, flows along the east coast of South Africa playing a vital role in water circulation along the KZN coast (Harrison, 2004). The average surface sea temperature off Durban generally exceeds 22°C

but drops as the Agulhas current flows offshore in a southward direction (Harrison, 2004). Variations in climate, topography and catchment geology give rise to a variety of estuarine types, but from a hydrodynamic perspective all estuaries in South Africa can be classified in one of two key categories, namely permanently open estuaries or temporarily open estuaries. (Whitfield and Bate, 2007).

#### **1.4.2.3 General climatology**

KwaZulu-Natal has a varied climate which is attributed to the complex topography (Abed, 2009). Generally, the coastal areas are warm and humid with the inland areas becoming progressively colder. The average annual rainfall within the province ranges between 900 mm and 1000 mm (Tyson and Preston-Whyte, 2000) with the coastal areas receiving an average annual rainfall exceeding 1000 mm (DWAF, 2004a). Additionally, approximately 80 % of the rainfall occurs in the summer months, between October and March, along with infrequent flood events (Cooper, 1993a). The winter months of June to August are generally the driest (Ward, 1980) therefore the fluvial flow and flushing capabilities are stronger in summer.

Cooper (1994) indicates that the occurrence of rainfall in the winter months is as a result of coastal lows and cold fronts experienced. Coastal lows create instability and are often associated with localized rainfall (Tyson and Preston-Whyte, 2000). Tyson and Preston-Whyte (2000) further elaborated that the formation of restricted offshore mountain-plain winds can give rise to rainfall peaks during the late evenings. Periodically intense rainfall events, associated with cut-off lows isolated usually over a few days, results in extensive flooding in the province (Cooper, 1993a). The September 1987 flood event was one of the biggest experienced in the province and arose from high intensity rainfall over a period of a few days (Cooper, 1994). This event had drastic effects on rivers in KZN (Sukdeo, 2010). Similar flood events have occurred in 2007 and 2008.

Wind patterns associated with coastal lows are cool onshore winds behind the system, with warm off-shore winds in front (Tyson and Preston-Whyte, 2000). The coast experiences morning sea breezes followed by evening land breezes (Abed, 2009). The KZN coast is dominated by south-westerly and north-easterly winds (Pillay, 1996; Sukdeo, 2010). Sea breezes eventually transform into north-easterly winds along the coast and this is attributed to the deflecting influence of the coriolis effect (Tyson and Preston-Whyte, 2000). Winds are seasonally variable, strongest in October and November, while the calmest period is

experienced in June (Moodley, 2010). Berg winds arising from the interior of the province warm the air and also result in higher maximum temperatures being recorded in winter along the coast (Tyson and Preston-Whyte, 2000). A mean annual temperature of 20.2°C with an annual variation of 4°C is experienced from this mean (Ward, 1980).

### 1.4.3 The Isipingo catchment and river system

The Isipingo catchment comprising of the Isipingo River and Estuary system is situated approximately 20 km south south-west of the Durban Central Business District within the province of KZN (Begg, 1978) (Figure 1.2). It is one of the smaller catchments in the province, with a catchment area of approximately 50 km<sup>2</sup> (Begg, 1978). The importance of the catchment lies in the fact that it has become one of the most highly developed regions in KwaZulu-Natal. The length of the Isipingo River is approximately 27 km, originating near the Iwabi area located approximately 16 km in a north-westerly direction from the mouth of the Isipingo Estuary (Kalicharran, 1990) (Figure 1.2). The name Isipingo is thought to be derived from the isiZulu word for the intertwining cat-thorn shrubs, *Scutia myrtina*, present in the area or the winding nature of the river itself (Begg, 1978).

The mouth of the Isipingo River consists of both a lagoon and estuary which is located at latitude of 30°00'S and longitude of 30°57'E (Figure 1.3). The estuarine system has an estimated area of 0.068 km<sup>2</sup> and is divided into 2 areas (known as the northern and southern arm) (Begg, 1978). The 'southern arm' contains the Isipingo Lagoon and the 'northern arm' which is the estuary proper extending in an arc on the northern side of the lagoon (Figure 1.3).

The uppermost catchment is characterized by sparse dwellings while dense housing developments within the floodplain of the Isipingo River dominate the upper to middle section of the catchment. The lower catchment is heavily developed and comprises of the Isipingo Wastewater Treatment Works (WWTWs), built in the late 1960's and discharges an average of 10.98 Ml/day of treated effluent into the Isipingo River (DWAF, 2009), the rehabilitated high hazardous Umlazi IV landfill, the Isipingo Diversion Works System (DWS) as well as the following developments which are located within the floodplain of the Isipingo Estuary system: the old Durban Airport, a number of refineries and other light and heavy industries of the Prospecton and Isipingo Industrial Nodes, informal agriculture and a residential area (Figure 1.4).

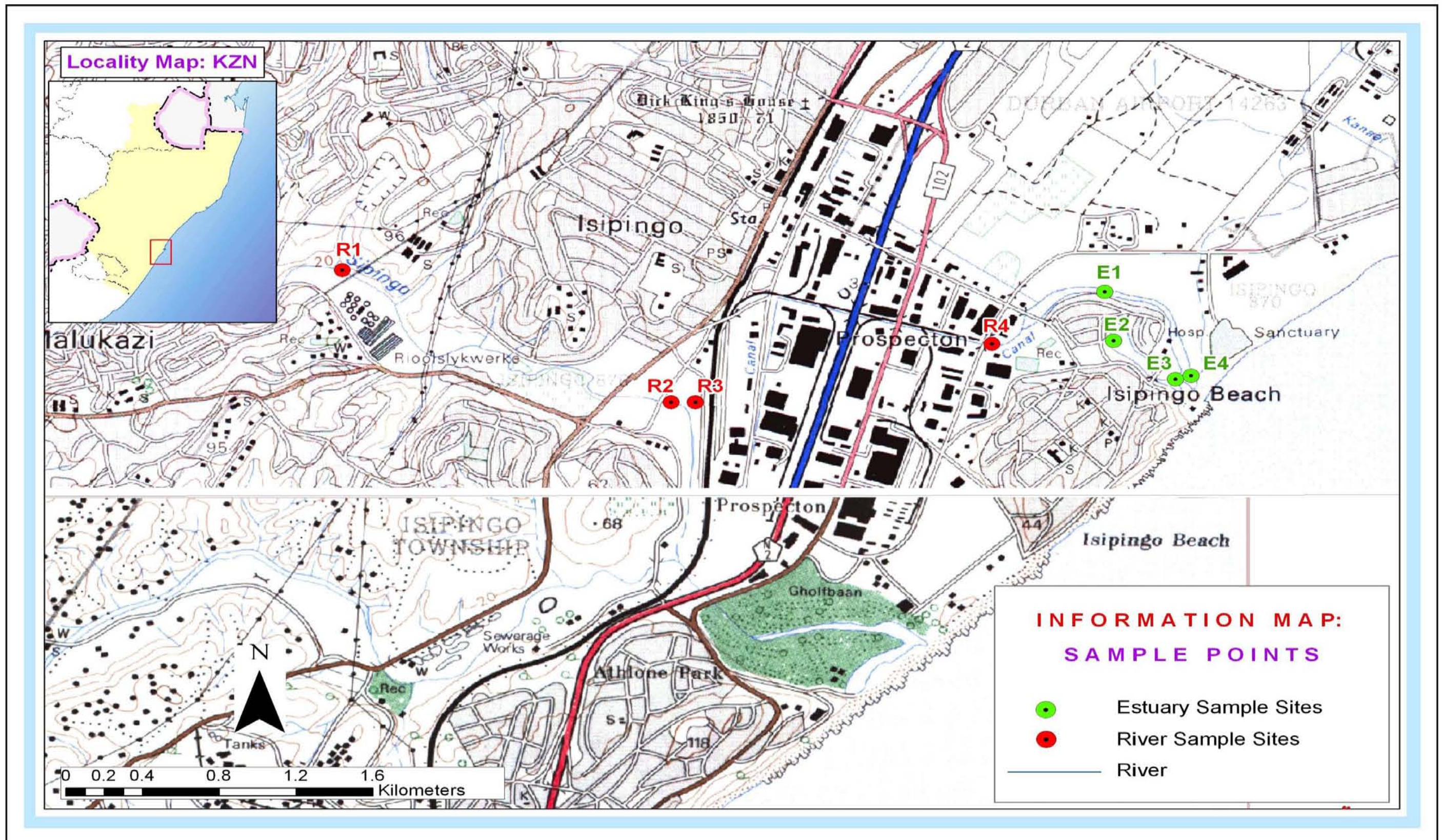


Figure 1.2: Study area: Isipingo River and Estuary (Adapted from 1:50 000 orthophoto with assistance from Naidoo, S., 2013). Inset: Location of the study area in relation to the Province of KwaZulu-Natal.



Figure 1.3: Photograph of Isipingo Estuary, lagoon and twin pipes (after KZN Wildlife, 2005)

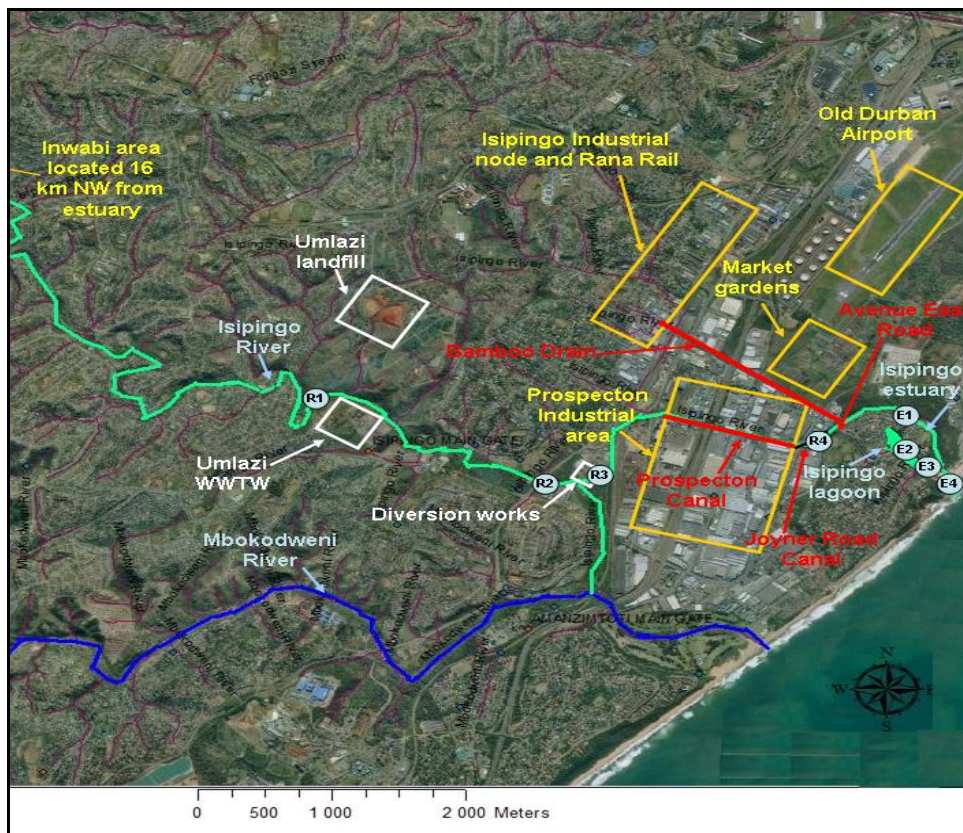


Figure 1.4: Google Earth® image depicting significant developments and water resources (Accessed and adapted by author, 2011)

Following the northward diversion of the Umlazi River (Figure 1.5) (which previously joined the Isipingo Estuary at the mouth) in the late 1950's (Begg, 1978; Swart, 1987) and the subsequent construction of the DWS (discussed further in section 1.4.3.2 of this chapter), the reduced fluvial flows caused protracted mouth closure of the estuary and necessitated the construction of twin concrete pipes to facilitate and maintain the tidal exchange between the estuary and the sea (Figures 1.6(a) and 1.6(b)).



Figure 1.5: Morphology of the Isipingo River, estuary, lagoon and the Umlazi River in 1931 (after eThekweni Municipality, 2010)





Figure 1.6(a): Photograph depicting the twin concrete pipes maintaining connectivity between the estuary and the sea



Figure 1.6(b): Photograph showing tidal inlet pipes on the estuarine side. Dune barrier separating the estuary from the marine environment

### **1.4.3.1 Topography**

The lower lying areas of the Isipingo catchment adjacent to the coastline are fairly flat while hilly, undulating topography dominates the upper reaches. Coastal dunes of wind-blown marine sand occur both north and south of the estuary mouth. Over the last 60 years, there have been many alterations to the geomorphological character of the lower catchment. These include, the diversion of the Umlazi River, the infilling of material on the Isipingo Flats, canalization of the Isipingo River as well as industrial and urban development.

### **1.4.3.2 Hydrology and drainage hydrodynamics**

Prior to 1952, the Umlazi River joined the Isipingo River at the estuary mouth and the combined contribution to mean annual flow from these two rivers was approximately 102 million m<sup>3</sup>/year (Swart, 1987) (Figure 1.5). The development of the Prospecton Industrial Area (PIA) (Figure 1.4) in the late 1960s necessitated the further modification of flow received from the Isipingo River to alleviate flooding (Ward, 2010). As a result the system referred to as the DWS was installed at the head of the Prospecton Canal System (PCS) (Swart, 1987). The main purpose of this system is to regulate the flow received from upstream and to permit a controlled flow to the PCS. The DWS is so designed to allow flows in excess of the carrying capacity of the canal system to be diverted towards the Mbokodweni River located due south of the Isipingo River (Figure 1.4). As a result, the catchment now experiences an estimated mean annual runoff of 3 million m<sup>3</sup> (Swart, 1987; Forbes and Demetriades, 2008).

Downstream of the Diversion Works system, the river has been adapted into concreted canal network (Figure 1.4), which drains the PIA before leading into an unmodified natural river segment downstream of the bridge located on Avenue East Road (Figure 1.4) that flows along the northern arm past a mangrove swamp towards the estuary mouth. The Bamboo drain (Figure 1.4) is a conduit for drainage and run-off stemming from part of the Central Business District of Isipingo, the residential area in the Isipingo Rail and the Rana Road area (Naicker, 2010). The Bamboo drain joins the Isipingo River downstream of Avenue East Road.

Inadequate water supply to the Isipingo Estuary has been experienced due to the periodic malfunction and irregular maintenance of the DWS (Sooklall, 2010) results in the diversion of water to the Mbokodweni River even during low flow conditions (Philip, 2010). This implies

that during such periods, the only flow reaching the Isipingo Estuary is that of groundwater seepage, run-off and drainage from the Bamboo Drain and PCS in the Prospecton area. In addition, there appears to be little chance of flushing the system as the capacity of the sluice gates are considered to be insufficient and the quality of water received from upstream was deemed to be poor (SSI, 2011).

The reduction in fluvial flow of the Isipingo River has affected the scouring ability of the river at the estuary mouth resulting in prolonged mouth closure. The estuary mouth had to be mechanically breached in 1952 after it closed semi permanently (Begg, 1978). This necessitated the installation of twin one meter diameter pipes in 1961 to maintain the tidal interchange (Begg, 1978) (Figures 1.6(a) and 1.6(b). The Isipingo Estuary is said to be retreating by 0.43 meters per year due to marine transgression (Cooper, 1991). The coastline in proximity to the Isipingo is orientated roughly northeast-southwest and receives the brunt of the prevailing swell (Cooper, 1991). Consequently this area is very exposed marine attrition and is susceptible to increased damage in future arising from storms and sea-level rise impacts (Theron, 2003).

#### **1.4.3.3 Floods events**

The highest recorded flood level was shown to be 2.5 m above sea level (Begg, 1978). Begg (1978) refers to the last severe flood, prior to 1978, as having occurred in 1935. Perry (1989) also cited other major floods that were recorded in April 1856, October 1917, March 1925 and June 1935. The September 1987 flood event resulted in flooding of the low lying residential and industrial properties. This situation presently persists during high intensity rainfall events, although not as severe (SSI, 2011). This is partly attributed to the malfunction of the DWS and inadequate tidal exchange (Forbes and Demetriades, 2008). Following heavy rainfall event, the water in the estuary often back-floods due to the bottlenecking of water in the twin pipes.

#### **1.4.3.4 Geology and soils**

The geology of the Isipingo catchment comprises of outcrops of Dywka Tillite Formations with a lithology of tillite (diamictite) as well as the Natal Group Sandstones which comprise of Table Mountain sandstones, quartzites and shales (Brand, 1967; DWAF, 2004b) (Figures 1.7(a) and 1.7(b). Sandstone is much more easily erodible and consequently forms the majority of the soils in the catchment (Whitmore *et al.*, 2006). Tertiary and recent sediments

are more dominant closer to the coastline (Brand, 1967). Alluvium, modern dunes and weathered red sands surround the lagoon (Ward, 1980). Bedrock is said to lie at a depth in excess of 22 m (Orme, 1974 as cited in Begg 1978).

Ward (1980) highlighted that the low lying parts of the Isipingo Flats is characterized by alluvial and deltaic deposits of fine to coarse sand, clay and silt. The soils present in the study area have been anthropogenically modified through the infill of material which has been described by Ward (1980) as being *red clayey sand or sandy clay which contained gravel and pebbles.* In addition, dredged material from the Isipingo Lagoon and Estuary and even the Isipingo River bed was used as fill material in the low lying parts of Prospecton (Ward, 2010).

The Isipingo Estuary, in particular the bed material of the northern arm, has been described by (Begg, 1978) to be comprised of anaerobic black sludge. The southern arm and the lagoon comprises of silt (Begg, 1978).

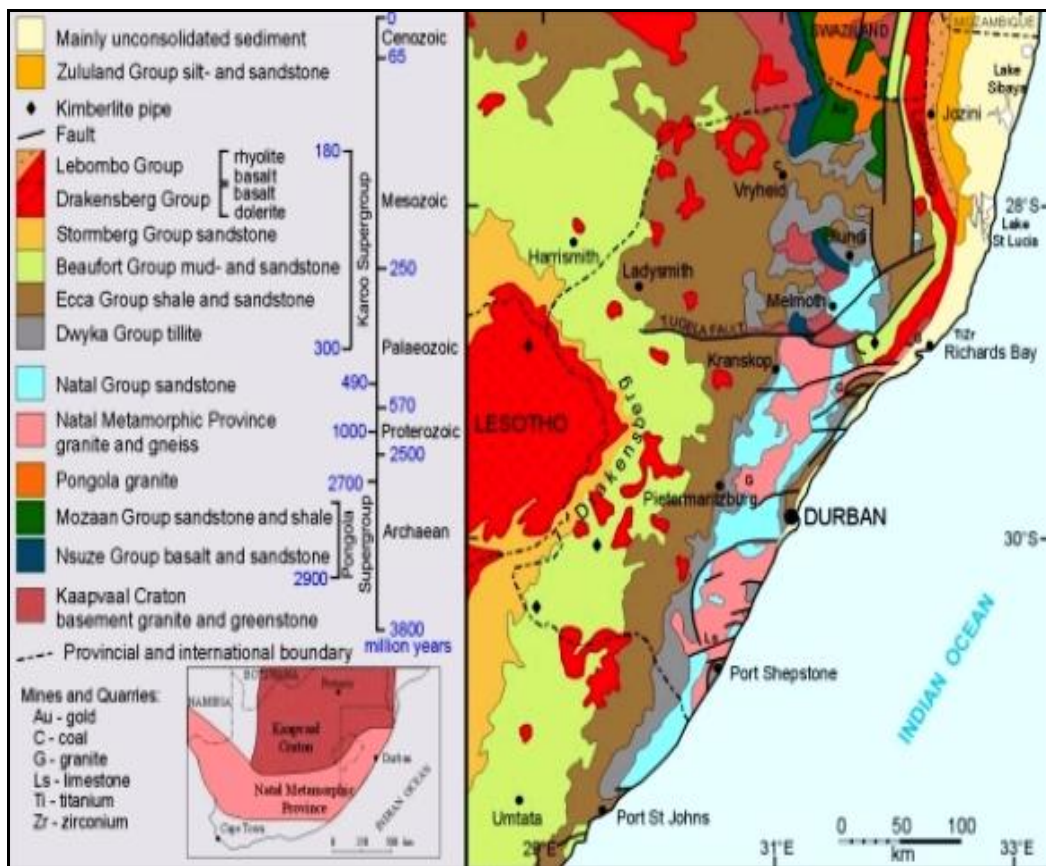


Figure 1.7: Geology of KwaZulu-Natal inclusive of the Isipingo catchment (after Whitmore et al., 2006)

#### **1.4.3.5 Water use**

The main activities associated with the estuary and lagoon are recreational, fishing and cultural practices. On the other hand, the river is utilised for domestic purposes such as the washing of clothing and recreational activities such as swimming (pers. observation). There are no dams, large scale abstraction or sand mining located on this river system.

#### **1.4.3.6 Flora and fauna**

The riparian vegetation remains intact in the upper reaches of the catchment but is in poor condition further down the catchment. The original vegetation in the vicinity of the estuary consisted of mangroves, low lying woodlands, marsh and scrub (Begg, 1978). Currently, the northern bank of the estuary is fairly well vegetated with mangroves but riparian vegetation around the lagoon has been reduced. The water hyacinth (*Eichhornia crassipes*) has remained a long term problem as reported by Begg (1978), Forbes and Demetriades (2008) and this study. The lower section of the northern arm of the estuary as far as the Isipingo Island hotel (Figure 1.8) as well as the upstream area above the footbridge is bordered by the common reed *Phragmites australis* (SSI, 2011).

The estuary is home to crabs, shrimp and other small fish. Begg (1978) also surveyed the lagoon area and recorded between 12 and 15 species of fish and crabs. Ramm (1987) also found an abundance of juvenile mullet, prawns and crabs in the estuary. Surveys conducted between 2007 and 2008 indicated a diversity of polychaete worms near the mouth of the estuary and a relatively small number of crustaceans and bivalve mollusks (Forbes and Demetriades, 2008). This survey also indicated that the number of species and total densities decreased in the upper reaches of the estuarine system.

According to Forbes and Demetriades (2008), the aforementioned survey indicated a catastrophic decline in the number of recorded fish species. The only fish caught in August 2007 were 16 Mozambique tilapia *Oreochromis mossambicus* and the only additions to this list in January 2008 were five longspine glassies *Ambassis ambassis* and four mullet.

There is no documented information for the rest of the Isipingo River but aerial photographs indicate that much of the riparian vegetation and floodplain has been affected by urbanisation and other activities. Alien vegetation is also rife.



Figure 1.8: Google Earth® image depicting the Isipingo Island Hotel in relation to the estuary and lagoon (Accessed and adapted by author, 2011)

#### 1.4.3.7 Characteristics of the Isipingo Estuary

Previously, the condition of the Isipingo Estuary was considered as one of the best, displaying the finest mangrove habitats in KwaZulu-Natal, however it has been regarded as one of the most severely degraded estuaries along the KwaZulu-Natal coastline (Kalicharran and Diab, 1993; Forbes and Demetriades, 2008). The characteristics of the estuary are summarized in Table 1.1.

Table 1.1: Characteristics of the Isipingo Estuary

Characteristics	Description
Area	7 hectares or 0.07 km <sup>2</sup> (measured using Google Earth <sup>®</sup> )
Axial Length	1.2 km along its northern arm (measured using Google Earth <sup>®</sup> )
Shoreline length	2.2 km (measured using Google Earth <sup>®</sup> )
Width	At its widest, the southern arm of the system is 100 meters
Mouth	Twin one meter concrete pipes facilitate permanent connectivity with the nearshore environment
Floodplain	± 250 m (Begg, 1978).
Berm	The berm at the mouth continually develops as a result of sea conditions and the reduced scouring of the mouth and, varies between 35 - 120 m (Pillay, 2013).
Shape	V shaped. Ward (1980) views the northern arm as part of the estuary and the southern arm to be the lagoonal area.
Bathymetry	In 1910, depths of 7.5 m and 0.15 m were reported in the lagoon and near the estuary mouth respectively (Begg, 1978). The depth of the estuary was recorded as 5.2 m in the western section of the southern arm (i.e. lagoon) and 3.7 m along the northern arm in 1984 (Begg, 1978) while a survey in 2007/2008 indicated a maximum depth of 4.4 m in the lagoon and 1.33 m in the northern arm (Forbes & Demetriades, 2008).
Nature of bottom sediments	Generally comprises of sand, silt and clays. Marine sand is washed into the mouth at high spring tide. The northern bank comprises of muddy black, anaerobic substrate which supports mangroves. The southern arm comprises of silt and a small amount of sludge. The mouth and lagoon sediments comprise mainly of medium (0.25 mm) to coarse (0.5 mm) sand with clay particles (< 0.063 mm) in localized areas in the middle to upper reaches of the system (Forbes and Demetriades, 2008). The organic content was less than 1% at the mouth while the lagoon area varied between 4.3% and 1.9% (Forbes and Demetriades, 2008). The organic content of the northern arm varied between 5.5% and 2.29% (Forbes and Demetriades, 2008).
Sandbar	The mouth position is against the southern bar. After the diversion of the Umlazi and Isipingo River, the scouring effect was lost resulting in a sandbar buildup. Twin concrete pipes maintain connection with the marine environment. Artificial breaching of the sandbar is required during flood events to prevent backing up of water in the estuary and subsequent flooding of residential properties and neighbouring industries.
Wave action	The south-easterly wave approach induces a northerly longshore drift current and the transport of sediments (Cooper, 1993a). Nearshore cell circulation may at times reverse the local longshore currents.
Physio-chemical characteristics	Begg (1978) described the northern arm as <i>–virtually devoid of oxygen</i> ” with occasional super-saturation due to algal blooms. Begg (1978) further described the southern arm as always having dissolved oxygen present in surface and bottom water, except in May 1982 where there was significant depletion. Forbes and Demetriades (2008) during their study recorded satisfactory dissolved oxygen levels in the northern arm however, oxygen depletion occurred in other parts of the estuary. Moodley (2010) also recorded low dissolved oxygen levels in the estuary.

## **1.5 Historical use and land use changes affecting the Isipingo River catchment**

The Isipingo catchment has historically been the focus of land use changes which have dramatically shaped and influenced a number of environmental factors, in particular water quality and quantity. Major changes in land use such as industrial and urban development, with concomitant alteration to the hydrology of the catchment and encroachment onto the floodplain appear to have caused the deterioration of the Isipingo River and its estuary. This has ultimately resulted in the landscape changing from one where the Isipingo River previously flowed past well established mangrove habitats to the current situation we observe today, where the reduced flow of the river passes through areas of industrial development and high density housing developments.

The section to follow documents the pertinent land use changes and catchment activities spanning a 172 year period from 1840 to present day, that have shaped the Isipingo catchment and ultimately influenced the quality and quantity of water within this catchment.

### **1.5.1 Vegetation**

Removal of indigenous vegetation began during the early European settlement (1840-1952) (Kalicharran and Diab, 1993). This activity was undertaken to make more land available for the cultivation of sugarcane, market gardening and township development. Despite this, the Isipingo River continued to function as a healthy system (Ward, 1980). This was reaffirmed by Harris (1987, p. 3) who described the Isipingo River during the 1930's as a *„fine, clear, tree-lined river, flowing between the cane fields of the Prospecton Sugar Estates.*'

In 1916, a golf course was developed on the north bank of the Umlazi River, upstream of the estuary, which resulted in the destruction of dune vegetation and forest (Figure 1.9) (Kalicharran, 1990). The Umlazi River joined the Isipingo Estuary at its mouth. This was diverted around 1952. Subsequently, the development of a military camp during the Second World War at Reunion Rocks resulted in further destruction to dune vegetation (Ward, 2010). The golf course was eventually leveled off and used as an aerodrome and army camp site during this period.

The original vegetation in the vicinity of the estuary consisted of mangroves, low lying woodlands, marsh and scrub in the vicinity of the estuary (Forbes and Demetriades, 2008).



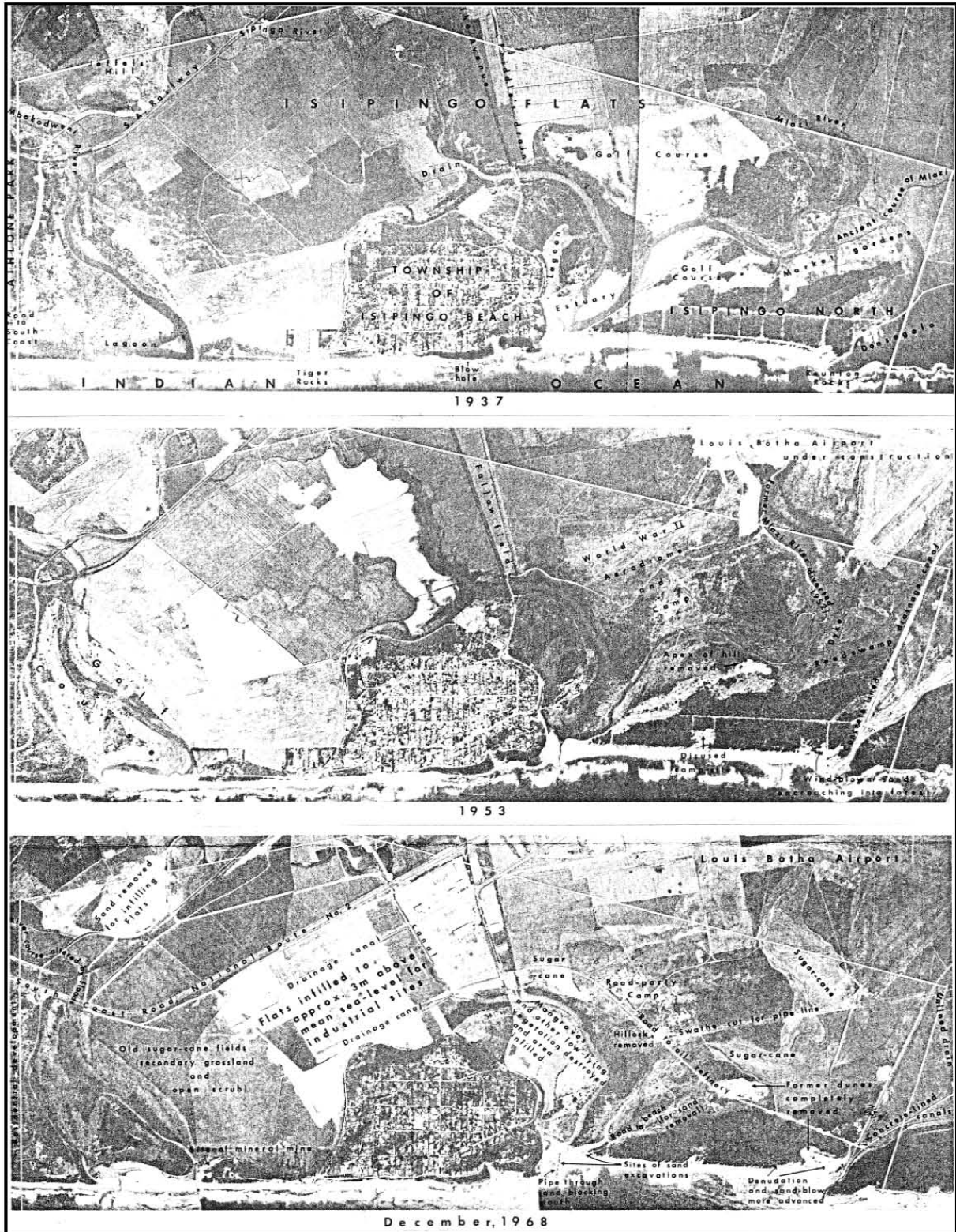


Figure 1.9: Land use changes to Isipingo Beach area between 1937 and 1968 (after Ward, 1980 as cited in Kalicharran, 1990) (An enlarged copy is attached as Appendix 1)

During 1946, the pre-construction phase of the former Durban Airport (known as Louis Botha Airport) commenced, which resulted in the removal of most of this original vegetation (Ward, 1980). Between 1966 and 1970, vast amounts of natural vegetation were removed to permit the development of the PIA. Figure 1.9 depicts the infill area.

In 1965 virtually all the mangrove swamps on the southern bank and the central island area was reclaimed for township development (Forbes and Demetriades, 2008). In 1967, mangroves were only present along the north bank of the Isipingo Lagoon (Figure 1.10) (Forbes and Demetriades, 2008). The year 1983 saw the removal of additional mangroves and a salt marsh located at the eastern end of the lagoon area. There was further removal of mangroves and wetland vegetation to the west of the lagoon but by 1989, the mangroves had colonized the south bank of the Isipingo River.

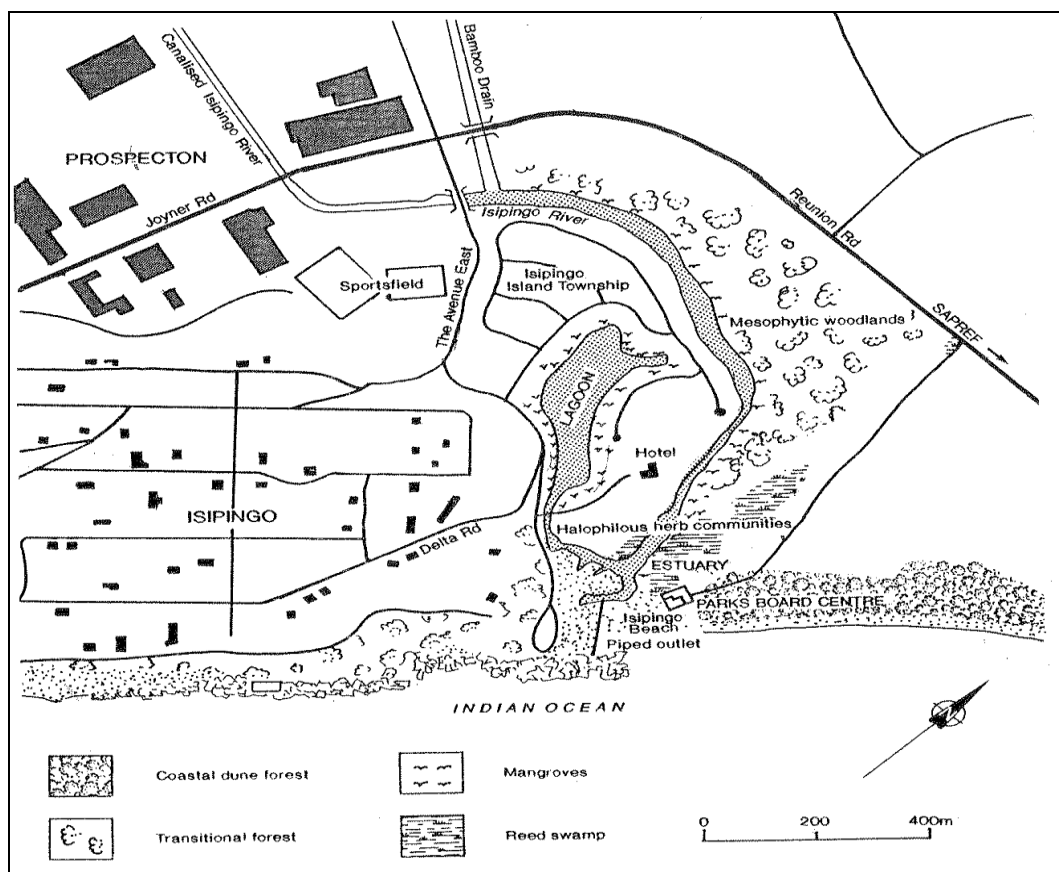


Figure 1.10: Canalised portion of the Isipingo and Prospecton Canal System (PCS) River and the Bamboo Drain also depicting the presence of mangroves along the north bank of the Isipingo Lagoon (after Begg, 1978)

Today, the northern bank of the estuary is observed to be well vegetated with mangroves while there is no riparian vegetation encompassing the lagoon (Figure 1.8). Forbes and Demetriades (2008) iterated that the eastern tip of the island and the area around the Island View Hotel are also well vegetated with mangroves while the southern bank in the region of the mouth has been cleared of vegetation for a road and car park (Figure 1.8). The southern bank of the main channel is fringed with a narrow strip of mangroves. The current type of mangroves comprise primarily of *Avicennia marina*, *Bruguiera gymnorrhiza* and *Rhizophora mucronata* (species of red mangrove found on the northern banks of the Isipingo Estuary) and inhabits an area of approximately 12.7 ha (Rajharen and Adams, 2006).

### 1.5.2 Modifications to the catchment and estuarine environment

Prior to 1952, the Umlazi River joined the Isipingo River just upstream of the estuary mouth. The combined contribution to mean annual flow from these two rivers was approximately 102 million m<sup>3</sup>/year (Swart, 1987) (Figure 1.11). According to Forbes and Demetriades (2008), the Isipingo River was recorded as being as wide as 40-50 meters (m) during the 1930's and only narrowed at the bridge on Avenue East.



Figure 1.11: Isipingo Estuary and Umlazi River in 1942 (after eThekweni Municipality, 2010)

After the Second World War in 1945, an earth berm or dyke was erected across the original course of the Umlazi River to prevent water of the north-eastern section of the Isipingo Flats from flowing towards this river (Kalicharran, 1990). This water was diverted in 1952 into a concrete lined canal draining into the sea at Reunion Rocks (Ward, 2010). This diversion reduced the discharge of the Umlazi River, which at the time still flowed towards the Isipingo Estuary, to 6 million m<sup>3</sup>/year (Swart, 1987; Ward, 2010) and can be deemed to be the start of the restriction of flow to the Isipingo Estuary.

Following the diversion of the Umlazi River in the late 1950's, the reduced fluvial flows diminished the scouring effect at the mouth leading to wave induced sand accumulation which caused protracted mouth closure of the estuary. Mechanical breaching was subsequently initiated and in 1955 an attempt to increase tidal interchange was undertaken by installing a one metre diameter steel pipe through the sand bars (Ward, 1980; Forbes and Demetriades, 2008). The failure of this attempt necessitated the construction in 1961 of twin concrete pipes of one meter diameter each below the sandbar (Ward, 1980), which at present still facilitates and maintains some tidal exchange between the estuary and the sea (Forbes and Demetriades, 2008) (Figures 1.6(a) and 1.6(b)).

The pressures arising from the need to develop the Prospecton Industrial area (late 1960s) resulted in the flow of modification of the upper Isipingo River with the construction of the DWS between 1969 and 1970 (Figures 1.12(a) and 1.12(b)). This system together with sluice gates was installed at the head of the Prospecton Canal System (PCS) (Swart, 1987) to regulate the flow received from the upper catchment and to permit a controlled flow to the PCS.

The Isipingo River was canalized for more than 1 km above the Avenue East Bridge during this period to assist with stormwater drainage (Forbes and Demetriades, 2008) and this canal system is still in existence today (Figure 1.8). The system was designed to divert high flow levels to the Mbokodweni River during times of floods while permitting low flow levels through to the PCS and eventually the Isipingo Lagoon and Estuary (Philip, 2010). The flow of the Isipingo River was thus reduced to 3 million m<sup>3</sup>/year, only three percent (3 %) of its original flow (Swart, 1987). Due to poor maintenance and mechanical problems of the sluice gates, the flow has often been reduced further (Swart, 1987).

In November 2009, the Coastal, Stormwater and Catchment Management Section of the eThekweni Municipality undertook remedial measures. Accumulated sediment and water

hyacinth was removed from the pond ahead of the DWS. The pond was created to channel and slow down the water prior to flowing through the DWS. Further excavations of the pond were undertaken and a concrete trash tract with palisade beams was installed instead of steel to dissuade theft. Maintenance is expected to be conducted every 3 months as well as immediately after heavy rainfall events to maintain the water height, remove water hyacinth and sediment in the pond.

According to Sooklall (2010), the maximum flow that can be permitted through the inlet of the sluice gates calculated by engineers of the eThekweni Municipality is  $5.4 \text{ m}^3/\text{s}$ . Repairs to the DWS have been undertaken but due to the irregularities in the maintenance of the system, there are periods during which the Isipingo River, just above the DWS, is still being diverted to the Mbokodweni River.

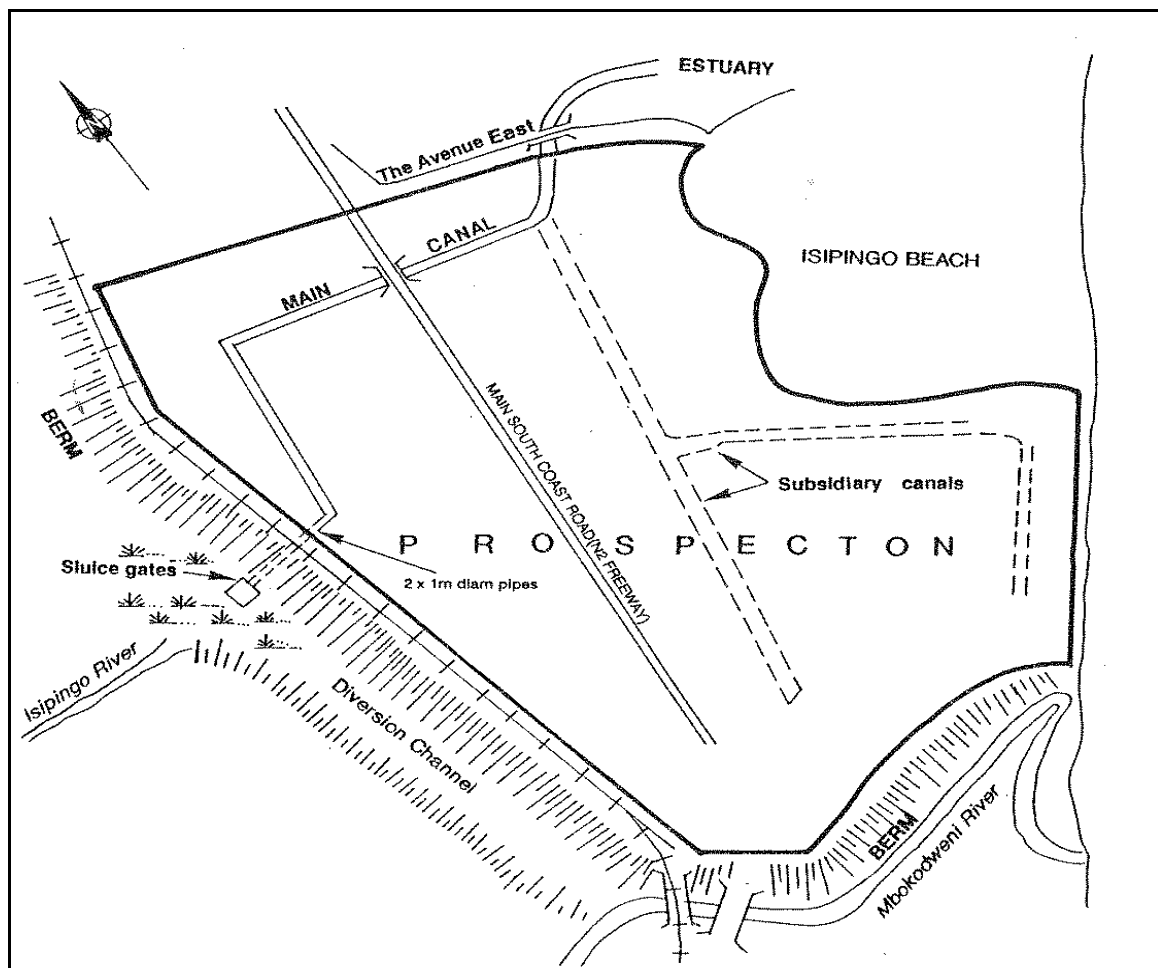


Figure 1.12(a): Diversion Works System (DWS) and Prospecton Canal System (PCS) built between 1969 and 1970 (after Begg, 1978)



Figure 1.12(b): The Diversion Works System (2010) showing the large concrete structure which houses the sluice gates that allows pooled water to flow into the PCS. Water hyacinth is present in the background (Taken on 16 November 2010)

### **1.5.3 Township and Industrial development and sanitation**

In 1905, an unnamed township was developed at Isipingo Beach (Kalicharran, 1990), on the southern bank of the estuary (Forbes and Demetriades, 2008). Infilling of wetland areas along the Isipingo River near the DWS took place in the late 1980's (Kalicharran, 1990) and, infilling of the low-lying areas to the north of the Isipingo Estuary for the development of the South African Petroleum Refinery (SAPREF) commenced in 1961 (Kalicharran, 1990).

The Isipingo Flats from Avenue East (main access road to Isipingo Beach) was infilled in 1966, together with the canalization of the river and its tributaries to allow for industrial development (Kalicharran, 1990). The Prospecton area was infilled to three meters (3m)

above mean sea level (Ward, 2010), and in 1969 this level was increased using dredged material from the Isipingo Lagoon, Estuary and the river (Figure 1.9) (Ward, 1980).

Town Board status was granted to Isipingo Beach and Isipingo Rail in 1972 and the area became known as the Borough of Isipingo (Wiley *et al.*, 1996). Abolishment of the influx control laws (those preventing people other than of European descent from inhabiting the area) in the mid 1980s allowed informal settlements to develop and expand on the outskirts of Isipingo (Wiley *et al.*, 1996). These developments lacked the provision of basic services including proper sanitation facilities. Residences near the Isipingo Estuary and Lagoon used septic tank systems converting to waterborne sewage in the late 1960's (Gravelet-Blondin, 2010).

Since 1994, the Boroughs of Isipingo and Amanzimtoti (a town adjacent to Isipingo in a southerly direction) were dissolved and now fell under the jurisdiction of the eThekweni Municipality. The post apartheid era resulted, through the Reconstruction and Development Programme (RDP), in the formalization of existing townships. There was a need for development of low to medium cost housing and access to proper sanitation facilities in the middle to upper areas of the Isipingo catchment and extensive upgrades to the sewer lines in the Umlazi area (located in the upper reaches of the catchment and beyond, with the main trunk sewer line being upgraded between 2006 and 2007 (Mhlonga, 2010).

These developments have led to further removal of riparian vegetation in the middle to upper catchment which has increased the degradation of the riverine system. Since 1994, there has been extension of the Prospecton and Isipingo industrial areas and the growth of more commercial industries all of which contribute to considerable increases of environmental stress upon the Isipingo River and Estuarine system.

#### **1.5.4 Sand mining**

Sand mining commenced in 1961 immediately north of the Isipingo Estuary mouth (Kalicharran, 1990). This was then followed by the mining of sand on the southern side of the estuary mouth. According to Ward (2010), more than 10 million cubic meters of sand could have been removed from the system. There are no longer any sand mining activities taking place at the Isipingo Estuary or along the length of the Isipingo River.

### 1.5.5 Water pollution

The water quality along the Isipingo River and in particular the Isipingo Lagoon and the estuary has a history of being of poor quality. Griffiths (1987) attributed the main reason for the poor water quality to faecal contamination and nutrient enrichment, apart from insufficient flow to the estuary. In 1953, Harris found the Isipingo Lagoon to be polluted by effluent from the septic tank system. Sampling undertaken in 1964 and the 1970's demonstrated that both the river and lagoon were organically and faecally polluted (Brand, 1967; Begg, 1978). Brand (1967) also concluded that the water in the Isipingo River approximately 2.5 km above the lagoon was chemically of poor quality. As cited in Begg (1978), (Turner *et al.*, 1974; Grindley, 1970), the lagoon was examined for heavy metal contamination and this drew attention to pollution of the Isipingo lagoon by detergents.

Between 1981 and 1982, foaming of the water in the lagoon was noticed and attributed to detergent manufacturers in the PIA. Griffiths (1987) noted that the flow to the Isipingo wastewater treatment works had dropped from 67% in January 1985 to 26% in March 1986 implying that the volume of sewage meant to be received by the works for treatment was not reaching the works. Instead, raw sewage ranging from possibly 3.67 to 6.7 ML/day was entering the Isipingo River and Estuary. A similar situation occurred in the latter half of 1991 when political and social unrest in the Umlazi area prevented work crew from repairing and clearing blockages to the sewer lines (Rankin, 1992). Between July 1991 and March 1992, sludge was disposed off illegally within the floodplain of the Isipingo River, just ahead of the DWS (Rankin, 1992).

Surveys undertaken by Umgeni Water in the late 1980's also attest to the poor quality of water in the lower reaches of the Isipingo River. Total phosphate and suspended solids levels were found to be exceeding the standards set by the Department of Environmental Affairs at most of the sampling sites monitored by Umgeni Water (Kalicharran and Diab, 1993). Moodley's (2010) analysis of the health of the Isipingo Estuary concluded that nutrient (ammonia and nitrates) concentrations are at levels that could lead to eutrophication of the system. The study also recorded low dissolved oxygen levels in the estuary and lagoon.

According to Ramm (1987), the survey conducted by the Council for Scientific and Industrial Research (CSIR) in August 1985, the dissolved oxygen levels in the lagoon at the surface and the bottom was approximately 6 ppm which is considered to be about 50% saturation.



At the southern arm, dissolved oxygen has always been present in surface and bottom water (Begg, 1978; Forbes and Demetriades, 2008). According to Philip (2010), the bottom sediment along the mangrove area (i.e. near the northern arm) consists largely of sludge which leads to the creation of an anoxic zone. The northern arm was virtually devoid of oxygen' although at times, due to algal blooms, the surface water became super saturated, whilst the bottom water remained anoxic (Begg, 1978). Forbes and Demetriades (2008) in their study conducted between 2007 and 2008 indicated the presence of oxygen in the northern arm however, all other parts of the estuary exhibited signs of either depletion, attributed to the decomposition of organic materials, or supersaturation as a result of eutrophication. The estuary is characterised by the accumulation of very fine, soft anaerobic material in the mid and upper reaches and the sediment contains high metal concentrations including iron, mercury, lead and zinc (SSI, 2011). Little change appeared to have occurred by the late 90s when Harrison et al (2000) assessed the water quality and the aesthetics as poor.

There has also been an increase in the frequency of fish kills at the lagoon area between 2002 and 2008, which has been attributed largely to sewage overflows as a result of pump station failures, breaks in the sewer lines and blocked manholes (Philip, 2010). The water quality upstream of the sluice gates is also considered unacceptable (Forbes and Demetriades, 2008).

## **1.6 Conclusion**

Water is a fundamentally important resource to social and economic development as well as the aquatic environment. The increase in global water demand has brought to the forefront the need to adequately protect this natural resource. With South Africa being a water scarce country, there is an urgent drive to not only secure water availability but also good quality water. This is true of all water resources in the country, including the smaller fluvial systems whose catchments are greatly modified by development. The Isipingo River and Estuary in KwaZulu-Natal, the focus of this study, is one of several such systems in the province and merits study, rehabilitation and proper management. This chapter accordingly outlines the background and purpose of this study including a description of the study area and traces the historical changes that have impacted on all aspects of the Isipingo River and Estuary.

## CHAPTER TWO

### THEORETICAL FRAMEWORK

#### 2.1 Introduction

This chapter initially examines the effects that changes in land use have on the environment with a focus on water quality effects (such as contamination by pathogens, heavy metals, nutrients and inorganic contaminant loading) on fluvial systems. This section is followed by a brief summary of the theoretical aspects of riverine and estuarine processes. Contaminant concentration loadings such as heavy metal accumulation in sediment and its effects are also examined. This literature review also presents aspects of the South African legislation pertaining to regulation of land use developments, water quality and estuarine management. Principles of developing a sound management plan for a heavily impacted catchment such as the Isipingo, which is the focus of this study, are examined. Additionally, a review of past research conducted on the Isipingo River and Estuary is also briefly discussed.

#### 2.2 Land use: A Catchment Perspective

A river catchment is the land area that contributes water, sediment and other surface derived material to a river (Rowntree, 2006). Rivers thus act as conduits for the transportation of these materials. Estuaries are the recipients of material leached from land into rivers and are viewed by Nedwell and Trimmer (1996) as the interfaces between land and coastal seas.

Fuggle and Rabie (1994) identified the exponential increase in the world's population and the process of industrialization as the two main causes of environmental degradation of the earth and its natural resources. Rivers systems worldwide are under threat of degradation due to the combined effects of these main factors which often find expression in the expanding informal settlements in riparian zones, the malfunctioning of sewage plants, unregulated industrial effluent disposal, excessive water abstraction and, channel and floodplain modification to accommodate development projects (Pillay, 2013).

Numerous studies attest to the fact that globally, aquatic ecosystems are detrimentally affected as a consequence of anthropogenic impacts. For instance, Taghinia et al (2010) used advanced statistical techniques to investigate the provenance of heavy metal concentration in the sediments of the Kabini River in Karnataka, India and were able to distinguish natural and anthropogenic heavy metal pollutant sources with significant

concentrations derived from industrial effluents, agricultural return flows and domestic sewage. Shinn et al (2009) studied the temporal variation of heavy metal contamination in fish in the River Lot in southern France and found that although there were improvements in contaminant levels compared to assessments made in the 1990's, levels of cadmium in fish muscle were exceedingly high in 2007. Similarly, Chust et al (2009) found that local anthropogenic impact was the major threat to Basque coastal and estuarine habitats, compared with natural erosive processes and global climate change driving forces over recent times.

Whilst the level of industrial development in developing countries may not mirror those of developed regions of the world, aquatic systems in the former are no less at risk. Studies from African countries including those of Linnik and Zubenkore (2000); Lwanga et al (2003); Awofolo et al (2005) and Idrees (2009) all report loading of freshwater systems variously from industrial wastewater discharges, sewage wastewater and fossil fuel combustion. Also Kansiime et al (1995) noted significant organic and inorganic pollution of the Nakivuko Channal in Kampala, Uganda.

South Africa's rapidly developing economy is similarly finding negative expression in the pollution of freshwater aquatic systems, particularly its rivers. In the country's State of the Nation Report, it is noted that South Africa's freshwater resources, including rivers, artificially created lakes and groundwater, are under increasing stress from a growing population and expanding economy. In addition, almost all of the country's freshwater resources have now (2005) been fully allocated, while increased pollution caused by industry, urbanization, afforestation, mining, agriculture and power generation has been attributed to the decline in the water quality of these resources (Oberholster and Ashton, 2008).

Most of South Africa's metropolitan areas are located on the watersheds of river catchments and rivers draining away from these watersheds have the dual burden of providing water supplies and transporting waste material' (CSIR, 2010a, p 8.) and are susceptible to combined effects of land use activities and patterns. In KwaZulu-Natal, anthropogenic despoliation of river systems have been reported by several researchers (Meyer and Van Antwerpen, 1995; Brijlal, 2005; Cyrus *et al.*, 2008; Govender, 2009; Sukdeo, 2010; Cyrus *et al.*, 2011; Sukdeo *et al.*, 2011; van der Laan *et al.*, 2012 and others). The Isipingo catchment is no exception, with the lower river system and estuary having been transformed over a period of approximately 60 years, from a thriving ecosystem into a system that suffers from insufficient water supply and poor water quality (Philip, 2010).

## **2.3 Connection to land use: Factors influencing water quality**

The physical, chemical and biological characteristics of a river are to a large degree influenced by the natural characteristics of the catchment (Davies and Day, 1998). However, it has been demonstrated that river systems bear the burden of increased land use pressures and poorly regulated activities (Tang *et al.*, 2005). Declining water quality of rivers has been attributed to poorly managed land use practices (Madsen *et al.*, 2003).

In South Africa, economic expansion and rapid population growth has placed greater pressure on the country's scarce water resources (DWA, 2010). Water quality monitoring data published by the Council for Scientific and Industrial Research (CSIR) has indicated that the water quality of South Africa's water resources and reservoirs have steadily declined over the last twenty years (CSIR, 2010a).

Currently much of the water quality of South Africa's water resources is influenced by wastewater discharges as well as impacts associated with other types of land based activities (DWA, 2010). The Department of Water Affairs (DWA) has recognized the impact that land use activities have on water resources and has put in place several measures to regulate such activities. Some of these measures include the issuing of authorizations in the form of water use licences to regulate the abstraction and storage of water, the storage of waste material as well as the discharge and irrigation of effluent (NWA, 1998). In response to the impacts and stresses placed on the water quality of South African water resources, the DWA is currently in the process of implementing a new measure called the waste discharge charge system. The aim of this system is to promote waste reduction to water resources by introducing a monetary charge on all activities that discharge, irrigate or store effluent (DWAF, 2007).

### **2.3.1 Natural processes**

There are many natural factors which influence the chemistry of water and, in turn, its quality. Natural water quality may vary from place to place. As such, natural variations in water quality can be attributed to seasonal changes, climatic changes and geology (soil and rock types) of the landscape through which the water flows (DWAF, 2000). Changes in temperature can affect the rates of reaction of some chemicals in water (Davies and Day, 1998). Higher temperatures also increase the rate of evaporation and in catchments that experience low rainfall; this can affect the quantity of water available. Low flow affects the

ability of a river system to dilute chemical substances in water which consequently increases the concentrations of the chemicals in water (Davies and Day, 1998).

According to Bucas (2006), the chemical weathering of bedrock is the principle natural factor that controls the chemistry of water. The characteristics of the bedrock such as its mineralogical composition, chemical signature, texture, purity and size of rock minerals, porosity and exposure time all influence the natural water quality (Bucas, 2006). Catchments that experience higher temperatures experience higher solubility and dissolution rates of minerals than cooler regions (Bucas, 2006).

Aquatic organisms and plant matter also affect the quality of water. Photosynthesis rates affect the availability of oxygen within the system. In addition, the process of decomposition has an affect on the amount of oxygen present in the water body as well as the nutrient content. In South Africa, there are six basic regionally distributed natural water quality types that are recognized and characterized based on the combined effects of climate (rainfall, evapotranspiration and temperature), geology, soil type and vegetation (CSIR, 2010a) (Figure 2.1).

### **2.3.2 Anthropogenic activities**

A range of human activities such as agricultural activities, urban and industrial development, mining and recreation, have the potential to significantly alter the quality of natural water resources, thereby effecting the water use potential (DWAF, 2001a).

According to the National Water Act (Act 36 of 1998, p. 8), "pollution" implies:

*"The direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it -*

- (a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or*
- (b) harmful or potentially harmful -*
  - (i) to the welfare, health or safety of human beings;*
  - (ii) to any aquatic or non-aquatic organisms;*
  - (iii) to the resource quality; or*
  - (iv) to property"*

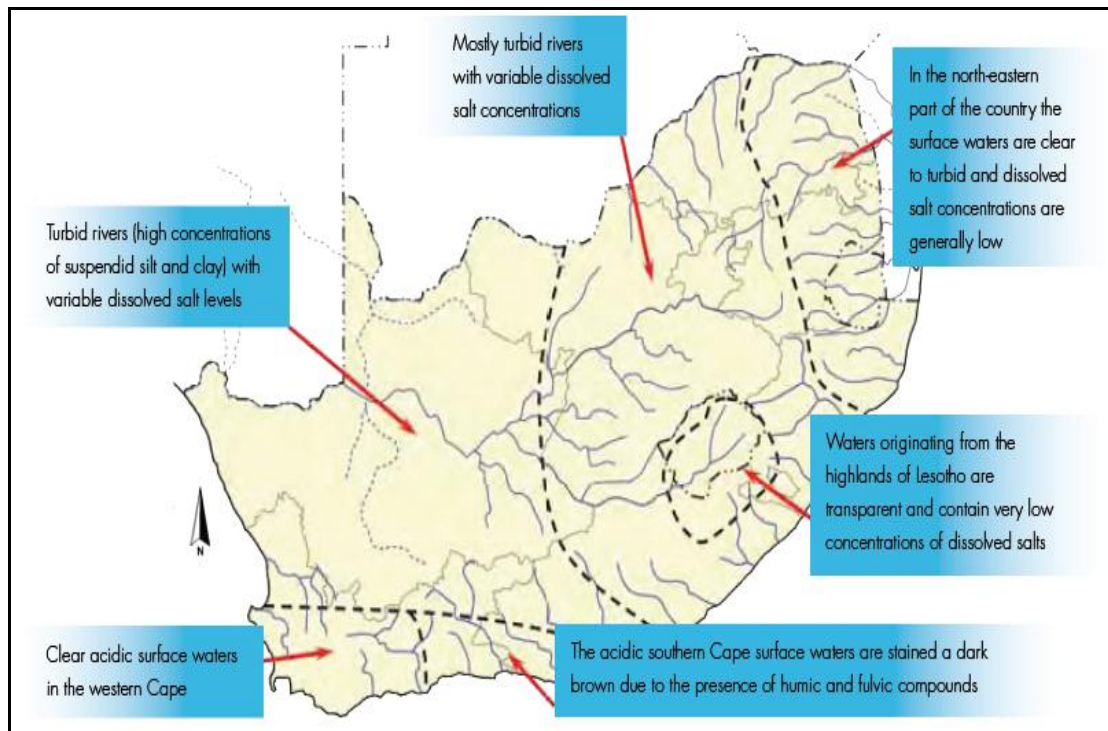


Figure 2.1: Natural background water quality recognised in South Africa (after CSIR, 2010a, p. 8)

Water quality is strongly linked to the use of water and the economic climate of a country (Krantz and Kifferstein, 1996 as cited in Sukdeo, 2010). Social, political and economic factors drive environmental change and within the current South African environment this implies increased pressure to develop the economy. *„Economic growth implies industrialisation and urbanisation, which could result in further deterioration of the country’s water resources’* (CSIR, 2010a, p.5). The economic sectors that bring about the most pronounced change to water quality in South Africa are discussed below.

### 2.3.2.1 Urbanisation

Research conducted by Tabayashi and Yamamuro (2009) examined changes in chloride and nitrate concentration in some of Japan’s streams attributing the increase in levels due to the increase in urbanisation. Because there were no significant changes in natural conditions, this study established a positive correlation between the impact associated with urbanisation and deteriorating water quality. Caraco (1995) demonstrated that the flux of nutrients in rivers increased with population density and the proportion of the catchment that is urbanised. Other studies have also reinforced the link between urbanisation and changes

in water quality of rivers (Gove *et al.*, 2001; Jarvie *et al.*, 2002; Deacon *et al.*, 2005 and Zhang *et al.*, 2009). Research conducted on rivers in New Jersey demonstrated a decline in water quality which was strongly associated with increasing urban land use (Madsen *et al.*, 2003).

The replacement of permeable surfaces with impermeable surfaces results in increases in the volume and rate of surface runoff and decreases in groundwater recharge and base flow (Andersen, 1970; Lazaro, 1990; Calder *et al.*, 1995; Moscrip and Montgomery, 1997). This in turn leads to disruptions in stream flow. Reduced stability of stream flow leads to high flood vulnerability in areas around a watercourse; destabilizes the banks of a watercourse, increases erosion and sediment, disrupting the habitats of aquatic organisms and reduces the rate at which rainwater replenishes aquifers (Madsen *et al.*, 2003).

The quality of stormwater flowing from urbanised areas has also been proven to degrade over time. Monitoring and modeling exercises undertaken by Schueler (1995) has shown that pollutant loads from urban areas increase with imperviousness. Such pollutants can include nutrients, heavy metals, sediment, oil and grease as well as faecal coliforms which eventually end up rivers.

High density populated areas concomitant with inadequate sanitation facilities and poor maintenance of sewerage infrastructure contribute significantly to pollution of water resources by human excreta. In addition, littering and a lack of removal of domestic and other wastes also contribute to pollution (DWAF, 1997).

### **2.3.2.2 Industrial Activities**

Unregulated and non-compliant discharges from sewage works and industrial activities can lead to degradation in water quality through the increase of pollutant levels. Excessive nutrients promote growth of aquatic vegetation which can lead to eutrophication. When vegetation decomposes, it results in the reduction of available oxygen in the water which can result in the death of fish and other aquatic organisms (USEPA, 2006).

Impoundments such as dams trap the larger grain size sediment and together with excessive abstraction result in decreases in river discharge and the reduction in the natural flushing of accumulated sediment to the marine environment. This reduction in river flow reduces the systems' ability to dilute contaminant concentrations (Madsen *et al.*, 2003).

In KwaZulu-Natal, a number of rivers are subjected to intensive sandmining (Marine and Estuarine Research, 2007). The impacts associated with such activities include the clearing of riparian vegetation and increased sedimentation which affects instream fauna and flora, reduces visibility and deteriorates water quality (Madsen *et al.*, 2003)

### **2.3.2.3 Agricultural activities**

The most profound effect of land use changes in a catchment emerges from large scale clearing of land for agricultural purposes (Wasson, 1992) which results in increased surface run-off of sediment, nutrients and other contaminants into river systems as demonstrated by numerous studies (Cooper, 1993b; Richards *et al.*, 1996; Johnson *et al.*, 1997). A strong linear relationship has also been demonstrated between concentrations of inorganic nutrients in rivers, particularly nitrogen and phosphorus, and the degree to which land has been cleared for agricultural use (Omernik *et al.*, 1981). Compacted and bare soils shed water at a much higher rate which increases the run off and load of sediments, chemicals and bacteria to a water resource (Wasson, 1992).

Encroachment of the natural vegetative buffer zones along water resources (Madsen *et al.*, 2003), is common to all land use activities. Natural buffers serve as filters and assist with the purification of water before it reaches a watercourse, thereby reducing the amount of sediment and chemicals that lead to water pollution. Buffers also serve to attenuate floods by dissipating the energy of flow which in turn reduces erosion and subsequently reduces the sediment load to a water resource.

Agricultural activities through runoff and seepage, may add chemicals derived from pesticides, herbicides and fertilizers into rivers (Sukdeo, 2010). Waste and wastewater from animal feedlots, poultry farms and livestock are known to contain extremely high concentrations of organic matter (i.e. high biological oxygen demand and chemical oxygen demand) and organic nitrogen and phosphorus (DWAF, 1997) as well as faecal matter (DEAT, 2006).

## **2.4 Hydraulics of river systems**

Hydrological measurements are fundamental to the interpretation of water quality data and for water resource management (UNEP/WHO, 1996). Factors such as the discharge, the velocity of flow, turbulence and depth all influence water quality to some degree (Dickinson,



1967). For instance, measuring the discharge is a critical component in the calculation of the mass flux of chemicals in the water (UNEP/WHO, 1996).

Human activities within a catchment such as dam or impoundment construction can also modify river discharge considerably (Philip, 2010). Changes in discharge patterns arising through natural influences such as seasonal changes or human-induced influences such as excessive abstraction of water from rivers are also important aspects that must be considered when quantifying pollutant loads (Crosa *et al.*, 2006; Ouyang *et al.*, 2006 and Guo *et al.*, 2008). Such activities as well as the diversion of watercourses reduce river flow and energy potential, thus reducing the rivers' competence and capacity. This culminates in the deposition of material and sediment.

The canalization of the lower reaches of the Isipingo River and the associated Diversion Works System (DWS) (i.e. system designed to divert high flows and prevent flooding of the low lying areas) has resulted in a substantial reduction in discharge and concomitantly; the resultant loss of fluvial competence and capacity has resulted in the canal system of the Prospecton Industrial Area (PIA), the lower reaches of the river and estuary becoming sediment depocenters. These sediment deposits together with solid matter pollution (paper, plastic, tyres, etc) have to be regularly removed by the eThekweni Municipality.

## **2.5 Estuaries: A definition**

Pritchard (1967) in Day (1981, p. 198) defined an estuary as “*a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted by freshwater derived from land drainage.*” Estuaries are the interface between terrestrial drainage systems and coastal seas and are therefore the recipients of material leached from land, thus making them vulnerable to catchment activities (Jennings, 2005; Nedwell and Trimmer, 1996).

In South Africa, there are a number of estuaries that are not permanently open to the sea due to variations in climate, rainfall, morphological and marine conditions (Cooper, 2001) which do not satisfy the definition provided by Pritchard (1967). Day (1981) proposed a new definition of an estuary which is also similar to the definition provided in the South African National Water Act, 1998 (Act 36 of 1998, p. 8) which defines an estuary as:

*„a partially or fully enclosed body of water -*

*(a) which is open to the sea permanently or periodically; and*

*(b) within which the sea water can be diluted, to an extent that is measurable, with fresh water drained from land.'*

For the purpose of this dissertation the definition provided in the National Water Act, 1998 (Act 36 of 1998) will be used.

Landuse practices in catchment hinterland regions together with other natural processes therefore impact on all estuaries. The pollutant residence time within estuaries depend on whether there is free access to the sea and the prevailing estuarine geochemical and hydrodynamic processes (Pillay, 2013).

Internationally, numerous researchers have published work focused on all aspects of estuarine contamination and the flux of material between estuaries and the nearshore environment. Examples of such recently published work include that of Devesa-Rey et al (2010) who analysed cores of the Anillo's River and estuary bed sediments in order to evaluate the downcore and downstream variations in their chemical composition and noted that concentrations of several heavy metals surpassed quality guidelines and revealed the need for regular monitoring; Kamaruzzaman et al (2008) study of the geochemistry of sediment of the major Malaysian estuarine mangrove forest of the Terengganu Region; Strady et al (2009) work on dissolved U, V and Mo in the Gironde Estuary, France; the work of Ravelonandro et al (2010) in assessing heavy metal concentrations in coastal sediments in north-western Madagascar; etc. Some other notable work are those of Kamau (2002); Fratini et al (2008); Karbassi et al (2008); Waeles et al (2008); Ram et al (2009); Olubunmi and Olorunsola (2010) and Sousa et al (2010).

The literature on southern African estuaries is diverse and extensive, covering physical, biological and socio-economic aspects as well as topics on modelling particularly those associated with global warming and sea-level rise aspects of global climate change. The earliest and most extensively consulted works are those of George Begg (1978). Day (1981) addressed the nature, origin and classification of estuaries with particular focus on South African estuaries whilst Whitfield also examined the characterization of southern African estuarine systems with some emphasis on estuarine biology. Allanson and Baird (1999) edited an important text focused on the estuaries of South Africa (Allanson and Baird, 1999) whilst more recently in 2007, Whitfield and Bate edited a comprehensive review of information on temporarily open/closed estuaries in the warm and cool temperate biogeographic regions of South Africa focussing on the influence of river flow.

Several of the published work on estuaries includes management perspectives (for instance the research of Mason and Wright, 1993; CERM, 1995; Lindsay, *et al.*, 1996a, 1996b; Sukdeo, *et al.*, 2011 and others). Turpie et al (2002) assessed the conservation priority status of South African estuaries for use in management and water allocation. In this important study, the authors used quantitative techniques to assess the relative conservation importance of estuaries, then prioritised them in terms of the existing and generated information and, proposed a network of estuarine protected areas. This set of information was then utilized classify estuaries and to develop a system of estuary management based on the classes established.

Allanson's (2001) paper provided a critical review of the important factors (influence of geomorphological structure, development, biogeochemical processes and global warming) upon the water quality of microtidal estuaries in South Africa. Whilst J.A.G. Cooper is credited with having provided much of the hydro-dynamic and sediment-dynamic estuarine research output covering much of the KwaZulu-Natal coastline, many of these papers were published between 1990 and 2005. Two important publications from Cooper deal with the classification of southern African estuaries (Cooper, 1991; Cooper, 2001). Similarly, Wright (1995); Lindsay et al (1996a, 1996b); Pillay et al (2003) and others have worked on the morphological changes and sediment dynamics related to river flow in systems located along the northern KwaZulu-Natal coastline.

Since modification of the barrier environment by dredging has, in the past, often been viewed by local authorities as a solution to the reconnection of the estuarine and marine environments, particularly during periods of low fluvial flow, many researches have studied the impacts of such dredging upon flow dynamics, sediment movement and aquatic biota. Some of the prominent work related to these issues include those of Cyrus (1988); Mason and Wright (1993); Lindsay et al (1996a, 1996b) and Cyrus et al (2008).

### **2.5.1 Estuarine Classification**

Several estuarine classification systems are utilised by estuarine scientists (e.g. Hayes, 1979; Pethick, 1984; Dairymple *et al.*, 1992 and Cooper, 2001). The Council for Scientific and Industrial Research (CSIR) in South Africa adopted an approach which focuses on the hydrodynamic processes within estuarine systems (van Niekerk, 2007). Based on the hydrodynamic classification system, estuaries in South African would fall under two broad categories, namely, permanently open estuaries (POE) and temporarily open closed

estuaries (TOCE) (van Niekerk, 2007). Research conducted by the CSIR has also indicated a third mouth state known as the semi-closed state which is described as a *„mouth that is nearly closed with only a shallow, narrow opening allowing water to trickle out to sea’* (Taljaard *et al.*, 1997; van Niekerk, 2005). The factors that influence the hydrodynamics of an estuarine system are discussed below in the subsequent sections.

#### **2.5.1.1 Catchment size, river inflow and mouth status**

River inflow (baseflow) is considered to be a major factor in maintaining open mouth conditions in many of South Africa’s estuaries (van Niekerk, 2007). Huizinga and van Niekerk (2005) indicated that high energy coastlines such as KwaZulu-Natal, requires a flow of between 5 to 10 m<sup>3</sup> s<sup>-1</sup> to maintain open mouth conditions while the south-western Cape coastline requires a flow of 1 to 2 m<sup>3</sup> s<sup>-1</sup>.

Decreased river flow or drought conditions affect the volume of water flowing into an estuary. The slow flow rate often leads to mouth closures and poor flushing of the estuary. Catchments that receive more rainfall will have an increase of water to the estuary while high evaporation rates can lead to a more saline dominated estuary. This situation is further exacerbated by low river flows.

Reduction in fresh water flow can cause permanent mouth closure. The Isipingo catchment area is approximately 50 km<sup>2</sup> (Perry, 1989; Begg, 1978; Kalicharran and Diab, 1993) and illustrates the problem experienced by fresh water reduction. The reduction in the mean annual runoff by 97% due to the diversion of the Umlazi River (which joined the Isipingo estuary at its mouth) and installation of the DWS resulted in mouth closure (Kalicharran and Diab, 1993; Forbes and Demetriades, 2008). However, permanent connectivity with the near shore environment is maintained by constructed twin pipes.

During the open state the estuary remains connected to the marine environment allowing for the exchange of estuarine water and seawater, however, during low flow conditions, limited connectivity is maintained during a normal tidal cycle (van Niekerk, 2007). When the mouth is closed, the estuary is isolated from its connection with the sea. Mouth status is linked to river flows and is thus subject to variations in runoff. The duration of mouth state is strongly dependent on river inflow (van Niekerk, 2007).

### **2.5.1.2 Estuary size, tidal flow and salinity**

In estuaries that are larger than 1.5 km<sup>2</sup>, tidal flow is sufficient to maintain the open mouth state during the low flow season however, in medium sized estuaries which are less than 1.5 km<sup>2</sup>, tidal flows can only maintain an open mouth state during spring tides and often close during neap tides (DWAF, 2005). The Great Brak and Seekoei estuaries are examples of the latter (CSIR, 2003).

The Isipingo estuary has an area of approximately 0.068 km<sup>2</sup> (Begg, 1978). The amount of water flowing through the system prior to the diversion of the Umlazi River and the installation of the DWS was sufficient to maintain a natural permanently opened mouth. Currently the system only receives 3% of the original flow (Swart, 1987). Flow to the estuary has been further reduced due to maintenance problems experienced at the DWS. This has resulted in river flow being directed toward the Mbokodweni River, with the estuary only being fed by surface runoff and drainage received from the Bamboo Drain and the Prospecton area.

Decreases in river inflow of permanently and temporary open estuaries can result in increased salinity similar to that of seawater near the mouth of the estuary (van Niekerk, 2007). As river flow decreases, the ability to maintain an open mouth status diminishes which can lead to a semi-closed or permanently closed mouth which reduces tidal intrusion. Depending on the duration of the closed mouth state, the estuary can become more saline due to evaporation or gradually fresher if river inflow exceeds the evaporation rate until natural breaching occurs. With reference to the Isipingo Estuary, the area commonly referred to as the southern 'blind' lagoon, exhibits high saline conditions with electrical conductivity results ranging between 1000 to 5000 mS/m (Begg, 1978; Begg, 1984).

### **2.5.1.3 Water column stratification**

Beer (1983) stated that the amount of mixing between fresh and salt water, and the rate at which this mixing takes place are the two main aspects controlling estuarine water. In turn, these are controlled by river inflow, precipitation, evaporation, tidal variations, wind strength and estuarine topography (Beer, 1983).

Water column stratification is dependent on the extent to which water with varying temperature and salinity mix (van Niekerk, 2007). Due to the different densities of seawater, mixed water (fresh and seawater) and fresh water, there are three types of stratification that

can exist namely, highly stratified, partially stratified and non-stratified (Pethick, 1984) According to van Niekerk (2007), stratification within an estuary changes in space and time. For example, a situation can exist where an estuary can be highly stratified during high river flow periods and well mixed during low flow periods or well mixed during spring tide and partially stratified during neap tide. An estuary can also be well mixed near the mouth and stratified in its upper reaches. Schumann et al (1999) emphasised that there is usually little difference in density between surface and bottom waters of well mixed estuaries.

There are generally 3 types of estuarine classes based on the mixing levels. These are salt wedge estuaries (predominately fresh water flow), partially mixed estuaries (predominately tidal flow) and fully mixed estuaries (wide estuaries with dominant tidal flow). The effects of stratification can be significant in terms of pollutant distribution within an estuary (Villars and Delvigne, 2001). Research undertaken by Tyler and Seliger (1989) demonstrated that highly stratified estuaries isolate both the surface and bottom waters which can result in enhanced deposition within the system, development of anoxic conditions closer to the pycnocline (layer of water where the water density changes rapidly) as well as inhibiting the horizontal transport of material out of an estuary.

Begg (1978) commented on the contrast in salinity layering between the northern and southern arm of the Isipingo Estuary. Both arms exhibited bottom salinities of approximately 30‰ while the surface levels were between 20‰ to 34‰ in the southern arm and 0‰ to 5‰ in the northern arm. Work conducted by Forbes and Demetriades (2008) confirmed a similar situation. The pattern of greater stratification in the northern arm can be attributed to the fresh water input in comparison to the southern arm (lagoon).

#### **2.5.1.4 Ebb and Flood tidal flows and tidal asymmetry**

The two flows within an estuary are the tidal currents which result from the ebb and flood and residual currents as a result of the mixing of fresh and saline water. Estuaries experience alternating flood tide currents (incoming currents which are landward directed) and ebb tide currents (outgoing currents which are seaward directed) with considerable changes experienced in current velocity throughout the tidal cycle (Bird, 2000). According to Masselink and Hughes (2003), during a complete tidal cycle, flood and ebb tidal currents are experienced in equal periods (i.e. tidal symmetry). Tidal asymmetry occurs as a result of cyclic asymmetry in the ebb and flood tidal currents which imply that in some estuaries the flood tide currents may be higher than the ebb tide currents (Beck *et al.*, 2004) and this is

further elaborated on below. Tidal symmetry and asymmetry are therefore influential in the transport as well as residence time of materials within estuaries (Fernandes, 2011).

There are several reasons for tidal asymmetry and Schumann et al (1999) attribute shallow depths and constrictions at the estuary mouth as one of the causes. Masselink and Hughes (2003) cited the difference between the wave velocity of the crest and trough of the tidal wave as another reason for tidal asymmetry. Both Pethick (1984) and Dyer (1997) highlighted that the crest of the tidal wave moves faster than the trough in shallow and frictionless estuaries that exhibit large tidal variations in water depth. This gives rise to a shorter flood tide and a longer ebb tide, with maximum velocity experienced on the flood tide (Dyer, 1997).

Masselink and Hughes (2003) emphasised that maximum flood and ebb tide velocities occur at high and low tide respectively while current reversal and zero velocities (i.e. slack water conditions) takes place during mid tide (Figure 2.2).

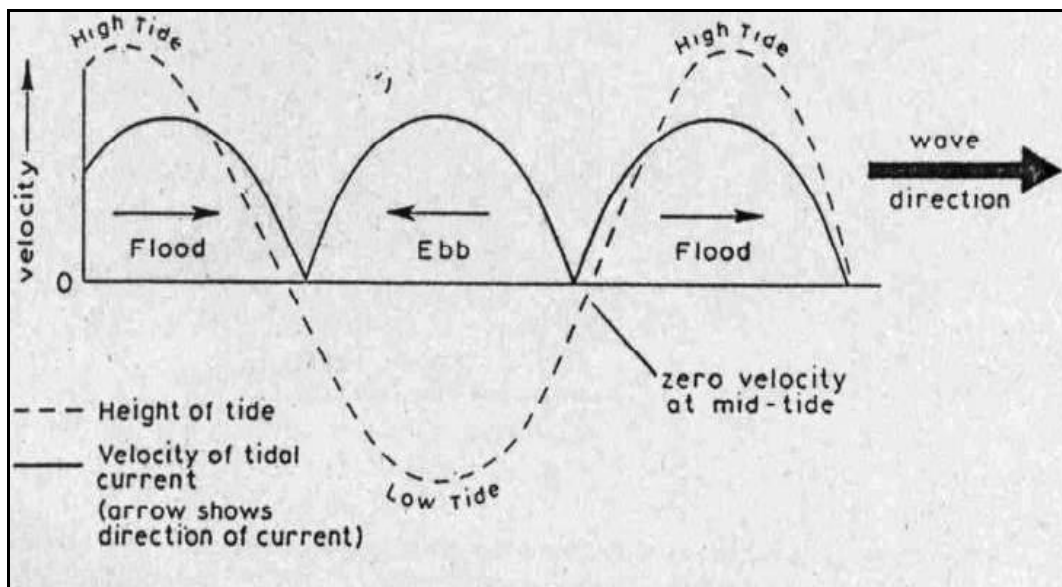


Figure 2.2: Tidal-stage velocity at estuary mouth depicting maximum velocities achieved at high and low water and the concept of zero velocity attained at mid tide (after Pethick, 1984, p. 164)

The velocities attained during tidal flows depend partly on the characteristic of the tidal wave, such as the tidal range and asymmetry of the tide and partly on the morphology of the channel through which the currents flow. Beck et al (2004) further explained that flood and ebb dominated estuaries are related to the dominance of flood and ebb tide currents in

estuaries. In estuaries that are flood dominated, the flood tide is larger in velocity and magnitude as well as a shorter in duration than the ebb tide and the opposite true for ebb dominated estuaries (Masselink and Hughes, 2003).

## **2.6 Assimilative capacity of water resources**

Many rivers in South African have been impacted by different land use activities and practices and as such serve as conduits of pollution which eventually ends up in estuaries and the sea (Philip, 2010). Estuaries, being the recipients of materials transported along rivers, can act as either a trap or a source or both of materials such as nutrients, heavy metals and sediments.

The concentration and load of materials or pollutants can change considerably as the river meanders through the landscape. The *„assimilative capacity’* of a water body refers to the ability of that water body to tolerate the input of waste material by absorbing, degrading or transforming it (i.e. a certain quality and load) without creating a situation whereby the quality of water deteriorates to such a state that other water uses are adversely affected (DWAF, 2000). Assimilative capacity differs between water bodies depending on the nature of the waste material and the characteristics of the receiving water body in terms of its ability to dilute, disperse and degrade contaminants (CSIR, 2010a).

Water in rivers usually has a residence time of about two weeks (DWAF, 2001a). Based on this, a single pollution incident such as the spillage of sewage from a sewer line would have a short term impact as the water would leave the river environment. However, the severity of the impact would depend on the volume of sewage that was released into the environment, the assimilative capacity of the water resource and whether or not any of the pollutants adhered to the sediment in the river bed. Pollution problems are more likely to result from chronic processes which discharge pollutants directly into rivers or onto land over an extended period of time (Keller, 1992; DWAF, 2001a).

### **2.6.1 Water quality**

The term water quality is used to describe the physical, chemical, biological and aesthetic properties of water which determine its fitness for use and its ability to maintain the ~~health~~ integrity of aquatic ecosystems (National Water Act, 1998). These properties are affected by the amount of either dissolved or suspended matter or constituents found in water.



According to the Department of Water Affairs and Forestry (1996c), the quality of water determines its fitness for use. The concept of fitness for use implies that different users (e.g. agriculture, domestic or industrial) would require water of a certain quality or standard for use. This means that water which would be ideally fit for use for one specific user group may not be ideally suited for another. The South African Water Quality Guidelines (SAWQG) for freshwater resources were produced by the Department of Water Affairs and Forestry (now known as the Department of Water Affairs, DWA) to determine a target level for each specific water user namely: domestic, recreational, aquatic ecosystems, industrial and agricultural (irrigation, livestock watering and aquaculture), where there would be no detrimental health effects.

### **2.6.1.1 Eutrophication**

Eutrophication is a process whereby aquatic ecosystems become progressively enriched with plant nutrients over time (Figure 2.3); however, the problem can be exacerbated by enrichment from anthropogenic sources (Walmsley, 2000). The rate and extent of aquatic plant growth is dependent on the concentration and ratios of nutrients present in the water. Phosphorus (P) and nitrogen (N) have been identified as the key nutrients in the eutrophication process (Walmsley, 2000). Phosphorus is recognized as the fundamental cause of eutrophication (Chiaudani and Premazzi 1988; Carbiener, 1990) and is described as the controlling or limiting factor in aquatic systems (Hart *et al.*, 1992; DWAF, 1996b).



Figure 2.3: An example of eutrophication of a water resource (after Roussouw and Forster, 2008, p. 7)

South Africa's freshwater resources are excessively enriched and are considered to be moderately to highly eutrophic (CSIR, 2010a). As nutrients are present in sewage effluent, the problem is accentuated wherever there is a concentration of humans or animals (DWAF, 2004a). Other sources include agricultural runoff and industrial effluents. Algal blooms are experienced which can result in oxygen depletion when the plant matter decays causing fish kills. Algae cause problems with water purification, e.g. undesirable tastes and odours, and the possible generation of potentially carcinogenic substances in water that is treated with chlorine for potable purposes (DWAF, 1997).

### **2.6.1.2 Water borne diseases**

About 25% of all deaths worldwide are the result of infectious diseases caused by pathogenic micro-organisms (UNEP, 1996). Pathogens include bacteria (*Escherichia coliforms* or *E. coli*, faecal coliforms) viruses, protozoa and parasitic worms, fungi and viruses (DWAF, 1996a). The main sources of pathogens include raw sewage originating from areas that do not have adequate sanitation facilities, insufficiently treated effluent from sewage treatment works and uncontrolled runoff from feedlots.

Some of the diseases include typhoid fever, cholera, dysentery, enteritis, schistosomiasis and giardiasis (DWAF, 1996b). Some of the pathogens use aquatic organisms as hosts such as *Schistosoma sp.*, which causes bilharzia via a type of aquatic snail called *Biomphalaria sp.* (Sukdeo, 2010). The World Health Organisation confirmed that that over 90% of the total cases of cholera reported in 2009 originated from the African continent (WHO, 2009) stemming from inaccessibility to proper sanitation facilities as well as improper management and maintenance of sanitation systems which has resulted in poor water quality of aquatic ecosystems.

### **2.6.1.3 Sedimentation**

Average sediment yields for South African catchments range from less than 10 to more than 1 000 tonnes/km<sup>2</sup>/annum (DWA, 2010). The average annual sediment yields derived from simulated daily sediment loads as part of Rooseboom's study (1992) on the Umgeni River system ranged from 20 to 723 tonnes/km<sup>2</sup>/annum. Land degradation and overgrazing, soil erosion, mining, informal dense settlements and subsistence agriculture are amongst the biggest drivers of sedimentation problems experienced (DWA, 2010). In some parts of the country erosion has increased by as much as tenfold as a result of human impacts (DWA,

2010). Natural flood events also contribute to sedimentation. The September 1987 flood event resulted in the scouring of between  $1.86 \times 10^6$  and  $3.5 \times 10^6$  m<sup>3</sup> of sediment from the estuary, which was deposited into the Indian Ocean while fine sand and mud was deposited on the river banks after the flood waters subsided (Garland and Moleko, 2000). Mason and Wright (1993) recorded values of greater than 600 000 m<sup>3</sup> of sediment that accumulated in the St. Lucia Estuary mouth from February 1988 to November 1989.

Sedimentation can reduce the visibility in water and limit sunlight required by aquatic plants for photosynthesis. Substances such as metals, organic compounds and bacteria attach to sediment and are transported along river systems and are eventually deposited. Sedimentation also reduces capacity of dams and reservoirs thereby decreasing retention and conveyance capacity which can lead to increased flooding (DWAF, 2002; DWA 2010). Archer (1996) calculated a sediment inflow of 357 m<sup>3</sup>/km<sup>2</sup>/annum to the Kamburu reservoir located on Kenya's Tana River. Another effect of sedimentation is the loss of benthic habitat emanating from the smothering of benthic organisms, including the eggs and immature forms of aquatic organisms (DWAF, 2000).

#### **2.6.1.4 Toxicity (metals)**

Many metals and other toxic pollutants can attach to suspended solids and may accumulate in the bottom sediments of rivers (DWAF, 1997). These metals and pollutants can persist for many years and can become concentrated in bottom sediments and can lead to adverse impacts on benthic organisms. Research has indicated that the accumulation of pollutants in bottom sediments may also adversely affect fish during periods of continuous low flow (DWAF, 2002).

### **2.7 Material exchange between estuaries and the marine environment**

Estuaries have a prominent role in regulating material fluxes from land to sea (Crossland *et al.*, 2005). Costanza *et al* (1997) noted the valuable role played by estuaries in terms of their capacity to reduce riverine nutrient loads to sea. A study conducted on the Palmones Estuary in Spain demonstrated the systems' ability to export nitrogen and phosphorus to the marine environment. Other international studies that quantified the amount of material entering the marine environment included work by the North Sea Task Force (1993); Balls (1994); Talyor *et al* (1995); Yin and Harrison (2000) and Cole *et al* (2001).

There is limited information available in South Africa with regard to the exchange of material (nutrients, metals, inorganic and microbiological variables) between estuaries and the near-shore environment. The 'outwelling hypothesis' is the idea that estuarine systems produce more material (both dissolved and particulate) than can be utilized or degraded within the system, and that excess material is exported to the coastal marine environment where it may contribute to marine productivity (Winter and Baird, 1991). Outwelling is affected by a number of different factors such as the primary production of an estuary, the tidal amplitude and geomorphology (Odum, 2002). Odum (2002) explained that outwelling is not a steady process and is affected by rainfall events. The quantity and quality of the material imported or exported depends of whether the estuary is dominated by river flow or tidal action (Jennings, 2005). Estuaries that receive less freshwater inflow as a result of excessive water abstraction activities in the catchment, diversion of water and the development of impoundments are more likely to import material if tidal action is more dominant than river inflow. The Kariega estuary located along the Eastern Cape coastline is an example of a system where tidal volume is larger than river inflow by a ration of 106:1 (Bate *et al.*, 2002). In freshwater dominated estuaries, there is a net export of dissolved and particulate material to the marine environment (Dame and Allen, 1996).

In South Africa most estuaries are flood-dominant, which means that it is common for flood tides to move in more material than that removed by the ebb tides. The ebb and flow of sea water into and out of an estuary influences not only the distribution of materials within a system, but is also responsible for the export and import of enormous quantities of organic and inorganic matter (Winter and Baird, 1991).

There have been previous studies conducted on material exchange between estuaries and near shore environments which have reported a net export of particulate organic material and inorganic nutrients (Baird and Winter, 1989; Dame and Allen, 1996). Baird *et al* (1987) studied carbon fluxes as well as inorganic and organic particulate matter transfer between the Swartkops Estuary near Port Elizabeth and the nearshore environment and concluded that the Swartkops Estuary was a net exporter of total suspended particulate matter. A study conducted in a New England salt marsh found no evidence of outwelling and concluded that the system was importing carbon (Nixon, 1980). Fernandes (2011) investigated net flux for three estuaries within the eThekweni Municipality namely the Isipingo, Umgeni and Tongati Estuary. The findings demonstrated that the Isipingo Estuary was a net importer of nitrates on the spring tide for all seasons except winter while the Umgeni system exported nitrates

for all season except autumn, when nitrates were imported on both the spring and neap tide. The Tongati Estuary was a net exporter of nitrates throughout the year (Fernandes, 2011; Fernandes and Pillay, 2012). Other research studies conducted by Baird and Winter (1992) and Taylor and Allanson (1995) has demonstrated that in micro-tidal estuaries, the 'outwelling hypothesis' does not hold true and material is being imported into some estuaries.

## **2.8 Estuarine and Riverine sediments**

Fluvial sediment reflects the parent geology of the catchment from which it is derived (Schumann *et al.*, 1999; Sukdeo, 2010). Finer sediments are kept in suspension and tend to be transported over larger distances (David, 2006) and tend to build up within the upper section an estuary (Schumann *et al.*, 1999). Estuaries are therefore basins for fine grained sediments that are easily reactive to heavy metals (Ujevic *et al.*, 2000; Carrasco *et al.*, 2003; Prego and Cobelo-Garcia, 2003; Rosales-Hoz *et al.*, 2003; and Cobelo-Carcia *et al.*, 2004). Partially or completely closed estuaries may develop a high level of contamination in their sediments (Rosales-Hoz *et al.*, 2003) due to the low ability of these systems to flush pollutants to the marine environment (Sukdeo, 2010).

Contaminants tend to adhere to fine grained sediment (< 0.063mm) such as clays and silt with large grained particles playing no role in contaminant transport; however large grained particles are important in shaping the morphology of river and estuary systems (Villars and Delvigne, 2001). During transportation to and deposition in an estuary, sediments can undergo changes due to chemical and biological processes, salinity variations, vegetation, etc. The physiochemical interactions between fine sediment and the water column influences water quality (Sukdeo, 2010) and are discussed briefly below.

### **2.8.1 Geochemistry**

Sediment chemistry is also closely linked to the water quality of the overlying water body and according to Sager (1992), the sediment-water interface is very important as chemical reactions tend to occur at or near the vicinity of these geochemical boundaries. There are four factors which can influence sediment chemistry (Hardman *et al.*, 1993), specifically, a change in pH (generally associated with pH reduction), change in salinity (normally related to increases in salinity), increase of the concentration of natural and synthetic agents, and the alteration of redox conditions of sediment (Hardman *et al.*, 1993). Changes in water

quality can lead to the development of reducing or oxidizing conditions which can result in the mobilisation or adsorption of substances from or onto sediment particles. Cadmium and iron for example are more mobile under oxidizing conditions and tend to adhere to bottom sediment under reducing conditions (DWAF, 1996c).

Flocculation of fine electrically charged particles is enhanced in saline environments. Clay and colloidal particles (<0.063 mm) have high surface area to volume ratios and may carry electrical charges (Lewis and McConchie, 1994 as cited in Sukdeo, 2010). Electrically charged contaminants may be easily adsorbed onto floccules which precipitate out and become incorporated in the estuarine bed sediments. The processes of flocculation and deflocculation are considered to be very important assessing sediment and water column pollutant status (Villars and Delvigne, 2001).

Physical processes such as wind induced wave turbulence or variation in flow velocity due to changes in freshwater discharge or tidal pattern and can cause the re-suspension of bottom sediment and hence increase suspended particle concentrations in the water column.

Sediment is an important component of aquatic ecosystems but can also serve as a sink and reservoir for a variety of contaminants introduced into surface waters (CSIR, 2010a; Milenkovic *et al.*, 2005). Due to some contaminants affinity for organic matter, contaminant concentration in the water column is very variable and therefore water samples only provide a snapshot of what is occurring within the water column at a specific moment in time. Sediments on the other hand integrate contaminants over time and are in constant flux with the overlying water column (Binning and Baird, 2001). The detection of elevated concentrations of contaminants such as heavy metals in sediment is a good indication of human-induced pollution and high levels of contaminants can often be attributed to anthropogenic influences, rather than natural enrichment of the sediment by geological weathering (Davies *et al.*, 1991; Binning and Baird, 2001).

Sediment-associated pollutants can influence the concentrations of trace metals in both the water column and biota if they are desorbed or become available (Milenkovic *et al.*, 2005). In hydro-dynamically low energy environments (such as estuaries), where there is little sediment redistribution, contaminants can accumulate in bottom sediment to concentrations high enough to adversely affect organisms (Chapman, 1989 as cited in CSIR, 2010b).

## 2.8.2 Determining the level of sediment contamination

High metal concentrations in sediment do not automatically imply that contamination has taken place. These concentrations can signify the chemical composition and mineralogy of the parent rock. Hanson et al (1993) as cited in the CSIR (2010b) stated that naturally occurring and anthropogenically introduced metals tend to accumulate in the same areas. This is why the mineralogic and granulometric factors that influence the natural variations of metal concentration in sediment must be firstly compensated for. This will then differentiate naturally occurring metal concentrations from anthropogenic concentrations.

Geochemical normalization is a process that is used to compensate for these differences by normalizing metal concentrations to co-occurring conservative element (the normaliser or reference element) that provides the tracer of crustal decomposition (Kersten and Smedes, 2002 as cited in CSIR, 2010b). Aluminium and iron are often used as normalisers. Aluminium is more preferable, according to Kersten and Smedes (2002) as it is stable and unaffected by redox effects. Iron on the other hand, is highly mobile in anoxic sediments which leads to its enrichment at the sediment surface through deposition of iron oxides (Finney and Huh, 1989 as cited in CSIR, 2010b) or in deeper sediments through co-precipitation with sulphides (CSIR, 2010b) which can lead to an underestimation of the enrichment of other metals not similarly affected when iron is used as the normaliser. This makes its use as a normaliser potentially limiting.

Geochemical background refers to the natural abundance of an element in a particular material (e.g. soil, sediment, rock) of a specific geological type or with reference to a particular area (Martinez *et al.*, 2007; Devesa-Ray *et al.*, 2009). These values are generally used when determining whether the concentrations of certain elements in sediment are due to natural or anthropogenic sources (Martinez *et al.*, 2007). When local background values are not available, then a direct comparison with average crustal (also known as Clarke values) or shale values can be utilised (Devesa-Ray *et al.*, 2009).

The parent geology of the Isipingo catchment is composed predominantly of sedimentary rocks. In the absence of sediment quality guideline values in South Africa as well as background sediment quality concentrations for the Isipingo catchment, Clarke values for sedimentary rocks were used as background values in this study and are representative of the mean elemental composition of sedimentary rocks.

Numerous techniques have been developed to assess the degree of contamination in aquatic sediments. These include the computation of the Enrichment Factor (EF), Contamination Factor (CF), degree of Contamination ( $C_d$ ) and the Geo-accumulation Index ( $I_{geo}$ ) which is discussed in greater detail in Chapter three.

## **2.9 Water Quality Variables**

### **2.9.1 pH**

pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body (Chapman, 1992). The pH value is a measure of the hydrogen activity in water and the equilibrium between  $H^+$  and  $OH^-$  ions is influenced by reactions with acids and bases (DWAF, 1996a). According to DWAF (1996a), pH fluctuations over a 24 hour period can be attributed to photosynthesis and respiration while higher pH values may be exhibited in systems that are eutrophic as a result of increased biological activities. Effects of drastic pH changes can upset the osmotic balance of organisms and can increase toxicity of certain substances. The South African Water Quality Guidelines (SAWQG) indicates a Target Water Quality Range (TWQR) of 6.0 – 9.0 for domestic use and a TWQR of 6.5 – 8.5 for recreational use (full contact). For aquatic ecosystems, the pH should not be allowed to vary from the range of the background pH values for a specific site and time of day by  $> 0.5$  or by  $> 5\%$  (DWAF, 1996c).

### **2.9.2 Electrical Conductivity**

This refers to the ability of water to conduct an electric current (Chapman, 1992; DWAF, 1996a). The degree to which ions dissociate, the amount of electrical charge on each ion, ion mobility and temperature of the water body influences conductivity (Chapman, 1992). It is related to the concentrations of Total Dissolved Solids (TDS). The conductivity of most freshwater systems ranges between 10 to 1000  $\mu S/cm$  (Chapman, 1992).

### **2.9.3 Total Dissolved Solids**

The Total Dissolved Solids (TDS) concentration is a measure of the quantity of all ionized and un-ionized compounds, both inorganic and organic, dissolved in water (DWAF, 1996a). In natural waters, inorganic ions such as sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), bicarbonate ( $HCO_3$ ), carbonate ( $CO_3$ ), chloride (Cl) and sulphate ( $SO_4$ ) contribute greatly to TDS. Other less common inorganic ions include the macro-nutrients,



nitrate ( $\text{NO}_3$ ) and orthophosphate ( $\text{PO}_4$ ) and certain metals (Dallas and Day, 1993). Air moving inland from the sea, can carry significant quantities of sea-salt which is introduced to the water body via precipitation (Dallas and Day, 1993). In South Africa, TDS is generally equivalent to conductivity multiplied by a factor of 6.6 (Dallas and Day, 1993).

According to the SAWQG for domestic use the TWQR is between 0 and 450 mg/l while for aquatic ecosystem, Total Dissolved Solids concentrations should not be changed by > 15% from the normal cycles of the water body under unimpacted conditions at any time of the year (DWAF, 1996c).

#### **2.9.4 Dissolved Oxygen**

The oxygen content of water bodies vary with temperature, salinity, turbulence, photosynthetic activity of algae and plants and atmospheric pressure (Chapman, 1992). The solubility of oxygen decreases as temperature and salinity increases (Chapman, 1992). High organic material and nutrient can also lead to extremely low dissolved oxygen concentration close to the bottom waters due to the decomposition of this material. Photosynthesis by aquatic plants and re-aeration from the atmosphere or turbulence in the water resource increases dissolved oxygen levels (Dallas and Day, 1993). Low dissolved oxygen concentrations can lead to the remobilization of some metals from sediment (DWAF, 1996c). Under such conditions increased toxicity of zinc, lead, copper, cyanide, sulphide and ammonia have been observed (DWAF, 1996c). Super-saturated water bodies inhibits photosynthesis of green algae but this environment then starts to favour blue-green algae (DWAF, 1996c).

Dissolved oxygen levels of below 5 mg/l can affect the functioning of biological communities while levels of below 2 mg/l may lead to the death of most fish (Chapman, 1992). However, Snow and Taljaard (2007) indicated that dissolved oxygen concentrations greater than 3 mg/l is unlikely to result in the stress or death of organisms. Generally, healthy aquatic ecosystems can have dissolved oxygen concentrations close to, but less than, 10 mg/l (UNEP/WHO, 1996). However, according to the water quality guidelines dissolved oxygen above 6 mg/l are aquatic to sustain aquatic life (DWAF, 1996c) while Dallas and Day (1993) recommend a level greater than 4 mg/l.

## 2.9.5 Nutrients

Nutrients are chemical substances used for the maintenance and growth that are critical for survival (USEPA, 2006). Plants require a number of nutrients such as nitrogen, phosphorus, silica, magnesium, potassium, calcium, iron, zinc and copper to grow. Of these, nitrogen and phosphorus are of particular concern as high concentrations of these nutrients in water bodies can lead to eutrophication which results in excessive algal blooms. Die-off of algae can result in the depletion of oxygen in the water due to decomposition. Slow moving water bodies and estuaries with insufficient mixing can become hypoxic (low in oxygen) and under extreme conditions, the bottom waters of an estuary can become anoxic (without oxygen). In the United States, over 50% of estuaries have been classed as being hypoxic due to excessive nutrient levels (USEPA, 2006). According to DWAF (1996c), unimpacted systems have a N:P ratio greater than 25-40:1 while impacted systems have a N:P ratio of less than 10:1.

### 2.9.5.1 Nitrogen

Inorganic nitrogen comprises of ammonia ( $\text{NH}_3$ ), ammonium ( $\text{NH}_4^+$ ), nitrate ( $\text{NO}_3^-$ ) and nitrite ( $\text{NO}_2^-$ ).  $\text{NH}_3$  and  $\text{NH}_4^+$  are the reduced forms of inorganic nitrogen and their proportions are controlled by water temperature and pH and both can exist in the dissolved form or can be adsorbed onto sediment (DWAF, 1996c).  $\text{NO}_2^-$  is the inorganic intermediate and  $\text{NO}_3^-$  is the end product of the oxidation of organic nitrogen and ammonia. Under aerobic conditions nitrite is oxidized to nitrate while under anaerobic conditions, the nitrate is reduced to nitrite (USEPA, 2006). According to the TWQR for aquatic ecosystem, inorganic nitrogen should not change by more than 15% from that of the water body under local impacted conditions (DWAF, 1996c).

According to Chapman (1992, p. 17), „the biological transformations consist of:

- a) *assimilation of inorganic forms (ammonia and nitrate) by plants and micro-organisms to form organic nitrogen e.g. amino acids;*
- b) *reduction of nitrogen gas to ammonia and organic nitrogen by micro-organisms;*
- c) *complex heterotrophic conversions from one organism to another;*
- d) *oxidation of ammonia to nitrate and nitrite (nitrification);*
- e) *ammonification of organic nitrogen to produce ammonia during the decomposition of organic matter; and*

- f) *bacterial reduction of nitrate to nitrous oxide (N<sub>2</sub>O) and molecular nitrogen (N<sub>2</sub>) under anoxic conditions (denitrification).*

### 2.9.5.1.1 Ammonia

Ammonia may be present in water in the unionized form (NH<sub>3</sub>) or in ionized form as ammonium ion (NH<sub>4</sub><sup>+</sup>). In aqueous solution, ammonia exists in equilibrium with the ammonium ion and the position of equilibrium is governed by pH and temperature (DWAF, 1996c) (Figure 2.4). The sum of both these forms is total ammonia (Chapman, 1992).

The NH<sub>3</sub> form is toxic while the NH<sub>4</sub><sup>+</sup> form has little or no toxicity to aquatic organisms (DWAF, 1996a). Common sources of ammonia include sewage discharges, atmospheric deposition, fertilizers, industrial effluents that use ammonia or ammonium salts in their processes (DWAF, 1996c). An increase in water temperature and pH increases the proportion of ammonia in a water body as well as its toxicity (DWAF, 1996a). Under acidic conditions ammonia has low toxicity as it is available in the ammonium ion form. Toxicity to fish also increases as dissolved oxygen decreases. The TWQR for aquatic ecosystems is < 7µg N/l or 0.007 mg N/l while that for domestic use is between 0-1 mg N/l. Inorganic nitrogen concentrations < 0.5 mg N/ l are considered to be low enough to limit eutrophication but in the presence of phosphorus, nitrogen fixing organisms can fix atmospheric nitrogen enabling excessive plant growth (DWAF, 1996c).

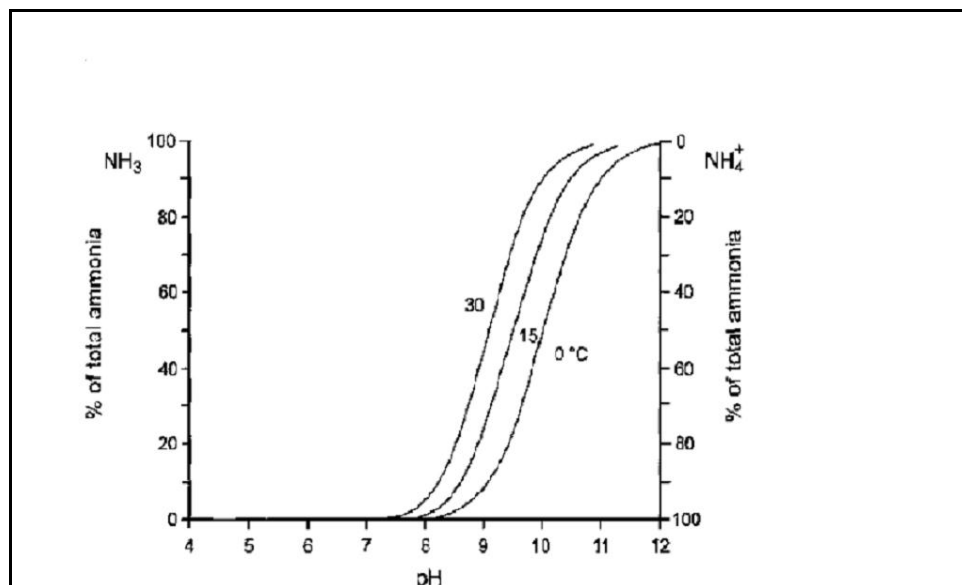


Figure 2.4: Relationship between the percentage of un-ionised and free ammonia and varying pH in freshwaters (Chapman, 1992).

### 2.9.5.1.2 Nitrate and nitrite

The nitrate ion ( $\text{NO}_3^-$ ) is the common form of combined nitrogen found in natural waters (Chapman, 1992). Through the process of denitrification, it is reduced to nitrite ( $\text{NO}_2^-$ ), usually under anaerobic conditions. Nitrate is formed through the oxidation of  $\text{NH}_3$ ,  $\text{NO}_2$  and inorganic nitrogen. Sources can include sewage effluent, industrial effluent, agricultural fertilizers, etc. Nitrate in drinking water is a health concern as it can be readily converted in the gastrointestinal tract to nitrite as a result of bacterial reduction (DWAF, 1996a). When this occurs, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin to form methaemoglobin, which is incapable of carrying oxygen. This condition is termed *methaemoglobinaemia* and often results in the death of infants known as 'blue baby syndrome' (DWAF, 1996a). The TWQR for domestic use is between 0-6 mg N/ l while there is no TWQR specified for aquatic ecosystems.

### 2.9.5.2 Phosphorus

Phosphorus is an essential nutrient for living organisms and can exist in the following forms in water: organic phosphate, orthophosphate (inorganic, dissolved phosphorus), total phosphorous (dissolved and particulate) and polyphosphates (detergents) (USEPA, 2006, Walmsley, 2000) (Figure 2.5). Phosphorus occurs mostly as dissolved orthophosphates and polyphosphates, and organically bound phosphates in natural waters and in wastewater. (Chapman, 1992). Natural sources of phosphorus occur mainly due to the weathering of phosphorus-bearing rocks and the decomposition of organic matter (DWAF, 1996c). Excess phosphates can also enter water bodies from sewage treatment works, fertilizer run-off, industrial effluents and domestic waste waters, particularly those containing detergents.

Phosphate is very reactive under oxidising conditions and reacts with cations to form insoluble compounds that precipitate out of water (DWAF, 1996c). Phosphates can also be adsorbed to inorganic colloids and organic compounds such as clays. During periods of low river flow, sediments act as a sink for phosphorus. Under high flow or anoxic conditions adsorbed phosphorus can be released from sediments (Figure 2.5). Orthophosphate ions are adsorbed by clays and iron or aluminium oxides in the soil. Precipitation of phosphate (with either iron or aluminium oxides or dissolved calcium) forms solid compounds in the soil or water column, which may represent relatively long term storage of phosphorus as regeneration is very slow due to the stability of the complexes formed (DeBusk, 1999).

Orthophosphates are the only form of dissolved inorganic phosphorus directly utilizable by aquatic biota (Lawrie, 2007).

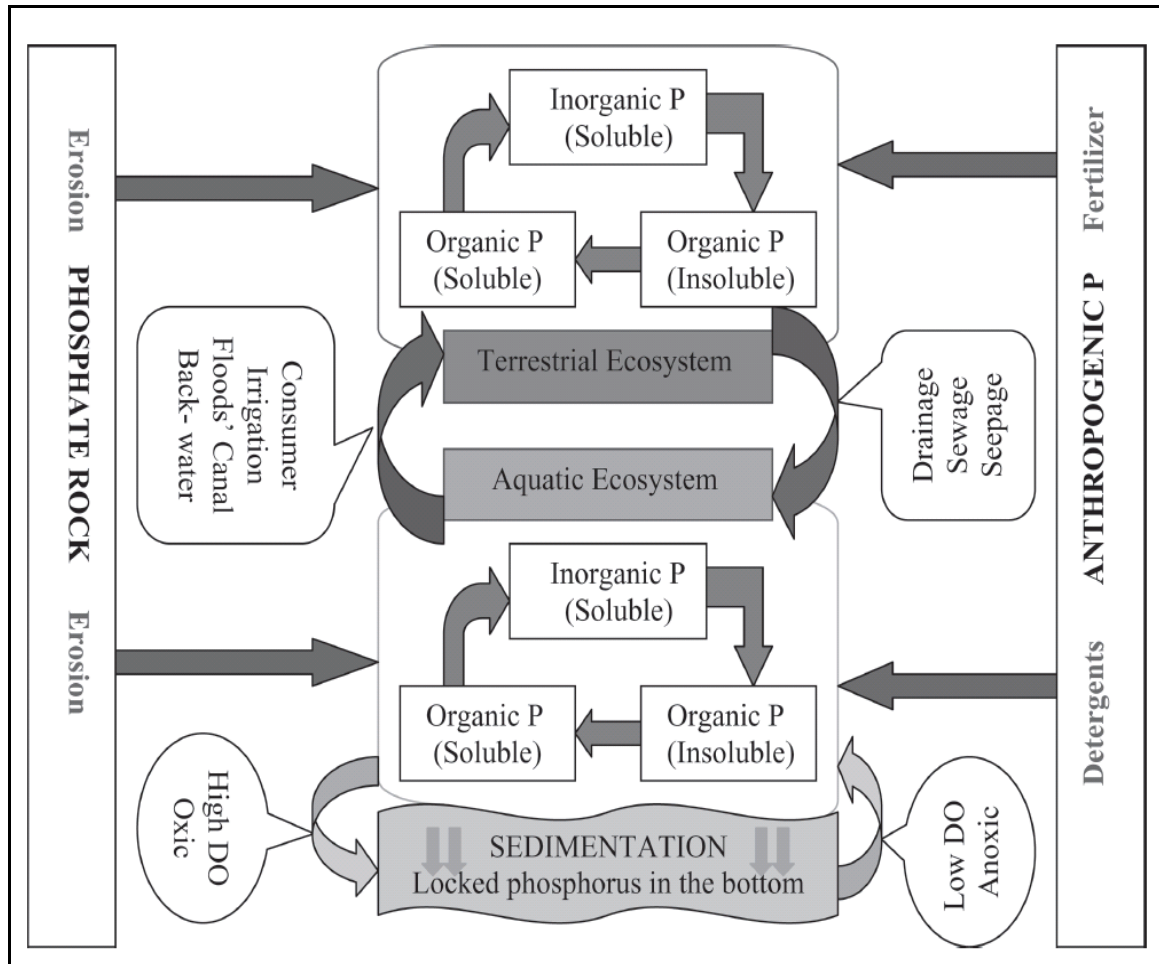


Figure 2.5: The Phosphorous cycle (Khan and Ansari, 2005, p. 459)

### 2.9.6 Major cations (commonly referred to as micro-nutrients)

The ions that are most commonly found in natural waters are calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) which are referred to as cations (positively charged ions) while the most common negatively charged ions (anions) are bicarbonate ( $\text{HCO}_3^-$ ), carbonate ( $\text{CO}_3^{2-}$ ), chloride (Cl) and sulphate ( $\text{SO}_4^{2-}$ ) (Dallas and Day, 1993). The cations are also commonly classified as micronutrients. This study was confined to analyzing the cation concentration in the Isipingo system and therefore only the major cations will be discussed in more detail below.

### **2.9.6.1 Calcium**

Calcium is one of the contributors to water hardness. Mineral deposits of Ca occur mainly as calcium carbonate, calcium phosphate and calcium sulphate (DWAF, 1996a). Typically, the concentration of Ca in fresh water is 15 mg/l and is usually present as  $\text{Ca}^{2+}$  (DWAF, 1996a). Industrial effluent as well as water and wastewater treatment processes can contribute to Ca in surface water. The solubility of Ca in water governed by carbonate/bicarbonate equilibrium and is influenced greatly by pH and temperature (DWAF, 1996a). Calcium also interacts with other cations as well as with organic and inorganic anions. Calcium influences integrity of cell membranes and therefore influences adsorption and toxicity of heavy metals (Dallas and Day, 1993).

### **2.9.6.2 Magnesium**

Magnesium is a common constituent of water and also contributes to water hardness (DWAF, 1996a). It is also an essential nutritional element and a basis essential element for plants (Dallas and Day, 1993). The typical concentration of Mg in fresh water is 4-10 mg/l (DWAF, 1996a). Magnesium can occur naturally in water as a result of the weathering of ferromagnesium minerals and carbonate rocks (DWAF, 1996a). The general solubility of Mg in water is governed by pH. Magnesium hydroxide ( $\text{MgOH}$ ) is soluble at pH 7 but decreases in solubility as pH increases (DWAF, 1996a). Magnesium also interacts with Ca, various anions and organic acids (DWAF, 1996a). According to DWAF (1996a), adverse effects such as the suppression of the central nervous system and heart function are rarely seen as excess Mg is readily excreted by the kidney. However, excessive intake of magnesium sulphate results in diarrhoea.

### **2.9.6.3 Sodium**

Sodium is ubiquitous in natural waters and in many inland South African waters (Dallas and Day, 1993). It is also one of the major cations in the composition of sea water. The concentration of Na in fresh water is generally low in areas with high rainfall. Some sources of high Na includes industrial wastes, domestic wastewater and the agricultural sector arising from surface runoff and via leaching from irrigated soils (DWAF, 1996a). Sodium is very soluble in water and doesn't precipitate when water evaporates unless saturation occurs (DWAF, 1996a). It also metabolically interacts with potassium (DWAF, 1996a). According to DWAF (1996a), the excessive intake of Na can exacerbate certain disease

conditions such as hypertension, cardiovascular or renal diseases. In fresh water resources, the ideal concentration of Na is <100 mg/l in the no effects health range (DWAF, 1996a).

#### **2.9.6.4 Potassium**

Potassium always occurs in water in association with anions, usually chloride, but can also occur with sulphate, bicarbonate, or nitrate (DWAF, 1996a). Generally the concentration of K in fresh water is between 2 to 5 mg/l (DWAF, 1996a). Potassium salts are often used in industry and in fertilizers for agricultural purposes and as such high concentrations can occur in runoff from irrigated land, fertilizer and domestic wastes. Urine has a high concentration of potassium (DWAF, 1996a). Rocks which contain K are resistant to weathering. According to DWAF (1996a), potassium salts are highly soluble in water. The consumption of high concentrations of K can cause nausea and vomiting while electrolyte disturbances can occur, mainly in infants or in patients with kidney pathologies on a potassium-restricted diet (DWAF, 1996a).

#### **2.9.7 Microbiological variables**

There are a number of pathogenic viruses, protozoa and bacteria that can be transmitted through the medium of water (DWAF, 1996a) which can cause a multitude of diseases such as gastroenteritis, typhoid fever, cholera, eye, ear, nose and skin infections (DWAF, 1996b). Many of these microorganisms originate from water polluted with human excrement. The health risk to man as a result of the presence of these pathogens depends on the use of the water (domestic, recreational activities, irrigation, shellfish harvesting) and on the concentration of these pathogens in the water resource (Ouattara *et al.*, 2009).

Several physical, chemical and biological factors such as exposure to sunlight, temperature, pH, turbidity, nutrients and toxic substances play a pivotal role in the survival or elimination of micro-organisms in aquatic systems (DWAF, 1996c). Other natural processes such as sedimentation, adsorption, coagulation and flocculation may remove micro-organisms from water with or without inactivation (CSIR, 2010a). These micro-organisms can even multiply under favourable conditions such as sufficient availability of nutrients and high temperatures (DWAF, 1996c).

Faecal coliforms are a subgroup of Total coliforms and relates more closely to faecal pollution. Total coliforms may be comprised of Faecal coliforms and other bacteria found in the natural environment, soil and/or water. *Escherichia coli* (*E. coli*) is a highly specific

indicator of faecal pollution. The difference between *E. coli* and other coliforms is that *E. coli* is found exclusively in the faeces of humans and warm-blooded animals (DWAF, 1996a). *E. coli* in water bodies indicates recent contamination by sewage or animal waste and it also indicates the presence of disease-causing bacteria, viruses and protozoa (DWAF, 1996a).

A summary of the effects of common indicator bacteria groups (Total coliforms, Faecal coliforms and *Escherichia coli*) are tabulated in Appendix 2.

## **2.10 Heavy Metal: Definition and sources**

Metals are intrinsic, natural constituents of our environment (Aderinola *et al.*, 2009) and are generally present in low concentrations (Nussey, 1998). Dallas and Day (1993, p. 123), defined a metal as “*an element that is a good conductor of electricity and whose electrical resistance is directly proportional to the absolute temperature.*” In geological terms, trace metals are considered to be those metals occurring at less than or equal to 1000 ppm in the earth’s crust (Dallas and Day, 1993). Iron and aluminium are included as trace metals as they often occur in trace amounts in water. The term “heavy metals” refers to any metallic elements that have a relatively high density and are toxic or poisonous even at low concentrations (Lenntech, 2004). According to Garbarino *et al* (1995) and Hawkes (1997), heavy metals is a term given to the group of metals and metalloids with atomic densities greater than 4g/cm<sup>3</sup> or 5 times or greater than water. Viljoen (1999) considers, zinc (Zn), copper (Cu), lead (Pb), mercury (Hg), cadmium (Cd), nickel (Ni) and chromium (Cr) to be the most important heavy metals affecting water resources and aquatic ecosystems. Other heavy metals include arsenic (As), silver (Ag), Iron (Fe), and the platinum group elements (Duruibe *et al.*, 2007). Arsenic (As), Selenium (Se) and Strontium (Sr) although not strictly considered heavy metals are nevertheless included as they contain similar properties in environmental behaviour.

According to Biney *et al* (1994) there have been many countries in which the occurrence of heavy metals in excess of natural loads has become a great concern. Apart from natural sources, heavy metals can also be introduced into the environment by anthropogenic sources. Anthropogenic sources include industrial activities and process that have metal residues in their liquid and solid wastes. Examples of industries include breweries, textile companies, metal finishing companies, mining activities, electroplating activities as well as dyeing and printing industries. Biney *et al* (1994) cited rapid population growth, increases in industrial activities, urbanisation, exploitation of natural resources, agricultural practices,



socio-economic activities as well as the lack of enforcement of legislation as reasons for increases in heavy metal concentrations.

### **2.10.1 General metal toxicity and chemical interactions in the aquatic environment**

Heavy metals, unlike other classes of pollutants, are non-biodegradable (Wepener *et al.*, 2001), toxic and persistent (Jumbe and Nandini, 2009), hence they tend to accumulate in the environment. In natural waters, metal ions occur as free aqueous ions, complexes with organic or inorganic ligands or adsorbed onto the surfaces of particles (Brezonik *et al.*, 1991). According to James *et al.* (1998), free metal ions cause more serious damaging effect on aquatic organisms than their more complex forms. Duruibe *et al.* (2007) also states that the dissolved species have the greatest potential of causing deleterious effects.

*„The environmental fate and toxicity of metals and metalloids is mainly managed by their physical-chemical form that is, the chemistry and speciation’* (Hardman *et al.*, 1993, p. 234). Metals can be present in water in the soluble or insoluble forms (ranging from organic species, ionic species or suspended particulate matter). Furthermore, metals may form a variety of complexes with inorganic and organic ligands (Hardman *et al.*, 1993).

According to Chapman (1992), the toxicity of metals in water depends on the degree of oxidation of a given metal ion in conjunction with the form in which it occurs. Chapman (1992) further states that as a rule of thumb, the ionic form of most metals is the most toxic form. Heavy metals might be altered into more toxic forms or complexed to become more stable and less toxic compounds (Viljoen, 1999). The toxicity of metals can increase or decrease depending on a number of conditions within the aquatic environment such as oxygen, water hardness, pH and temperature (Cairns and Mount, 1990). Some metals such as silver (Ag), cadmium (Cd), mercury (Hg) and lead (Pb) are highly toxic, even at low levels (DWAF, 1996c).

At high alkalinity and pH, some metals (such as Pb and Cd) precipitate by forming complexation products, resulting in a range of chemical speciation of metals that significantly influence metal toxicity (Van Aardt and Booysen, 2004). Santos Bermejo *et al.* (2003) stated that heavy metals such as Pb, copper (Cu), nickel (Ni) and zinc (Zn) are usually deposited in sediments not deeper than 15 cm' while Callow (1994) states that, the highest levels of heavy metals occur within the initial 10 cm of undisturbed sediments.

According to Davies et al (1991), the accumulation of metals from the overlying water to the sediment is dependent on a number of external environmental factors such as pH, ionic strength, redox potential, anthropogenic input, the type and concentration of organic and inorganic ligands as well as the available surface area for adsorption caused by the variation in grain size distribution. A summary of the effects and interaction of each heavy metal in the environment and analysed for as part of this study, is provided in Appendix 3.

### **2.11 Previous studies on the Isipingo System**

The current state of the Isipingo Estuary is the product of progressive development and dramatic transformation of the entire Isipingo river catchment from as early as 1840. The estuarine system is currently in a very poor state and has received a Provisional Ecological Status of a category F (i.e. a highly degraded system) (SSI, 2011) based on limited water quality data.

Extensive research on the estuarine system has been conducted over the last three decades (Begg, 1978; Begg, 1984; Ramm *et al.*, 1985; Furness, 1988; Umgeni Water, 1989; Anderson, 1992; Kalicharran and Diab, 1993; Harrison *et al.*, 2000; Forbes and Demetriades, 2008; Moodley, 2010) focusing mainly on water quality and the hydraulics of the estuarine system. The research undertaken by (Begg, 1978; 1984) which remains to date, the most extensive investigation performed on this estuarine system. These studies are elaborated on in Chapter one (section 1.5.5).

### **2.12 Legislation related to the protection of water resources in South Africa**

The advent of a democratic South Africa brought to the forefront the promulgation of new legislation. This resulted in a shift from the previous fragmented approach to the management and regulation of environmental resources in a more integrated and holistic manner.

The rehabilitation and management plans proposed by Kalicharran and Diab (1993) were based on the past fragmented legislation and the division of control, implementation and regulation of activities posed a number of problems in terms of the management of the Isipingo Estuary (Diab and Scott, 1989).

There are currently a number of pieces of legislation, policies and bylaws that can be utilized to afford protection as well as regulate the sustainable use of water resources in South

Africa (DWAF, 2001b). Table 2.1 provides a brief overview of applicable legislation pertaining to water resource protection within the South African.

Table 2.1: Legislation related to water resources management and protection in South Africa

Name	Description
The Constitution of the Republic of South Africa (Act 106 of 1998) (Section 24)	Section 24 of the Constitution's Bill of Rights provides all citizens the right to an environment that is not harmful to their health or well-being as well as to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that: prevent pollution and ecological degradation; promote conservation; and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.
Water Services Act (Act 108 of 1997)	This Act provides for the national management of water services through inter alia: <ul style="list-style-type: none"> <li>- Management of right of access to basic water supply and basic sanitation necessary to secure sufficient water and an environment not harmful to human health or well-being;</li> <li>- Management and control of water services, in general, including water supply and sanitation;</li> <li>- Regulation of industrial use of water, both in terms of use and disposal of effluent or wastewater; and</li> <li>- Preparation and implementation of Water Services Development Plans by water services authorities. This normally is included as part of Integrated Development Plans.</li> </ul>
National Environmental Management Act (Act 107 of 1998)	NEMA makes provision for co-operative environmental governance through the establishment of national environmental management principles, and procedures. Environmental Impact Assessment Regulations that have been promulgated under this Act list activities requiring assessment and environmental authorization and make provision for environmental, social and economic impacts to be considered with respect to developments.
National Water Act (Act 36 of 1998)	This Act ensures the protection of South Africa's water resources and aquatic ecosystems through the development of policies to provide guidance in developing resource quality objectives as well as the regulation of water use as well as the disposal of water containing waste. The Act identifies concepts of the Reserve (water that must remain in a water resource to support basic human needs and the aquatic environment). The Act makes provision for the regulation of abstraction of freshwater, discharge and storage of wastewater through the issuing of authorizations.
National Health Act (Act 61 of 2004)	The responsibility to deliver environmental health services in terms of this Act is delegated to local municipalities. Municipalities are therefore responsible for ensuring that appropriate municipal health services are effectively and equitably provided in their respective area of jurisdiction. Such services include (within the ambits of human health protection): <ul style="list-style-type: none"> <li>- water quality monitoring;</li> <li>- waste management; and</li> <li>- Environmental pollution control.</li> </ul>
National Environmental Management: Integrated Coastal Management Act,	This Act provides a framework for the coastal management and includes estuarine environments. The Act also calls for the development of Estuarine Management Plan for individual estuaries,

2008 (Act 24 of 2008)	which must a vision and objectives for the estuary, outline strategies and guidelines to manage the estuary, define roles and responsibilities of organs of state and provide a mechanism for community involvement.
National Environmental Management: Waste Act (Act 59 of 2008)	This Act proposes to regulate waste management in order to protect the health and the environment by providing reasonable measures for the prevention of pollution and ecological degradation and for securing ecologically sustainable development while promoting justifiable economic and social development; to provide for national norms and standards for regulating the management of waste by all spheres of government and for specific waste management measures. Contaminated land and remediation of said land is required in terms of this Act. Issues of illegal dumping are also addressed within the Act.

## 2.13 Water Quality Management Plans

*„Environmental management is the management of human’s activities within the carrying capacity of environmental systems’* (DWAF, 2001a, p. 12). According to DWAF (2000a), the visualization of the aquatic environment as a water resource allows for the integration of land based catchment activities, which affect water quality, with the management of the aquatic environment. This allows land based human activities to be regulated and managed in order to ensure that the water quality and overall functioning of the aquatic environment is maintained at a level that supports its fitness for use (DWAF, 2000).

A typical water quality management plan will require *inter alia the* following information in order to formulate the plan:

- *„Knowledge of the users and their requirements;*
- *Understanding of the land uses and their impacts on water resources, including estuarine and coastal environments, when applicable;*
- *Information regarding surface and groundwater resources and associated water quality;*
- *The setting of water quality management objectives;*
- *The development and implementation of management strategies and tools; and*
- *The involvement of all roleplayers (interested and affected parties)’* (DWAF, 2000, p. 10)

The setting of a “Vision” for the future desired state of the Isipingo catchment, followed by the development of strategic objectives and management strategies to achieve the future agreed upon state are part of the fundamental processes followed in preparing water quality management plans. Arising from this would be the development of a management action

plan to achieve the objectives. The implementation of the plan must be continually monitored to determine the success.

## **2.14 Conclusion**

There are both natural and anthropogenic sources that impact upon rivers and estuarine systems. Activities within catchments lead to land derived material entering river systems and eventually being deposited in estuaries. Estuaries can function as a source and sink for material. Estuaries can also serve as either net importers or exporters of material. Quantity and quality of water are important in maintaining healthy ecosystems. The physical, chemical and biological states of river and estuarine systems are influenced by material entering these environments. These systems have a limited capacity with respect to the amount of material that they can receive prior to experiencing deterioration. The development of improvement or management plans for a catchment are aimed at identifying sources that negatively impact on systems and the measures to be taken to improve the current state of river and estuarine systems. Effect must be given to legislative requirements particularly with respect to the regulation of land-based activities that impact water resources.

## CHAPTER THREE

### RESEARCH METHODOLOGY

#### 3.1. Introduction

This chapter outlines the research methodology employed for data collection, analytical procedures and data analysis and also provides a description of the sample sites that formed part of this study.

#### 3.2. Research methodology

The methodology used while undertaking this study incorporated historical data collection through informal focused interviews with selected individuals knowledgeable about the catchment. A systematic program of water and sediment sampling was instituted after an intensive reconnaissance survey. These samples were analysed for a range of chemical constituents in independent laboratories. Water quality data were then examined and compared to the South African Water Quality Guidelines (SAWQG) for freshwater systems, for domestic use, recreational use, aquatic ecosystems and ecological environment (DWA, 1996a, 1996b and 1996c) for the samples.

Sediment samples were analysed for heavy metals and the results normalized using aluminium as the normalizing agent. Since the catchment studied comprises largely sedimentary rocks, the world averages for metals in sedimentary rocks were used as the background concentrations in the equations used to calculate the contamination factor, degree of contamination, enrichment factor and the geo-accumulation index (Rösler and Lange, 1972). In order to determine whether the Isipingo estuary is a net importer or exporter of material, hourly sampling representative of seasonal spring and neap tides was undertaken at the estuary inlet (i.e. at the tidal pipes) for chemical analysis. At the same time, the stage height of water in the pipes as well as the flow velocity was recorded to facilitate material flux determinations.

#### 3.3. Water quality characteristics

The term water quality is used to describe the physical, chemical, biological and aesthetic properties of water which determine its fitness for use and its ability to maintain the "health"/integrity of aquatic ecosystems (National Water Act, 1998).

Water quality parameters that may be assessed include:

- The physical properties of water relate to the aesthetic and palatable acceptance. Such properties include conductivity, odour, temperature and suspended solids.
- Water is a solvent with the ability to interact with dissolved or particulate material. The concentrations of substances in water are influenced by a number of factors including *inter alia*, the solubility of the substance, the temperature of the water, the pH of water, etc (Hounslow, 1995, Naidoo, 2005).
- This includes pathogenic and non pathogenic micro-organism in water. For the purpose of this study, Total Coliforms, *Escherichia coli* (*E. coli*) and Faecal Coliforms were analysed for.

### **3.4. Data collection**

Primary data collection for the study comprised of water and sediment samples at selected sites along the lower reaches of the Isipingo River and Estuary as well as water samples taken at the estuary inlet. Secondary data collection included published articles in journals, articles and research papers accessed from the internet, text books and dissertations. Informal interviews conducted with individuals knowledgeable about the history of the catchment as well as the use of photographs, topographical maps and Google Earth® images also formed part of secondary data collection.

### **3.5. Site selection**

A total of eight sample sites were selected for the purpose of this study (Figure 3.1). Within this selection, specific sites were used for particular aspects of this study. Sites were so chosen so as to reflect the impacts of the dominant land uses in the catchment. Initial site identification was aided by use of aerial photographs and verification *via* site visits. The middle to upper reaches of the Isipingo catchment is dominated by dense residential development (formal and informal) and the impacts associated with this land use was adequately assessed by locating a sample site in the Isipingo River and approximately 500 meters upstream of the Umlazi Wastewater Treatment Works. No sites were established further upstream due to accessibility and safety concerns.

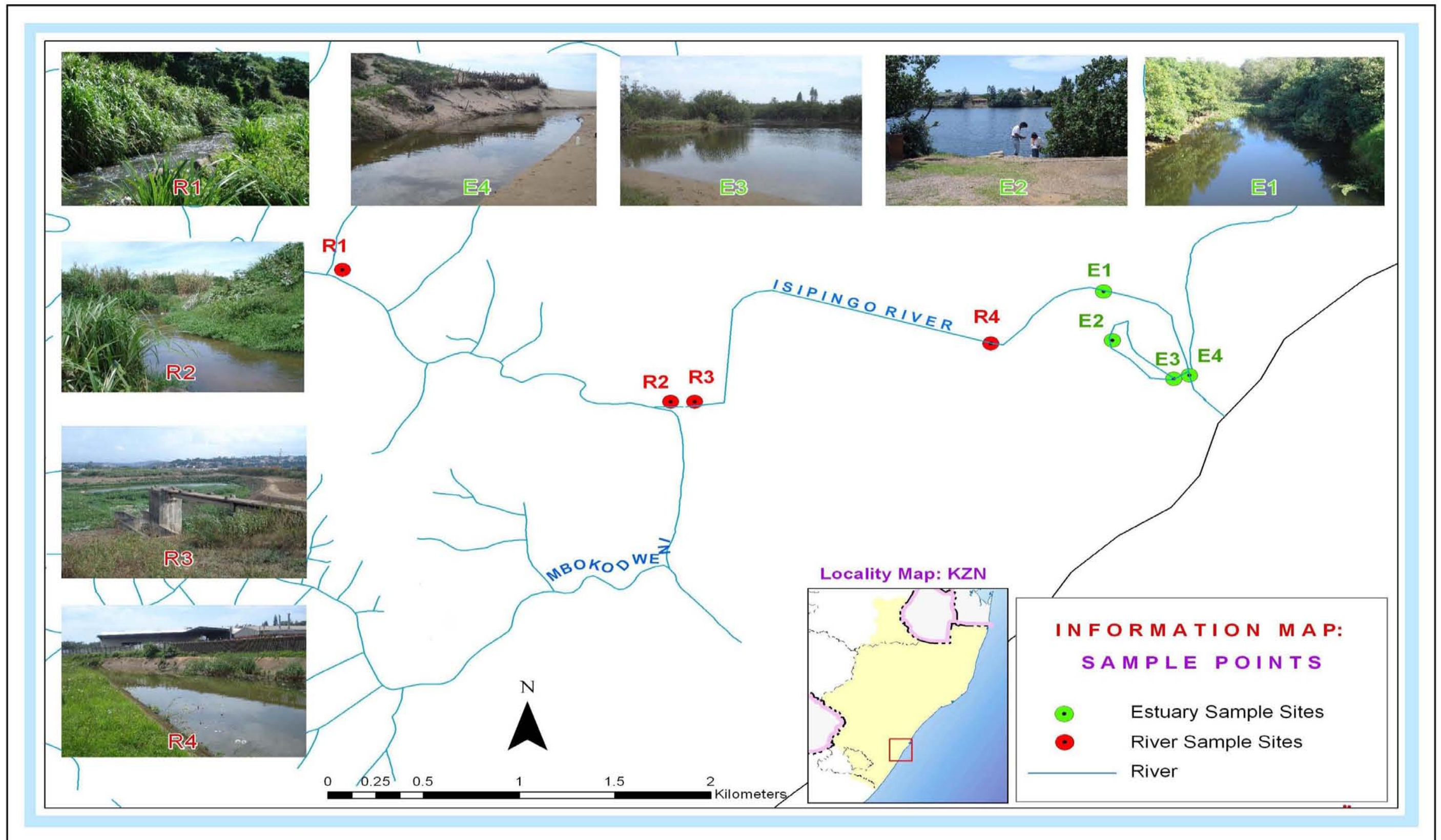


Figure 3.1: Sample sites along the Isipingo River (Assisted by Naidoo, S., 2013).



### **3.6. Sampling location**

The sites include in order (Figure 3.1):

1. R1: the Isipingo River upstream of the Umlazi Wastewater Treatment Works and Umlazi Landfill Site (This site is also downstream of dense formal and informal housing developments);
2. R2: the Isipingo River downstream of the Umlazi Wastewater Treatment Works and Umlazi Landfill Site (This site is upstream of the Diversion Works System (DWS));
3. R3: the Isipingo River at the DWS (Upstream of the Prospecton Industrial Area (PIA));
4. R4: the canalized portion of the Isipingo River located at the Joyner Road Canal (Downstream of the PIA but upstream of the Bamboo Drain);
5. E1: the Isipingo River at the Mangrove area (near the boardwalk) (Downstream of the Bamboo Drain);
6. E2: the Isipingo Lagoon;
7. E3: the Isipingo Lagoon arm entrance and,
8. E4: the Isipingo Estuary inlet.

The location of each sampling point was fixed using a Global Positioning System (GPS) to enable accurate location data for use on subsequent field surveys. Sediment samples were taken at sites R1, R2, E1 and E2 while water samples were taken at all eight points. In addition, water samples were taken at hourly intervals for chemical assessment over a tidal cycle at the twin tidal pipes near the estuary inlet (E4) (Figure 3.2).

### **3.7 Sampling frequency and procedures**

Monthly water quality samples were taken from all eight sites in a sequential manner starting from site R1 and ending at site E4. These samples were taken on the last Monday of each month commencing in February 2010 to January 2011 providing one year's data while sediment samples were taken seasonally in the dry and wet season. Tidal sampling was conducted on an hourly basis through complete seasonal spring and neap tidal cycles. A

total of 288 water samples were taken during this study period for both chemical and microbiological analysis.

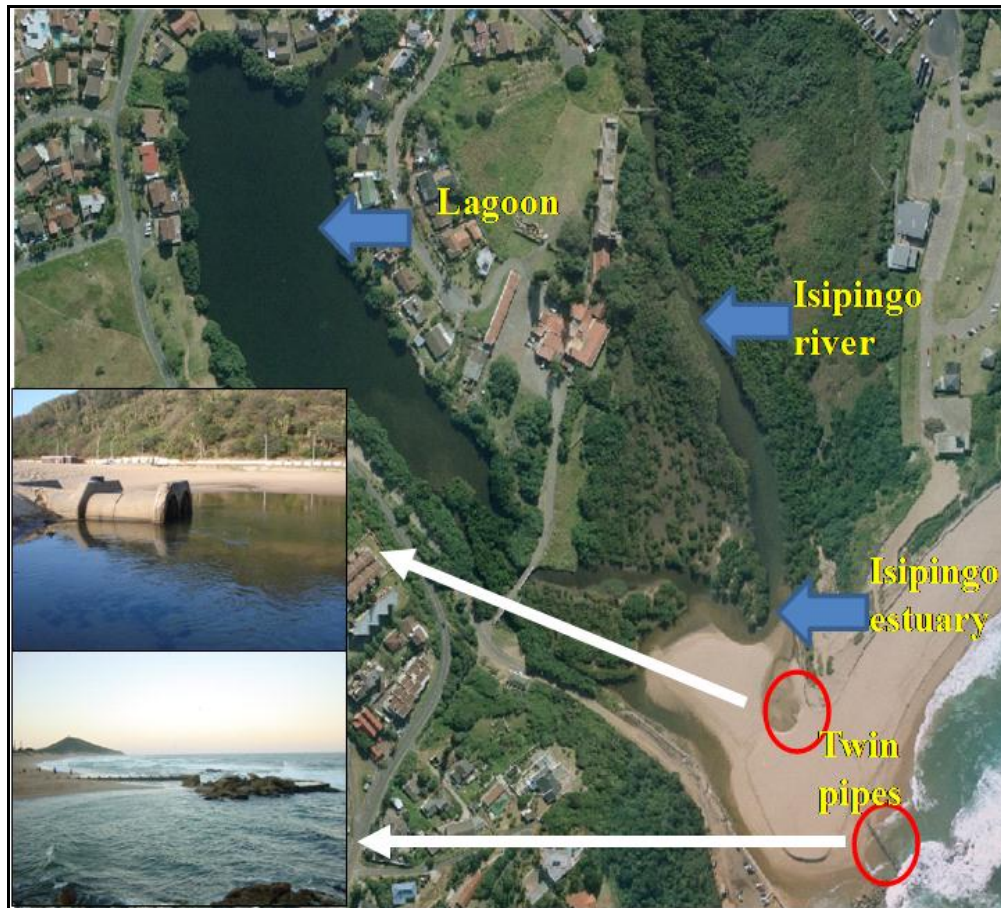


Figure 3.2: Sample point E4 (Isipingo estuary mouth) showing the twin pipes (Adapted from eThekweni, 2008)

Water samples for chemical analysis were collected in one litre polyethylene bottles while samples for microbiological analysis were collected in 500ml sterilized glass bottles. Sample bottles were labeled to include the name of the sampler, date and time when the sample was taken, sample point name, number and location.

All water samples were placed on ice and transported to the laboratory for analysis within a 24 hour period. Chemical analyses of the water and sediment samples were conducted at the University of KwaZulu-Natal's analytical chemistry laboratory under the guidance and supervision of the laboratory technician while the microbiological samples were analysed by the Department of Water Affairs. The monthly water samples were collected at each site at mid-depth of the water column. All samples below the DWS were taken during ebb tide.

In order to determine the net material exchange between the Isipingo Estuary and its near shore environment, water samples were also collected at hourly intervals over a tidal cycle as proposed by Kjerfve et al (1980) to include a complete tidal cycle. The samples were taken at the estuary inlet (i.e. at the twin pipes at mid-depth on a seasonal basis and during consecutive Spring and Neap tides).

The mouth of the Isipingo Estuary consists of two concrete pipes, which play a crucial role in maintaining connectivity between the estuary and the nearshore environment. Other parameters measured included the flow velocity and direction and, the stage height of water in the tidal pipes.

Santos Bermejo et al (2003) stated that heavy metals such as lead, copper, nickel and zinc are usually deposited in sediments not deeper than 15 cm' while Callow (1994) states that, the highest levels of heavy metals occur within the initial 10 cm of undisturbed sediments. Bed sediment samples were taken at sampling points R1, R2, E1 and E2. All samples were taken from the top 10 cm of the sediment surface. Sediment samples were collected in tightly sealed plastic bags which were half filled, sealed and stored on ice prior to transportation to the Department of Physics and Chemistry of the University of KwaZulu-Natal for analysis within a 24 hour period.

### **3.8. Laboratory analysis of water samples**

The following chemical and physical variables: Aluminium (Al), Ammonium ion ( $\text{NH}_4^+$ ), Arsenic (As), Barium (Ba), Calcium (Ca), Chromium (Cr), Cobalt (Co), Copper (Cu), Dissolved oxygen (DO), Electrical conductivity (EC), Iron (Fe), Lead (Pb), Magnesium (Mg), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Nitrate ( $\text{NO}_3$ ), pH, Phosphorous (P), Potassium (K), Selenium (Se), Sodium (Na), Strontium (Sr), Titanium (Ti), Total Dissolved Solids (TDS), Vanadium (V), Zinc (Zn) and Zirconium (Zr).

The water samples were also analysed for the following microbiological variables at the Department of Water Affairs laboratory:

Total coliforms

Faecal coliforms

*Escherichia coliforms (E. coli)*

### **3.9. Laboratory analysis of sediment samples**

Skoog and West (1982) highlighted the importance of using the correct reagents and techniques for decomposing and dissolving analytical samples such as sediment samples. As part of this study, sediment samples were oven dried at 100°C over a 24 hour period. Approximately half a gram (0.5g) of the dried sample was digested using 15ml of *aqua regia* solution (3 HCl (conc.) : 1 HNO<sub>3</sub> (conc.)). This solution was subsequently covered with a watch glass and boiled for thirty minutes. During this period the sample was checked to ensure that it did not boil to dryness. The solution was then cooled and gravimetrically filtered and made up in a 100ml volumetric flask using de-ionised water. This solution was then transferred into plastic bottles for analysis. Each sediment sample was prepared using the same procedure.

### **3.10. Physical parameters: Methodology**

#### **3.10.1 pH**

An electronic pH meter was used to measure pH. A pH meter comprises of a glass and reference electrode, potentiometer and a temperature-compensation device (Christian, 2007). The instrument was submerged into the sample upon calibration with standard solutions. The glass electrode converts the H<sup>+</sup> ion concentration signal activity to an electric current which is read as electrode potential or pH (Christian, 2007). The pH was then recorded.

#### **3.10.2 Total Dissolved Solids (TDS)**

The measurement for TDS was conducted using an electronic TDS meter. The movement of the ions result in the generation of an electric current and the meter then records the amount of ions that pass between the electrodes (Christian, 2007). Calibration of the instrument was conducted using standard solutions upon which the instrument was submerged into the sample and the TDS value was recorded.

#### **3.10.3 Electrical Conductivity**

Conductivity was measured using an electronic conductivity meter and this measures the electrical resistance of a solution. A conductivity meter comprises of a conductivity cell and meter with the conductivity cell comprising of two platinum plate electrodes connected by cables to the meter (Ngila, 2008). The electric current source in the meter applies a potential

to the plates and the meter measures electrical resistance of the solution (Ngila, 2008). The resistance is read in the units of conductivity which are micro-siemens per centimeter ( $\mu\text{S}/\text{cm}$ ) which can be converted to milli-siemens per meter ( $\text{mS}/\text{m}$ ).

### 3.11. Chemical parameters: Methodology

#### 3.11.1 Ammonia

In aqueous solution, ammonia exists in equilibrium with the ammonium ion and the position of equilibrium is governed by pH and temperature (DWAF, 1996a). An ion-selective electrode coupled to the YSI 6920 V2 probe was used to analyse the ammonia concentration in solution.

#### 3.11.2 Nitrates

Nitrates were measured using the YSI 6920 V2 Compact Multi-Parameter Sonde with the YSI 650 Multi-Parameter Display System water quality meter (Figure 3.3). The instrument was calibrated for nitrates using calibrants of 1, 10 and 100 mg/L of nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ) (Chetty, 2010).



Figure 3.3: Image of the YSI 6920 V2 Compact Multi-Parameter and YSI 650 Multi-Parameter Display System water quality meter

The calibrant was placed in a beaker and the probe end of the sonde was immersed into this solution for a minute and thereafter calibrated. The instrument is self-calibrating and simply requires following the prompts displayed on the 650 display logger connected to the sonde. The same procedure was used for each of the calibrants mentioned above. The probe was then immersed into each water sample collected as part of the study for approximately one minute and the nitrate concentrations recorded. After each reading, the probe was rinsed with deionised water.

### **3.11.3 Sodium and potassium**

A flame photometer was used to measure the sodium and potassium cation concentrations. The procedure involves blending the metal ions solution in a low temperature flame to enable electrons to jump to higher energy states (Ngila, 2008). In turn, these electrons become unstable and return to groundstate emitting a distinct wavelength of visibility light which is detected by a photo-detector (Ngila, 2008). Within the instrument, the electrical signal from the photo-detector is displayed as a digital readout. The emission lines are isolated by an optical filter and the emitted light is detected by a photo-detector.

### **3.11.4 Dissolved oxygen (DO)**

Dissolved oxygen was determined using the Winkler method and consisted of a series of titrations to obtain the dissolved oxygen concentrations (Ngila, 2008). A combined solution of manganous sulphate, potassium hydroxide, sodium azide and potassium iodide was used to treat the sample which was then finally treated with sulphuric acid (Ngila, 2008). Manganese hydroxide combines with the dissolved oxygen in the sample and forms a brown precipitate. Upon acidification, manganese sulphate was formed which released iodine from the potassium iodide. The iodine was titrated with sodium thiosulphate to give the dissolved oxygen concentration. Indicators are used to determine the equivalence point of the reactions attained, where the final calculation is based on volume measurements (Chetty, 2010).

### **3.11.5 Metal ions**

According to Robin (1988) of the many analytical techniques available for trace metal determination, Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) is one of the most useful. This technique was therefore used in the analysis of the metal ions and employs a flame to heat the metal ions in solution which results in the metal electrons being

excited to a higher energy state (Skoog and West, 1982). During the cooling period, the electrons begin to release energy and the metal intensity reading is recorded. This intensity is the measurement of the excited state of the metal electrons after energy has been released and this reading is used in determining the actual metal concentrations. In order to determine the concentrations in each sample, a set of standards for all metals were developed (Christian, 2007). These standards were developed from a set of standard solutions of metal concentrations of 5, 10, 25, 50 and 100 mg/l. The solution was injected into an Optical Emission Spectrometer which determines the intensity readings of the metals in solution. These intensity readings were plotted on graphs (each graph represent a single metal) and was used to determine the actual concentration of the metals in each sample.

The water and sediment samples were then prepared and injected into the Optical Emission Spectrometer which produced an intensity reading for each metal in each sample. These readings were then used to calculate the actual metal concentration by using its specific graph of standards produced. This is done by substituting the metal intensity reading into the graph equation. Using ICP-OES, the following metal concentrations were determined: Al, As, Ba, Ca, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, P, Pb, Se, Sr, Ti, V, Zn and Zr.

### 3.12 Microbiological parameters: Methodology

The samples were prepared using the lower filtration volumes using a quarter strength Ringer's dilution solution up to a dilution factor of ten thousand (Table 3.1).

Table 3.1: Dilution factors used in preparation of samples for microbiological tests (Talbot, 2012)

Dilution concentration	Sample volume	Diluents volume
0.1ml/(10x)	10ml	90ml (dilution A)
0.01ml/(100x)	10ml of dilution A	90ml (dilution B)
0.001ml/(1000x)	10ml of dilution B	90ml (dilution C)
0.0001ml/(10 000x)	10ml of dilution C	90ml

Total coliform bacteria and faecal coliforms were analysed by using membrane filtration. The water samples were filtered through a membrane filter upon which the bacteria are entrapped. The filter was then placed on a selective growth medium (m-Endo or m-FC Agar) and incubated at 35°C or 45°C for 24 hours, after which all colonies characteristic of coliforms are counted (George *et al.*, 2002).

*Escherichia coliforms* (*E. coli*) are defined as coliform bacteria that produce the enzyme  $\beta$  – glucuronidase and hydrolyze the fluorogenic substrate 4 -methylumbelliferyl- $\beta$ -D-glucuronide (MUG) to produce a blue fluorescence around the periphery of the colony when grown in a NA-MUG (Nutrient Agar + MUG) medium at  $35^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$  for 2-4 hours (Garcia-Armisen *et al.*, 2005). This method is employed to verify the presence of *E. coli* from a total-coliform-positive membrane filter on m-Endo Agar or from m-FC Agar used in the faecal coliform membrane filter procedure.

### 3.13. Data analysis and interpretation of water sample results

The water quality results from this study for all river samples were compared to the TWQR for ideal conditions as prescribed in the SAWQG for domestic use, recreational use, aquatic ecosystem and the ecological environment. The TWQR for a particular constituent and water use is defined as the range of concentrations or levels at which the presence of the constituent would have no known adverse or anticipated effects on the fitness of the water assuming long-term continuous use, and for safeguarding the health of aquatic ecosystems and other users (DWAF, 1996c). For the purpose of this study the TWQR (ideal conditions) was used for comparative purposes.

The flux of a chemical constituent entering or leaving the estuary is dependent on its concentration in the water; which in turn is related to the physico-chemical properties of the aquatic environment. Estuarine mixing behaviour of a constituent is derived mathematically by studying the relationship between the concentration of the constituent and the prevailing salinity (Boyle *et al.*, 1974; Officer and Lynch, 1981; Wen *et al.*, 1999). Constituents flux can then be determined from the relations determined. In this study, the metal concentrations were determined directly from water samples taken under prevailing physico-chemical conditions. Hence the flux of constituents exiting the estuary on the ebb tide is given as:

$$F_E = QC^{\circ} \quad (1)$$

And the flux of constituents entering the estuary on the flood tide is given as:

$$F_F = QC^* \quad (2)$$

The total fluxes to the ocean ( $F_{ET}$ ) are estimated by integrating all ebb fluxes for the duration of the ebb tide. The same process is employed in determining the total import loading ( $F_{FT}$ ) of the constituent into the estuary on the flood tide. The difference between these flux totals



yields the net import or net export of the constituents under consideration. The net flux is an important parameter that provides a measure of the flushing capability of the estuary and hence its ability to maintain a relatively healthy status. The net import of heavy metals between the Isipingo Estuary and adjacent marine environment is denoted by (\*) while the net export is denoted by (°).

Due to the connectivity of the Isipingo Estuary with the sea by two 1.1 meter diameter pipelines, the cross sectional area was calculated mathematically using the measured stage height of water in the pipes at the time of sampling. The mathematical calculation used is the same calculation used to determine the area of a segment of a circle and is as follows:

$$A = \frac{h}{6c} (3h^2 + 4c^2) \quad (3)$$

### 3.14. Data analysis and interpretation of sediment sample results

The level of contamination in sediment can be determined by calculating the Enrichment Factor (EF), Contamination Factor (CF), Degree of Contamination ( $C_d$ ) and the Geo-accumulation Index ( $I_{geo}$ ) (Chakravarty and Patgiri, 2009).

The Enrichment Factor for each heavy metal in the soil was calculated using the following equation proposed by Huu *et al.*, 2010):

$$EF = [C_{\text{metal}} / C_{\text{normaliser}}]_{\text{soil}} / [C_{\text{metal}} / C_{\text{normaliser}}]_{\text{control}} \quad (4)$$

Where  $C_{\text{metal}}$  and  $C_{\text{normaliser}}$  are the concentrations of the heavy metal and normaliser in the sediment and in the unpolluted control. In this case Clarke Values for heavy metals were obtained from world averages of metals in sedimentary rock.

The EF was then used to differentiate heavy metals arising through natural or anthropogenic activities and was used to assess the degree of anthropogenic influence (Chakravarty and Patgiri, 2009). As the value of EF increases, the contribution of anthropogenic influence also increases. The following categories are recognised on the basis of the EF (Sutherland, 2000):

- $EF < 1$  implies no enrichment
- $1 \leq EF < 2$  implies deficiency to minimal enrichment
- $2 \leq EF < 5$  implies moderate enrichment

- $5 \leq EF < 20$  implies significant enrichment
- $20 \leq EF < 40$  implies very high enrichment
- $EF \geq 40$  implies extremely high enrichment

The Contamination Factor is calculated for each sample site as follows:

$$CF = \text{Metal concentration in sample} / \text{Clarke value of metal} \quad (5)$$

The level of contamination can be classified as follows:

- $CF < 1$  implies low contamination
- $1 \leq CF < 3$  implies moderate contamination
- $3 \leq CF < 6$  implies considerable contamination
- $CF \geq 6$  implies high contamination

The degree of contamination ( $C_d$ ) is calculated for each sample site and is defined as the sum of all contamination at a particular site (Håkanson, 1980). The following terminology is used to describe the contamination degree:

- $C_d < 6$  implies low contamination degree
- $6 \leq C_d < 12$  implies moderate contamination degree
- $12 \leq C_d < 24$  implies considerable contamination degree
- $C_d \geq 24$  implies very high contamination degree

The Geo-accumulation Index ( $I_{geo}$ ) was first introduced by Muller (1979) and is used to determine the extent of heavy metal accumulation in sediments and to measure the degree of heavy metal pollution in sediments. This is calculated used the following equation:

$$I_{geo} = \text{Log}_2 C_{\text{metal}} / 1.5 C_{\text{metal}(\text{control})} \quad (6)$$

Where  $C_{\text{metal}}$  is the concentration of the heavy metal in the sediment sample and  $C_{\text{metal}(\text{control})}$  is the concentration of the sample background sample (Clarke Value is used in this study). The factor of 1.5 is introduced to account for possible variation in background or control data due to lithogenic effect (Chakravarty and Patgiri, 2009).

The degree of heavy metal pollution is assessed in terms of seven contamination classes as follows (Huu *et al.*, 2010):

- $I_{geo} < 0$  implies unpolluted
- $0 \leq I_{geo} < 1$  implies unpolluted to moderately polluted
- $1 \leq I_{geo} < 2$  implies moderately polluted
- $2 \leq I_{geo} < 3$  implies moderately to strongly polluted
- $3 \leq I_{geo} < 4$  implies strongly polluted
- $4 \leq I_{geo} < 5$  implies strongly to very strongly polluted
- $I_{geo} \geq 5$  implies very strongly polluted

High metal concentrations in sediment do not automatically imply that contamination has taken place. These concentrations could signify the chemical composition and mineralogy of the parent rock. Hanson et al (1993) as cited in the CSIR (2010b) stated that naturally occurring and anthropogenically introduced metals tend to accumulate in the same areas. This is why the mineralogical and granulometric factors that influence the natural variations of metal concentration in sediment must be firstly compensated for. This is usually done by geochemical normalization which normalizes metal concentrations to co-occurring conservative element (the normaliser or reference element) that provides the tracer of crustal decomposition (Kersten and Smedes, 2002 as cited in CSIR, 2010b). Aluminium was used as the normalising element as it is stable and unaffected by redox effects and is therefore presumed not to be enriched by local contamination. The Clarke Values for heavy metals were obtained from world averages for trace metals in sedimentary rock.

### **3.15. Statistical analysis**

The use of statistics enables data to be objectively interpreted within a scientific context. Given the nature of the sampling protocol and the characteristics of the data collected, it was most appropriate to utilize the analysis of variance (ANOVA) to assess the degree of variability of the sample means between and within specified parameter groups. Furthermore, it was important to identify significant relationships in group means of the spatial and temporal measured parameters. The results are displayed in line with accepting or rejecting the null hypothesis and assessing the level of significance using the F-value and the corresponding p-value respectively.

### **3.16. Conclusion**

The Isipingo catchment, in particular the lower Isipingo River and its Estuary has historically been plagued by land use changes which have dramatically shaped and influenced a

number of environmental factors, in particular water quality and quantity. Water quality monitoring is vital in order to develop a sound management plan to improve this system. As part of this study, an intense programme of water and sediment sampling was undertaken and subjected to chemical and microbiological analyses yielding a wealth of data. Using the correct analysis techniques and methods is crucial as the results produced are utilized by scientists and other regulatory authorities and role players to make decisions regarding the state of the environment as well as to employ intervention measures to achieve desired objectives. These data were then utilized to calculate a range of pollution indices and parts of the data also subjected to statistical analysis and interpretation.

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSION**

#### **4.1 Introduction**

Due to the range of comprehensive assessments conducted and the range of water quality parameters analysed as part of this study, the and the vast amount of data generated this chapter will present the results and discussions as subsections.

#### **4.2 Water quality analysis and discussion**

This subsection presents the results and discussion of the water quality parameters analysed as part of this study. These will be discussed under the following subheadings: general water quality, nutrients, heavy metals and microbiology. Each subheading will culminate in a conclusion. It is pertinent to mention at the outset that the volume and variation of fluvial flow of the Isipingo River system is generally small, resulting in a negligible dilution effect. However, there were bouts of precipitation preceding some sampling events during this study which contributed to higher flows as well as periods when the Diversion Works System (DWS) was operational, thus permitting flow to the estuary from the upper catchment. The influence of these factors on water quality is also discussed.

##### **4.2.1 General water quality variables and cations**

The average wet and dry season results are tabulated in Appendix 4. Dissolved oxygen and the cations are included under this section.

###### **4.2.1.1 pH**

In terms of habitat quality, pH values typically range from 4 to 11 for surface waters and should not differ from background site specific values by more than 5% (DWAF, 1996c). The average pH across all sites both during the wet and dry season complied with the water quality guideline requirements for domestic and recreation use (full contact) however, there were several sites during the wet season where the pH exceeded the target water quality upper limit of pH 8 for the aquatic ecosystem (Figure 4.1). Some variations across the study area are noteworthy. These occurred at sites R1, R4, E1, E2, E3 and E4.

The average pH during the wet season (DWS was non-operational) was higher (mildly alkaline) than the dry season across all sample sites except site R2, which recorded a pH of 7.86. This increase may be attributed to the following: increased biological activity in systems experiencing eutrophication (DWAF, 1996c), the introduction of material of higher alkalinity into the system during rainfall events or *via* non-compliant or illegal discharges.

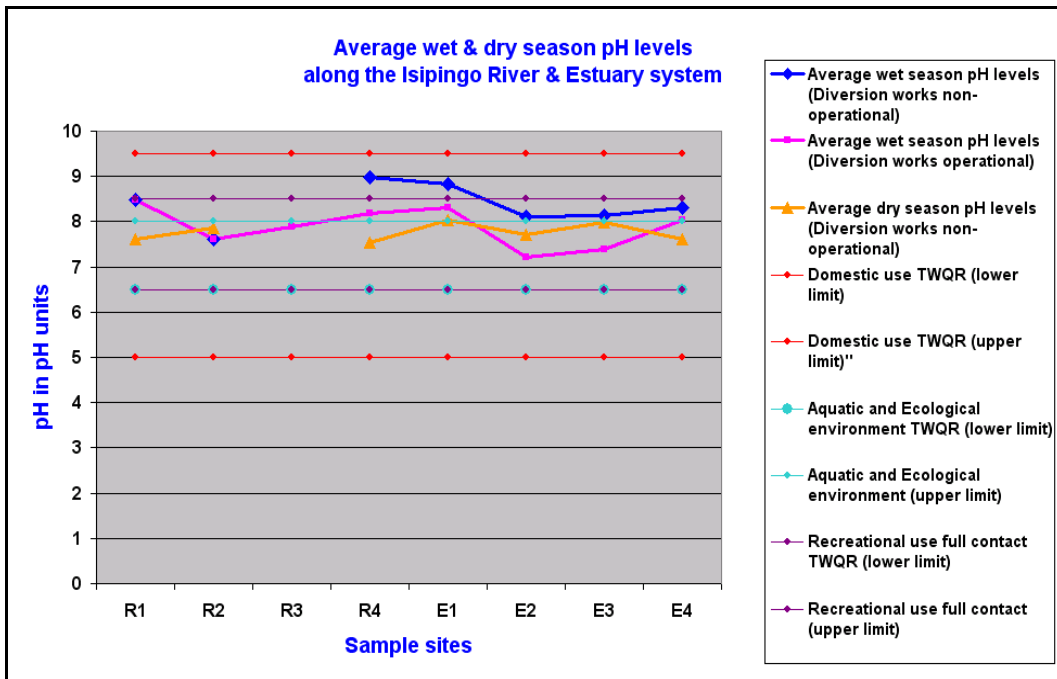


Figure 4.1: Comparison of average wet and dry season pH values to SAWQG

The drop in average pH during the wet season between sites R1 and R2 may be related to effluent discharge from the Umlazi wastewater treatment works, possible impacts from the transit camp or the recyclers and block makers located in the immediate vicinity of R2. The average pH of 8.99 recorded at site R4 was the highest average across all sites during the wet season (DWS is non operational) while an average pH of 8.19 was recorded for the wet season (DWS operational). When the DWS is non-operational, there is no water being received from the upper catchment. In addition, this site is located downstream of industrial activities which could be potential sources contributing to the increase in pH.

#### 4.2.1.2 Dissolved oxygen

The average dissolved oxygen (DO) across all sites was relatively lower in the dry season with the exception of site E4 (Figure 4.2). Higher DO levels are generally associated with the dry season due to the lower water temperature. However, during this study the Total

Dissolved Solids (TDS) levels are comparatively higher in the dryer months which could account for the lower dissolved oxygen levels encountered. Increased photosynthesis and flow turbulence can lead to higher DO measurements as recognized by Dallas and Day (1993). Higher DO levels were recorded in the wet season. Site R3 (DWS) recorded the highest DO reading and this can be attributed to the aeration of the water as it flows over the weir.

Past studies near the northern arm of the Isipingo Estuary by Begg (1978) demonstrated extremely high (super saturated) surface DO levels while the bottom waters were devoid of DO levels (anoxic). Forbes and Demetriades (2008) recorded DO levels of 5 mg/l and 5.6mg/l near the surface and levels of 2.5 mg/l and 2.2 mg/l near the bottom layers during 2007 and 2008 respectively. Moodley (2010) also recorded low DO levels in the estuary. Site E1 located along the northern arm (near boardwalk and mangroves) recorded much lower average dissolved oxygen levels in both seasons in comparison to other estuarine sample sites (Figure 4.2). The lower DO at E1 may be attributed to the slow release of organic material from the sludge located in the bottom sediment.

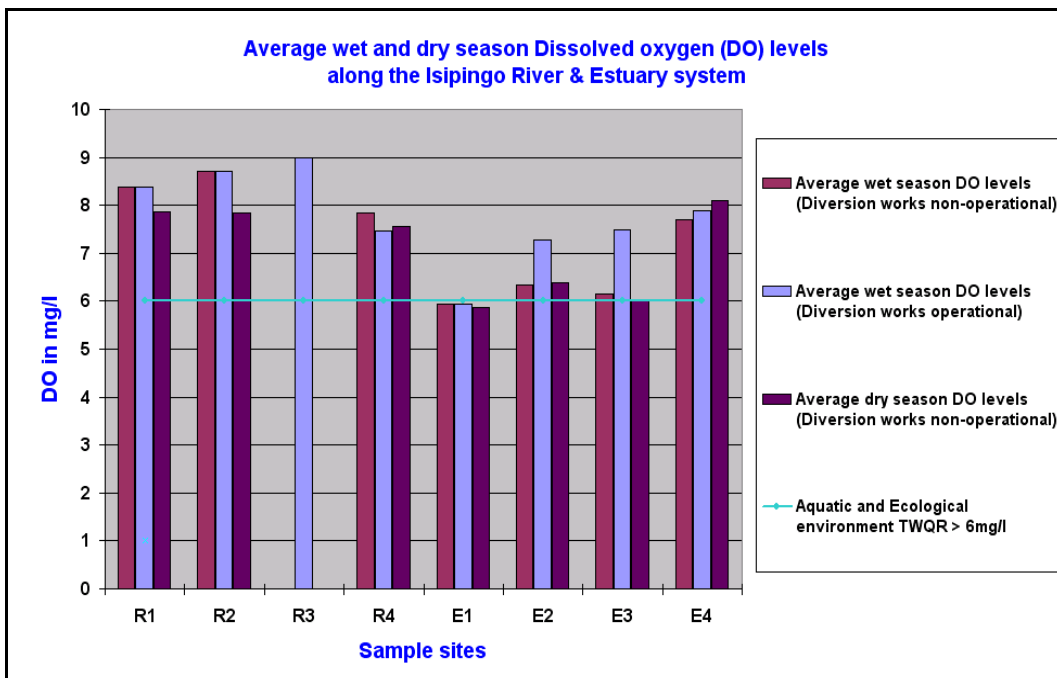


Figure 4.2: Comparison of average wet and dry season DO levels to SAWQG

The SA Guideline standards prescribe an acceptable range of 80-120% DO saturation for aquatic organisms (DWAF, 1996c). Dallas and Day (1993) indicate concentrations of > 4

mg/l as being acceptable while Hart et al (1992) reported on the Australian guideline of > 6 mg/l. Using these standards as references, the Isipingo system generally conforms to the expected standards.

#### 4.2.1.3 Electrical conductivity

The average Electrical conductivity (EC) was generally higher in the dry season however, for sites below the wastewater treatment works, this trend was reversed in the wet season. Higher conductivity was recorded at site E2 (lagoon) during both seasons as well as at sites E3 and E4 (Figure 4.3). Seawater entering the lagoon on spring high tide tends to remain in the system resulting in an increase in salinity and conductivity which may be exacerbated by evaporative losses or reduced during periods of excessive rainfall. The peaks in electrical conductivity also show a degree of correspondence to the TDS concentrations. The increase in the average EC between sites R1 and R2 both during the wet and dry season may be related to the contribution of material of high conductivity either as a result of runoff from the wastewater treatment works, the transit camp and possibly the light industries (recyclers and block makers) located between these two sample sites. The average EC recorded at points below the DWS in the wet season is much lower during the period when the works is operational versus when the system is non-operational. This could be attributed to addition flow being permitted via this system.

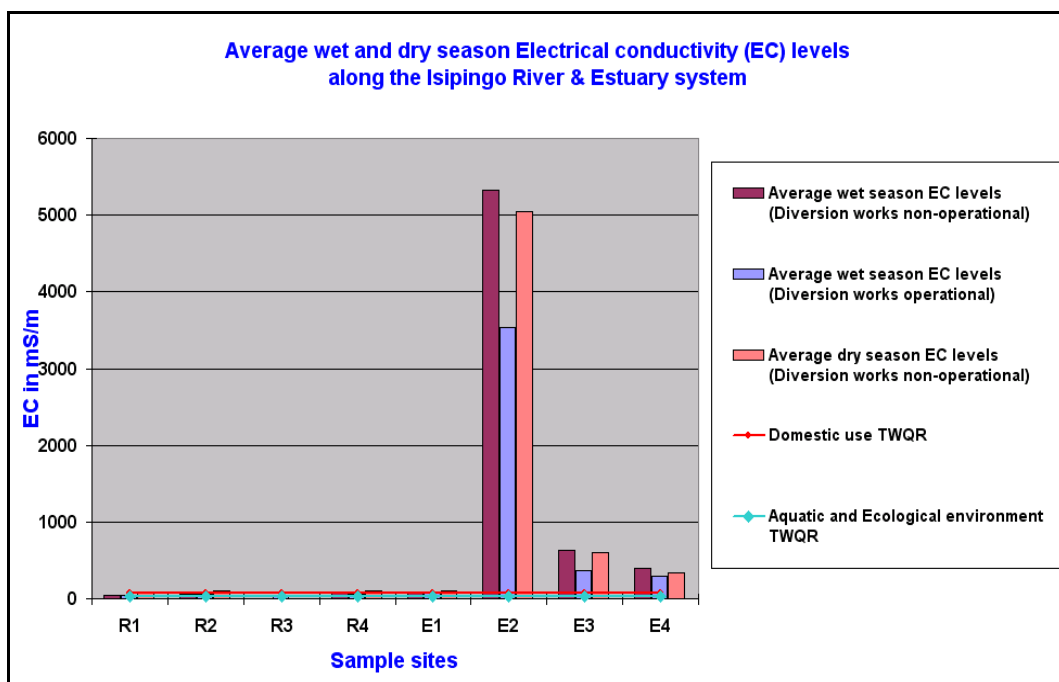


Figure 4.3: Comparison of average wet and dry season EC levels to SAWQG



The average EC during the dry season for the river sample sites fell within the domestic use water quality guidelines while the estuary sites exceeded the limits for this water use except at site E1. None of the sites achieved compliance to the aquatic ecosystem guideline values during the dry season. The majority of the sites during the wet season did not comply with the SA target (ideal) values for domestic use or the aquatic ecosystem.

#### 4.2.1.4 Total Dissolved Solids

The highest average Total Dissolved Solids (TDS) concentrations across all sample sites occurred in the dry season. Site E2 exhibited the highest average TDS levels followed by sites E3 and E4 (Figure 4.4). These sites are located near the twin pipes and are thus subjected to tidal influence which would explain the slightly higher TDS values. The effect of reduced rainfall and hence limited dilution potential within the river system can be attributed to the increase in average TDS concentrations during the dryer period and, when there is no flow received *via* the DWS during the wet season.

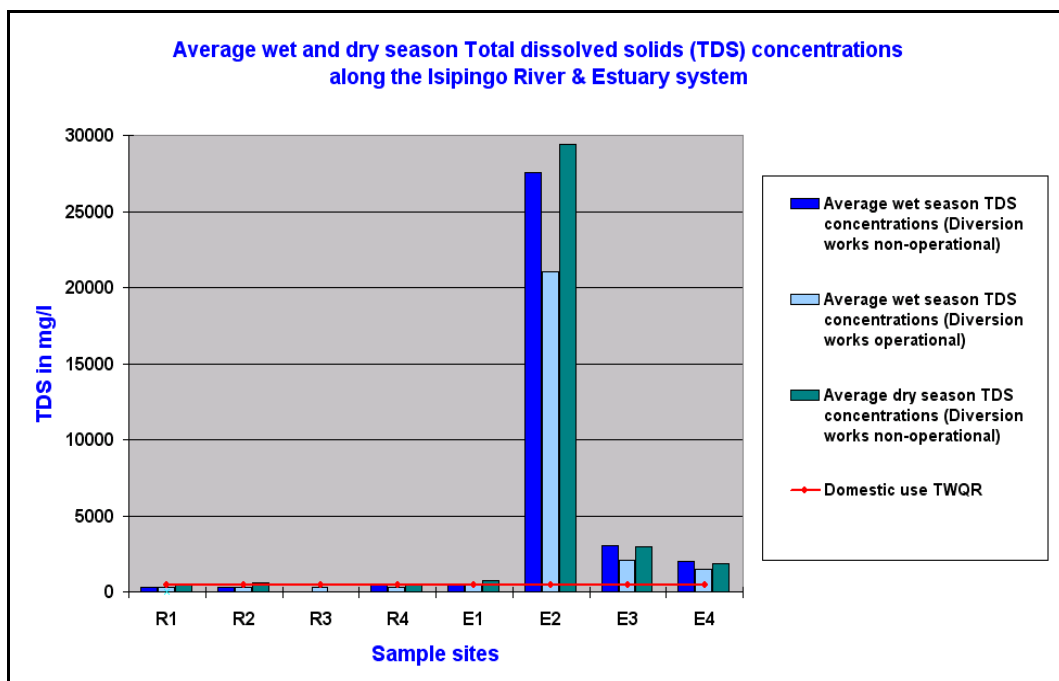


Figure 4.4: Comparison of average wet and dry season TDS concentrations to SAWQG

The increase in average TDS concentrations between sites R1 and R2 could stem from runoff and discharges from the Umlazi wastewater treatment work, the transit camps and the light industries (recyclers and block makers) located between these two sample sites. Peaks in TDS can also be related to dissolution of minerals from rocks (DWAf, 1996a). This

increase in average TDS between sites R1 and R2 is more pronounced in the dry season. During this period, most of the flow to the Isipingo River is supplied by the Umlazi wastewater treatment works located between R1 and R2, which may have a more notable impact during the dry season.

The average dry season TDS levels at all the river sample sites and E1 fall within the acceptable range for domestic use (Figure 4.4). Sites R1 and R2 complied with the ideal domestic use category during the wet season. No guidelines are available for the ecological environment or recreational use while the TDS levels for the aquatic ecosystem should not vary by more than 15% than the normal cycles or background levels.

#### 4.2.1.5 Calcium

The average calcium (Ca) concentrations were higher in the dry season than the wet season except for the majority of the estuarine sites and R4 (Figure 4.5). The reduction in average Ca concentrations in the wet season when the DWS was operational may be attributed to a higher volume of water entering the system resulting in the dilution of Ca concentrations below R3. During the wet season when the works was non operational, the Ca concentrations below R3 were higher and could point to other sources in the immediate surroundings.

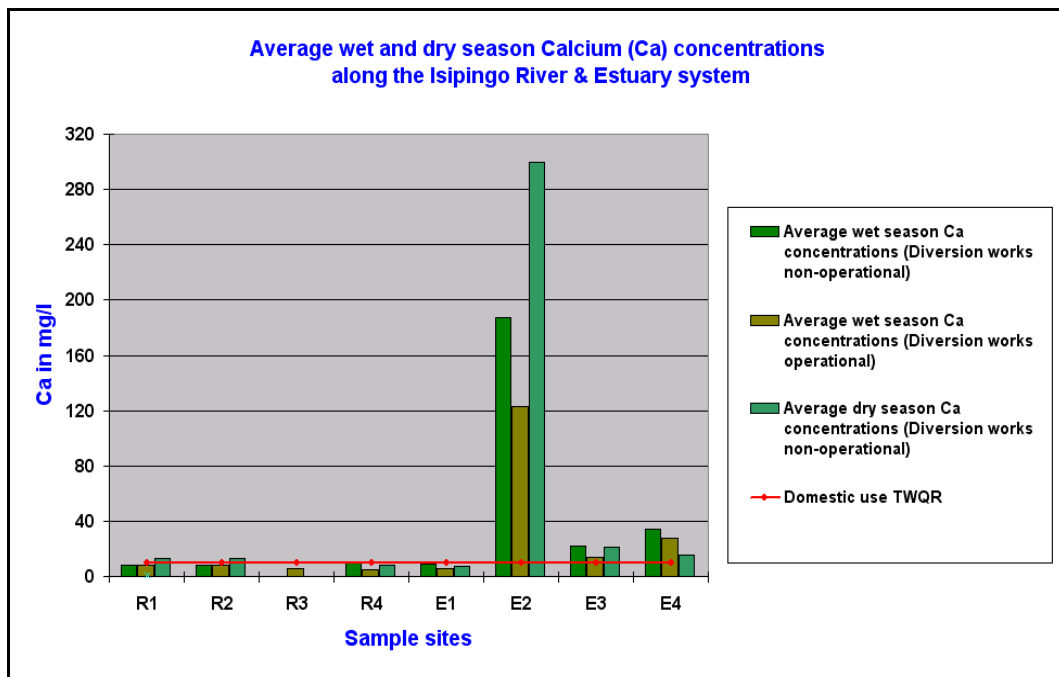


Figure 4.5: Comparison of average wet and dry season Ca concentrations to SAWQG

The lagoon (E2) once again displayed the highest average calcium concentrations in both the wet and dry season with the dry season exhibiting the higher average Ca concentrations (Figure 4.5). The estuarine sites with the exception of site E1 did not achieve compliance to the ideal domestic use guideline values in both seasons. The saline nature of the estuary due to tidal intrusion would account for the higher Ca values. During the dry season, the average Ca concentrations marginally exceeded the SAWQG for domestic use. This situation was reversed during the wet season and may be attributed to dilution effects. There are no values available for the aquatic or ecological ecosystems and for recreational use.

#### 4.2.1.6 Potassium

The average potassium (K) concentrations in the dry season across most sample sites were higher than that displayed during the wet season (Figure 4.6). Once again, the lagoon (E2) displayed concentrations much higher in magnitude when compared to the other sample sites. This can be attributed to tidal influence and the introduction of marine water into the estuary playing a pivotal role with respect to concentrations at these points.

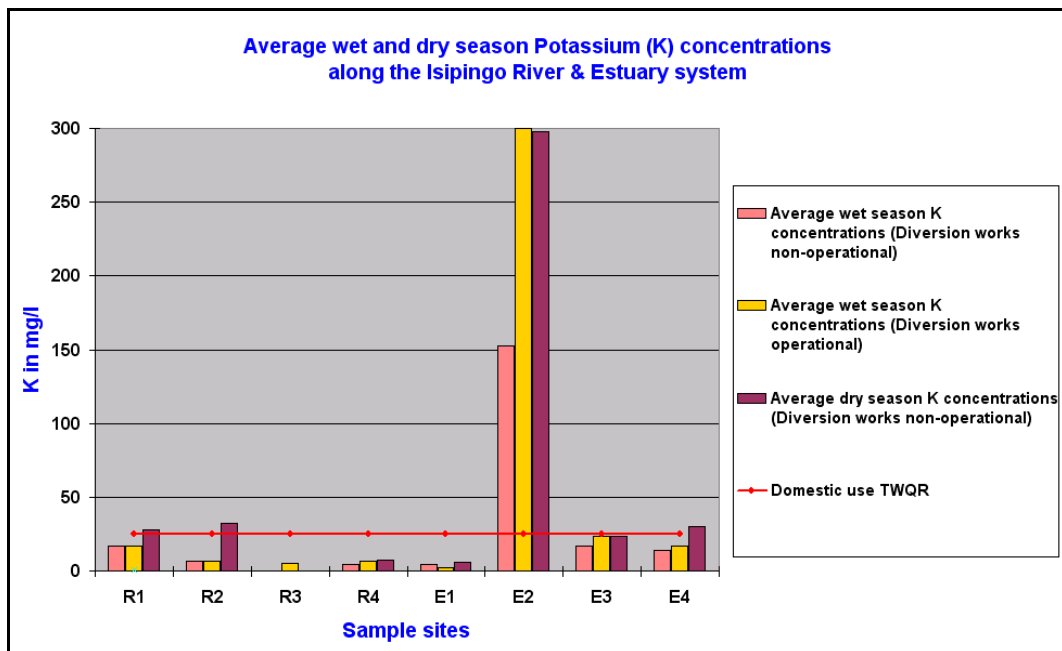


Figure 4.6: Comparison of average wet and dry season K concentrations to SAWQG

In the wet season, there is a substantial reduction in the average K concentration between sites R1 and R2. The higher concentration of K at R1 could be attributed to activities occurring in the upper catchment (comprising of residential developments and informal

settlements). Runoff including grey water (arising from washing of laundry, etc) is a likely source and may enter the river above site R1. The decrease in K levels at R2 may be attributed to riparian vegetation and the transformed wetland located above site R2, which appears to still perform certain purification and filtration functions.

In the dry season K concentrations are higher at R1 and reflect increases associated with evaporation which is experienced during the drier months (Figure 4.6). There is an increase of approximately 4 mg/l at site R2 in the dry season. This site is located immediately downstream of the transit camp. In natural waters potassium concentrations are usually less than 10 mg/l (Chapman, 1992). Generally there is compliance to the TWQR standards for domestic use except at E2 (lagoon) and sites R1, R2 and E4 in the dry season.

#### 4.2.1.7 Magnesium

Generally across most sites the average concentration of magnesium (Mg) was higher in the dry season. The lagoon (E2) once again displayed the highest concentration of Mg in both the wet and dry season (Figure 4.7). All sites achieved compliance with the TWQR for domestic use in both seasons, except for E2 which exceeded the prescribed value of 70 mg/l during both seasons and E3 which was non-compliant in the dry season only.

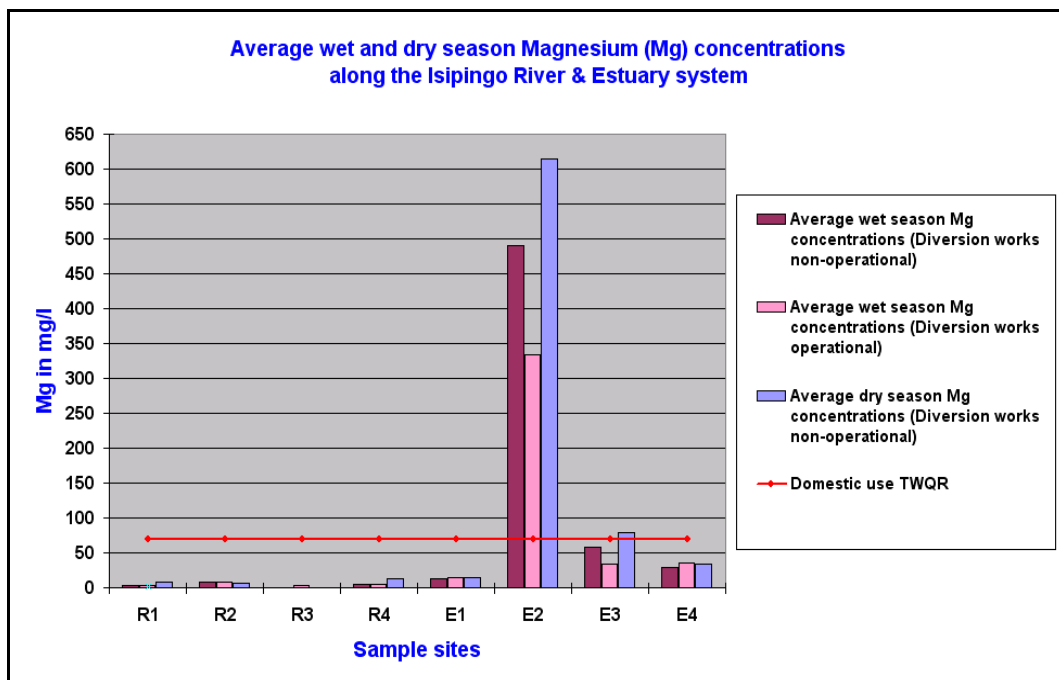


Figure 4.7: Comparison of average wet and dry season Mg concentrations to SAWQG

There is no recreational use, aquatic or ecological ecosystem guideline values for magnesium and therefore the fitness for use for this user groups could not be ascertained. The average Mg concentration increased in the wet season by almost double that recorded at R2 and then decreased by approximately half the concentration at site R3. Possible anthropogenic sources may include activities stemming from the transit camp, wastewater treatment works and light industries (recyclers and block makers). During both seasons, increases in the average Mg was observed at E1 despite lower concentrations recorded at R4. The increase seen at E1 may be attributed to runoff being received from the Bamboo Drain which merges with the Isipingo River downstream of site R4.

#### 4.2.1.8 Sodium

Sodium (Na) behaved rather differently from the other cations (i.e. micronutrients) analysed as part of this study in that Na generally yielded higher average concentrations in the wet season. This may be attributed to an increase in surface runoff carrying excess Na into the Isipingo system during heavy rainfall events. All sites located downstream of R3 (DWS) recorded comparatively higher Na concentrations during both seasons (Figure 4.8). Site E1 located downstream of R4 demonstrates a more pronounced increase during the dry season with the Na concentration doubling from that exhibited at R4.

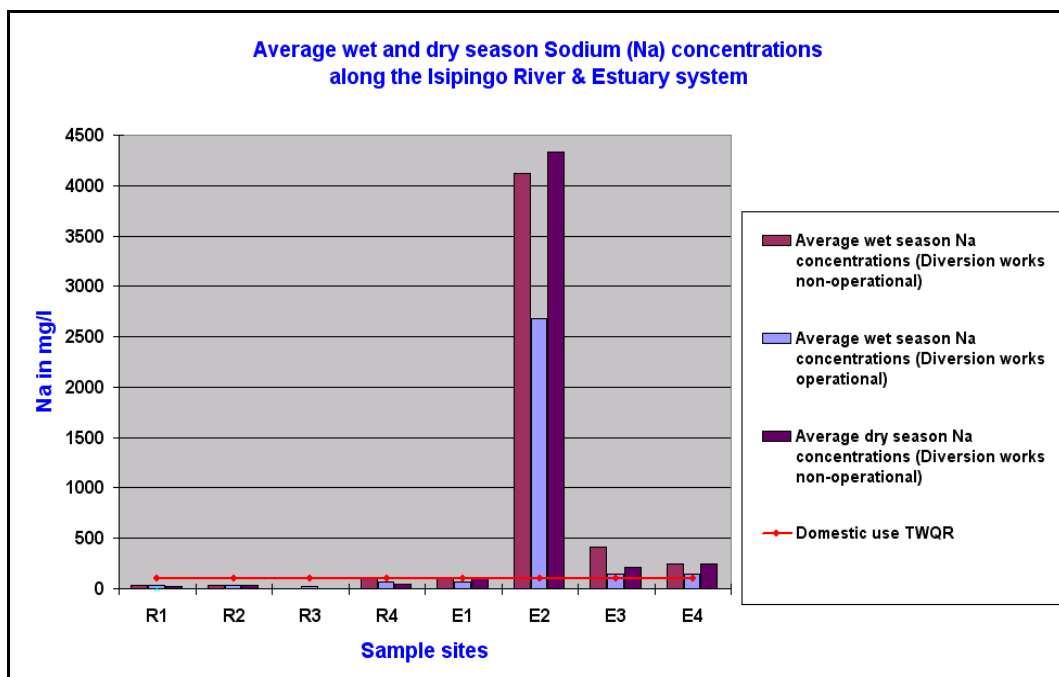


Figure 4.8: Comparison of average wet and dry season Na concentrations to SAWQG

This increase in Na levels could be due to the intrusion of saline water or could be attributed to input of Na rich runoff from the Bamboo drain which joins the estuary below R4. The lagoon (E2) displays extremely high Na concentrations due the large volume of seawater entering the lagoon particularly on spring high tide (Figure 4.8). The limited potential to flush water concomitant with high evaporation rates allows for an increase in the concentrations of various cations. While the Na values recorded at sites E3 and E4 are not as high as site E2, it is present at concentrations that indicate tidal influence. This would be expected considering the proximity of these sample sites to the estuary mouth.

While the Na values observed in the river samples are much lower than the estuary, marginal increases in Na concentrations are observed at R2 during both seasons. The introduction of Na into the system could arise from several anthropogenic sources such as the use of detergents, soaps or bleaches particularly if the river is being used for the purpose of washing clothes or may be attributed to the discharge of waste material containing Na. Site R4 exhibited higher average Na concentrations than sites located upstream of this site. This suggests potential anthropogenic sources stemming from runoff or illegal discharges from the surrounding industrial sites of Prospecton or may also indicate the possibility of the intrusion of marine water upward *via* the canal system through tidal influence.

There are no TWQR available for recreational use, aquatic or ecological ecosystems. Although Na is considered to be the least toxic cation, it is also one of the major cations involved in ionic, osmotic and water balance in all organisms (Dallas and Day, 1993). Drastic increases in Na concentration can potentially have deleterious effects on the osmotic regulatory function of aquatic organisms. The estuarine sites exceed the domestic use target values rendering water from the estuary being unfit for consumptive purposes. However, estuaries are saline environments by nature and high Na concentrations would therefore be expected. All river samples are within the 100 mg/l TWQR for domestic use.

#### **4.2.1.9 Analysis of variance of general water quality variables and cations**

Across all the sample sites, there is greater variability in the concentrations of all variables with the exception of K in the wet season (Table 4.1). This may be attributed to different sources with some sites contributing to increased concentrations arising from changes in land use. The effects of dilution could also account for the variability observed. Generally,

production rates increase in the summer months and this factor also plays a role in the variability observed.

The greatest variability occurred with the EC and TDS levels. The cations showed moderate levels of variability in comparison to EC and TDS. Sites that have greatest variability are the estuarine sites (E2 and E3) which are consistent with results and, possibly stemming from marine influences and land use effects. However, this seasonal difference is not statistically significant ( $p > 0.05$  and  $F < F_{crit}$ ) (Table 4.2). The variance in the concentrations in the dry season increased in the following order:  $pH < DO < Ca < K < Mg < Na < EC < TDS$  while variance in the wet season followed a similar trend except that the variability of Ca decreased while that of K increased.

Table 4.1: Variance of general water quality variables and cations concentrations

Variables	Wet season (Diversion works non-operational)	Wet season (Diversion works operational)	Dry season (Diversion works non-operational)
	Variance		
pH	0.26	0.2178	0.20183
DO	1.51	1.2915	0.94417
EC	4.46E+06	3.78E+06	1.46E+06
TDS	1.20E+08	1.00E+08	5.20E+07
Ca	5175	4318	1634
K	3425	2908	10456
Mg	37781	32148	12857
Na	2.67E+06	2.27E+06	8.52E+05

Table 4.2: Results of ANOVA general water quality variables and cation concentrations

Source of Variation	SS	df	MS	F	p-value	F <sub>crit</sub>
Wet season (Diversion works non-operational)	1.43E+08	7	2.04E+07	1.29	0.28	2.25
Wet season (Diversion works operational)	1.38E+08	7	1.97E+07	1.47	0.20	2.21
Dry season (Diversion works non-operational)	7.16E+07	7	1.02E+07	1.51	0.18	2.18
<b>SS = Sum of squares      df = Degrees of Freedom      MS = Mean squares</b>						

#### **4.2.1.10 Conclusion**

A neutral to slightly alkaline pH was observed across the sample sites with slight variations between sample sites. Overall pH complied with the domestic and recreational use SAWQG while certain sites exceeded the TWQR required for healthy aquatic ecosystems. The DO present at the surface is deemed sufficient to support aquatic life however, DO at mid-depth and bottom levels were not assessed. Due to the fluctuation of DO over a 24 hour cycle (Dallas and Day, 1993), it is recommended that the full diurnal range of DO concentrations is established over a number of days, including sunny and dull days. EC exhibited higher levels in dry season, with much higher conductivity recorded at site E2 (lagoon) during the wet and dry seasons, attributed to the influence of marine water. Sea water entering the lagoon on spring high tide tends to remain in the system resulting in an increase in the lagoons saline nature, which results in the system being non-compliant with the domestic use and aquatic ecosystem TWQR. TDS exhibited a similar trend to EC. The wet season demonstrated compliance to the domestic use TWQR of the river samples sites. This was reversed in the dry season. The estuarine sample sites did not comply with the prescribed TWQR for this user group due to its saline nature. The absence of TWQR for the cations for the aquatic and the ecological ecosystem makes it difficult to determine the health of the system to support and sustain aquatic life. The cations concentrations within the estuarine sample sites regularly exceeded the SAWQG due to the influence of salinity. The higher cation concentrations in the lagoon are explained by the larger volume of seawater entering the system, which occurs as a result of its limited capacity to flush water in conjunction with high evaporative rates. All the variables with the exception of K demonstrated a higher variance during the wet season across all the sample sites.

#### **4.2.2 Nutrients**

The average wet and dry season results for nutrients are tabulated in Appendix 5. A value of zero indicates the absence of the nutrient in the water column or could imply concentrations below the detection limit.

##### **4.2.2.1 Ammonia**

With reference to Figure 4.9, sites upstream of R3 displayed comparatively higher ammonia (NH<sub>3</sub>) results in the dry season and could infer to inputs of sewage or fertilizers from the upper catchment. The reduction in NH<sub>3</sub> at site R2 can be attributed to vegetation along the river banks playing a role in the purification of water through an assortment of filtration



process enhanced by the slower flow of water during the dry season. During the wet season (period of operation of the DWS, the concentration of ammonia dropped from 0.9 mg/l at R2 to 0 mg/l at R3 (Figure 4.9). The slow flow of water into the attenuation pond (attenuates flow prior to water flowing through the DWS) could have created conditions conducive for the complete oxidation of ammonia to nitrates.

Site R4 displayed increases in ammonia in the wet and dry season, even when flow from upstream of the DWS did not enter the Prospecton canal. This infers a source of ammonia emanating from the Prospecton area. Likely sources of ammonia could be sewage arising from manhole overflows, pump station failure and breakages in the sewerage system which has often been raised at the Isipingo Catchment Management Forum (ICMF), which is a forum that comprises of various role players with a view to manage impacts to water resources at a local level. Industrial discharges could also be a contributing factor and should not be ruled out as a likely source. Other potential sources could arise from the use of urban fertilizers and runoff.

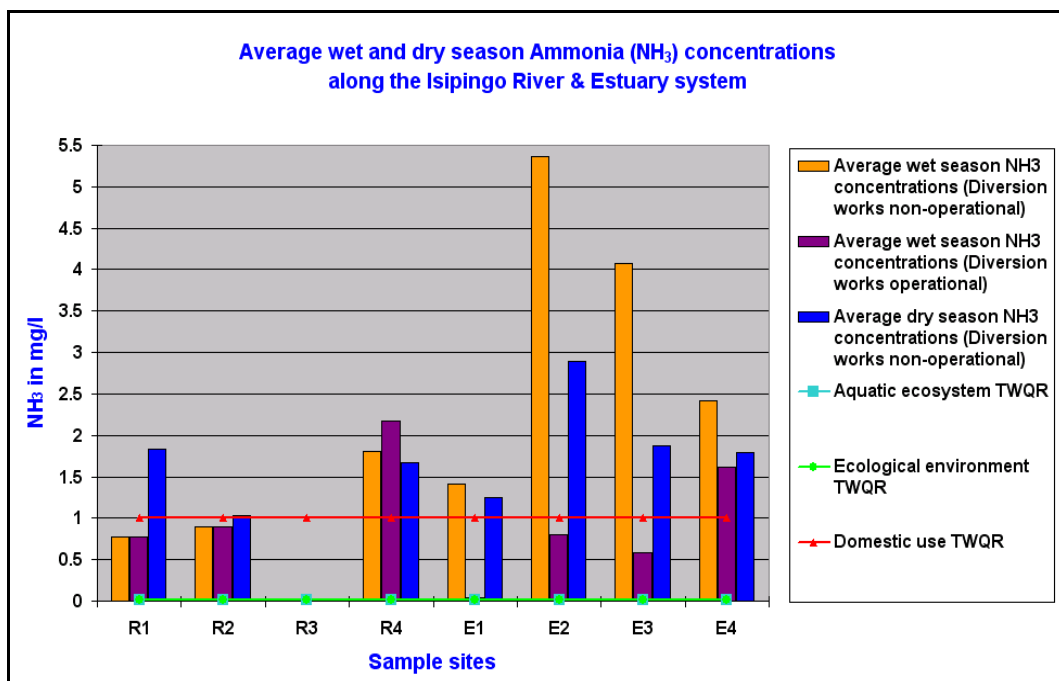


Figure 4.9: Comparison of average wet and dry season NH<sub>3</sub> concentrations to SAWQG

The lagoon (E2), lagoon arm entrance (E3) and the estuary inlet (E4: located below E1) exhibited some of the higher values of ammonia in the system both during the wet and dry season when the DWS was not in operation (Figure 4.9). The higher concentrations of

ammonia at some of the estuarine sites can be attributed to the reduction of nitrogen gas to ammonia by micro-organism or stem from conditions within the water body at the time which resulted in the ammonification of organic nitrogen to produce ammonia during the decomposition of organic matter (Chapman, 1992). Furthermore, the higher levels could also signify anthropogenic inputs arising from activities in the Prospecton Industrial Area (PIA) and residential area encircling the lagoon. Other sources could include sewage as there is a pump station located near E2 which has an emergency by-pass outlet directly to the lagoon. Under heavy rainfall conditions or when the system malfunctions, untreated sewage is directed to the lagoon (Cullis, 2012).

The aquatic or ecological ecosystem water quality targets were exceeded across all sample sites in both seasons. pH levels must be monitored as increases in pH towards more alkaline conditions increases the acute and chronic toxicity of ammonia which can have serious impacts to the health of aquatic organism, often resulting in death (Dallas and Day, 1993; DWAF, 1996c). The water is not fit for domestic use purposes across the majority of sites and levels above 2 mg/l are likely to comprise taste and odour (DWAF, 1996a).

#### **4.2.2.2 Nitrates**

The nitrate ( $\text{NO}_3$ ) concentrations complied with the domestic use guideline values except at site R4 during the dry season. Inorganic nitrogen (comprised of  $\text{NH}_3$ ,  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ , and  $\text{NO}_2^-$ ) below 0.5 mg/l is deemed to be sufficient to prevent eutrophic conditions (DWAF, 1996c). Taking into consideration, the ammonia and nitrate concentrations across the river and estuary system encountered during this study, it indicates a system susceptible to eutrophication as observed by the presence of water hyacinth across many of the sites.

Both ammonia and nitrate were lower at R2 in comparison to site R1 (Figure 4.10). There is some attenuation being achieved between these sites and this could be attributed to the vegetation along the banks and also demonstrates that the floodplain (although this has been modified and functionality reduced) still plays a pivotal role in purification. Evidence of water hyacinth growth was observed in the attenuation pond immediately above R3 for the duration of the study period. The reduction in flow through this pond creates a suitable environment for eutrophication. Photosynthetic action is able to convert the nitrate to organic nitrogen in the plant cells.

The average dry season nitrate concentration of 8.69 mg/l recorded at R4 was the highest average value observed during this study across all sample sites. There was visual evidence of sewage scum at this sample site and it was reported that there was a pump station failure which resulted in sewage entering the canal system in May and June 2010 (Naicker, 2010). Site E1 in both the dry and wet season yielded some of the highest nitrate concentrations observed for the estuarine sample sites (Figure 4.10). This could once again be attributed to conditions within the water body promoting the oxidation of ammonia to nitrate or could arise from the aerobic stabilization of organic nitrogen (Dallas and Day, 1993).

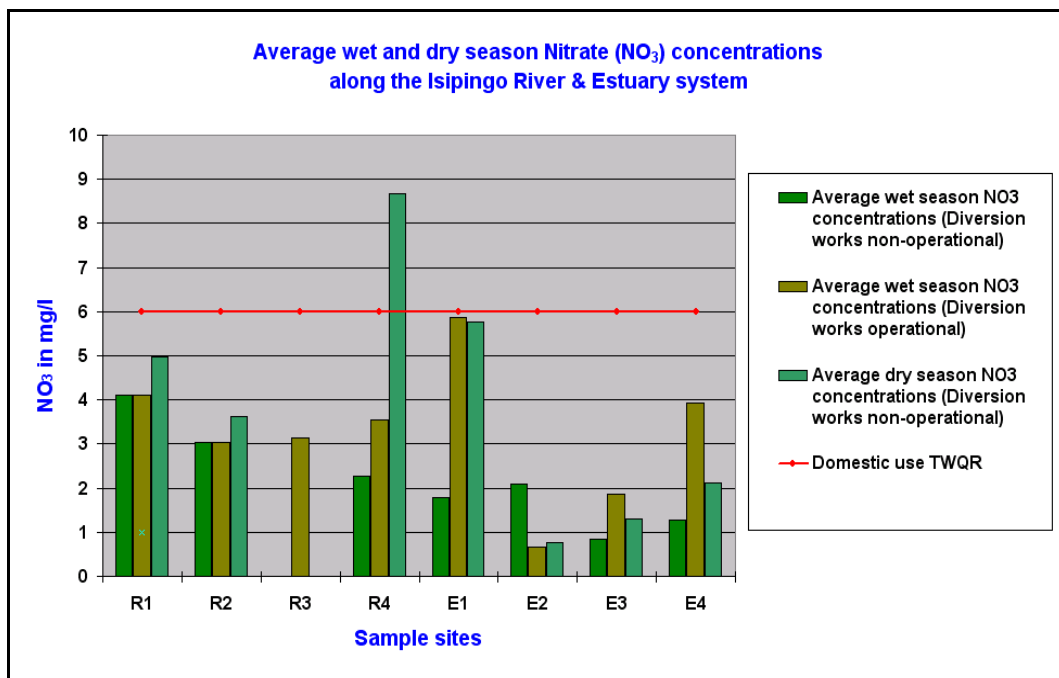


Figure 4.10: Comparison of average wet and dry season NO<sub>3</sub> concentrations to SAWQG

During periods of non-operation of the DWS, there was a reduction in nitrate concentrations observed between R4 and E1. This could be attributed to the uptake of nitrates by plants (i.e. the photosynthetic action converting nitrates to organic nitrogen in plant cells) such as water hyacinth which was observed at most of the sites during the year. The lagoon (E2) and lagoon arm entrance (E3) both recorded lower average nitrate concentrations (Figure 4.10). At these specific sites, ammonia concentrations were higher surmising the conversion of nitrates to ammonia. Furthermore, the saline nature of the lagoon, could have resulted in nitrates being bound to sediment. The estuary inlet (E4) which is downstream of E1 recorded lower nitrate concentrations than E1 during both seasons. This could be attributed to the adsorption of nitrate to sediment, the uptake of nitrate by aquatic plants or natural

attenuation process. Anthropogenic sources of nitrates within the estuary system could stem from sewage, urban fertilizer or industrial effluent.

#### 4.2.2.3 Phosphorus

Phosphorous (P) levels exceeded the level deemed sufficient to limit plant growth and eutrophication (Figure 4.11). The majority of the sample points recorded higher average P concentrations in the dry season. During the wet season, the average P concentration increased by an order of magnitude of nine times from site R1 to R2 with the situation reversed in the dry season (Figure 4.11). Dense residential development, the Umlazi wastewater treatment works and a transit camp is located upstream of site R2. The inadequate sanitation facility at the transit camp has on several occasions been cited as one of the sources by members of the ICMF (Taylor, 2012). Low flow and evaporative conditions in dry season may have resulted in river sediments or suspended material acting as a sink for P. There was an increase during the dry in the average P concentration between sites E1 and E4 season by approximately one and a half times the concentration recorded at site E1 (Figure 4.11).

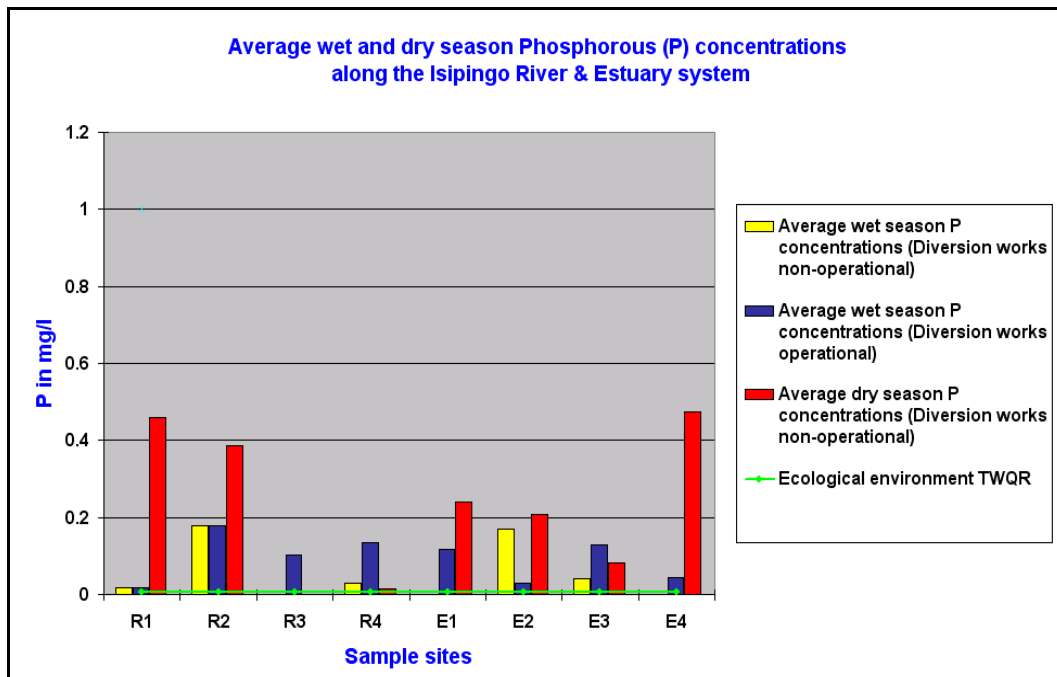


Figure 4.11: Comparison of average wet and dry season P concentrations to SAWQG

Anoxic conditions have been previously reported at E1 (Begg, 1978; Forbes and Demetriades, 2008) and this type of condition can give rise to the release of sediment bound

P back into the water column. During certain periods of this study, the saline nature of the lagoon could have resulted in the release of sediment bound P into the water column accounting for the presence of P at the lagoon (E2) and lagoon arm entrance (E3). The presence of P in the estuarine environment may be attributed to runoff or discharges from industry in the area, runoff from residential areas that utilize lawn fertilizer or the use of detergents. Domestic sewage is also high in P and any overflow of sewage could introduce P into the aquatic environment.

The higher values observed in the estuary during the dry season could also occur as a result of the relatively long retention time in the system and the amount of P in the bottom sediments. It is likely that when the bottom waters are anoxic, there is rapid regeneration of P from the sediments into the water column. Water hyacinth was also present during this study period. These aquatic plants and phytoplankton can remove P from the water column and could account for the lower levels observed. It is difficult to compare the wet season (period of operation and non-operation of the DWS as there could be other factors contributing to the removal and input of P to the samples located along the estuary.

#### 4.2.2.4 Analysis of variance of nutrients

ANOVA results yield a significant difference in the concentrations of nutrients across the sites for both seasons ( $p < 0.05$  and  $F > F_{crit}$ ) (Table 4.3).

Table 4.3: Results of ANOVA of nutrient concentrations

Source of Variation	SS	df	MS	F	p-value	F <sub>crit</sub>
Wet season (Diversion works non-operational)	23.45	2	11.73	8.41	2.63E-03	3.55
Wet season (Diversion works operational)	43.92	2	21.96	22.34	6.32E-06	3.47
Dry season (Diversion works non-operational)	46.47	2	23.23	8.41	2.64E-03	3.55
<b>SS = Sum of squares</b>	<b>df = Degrees of Freedom</b>		<b>MS = Mean squares</b>			

The greatest significant difference was recorded in the dry season. The order of variance during the dry season and the wet season (DWS operational) is  $P < NH_3 < NO_3$ . The following order of variance was experienced during the wet season (DWS non-operational):  $P < NO_3 < NH_3$ . P displayed the lowest variance during both seasons (Table 4.4). The higher  $NO_3$  concentrations observed at site R1 could stem from uncontrolled animal husbandry, sanitation infrastructure failures or the instream laundry in the upper catchment.

There is a particularly high variance in the NO<sub>3</sub> values in the wet season (DWS operational) and in the dry season (DWS non-operational) arising from the higher concentrations occurring at sites R4 and E1. This may be ascribed to activities within the PIA. The NO<sub>3</sub> concentrations within the estuarine sites are lower than the river sample sites during both seasons and may be attributed to biotic uptake resulting in its depletion. When the DWS is not operational, the high NO<sub>3</sub> at sites R1 and R2 is not expressed downstream at site R4 as this water is not contributing to sites downstream of the DWS.

Table 4.4: Variance of nutrient concentrations

Variables	Wet season (Diversion works non-operational)	Wet season (Diversion works operational)	Dry season (Diversion works non-operational)
	Variance		
NH <sub>3</sub>	2.97	0.54	1.76
NO <sub>3</sub>	1.20	2.40	3.89
P	6.13E-03	3.32E-03	0.267

#### 4.2.2.5 Conclusion

The ammonia concentrations across both the river and estuarine sample site do not comply with the TWQR for domestic use while nitrate concentrations fall within the prescribed range for this user group. A reconnaissance survey of the catchment and focused interviews with stakeholders of the ICMF cited sewage and agricultural subsistence activities as potential sources of macronutrients in the catchment. The phosphorus levels across all samples in both seasons were above the 0.005mg/l limit which is deemed sufficient to control plant growth. Additionally, the nitrate and ammonia levels at most of the sites were above the limit of 2.5 mg/l indicating the vulnerability of the system to being eutrophic. The system is prone to bouts of eutrophication as evident by the water hyacinth visible during most of the sampling events; particularly at sample points where a lower flow rate was observed. Nutrient input to the Isipingo River and Estuary system need to be more strictly controlled to reduce excess plant growth. Statistically significant differences were observed in the concentrations of nutrients across the sites for both seasons. P displayed the lowest variability in both seasons.

### **4.2.3 Heavy metals**

A value of zero in Tables 4.5, 4.6 and 4.7 indicates the absence of the respective heavy metal in the water column or that the heavy metal was present in the water column at concentrations below the detection limit.

#### **4.2.3.1 Wet season**

In the upper catchment, the wastewater treatment works appears to have a regulating effect on metal concentration, whilst the DWS further downstream has a similar (but opposite) effect. The dilution of upstream waters measured at site R2 showed a distinct decrease in concentration of all measured metals with the exception of Cr, Mo and Sr (Tables 4.5 and 4.6). The DWS on the otherhand requires substantial flow prior to allowing flow to the lower Isipingo system. During the period when the DWS was operational, marginal increases were observed at Site R3 for Al, Ba, Fe, Pb, Mn, Mo, V and Zr. An informal light industrial zone comprising of building block manufacturers and scrap metal recyclers is located between sites R2 and R3 (Table 4.6).

There was an observed absence of a number of heavy metals (Al, Cr, Co, Cu, Fe, Pb, Mn, Ni, Ti, V, Zn and Zr) in the estuarine environment and site R4 during the period when there was no flow received via the DWS (Table 4.5). Increasing salinity as the water flows into the estuarine sections together with other physico-chemical changes (higher pH, lower dissolved oxygen and redox reactions) has resulted in metal adsorption, flocculation and settling out, leading to low metal concentrations present in the water column, and at concentrations below the detection limit.

The prevailing conditions in the estuary during the sampling period when the DWS permitted flow to the lower Isipingo system, exhibited a slightly lower pH and higher dissolved oxygen levels, resulting in the release of heavy metals. With reference to Table 4.6, site R4 exhibited increased concentrations of Al, As, Cr, Pb, Se, Sr and Zr than that observed at site R3. It is noteworthy to mention that site R4 is located upstream of the estuary but immediately downstream of the PIA and site R3. During this period, sample events were preceded by heavy rainfall which would contribute to increased surface flow and consequently an increase in the flushing capability of the estuary which would agitate estuarine sediment contributing to metal release to the water column.

Table 4.5: Average wet season results of analysis of heavy metals along the Isipingo River and Estuary for the period February 2010 to January 2011 (in mg/l) (DWS non-operational)

Heavy metal concentrations (mg/l) (Wet season – diversion works non-operational)																	
Sample site	Al	As	Ba	Cr	Co	Cu	Fe	Pb	Mn	Mo	Ni	Se	Sr	Ti	V	Zn	Zr
R1	0.013	0.068	0.064	0.015	0.003	0.000	0.021	0.006	0.000	0.100	0.000	0.182	0.183	0.000	0.010	0.000	0.129
R2	0.006	0.063	0.060	0.016	0.002	0.000	0.020	0.006	0.000	0.116	0.000	0.071	0.174	0.000	0.010	0.000	0.129
R3	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
R4	0.000	0.000	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.341	0.000	0.000	0.000	0.000
E1	0.000	0.000	0.104	0.000	0.000	0.000	0.000	0.000	0.000	0.034	0.000	0.007	0.405	0.000	0.000	0.000	0.000
E2	0.000	0.006	0.108	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.211	1.024	0.000	0.000	0.000	0.000
E3	0.000	0.018	0.118	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.281	1.180	0.000	0.000	0.000	0.000
E4	0.000	0.000	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.000	0.094	0.724	0.000	0.000	0.000	0.000
TWQR DUI	0.15	0.01	na	0.05	na	1.00	0.50	0.01	0.10	na	na	0.02	na	na	0.1	20.00	na
TWQR AQI	0.005	0.01	na	0.007	na	0.0003	na	0.0002	0.18	na	na	0.002	na	na	na	0.002	na
TWQR ECI	0.02	0.02	na	0.024	na	0.0005	na	0.0005	na	na	na	na	na	na	na	na	na

**TWQR: Target Water Quality Range**  
**#: Diversion works non-operational**

**DUI: Domestic use – Ideal**  
**AQI: Aquatic ecosystems – Ideal**  
**ECI: Ecological environment – Ideal**



Table 4.6: Average wet season results of analysis of heavy metals along the Isipingo River and Estuary for the period February 2010 to January 2011 (in mg/l) (DWS operational)

Heavy metal concentrations (mg/l) (Wet season – diversion works operational)																	
Sample site	Al	As	Ba	Cr	Co	Cu	Fe	Pb	Mn	Mo	Ni	Se	Sr	Ti	V	Zn	Zr
R1	0.013	0.068	0.064	0.015	0.003	0.000	0.021	0.006	0.000	0.100	0.000	0.182	0.183	0.000	0.010	0.000	0.129
R2	0.006	0.063	0.060	0.016	0.002	0.000	0.020	0.006	0.000	0.116	0.000	0.071	0.174	0.000	0.010	0.000	0.129
R3	0.007	0.032	0.016	0.009	0.002	0.000	0.029	0.008	0.001	0.239	0.000	0.041	0.004	0.000	0.020	0.000	0.258
R4	0.062	0.078	0.016	0.033	0.002	0.000	0.112	0.022	0.001	0.220	0.000	0.164	0.052	0.000	0.019	0.000	0.259
E1	0.013	0.096	0.018	0.027	0.005	0.000	0.047	0.006	0.001	0.229	0.000	0.011	0.076	0.000	0.021	0.000	0.258
E2	0.023	0.285	0.018	0.022	0.005	0.009	0.060	0.032	0.001	0.261	0.000	0.643	0.993	0.000	0.021	0.000	0.275
E3	0.719	0.210	0.620	0.030	0.008	0.000	0.127	0.026	0.007	0.273	0.000	0.517	0.253	0.000	0.021	0.258	0.313
E4	0.015	0.101	0.000	0.022	0.002	0.000	0.046	0.000	0.004	0.171	0.000	0.193	0.194	0.000	0.029	0.000	0.244
<b>TWQR DUI</b>	0.15	0.01	na	0.05	na	1.00	0.50	0.01	0.10	na	na	0.02	na	na	0.1	20.00	na
<b>TWQR AQI</b>	0.005	0.01	na	0.007	na	0.0003	na	0.0002	0.18	na	na	0.002	na	na	na	0.002	na
<b>TWQR ECI</b>	0.02	0.02	na	0.024	na	0.0005	na	0.0005	na	na	na	na	na	na	na	na	na
<b>TWQR: Target Water Quality Range</b> <b>#: Diversion works non-operational</b>									<b>DUI: Domestic use – Ideal</b> <b>AQI: Aquatic ecosystems – Ideal</b> <b>ECI: Ecological environment – Ideal</b>								

#### **4.2.3.2 Dry season**

During the dry season, no water passed through the DWS into the lower Isipingo system and all water was diverted into the Mbokodweni River. The upstream concentrations of most heavy metals remained consistent between sites R1 and R2 with slight increases observed for Mo, Ni, Se and Zn (Table 4.7). The wastewater treatment works (receives industrial and sewage wastewater), and an informal light industrial zone comprising block manufacturers and scrap metal recyclers are located upstream of site R2. With reference to Table 4.7, site R4 located downstream of the PIA once again displayed higher concentrations of the following heavy metals: Al, As, Ba, Cu, Fe, Se, Sr, Ti, V and Zn in comparison to the upstream samples. The presence of these heavy metals at site R4 could be associated with illegal discharges of industrial effluent, breaks in the municipal sewer system (which also conveys industrial effluent) or contaminated stormwater from the PIA. The observations made in the wet season with respect to Cu, Ni, Ti and V is reversed in the dry season. These heavy metals are observed across all sample sites and at higher concentrations in the estuary. The release of sediment bound heavy metals is affected by physico-chemical conditions such as changes in pH, temperature, redox conditions and salinity.

The presence of organic material affects the rate of adsorption of Cu resulting in an increase of Cu in the water column (DWAF, 1996c) and could explain the presence of Cu during the dry season. Nickel compounds are often used in agriculture and most phosphate fertilizers contain Ni (Lenntech, 2004). Likely sources from which Ni may emanate are the market gardens and the residential areas in the vicinity of the estuary. The highest recorded Ni concentration was observed at the estuary mouth (E4). The source of Ni at this point remains unclear. Se and Sr displayed higher concentrations at the estuarine sites (Table 4.7).

#### **4.2.3.3 Heavy metal compliance to South African Water Quality Guidelines (SAWQG)**

With reference to Tables 4.5, 4.6 and 4.7, Cr and Mn were the only heavy metals to fall within the TWQR for the aquatic ecosystem across all river and estuarine sample sites. The following heavy metals (Al, As, Cr, Cu, Pb, Mn, Se and Zn) did not comply with the prescribed values as per the SAWQG from an ecological and aquatic ecosystem health perspective across most of the sample sites. This implies that there could be associated negative health impacts to aquatic organisms and possible health impacts to the public if fish is consumed.

Table 4.7: Average dry season results of analysis of heavy metals along the Isipingo River and Estuary for the period February 2010 to January 2011 (in mg/l) (DWS non-operational)

Heavy metal concentrations (mg/l) (Dry season – diversion works non-operational)																	
Sample site	Al	As	Ba	Cr	Co	Cu	Fe	Pb	Mn	Mo	Ni	Se	Sr	Ti	V	Zn	Zr
R1	0.034	0.042	0.030	0.000	0.000	0.011	0.020	0.000	0.000	0.015	0.008	0.035	0.122	0.007	0.008	0.144	0.000
R2	0.033	0.041	0.030	0.000	0.000	0.011	0.020	0.000	0.000	0.020	0.045	0.043	0.124	0.007	0.008	0.005	0.000
R3	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
R4	0.068	0.085	0.032	0.000	0.000	0.023	0.051	0.000	0.000	0.029	0.017	0.048	0.267	0.014	0.029	0.013	0.000
E1	0.054	0.060	0.031	0.000	0.000	0.012	0.020	0.000	0.000	0.019	0.009	0.035	0.220	0.007	0.015	0.005	0.000
E2	0.070	0.069	0.039	0.000	0.000	0.024	0.039	0.000	0.000	0.034	0.008	0.078	0.954	0.014	0.092	0.009	0.000
E3	0.068	0.025	0.038	0.000	0.000	0.088	0.017	0.000	0.000	0.030	0.017	0.061	0.682	0.014	0.082	0.009	0.000
E4	0.032	0.003	0.038	0.000	0.000	0.012	0.020	0.000	0.000	0.029	0.083	0.044	0.373	0.007	0.024	0.005	0.000
TWQR DUI	0.15	0.01	na	0.05	na	1.00	0.50	0.01	0.10	na	na	0.02	na	na	0.1	20.00	na
TWQR AQI	0.005	0.01	na	0.007	na	0.0003	na	0.0002	0.18	na	na	0.002	na	na	na	0.002	na
TWQR ECI	0.02	0.02	na	0.024	na	0.0005	na	0.0005	na	na	na	na	na	na	na	na	na
<b>TWQR: Target Water Quality Range</b> <b>#: Diversion works non-operational</b>									<b>DUI: Domestic use – Ideal</b> <b>AQI: Aquatic ecosystems – Ideal</b> <b>ECI: Ecological environment – Ideal</b>								

A comparison of the water quality to the domestic use SAWQG indicates that most heavy metals meet the prescribed values with the exception of As, Pb and Se. These metal display exceedingly higher concentrations at most of the estuarine sites and are toxic to human health if ingested in large quantities. The exceedance of Se with respect to both the domestic use and aquatic ecosystem water quality guidelines across all sample sites (river and estuary) is of concern as Se is toxic at low concentrations. Se also mimics sulphur and tends to replace sulphur in biologically important substances such as the thiol group of amino acids cysteine and methionine (Dallas and Day, 1993). The absence of aquatic ecosystem TWQR for Ba, Co, Fe, Mo, Ni, Sr, Ti, V and Zr makes it difficult to assess the health impacts associated with the levels observed during this study.

#### 4.2.3.4 Analysis of variance of heavy metals

The ANOVA results indicate that there is a significant difference in the variability of heavy metal concentrations both seasonally and across the sites ( $p < 0.05$  and  $F > F_{crit}$ ) (Table 4.8). The heavy metal concentrations demonstrated a relatively low variance (Table 4.9).

The higher concentrations of heavy metals in the estuarine environment may arise from the resuspension of metals in the water column and from industrial activities in the surrounding vicinity. As indicated in Table 4.9., Sr displays the greatest variance amongst all the heavy metals in both the wet and dry season with marked increases in concentration in the estuarine environment particularly at site E2 (lagoon).

Table 4.8: Results of ANOVA of heavy metal concentrations

Source of Variation	SS	df	MS	F	p-value	F <sub>crit</sub>
Wet season (Diversion works non-operational)	2.18	16	0.14	12.68	1.05E-17	1.74
Wet season (Diversion works operational)	1.07	16	0.07	4.00	5.06E-06	1.73
Dry season (Diversion works non-operational)	0.93	16	0.06	9.42	7.07E-14	1.74
<b>SS = Sum of squares                      df = Degrees of Freedom                      MS = Mean squares</b>						

Table 4.9: Variance of heavy metal concentrations

Variables	Wet season (Diversion works non-operational)	Wet season (Diversion works operational)	Dry season (Diversion works non-operational)
	Variance		
Al	2.56E-05	6.14E-02	3.20E-04
As	9.20E-04	7.38E-03	7.63E-04
Ba	6.50E-04	.4.44E-02	1.70E-05
Cr	5.73E-05	6.62E-05	0.00
Co	1.57E-06	4.84E-06	0.00
Cu	0.00	1.01E-05	7.83E-04
Fe	1.00E-04	1.66E-03	1.69E-04
Pb	8.57E-06	1.36E-04	0.00
Mn	0.00	5.84E-06	0.00
Mo	2.15E-03	4.24E-03	4.98E-05
Ni	0.00	0.00	7.84E-04
Se	9.97E-03	5.28E-02	2.40E-04
Sr	0.16	0.10	0.10
Ti	0.00	0.00	1.4E-05
V	2.38E-05	3.93E-05	1.24E-03
Zn	0.00	8.3E-03	2.66E-03
Zr	3.96E-03	4.55E-03	0.00

#### 4.2.3.5 Conclusion

The majority of the heavy metals achieve compliance with the domestic use levels as outlined in the water quality guidelines except for As, Pb and Se. There are also a number of heavy metals that exceed the aquatic ecosystem SAWQG (namely Al, As, Cr, Pb and Se in the wet season and Al, As, Cu, Se and Zn values in the dry season). The estuarine environment recorded higher heavy metal concentrations than the river sample sites. Depending on the physico-chemical factors such as pH, dissolved oxygen, redox reactions and salinity, metal adsorption and desorption and flocculation can occur leading to higher or lower metal concentrations present in the water column as observed during the study period. The results of ANOVA indicated that there is a statistically significant difference in the variability of heavy metal concentrations in both seasons across the sites. Hence, the conditions of the Isipingo Estuary waters would need to be closely monitored and also brings

to the fore the need to establish estuarine water quality guidelines. Point source contributors of heavy metals within the catchment require more detailed examination and the development of an industrial inventory is recommended.

#### **4.2.4 Microbiological water quality**

The monthly microbiological results conducted over the study period are tabulated in Appendix 6.

##### **4.2.4.1 *Escherichia coliforms (E. coli)***

Site R1 during the months of the December 2010 and January 2011 yielded *E. coli* levels in the order of 19 000 and 37 000 cfu/100ml respectively (Figure 4.12). Whilst it is beyond the scope of this study to ascertain the exact sources of the high *E. coli* levels, there are a number of likely sources. A reconnaissance survey of the catchment revealed considerably diverse subsistence agricultural practices amongst the inhabitants of surrounding settlements and the upper catchment. This includes small scale farming, and virtually every household maintains some poultry. Some households also keep cattle which are likely to graze along the river banks on a daily basis. Surface runoff from these households located along the river is likely to contribute towards the *E.coli* counts observed. The problem of the ingress of water after rainfall events and the resultant surcharge of sewage from sewer manholes has been regularly tabled at the ICMF (Cullis, 2012). Site R1 is also located below the trunk sewer line which conveys sewage from the Umlazi and surrounding areas to the Umlazi wastewater treatment works for treatment. Possible leakage from the trunk sewer line and overflows from manholes may explain the much higher *E. coli* levels observed during November 2010 to January 2011 at R1. Lower *E. coli* levels were recorded in the winter months and can be attributed to less rainfall received during these months and consequently less surface runoff (Figure 4.12).

With reference to Figure 4.12, during most months the *E. coli* levels at site R2 were lower than site R1 implying that the river system potentially has some assimilative capacity provided by the riparian vegetation and the transformed wetland, and the dilution effect of treated effluent from the wastewater treatment works. The same rationale can be used to explain the substantial decrease in *E. coli* levels between December 2010 and January 2011. According to the Department of Water Affairs (DWA), the Umlazi wastewater treatment works complied with the *E. coli* standards prescribed for discharge except during the month of March 2010 (DWA, 2011). However, it must be noted that DWA conducts audit

samples which means that the final effluent is sampled once a month implying the possibility of non-compliant effluent being discharged during certain periods. The months of May, June, November and December 2010 displayed an increase in *E. coli* counts at R2. This may be attributed to the poor management and provision of sewage services to the transit camp located near this site. According to Cullis (2012), the issue with the management of sewage and grey water from the transit camp has been raised on many occasions at the ICMF.

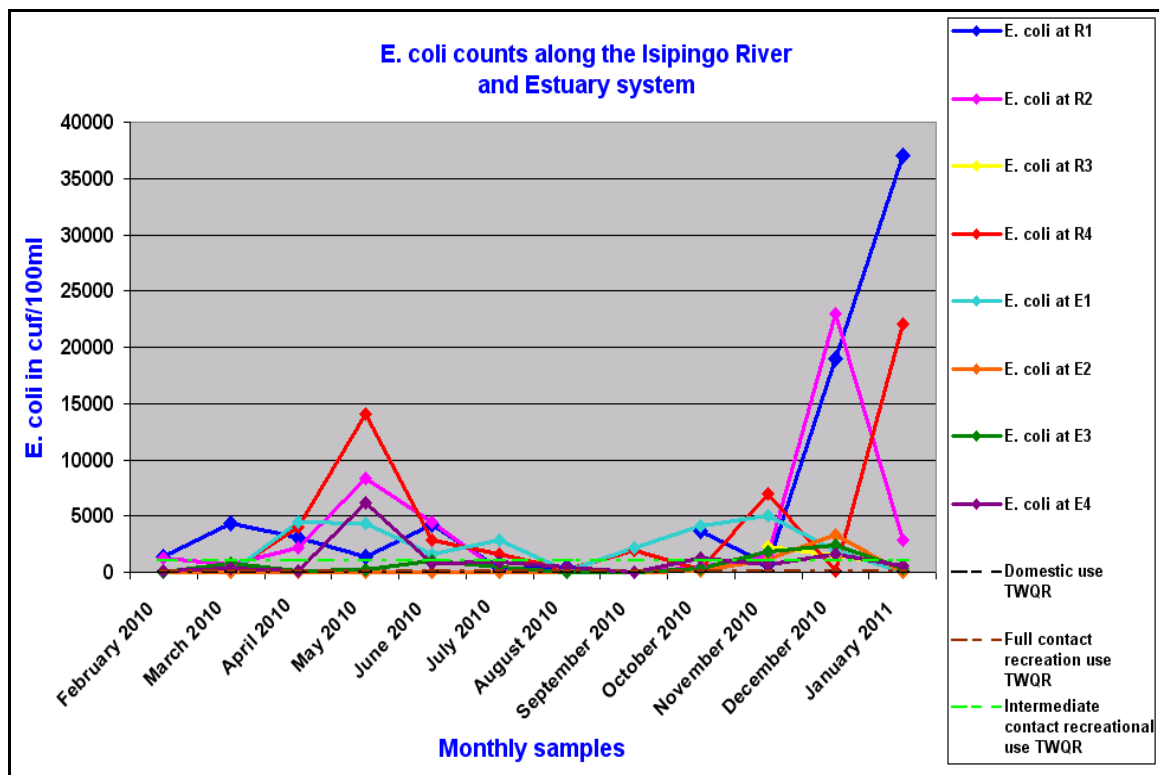


Figure 4.12: *E. Coli* counts observed between February 2010 and January 2011

The DWS did not function between February 2010 and October 2010 and during this period water from the upper catchment was diverted into the Mbokodweni River located to the south of the Isipingo catchment. During the months of November 2011 to January 2011, flow from the upper catchment joined the lower Isipingo system. Site R4 located downstream of the PIA, displayed the highest *E. coli* values of 20 000 cfu/100ml and 26 000 cfu/100ml in May 2010 and January 2011 respectively (Figure 4.12). The months of February 2010, April 2010, June 2010, July 2010 and November 2010 also recorded *E. coli* counts of between 10 000 and 14 000 cfu/100ml. According to Cullis (2012), malfunctioning of the sewage pump station located near site R4 is often reported to the ICMF by residents of the Isipingo

catchment, which results in untreated sewage entering the canalized portion of the Isipingo River at site R4.

Between the industrial site (site R4) and the upper estuary (site E1), some die-off of *E. coli* is observed during considerable parts of the year. Slight increases were observed in April 2010 and September 2010 whilst more notable increases occurred in July 2010, October 2010 and December 2010. It is noteworthy to point out that the Bamboo drain located downstream of Site R4, is a conduit for surface run-off emanating from the greater Isipingo Industrial node, and merges with the Isipingo River upstream of site E1. Sewer manhole blockages have been reported occasionally in this area (Naicker, 2010) and have the potential to be one of the sources contributing to the observed increases at site E1.

With reference to Figure 4.12, the lagoon (E2) yielded very low *E. coli* counts except in November 2010 and December 2010 (1150 and 3300 cfu/100ml respectively). These results are still much lower than that observed at other sample sites as part of this study. The lower counts may be attributed to the saline nature of the lagoon which creates an environment that is not conducive to the survival of *E. coli* bacteria. The higher results experienced in November 2010 and December 2010 could signify fresh pollution as a result of faecal matter most likely stemming from sewage. It is noted that there is a pump station located a few meters upstream of the lagoon. Periodic failure of this sewage pump station, located immediately upstream of lagoon and the subsequent spillage of untreated sewage into the lagoon has often been reported to the ICMF (Cullis, 2012). A reconnaissance survey of the land use practices surrounding the estuary show an extensive network of sewerage systems and pump stations. According to Singh (2012), a resident near the estuary, sewage spills are often reported at the ICMF.

The lagoon arm (E3) which is an extension of the lagoon also displayed relatively lower *E. coli* counts which may also be explained as a result of saline conditions. However, these values were higher than that recorded at E2. June 2010, November 2010 and December 2010 recorded much higher counts of 1000 cfu/100ml, 1800 cfu/100ml and 2400 cfu/100ml respectively. The estuary inlet (E4) is the last point within the estuary prior to water flowing out to the marine environment. The *E. coli* counts was also low when compared to other sample sites with the exception of May 2010, October 2010 and December 2010 which recorded counts of 6200 cfu/100ml, 1200 cfu/100ml and 1600 cfu/100ml respectively.



#### 4.2.4.2 Faecal coliforms (FC) and Total coliforms (TC)

TC comprises of a composite of bacteria found in soil and water and includes FC. The presence of the latter in a sample (water or sediment) is indicative of faecal pollution. *E. coli* is a subgroup of FC and is more indicative of contamination by human and animal waste. In Figures 4.13 and 4.14 below, the counts of TC and FC follow a similar trend across most sampling sites during the year. The contribution to TC counts by FC can be gauged by comparing the two results and gives an indication with respect to bacteria specific to faecal contamination versus that found in the natural environment.

Bacteria levels were highly variable during the wet and dry months. Sources of faecal pollution based on the previously discussed reconnaissance survey indicated potential sources arising from surface run-off, sewage, faeces of grazing livestock, settlements with poor sanitation facilities as well as the spreading of cattle manure on land. The decrease in faecal bacterial count can be explained by the combined actions of various biological (grazing by protozoa, virus-induced cell lysis) and physico-chemical processes (stress due to nutrient depletion, sunlight intensity, and temperature decrease) (Ouattara *et al.*, 2009). Some pertinent results relevant to Figures 4.13 and 4.14 are discussed in the text to follow.

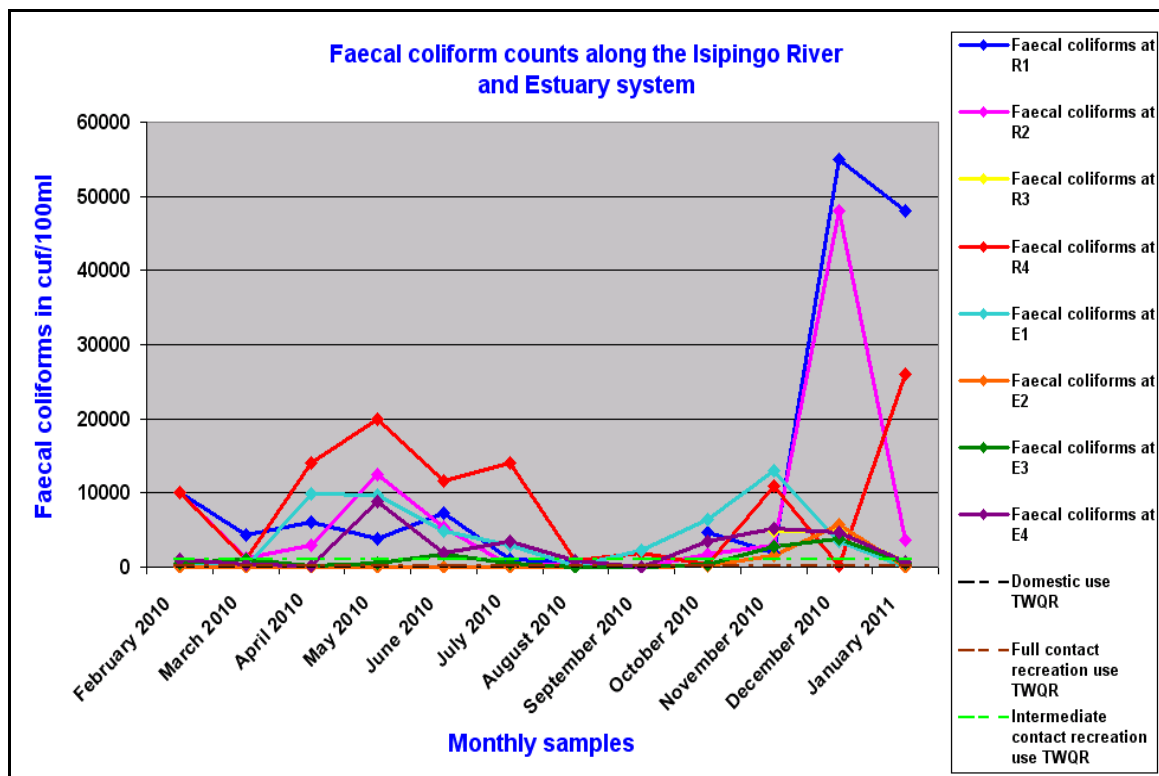


Figure 4.13: Faecal coliform counts observed between February 2010 and January 2011

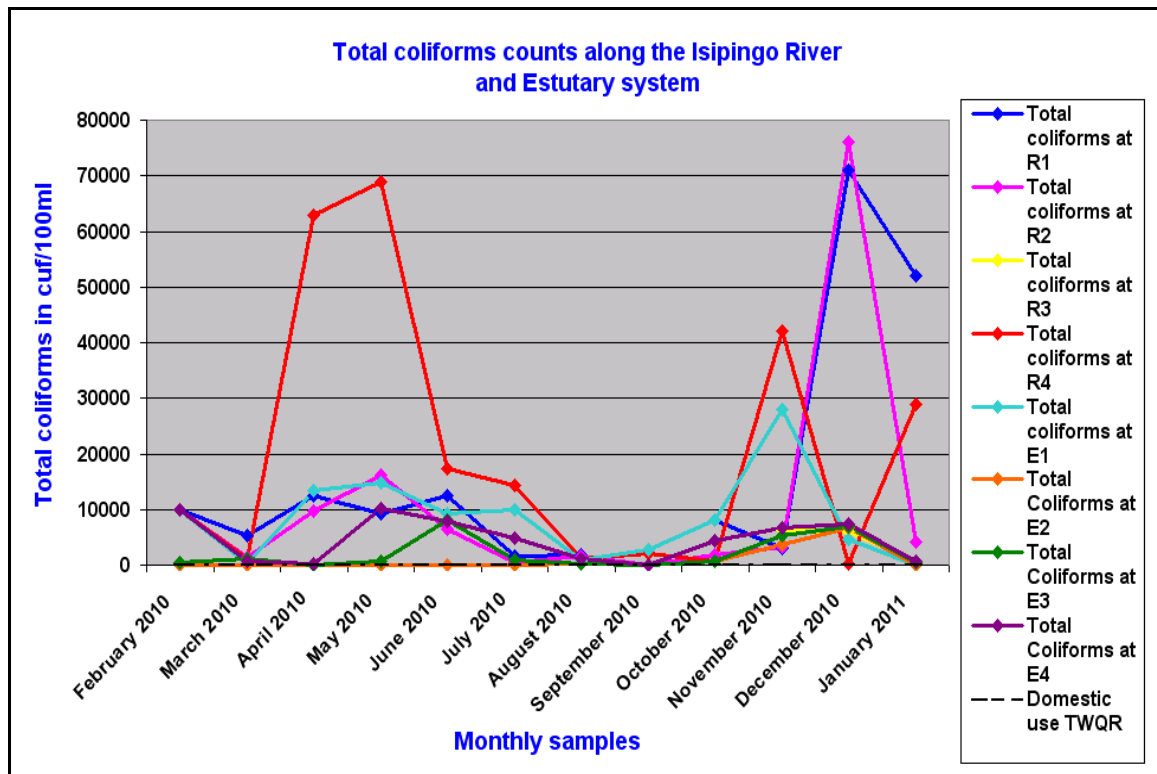


Figure 4.14: Total coliform counts observed between February 2010 and January 2011

Site R4 demonstrated a substantive increase in both TC and FC counts during April and May 2010. Whilst TC correspondingly peaked at 70 000 cuf/100 ml, the FC counts recorded during this period was 20 000 cuf/100 ml, indicating a smaller contribution of faecal matter to the TC levels. This implies that the TC counts recorded at site R4 comprised predominately of bacteria other than that of faecal origin. The levels at this site begin to taper between June 2010 and October 2010 with elevated levels of TC displayed in November 2010 at sites R4 and E1. There is an increase of TC and FC counts at sites R1 and R2 in December 2010. The TC levels recorded at R1 and R2 during this month are 71 000 cuf/100ml and 76 000 cuf/100ml in comparison to the FC levels (55 000 cuf/100ml at R1 and 48 000 cuf/100ml at R2). This indicates that a substantial contribution to the TC counts is attributed to pollution from faecal matter.

The TC counts drop significantly at R2 in January 2011. A closer examination of the FC counts in relation to TC in the preceding months showed a larger contribution from a source of faecal contamination. Other factors to explain the decrease include the dilution effect preceding sample events and assimilative capacity provided by the riparian vegetation and the transformed wetland. Although there was a decrease in TC in January 2011 (from 71

000 cuf/100ml to 52 000 cuf/100ml), the recorded FC and *E. coli* levels at R1 during this month were 48 000 cuf/100ml and 37 000 cuf/100ml respectively. This alludes to a significant contribution of pollution by faecal matter but more specifically from human and animal waste, as *E. coli* is indicative of this type of pollution. A similar situation occurs at site R4 with TC, FC and *E. coli* counts increasing in January 2011. The FC and *E. coli* counts comprise a larger portion of the TC counts recorded, again alluding to contamination by sewage.

#### **4.2.4.3 Microbiological compliance to South African Water Quality Guidelines**

Both the river and estuarine sites failed to comply with the TWQR for domestic use for *E. coli*, faecal and total coliforms which renders the water in the Isipingo system unfit for drinking purposes. The river sites also do not comply to the TWQR for full contact recreational use implying that the river should not be used for swimming or bathing purposes. The lagoon (E2) achieved 75% compliance to the TWQR for full contact recreational use however; the other estuarine sample sites did not comply with this target. The TWQR for intermediate contact recreational use (e.g. waterskiing, canoeing and angling) is 1000cuf/100ml. Sites E2, E3 and E4 achieved much greater compliance during the study period to this TWQR while the river sites exceeded this prescribed values.

#### **4.2.4.4 Analysis of variance of pathogens**

All sites with the exception of R2 and E2 displayed statistically significant differences in the levels of the pathogens ( $p < 0.05$  and  $F > F_{crit}$ ) (Table 4.10). There is also a significant difference of the levels of the 3 pathogens from month to month for each sampling period within the study period. The exception occurring at site E2 is attributed to the increased marine effects and saline nature of the lagoon which does not create an environment conducive for the survival of pathogens.

The variability of total coliforms is higher in the riverine section than the estuarine sites. This is attributed to land use effects in the riverine area. On the other hand the variance in total coliforms is lower at sites E2 and E3 due to marine effects. Faecal coliforms and *E. coli* follow a similar pattern of variance to that of the total coliforms, displaying some of the highest variances at R1 and R4 which can be attributed to impacts associated with activities in the upper catchment and the PIA respectively. Furthermore, sites E2 and E3 displayed a lower variance for these pathogens and are consistent with the results of this study.

Table 4.10: Variance between groups of pathogens

Source of Variation	SS	df	MS	F	p-value	F <sub>crit</sub>
R1	5.63E+08	2	2.81E+08	5.33	0.02	3.44
R2	3.09E+08	2	1.55E+08	2.79	0.08	3.44
R4	1.69E+09	2	8.47E+08	5.90	0.01	3.44
E1	2.43E+08	2	1.22E+08	10.16	7.50E-04	3.44
E2	1.95E+06	2	9.75E+05	2.52	0.10	3.44
E3	1.46E+07	2	7.29E+06	4.61	0.02	3.44
E4	7.04E+07	2	3.52E+07	10.28	7.05E-04	3.44
<b>SS = Sum of squares      df = Degrees of Freedom      MS = Mean squares</b>						

#### 4.2.4.5 Conclusion

The overall water quality of the Isipingo River and Estuary is microbiologically poor and does not comply with the SAWQG for domestic and recreational use. Therefore the system poses a health risk to the public. Due to the absence of guideline values for aquatic ecosystems, the impact to this user group could not be ascertained. There is a need to adopt a holistic approach to microbial water quality management in the catchment. Throughout the duration of the study period, there were considerably elevated levels of faecal matter in the river and estuarine sample sites. The saline environment of the estuary plays a role in limiting the growth and multiplication of bacteria. This is evident by the relatively lower coliform counts in comparison to the river.

A reconnaissance survey of the catchment and focused interviews with roleplayers of the ICMF revealed likely anthropogenic sources to be linked to sewage and associated faecal matter from informal subsistence agricultural activities (livestock farming). All sites with the exception of R2 and E2 displayed statistically significant differences in the levels of the pathogens highlighting the variable contributions of pathogens from different land uses in the study area. A more rigorous monitoring schedule needs to be implemented by the Department of Health with regard to the 'backdoor' poultry and cattle farms within the study area. The identification of point source contributors to faecal contamination and the implementation of 'zero' faecal coliform discharge standards would assist with reducing the current levels.

### **4.3 Geochemical assessment of heavy metals in the surface sediment of the Isipingo River and Estuary**

This section of the dissertation presents the findings of the range of indices used to assess the present day level of heavy metal contamination in sediment of the Isipingo River and Estuary. The following types of indices were used: Enrichment Factor (EF), Contamination Factor (CF), Degree of Contamination ( $C_d$ ) and the Geo-accumulation Index ( $I_{geo}$ ).

#### **4.3.1 Heavy metal concentrations**

The concentration of all detected heavy metals in the sediment is greater during the wet season and is indicative of increasing contaminants reaching the river through catchment runoff. Several metals were undetected at this site and these include As, Co, Cu, Mo, Pb, Se and Zr. At R2, the majority of heavy metal concentrations is relatively higher in the dry season with the exception of Cu, Pb and Zn for which higher concentrations occurred in the wet season (Table 4.11). This reversal relative to R1 is attributed to the treated effluent received from the Isipingo wastewater treatment works which treats landfill leachate received from the Umlazi landfill. With reference to Table 4.11, As, Co and Zr are not detected both during the wet and dry seasons at R2. Low concentrations of Mo and Se are detected in the sediment (0.05 ppm) during the wet season but both are absent during the dry season.

Site E1 displays the highest concentrations of the majority of heavy metals in the study area. This correlates well with prior studies (Begg, 1978; Forbes and Demetriades, 2008) and has previously been attributed to the highly organic nature of the bottom sediments in this part of the estuary. With the exception of Al, Ba, Se and Ti which exhibit slightly higher concentrations in the wet season, all other heavy metal concentrations in the sediment are higher in the dry season. No trace of Zr was detected in any of the sediment samples in either season.

Finally, at E2, all heavy metal concentrations with the exception of As and Ti were higher in the wet season. Zr was once again absent in all sediment samples taken at this site. Site E2 displayed the second highest concentration of the majority of heavy metals (Table 4.11). Sites E1 and E2 are located in the estuary which forms the receiving basin for all landward derived pollutants and fine sediment. The dominant fine-grained, organic rich sediment at these sites (Begg, 1978 and, Forbes and Demetriades, 2008) also ensures significant

adsorption of metals. At E2, the concentration of Al recorded in the wet season was three times greater than that recorded for the dry season sample while the concentrations of Fe and Sr in the wet season samples were approximately double that recorded in the dry season.

Table 4.11: Dry and wet season concentration (ppm) of heavy metals

Heavy metals	Clarke Value	R1		R2		E1		E2	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
Al	81300	134.2	82.95	106.5	147.4	775.1	751.6	560.6	195.5
As	5	0.00	0.10	0.00	0.00	0.04	0.26	0.19	0.45
Ba	260	1.23	1.07	1.47	2.77	3.32	2.28	2.40	0.85
Co	23	0.00	0.00	0.00	0.00	0.01	0.05	0.178	0.003
Cr	200	0.70	0.58	0.85	1.06	1.95	4.88	5.72	2.32
Cu	70	0.00	0.00	0.72	0.02	0.67	0.81	2.50	0.93
Fe	50000	302.1	225.4	335.4	394.4	476.1	826	735	412.2
Pb	16	0.10	0.00	0.20	0.14	0.90	2.66	2.25	0.66
Mn	1000	4.31	2.69	2.75	5.46	4.56	6.53	7.34	3.05
Mo	15	0.00	0.00	0.05	0.00	0.004	0.076	0.18	0.01
Ni	80	0.05	0.01	0.05	0.09	0.26	0.47	1.32	0.32
Se	*0.05	0.00	0.00	0.05	0.00	0.74	0.40	0.68	0.00
Sr	300	0.74	0.55	0.91	2.31	5.64	8.48	15.36	7.12
Ti	4400	10.65	8.16	10.19	11.26	53.52	47.54	47.48	56.23
V	150	0.65	0.53	0.75	0.84	1.64	1.90	3.45	2.44
Zn	132	0.69	0.60	1.20	0.97	4.53	7.36	7.88	1.35
Zr	*165	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Clarke values after: \*(Rosler and Lange, 1972) and (Martinez et al., 2007)

#### 4.3.2 Contamination Factors (CF)

Table 4.12 presents the Contamination Factor (CF) calculated for both the wet and dry season for each sample site. The data shows that across all sites with the exception of Se, the CF calculated for all heavy metals is less than one, which implies fairly low contamination. The CF for Se is very high in the estuarine environment with site E1 experiencing a high CF throughout the year while site E2 is characterized as being highly contaminated in the wet season (Figure 4.15). Se was undetected in the sediment sample at site E2 during the dry season therefore recording a CF of zero.

Standing or slow moving waters with low flushing rates can accumulate selenium in sediment (Lemly and Smith, 1987) which is characteristic of the Isipingo Estuary. These systems are generally characterized by high biological productivity and Se may be trapped through immobilisation processes or through direct uptake by organisms (Lemly and Smith, 1987). However, selenium is not permanently sequestered in sediment and may be mobilized through oxidation and methylation processes (Lemly and Smith, 1987).

Table 4.12: Contamination factors of heavy metals present in the Isipingo River and Estuarine sediments.

Heavy metals	Clarke Value	R1		R2		E1		E2	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
<b>Al</b>	81300	0.002	0.001	0.001	0.002	0.010	0.009	0.007	0.002
<b>As</b>	5	0.000	0.020	0.000	0.000	0.008	0.052	0.038	0.090
<b>Ba</b>	260	0.005	0.004	0.006	0.011	0.013	0.009	0.009	0.003
<b>Co</b>	23	0.000	0.000	0.000	0.000	0.0004	0.002	0.008	0.0001
<b>Cr</b>	200	0.004	0.003	0.004	0.005	0.010	0.024	0.029	0.012
<b>Cu</b>	70	0.000	0.000	0.010	0.0003	0.010	0.012	0.036	0.013
<b>Fe</b>	50000	0.006	0.005	0.007	0.008	0.010	0.017	0.015	0.008
<b>Pb</b>	16	0.006	0.000	0.013	0.009	0.056	0.170	0.140	0.040
<b>Mn</b>	1000	0.004	0.003	0.003	0.005	0.005	0.007	0.007	0.003
<b>Mo</b>	15	0.000	0.000	0.003	0.000	0.0003	0.005	0.012	0.0007
<b>Ni</b>	80	0.0006	0.0001	0.0006	0.001	0.003	0.006	0.017	0.004
<b>Se</b>	*0.05	0.000	0.000	1.000	0.000	14.800	8.000	13.600	0.000
<b>Sr</b>	300	0.002	0.002	0.003	0.008	0.019	0.028	0.051	0.024
<b>Ti</b>	4400	0.002	0.002	0.002	0.003	0.012	0.011	0.011	0.013
<b>V</b>	150	0.004	0.004	0.005	0.006	0.011	0.013	0.023	0.016
<b>Zn</b>	132	0.005	0.005	0.009	0.007	0.034	0.056	0.060	0.010
<b>Zr</b>	*165	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Clarke values after: *(Rosler and Lange, 1972) and (Martinez et al., 2007)									

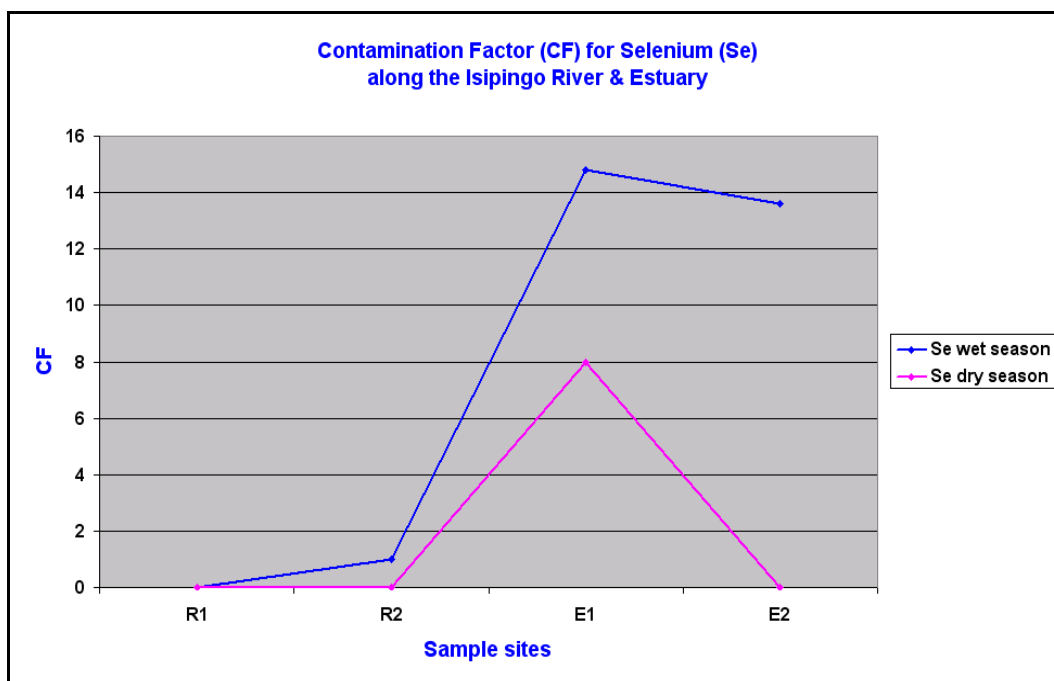


Figure 4.15: Contamination Factor (CF) for Selenium in the wet and dry season

#### 4.3.3 Enrichment Factors (EF)

The riverine sites both yield moderate enrichment of Cr, Fe, Mn, V and Zn in both seasons which indicate possible anthropogenic contributions. Additionally, moderate Ba enrichment at R1 and Sr at R2 were recorded. Moderate Ba enrichment is also obtained at R2 but only in the dry season. Similarly, moderate Pb enrichment is experienced at R1 only in the wet season. The EF for Co, Ni and Zr fall within the geological norm for both seasons as does Cu, Mo and Se for R1 and As at R2 (Table 4.13). Se is the only highly enriched metal suggesting anthropogenic enrichment at both riverine sites (Figure 4.16). At R2, Mo and Cr show significant increases in the wet season whilst Cu in the sediment fluctuates between significant and high enrichment during the wet season. Interestingly, an EF of zero was obtained at both R1 and R2 during the dry season.

Metals exhibiting enrichment at site E1 include As, Cr, Pb, Se and Zn (Table 4.13), with Se again reaching extremely high enrichment status in both the dry and wet seasons reaching an EF of 887 in the dry season (Figure 4.16). This points towards considerable anthropogenic input. Moderate to slightly significant enrichment is calculated for As with an EF of 5.6 in the dry season whilst minimal to slightly moderate enrichment is displayed by Cr in the wet and dry season respectively. Also, wet season concentrations indicate moderate



contamination for Pb and Zn but more significant enrichment for these metals in the dry season with Pb reaching an EF of 18. All other calculated EF's (with the exception of Pb in the dry season and Se in both seasons) indicate that they have been derived from natural sources.

Table 4.13: Enrichment factors (EF) of heavy metals in the Isipingo River and Estuarine sediments.

Heavy metals	Clarke Value	R1		R2		E1		E2	
		Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season
<b>Al</b>	81300	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
<b>As</b>	5	0.00	19.60	0.00	0.00	0.84	5.60	5.50	37.40
<b>Ba</b>	260	2.90	4.00	4.30	5.90	1.30	0.90	1.30	1.40
<b>Co</b>	23	0.00	0.00	0.00	0.00	0.05	0.24	1.10	0.05
<b>Cr</b>	200	2.10	2.80	3.20	2.90	1.00	2.60	4.10	4.80
<b>Cu</b>	70	0.00	0.00	2.70	0.06	0.35	0.44	1.80	1.90
<b>Fe</b>	50000	3.70	4.40	5.10	4.40	1.00	1.80	2.10	3.40
<b>Pb</b>	16	3.80	0.00	9.50	4.80	5.90	18.00	20.00	17.20
<b>Mn</b>	1000	2.60	2.60	2.10	3.00	0.48	0.71	1.06	1.27
<b>Mo</b>	15	0.00	0.00	2.50	0.00	0.03	0.55	1.74	0.28
<b>Ni</b>	80	0.38	0.12	0.48	0.62	0.34	0.64	2.39	1.66
<b>Se</b>	*0.05	0.00	0.00	782	0.00	159	887	2022	0.00
<b>Sr</b>	300	1.50	1.80	2.30	4.20	2.00	3.10	7.40	9.90
<b>Ti</b>	4400	1.50	1.80	1.80	1.40	1.30	1.20	1.60	5.30
<b>V</b>	150	2.60	3.50	3.80	3.10	1.10	1.40	3.30	6.80
<b>Zn</b>	132	3.20	4.50	6.90	4.10	3.60	6.00	8.70	4.30
<b>Zr</b>	*165	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Clarke values after: *(Rosler and Lange, 1972) and (Martinez et al., 2007)</b>									

With reference to Table 4.13, at site E2, there is zero to minimal enrichment of the sediment by Ba, Co, Cu, Mn, Mo and Zr while marginally moderate enrichment of the sediment is displayed by Ni. Moderate enrichment of the sediment is exhibited by Cr, Fe, Ti while Zn and V enrichment levels allude to slightly significant enrichment. This can be linked to either natural or anthropogenic sources. As still shows signs of marginally moderate to very high enrichment in the wet and dry season respectively. The high EF values for As (37.4 in the

dry season), Pb (20 and 17.2 in the wet and dry season respectively) and Se (2022 wet season) demonstrate significant enrichment and strongly suggests anthropogenic sources as the contributing factor to these very high levels of enrichment at site E2. Table 4.13, shows that the EF's for all heavy metals with the exception of As (sites R2 and E2), Pb (sites E1 and E2) and Se (sites R2, E1 and E2) vary between 0 and 10, indicating natural sources for these metals. They are therefore not affected by anthropogenic sources.

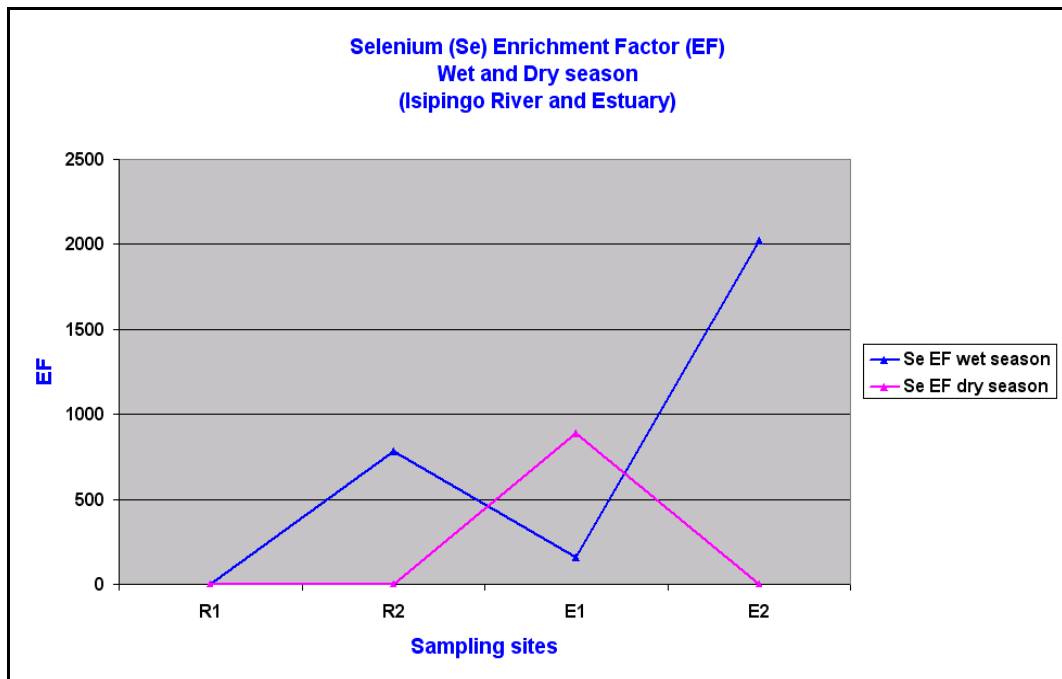


Figure 4.16: Enrichment Factor (EF) for Selenium during the wet and dry season

#### 4.3.4 Contamination degree ( $C_d$ )

Table 4.14 shows the degree of contamination ( $C_d$ ) for each sampling site in both the wet and dry season. The table also indicates the  $C_d$  for each sampling site with the exclusion of Se in the calculation to illustrate the affect this heavy metal has on the degree of contamination for the Isipingo system. All sample sites during the wet and dry season, when Se is excluded from the calculation indicates that there is a low degree of contamination for the system as a whole. The inclusion of Se, however changes the degree of contamination and classifies the estuarine sites as being considerably contaminated in the wet season with site E1 exhibiting signs of moderate contamination in the dry season. The calculation of the average contamination for the river sample sites show that there is very low contamination while the estuary is considered in the wet season to be a system with a considerable

contamination degree, indicating anthropogenic pollution as a consequence of Se loading in the system.

Table 4.14: Contamination degree ( $C_d$ ) at each sample site along the Isipingo River and Estuary

Sampling sites	$C_d$ (wet season)	$C_d$ (wet season) excluding Se	$C_d$ (dry season)	$C_d$ (dry season) excluding Se
R1	0.041	0.041	0.049	0.049
R2	1.067	0.067	0.065	0.065
<b>Average</b>	<b>0.550</b>	<b>0.050</b>	<b>0.060</b>	<b>0.060</b>
E1	15.00	0.200	8.420	0.420
E2	14.06	0.460	0.240	0.240
<b>Average</b>	<b>14.530</b>	<b>0.330</b>	<b>4.330</b>	<b>0.330</b>

#### 4.3.5 Geo-accumulation Index

The results of the Geo-accumulation Index ( $I_{geo}$ ) in sediment for the wet and dry season are illustrated in Figures 4.17 and 4.18 respectively. Figure 4.19 illustrates the  $I_{geo}$  of Se in the wet and dry season.

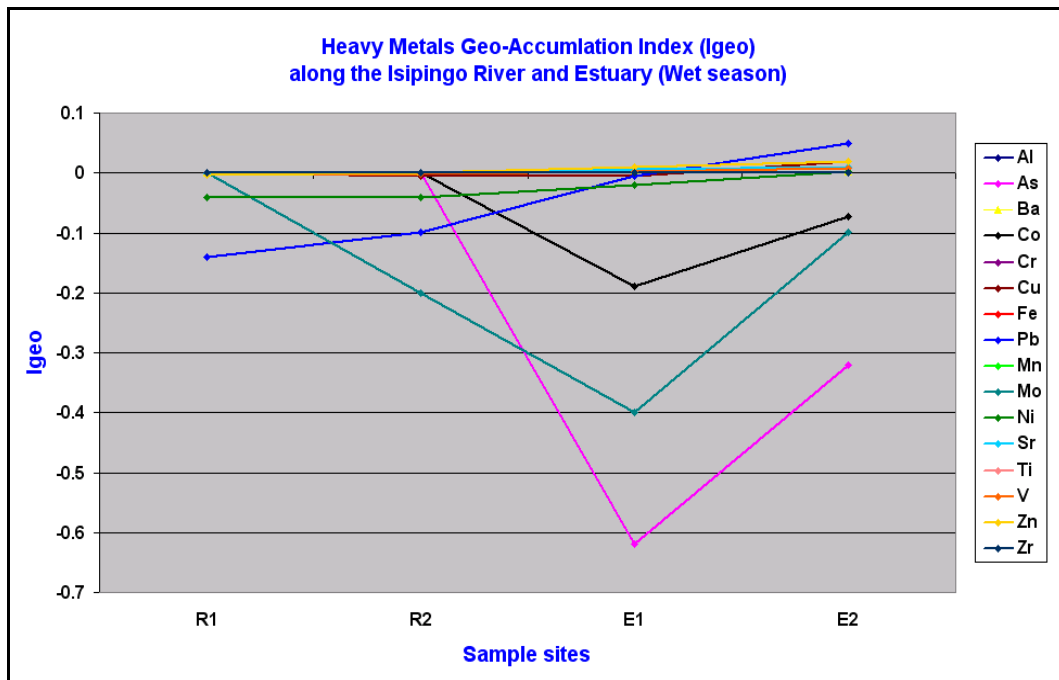


Figure 4.17: Geo-accumulation index of heavy metals along the Isipingo River and Estuary in the wet season

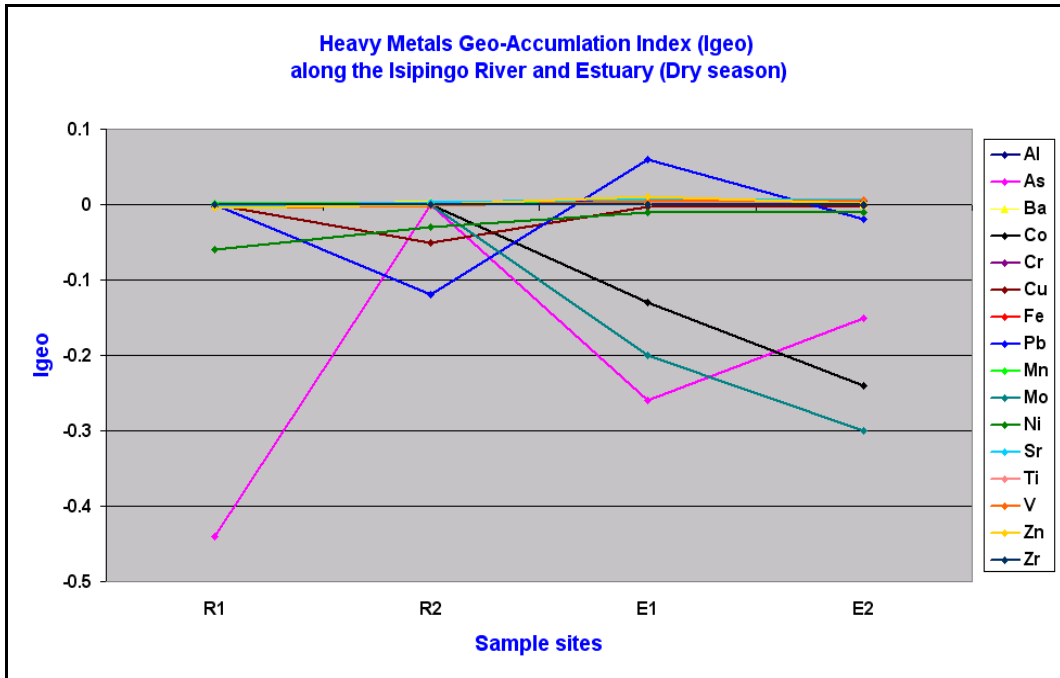


Figure 4.18: Geo-accumulation index of heavy metals along the Isipingo River and Estuary in the dry season.

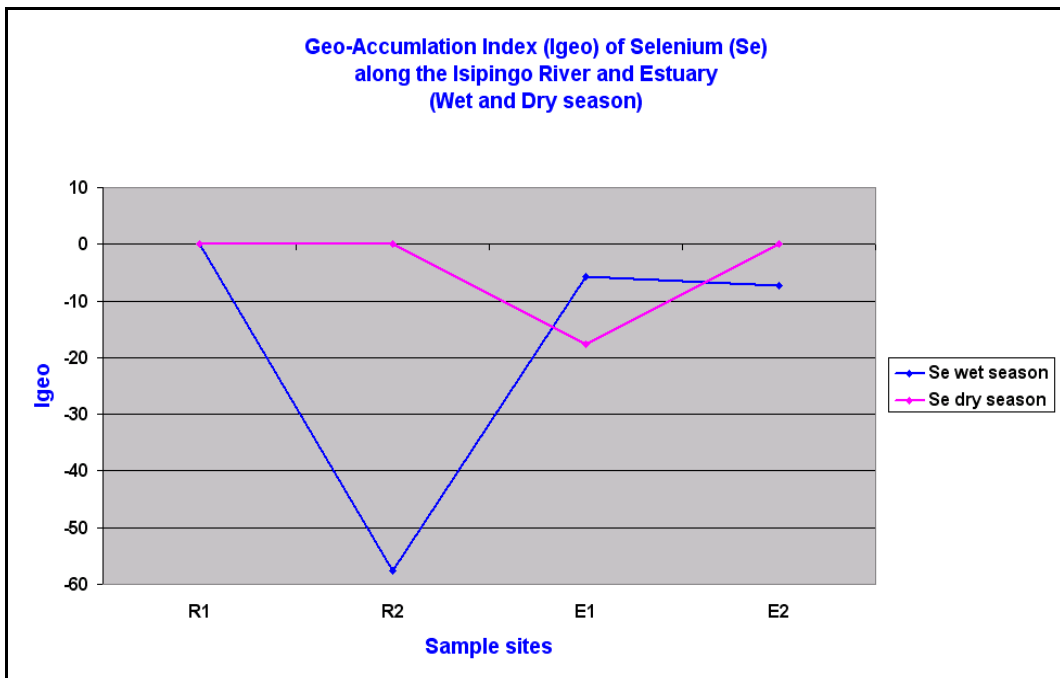


Figure 4.19: Geo-accumulation index of Selenium along the Isipingo River and Estuary representing the wet and dry season

The negative values are indicative of sediment that is unpolluted and values ranging between 0 and one range between unpolluted and moderately polluted. The  $I_{geo}$  values for the majority of heavy metals are either negative or very close to zero thus demonstrating and confirming generally unpolluted sediment as indicated by the other indices used. The  $I_{geo}$  factor is not readily comparable with EF due to the nature of  $I_{geo}$  calculation which involves a logarithm function and a background multiplication factor of 1.5.

#### **4.3.6 Conclusion**

Although several metals were undetected at certain river sites, the concentrations of heavy metals increased longitudinally from the river to the estuary. The estuary has been the receiving basin for fine grain material and has accumulated heavy metals in the sediment. With the exception of Se, the contamination factor is less than one which implies low contamination. The riverine sites yielded moderate enrichment by some heavy metals in both seasons. Se however is highly enriched suggesting an anthropogenic source. The estuary demonstrated enrichment with respect As, Cr, Pb, Se and Zn.

The enrichment factor for the lagoon indicated a high EF for As, Pb and Se in the dry season. The degree of contamination for each site with the exclusion of Se indicated a low degree of contamination while the inclusive of Se classifies the estuary as considerably contaminated in the wet season. The Geo-accumulation Index places the sediment in an overall unpolluted category however; this is not directly comparable to the Enrichment Factor due to the nature of  $I_{geo}$  calculation.

The purpose of this study was to assess heavy metal concentrations and distribution in surface sediments of the Isipingo River and Estuary and to quantify the levels of contamination that prevail through the use of geochemical assessment indices. The results of this study provide baseline data which can be used by authorities for the purpose of managing the system. It is recommended that a monitoring network is designed to trigger actions should thresholds be compromised. Sources contributing to heavy metals loads must be identified and a management plan to reduce the loads implemented. Because of selenium's high environmental mobility and relatively rapid elimination from the body, both animals and the ecosystems in which they live can recover rapidly (within years, not decades) from the effects of selenium once the source is controlled and sediment levels are reduced.

#### **4.4 Net flux of heavy metals and nutrients between the Isipingo Estuary and the nearshore environment**

##### **4.4.1 Heavy metal fluxes**

The heavy metal concentration and discharge for each seasonal Spring and Neap tide is displayed in Appendix 7. With reference to Table 4.15, the Isipingo estuary experiences tidal asymmetry throughout the year with the ebb flow being dominant. During the spring Spring tide, the estuary exported Al, As, Ba, Cu, Fe, Mo, Ni, Sr and V and imported Se, Ti and Zn (Figure 4.20). The spring Neap tide in comparison to the other seasonal Neap tides was unique in that all heavy metals were either absence or recorded concentrations below the detection limit, with the exception of Sr which was exported during this tidal cycle (Figure 4.21). The summer spring tide demonstrated a net import of heavy metals Cr, Cu, Ni and Se. The remaining heavy metals during this period were exported.

The system was dominantly export orientated during the summer Neap tide and behaved uniquely when compared to the spring, autumn and winter Neap tides in that the concentrations were recorded in the water column for the majority of heavy metals (Figure 4.20 and Table 4.15). During the autumn Spring and Neap tides As, Ba, Se and Sr were exported with the autumn Spring tide exporting a much higher volume of these heavy metals in comparison to the autumn Neap tide. With reference to Table 4.15, the winter Spring tide; demonstrated that Al, Cu and Zr were the only heavy metals imported into the estuary. All other heavy metals were exported during this period with the exception of Ba, Ni, Se and Zn. A number of heavy metals were absence from the water column or had concentrations below the detection limit during the winter Neap tide, with the exception of As, Ba and Sr which were exported and Se which was imported.

A majority of heavy metals were absence from the water column or recorded concentrations below the detection limit during the neap tide for all seasons except the summer Neap tide. This may be attributed to relatively stronger ebb flow recorded during the summer Neap tide in relation to the spring, autumn and winter Neap tides. The Isipingo system therefore displayed a greater flushing ability during the summer Neap tide. The estuary behaved as a net exporter of certain heavy metals during the neap tide in all seasons except winter during which 4.42 kg of Se was imported (Table 4.15). During certain periods within the spring, summer and winter Spring tides, the higher flow velocity of the flood resulted in certain heavy metals being imported. Sr was exported during all seasonal Spring and Neap tides.

Arsenic is also exported during all seasonal Spring and Neap tides with the exception of the spring Neap tide. The highest amount of As was exported during the spring Spring tide and summer Neap tide.

Table 4.15: Net flux of heavy metals over a tidal cycle in kilograms (kg)

Heavy metals	Net Flux (kg)							
	ST (spring)	NT (spring)	ST (summer)	NT (summer)	ST (autumn)	NT (autumn)	ST (winter)	NT (winter)
Al	37.42	0	37.93	195.17	0	0	(*)26.50	0
As	1644.05	0	121.15	1362.41	125.65	20.49	2.81	28.78
Ba	4.21	0	0	0	451.65	74.60	0	152.1
Cr	0	0	(*)26.36	41.42	0	0	9.83	0
Co	0	0	33.17	23.23	0	0	4.21	0
Cu	34.24	0	(*)157.64	0	0	0	(*)19.49	0
Fe	71.91	0	72.64	287.27	0	0	8.67	0
Pb	0	0	36.97	30.51	0	0	56.81	0
Mn	0	0	5.26	25.34	0	0	3.51	0
Mo	28.54	0	841.77	2074.44	93.97	0	58.35	0
Ni	15.73	0	(*)309.95	43.91	0	0	0	0
Se	(*)1570.54	0	(*)1.67	2432.59	982.31	257.02	0	(*)4.42
Sr	1848.53	399.5	1458.31	778.93	2741.72	386.44	481.35	956.28
Ti	(*)44.69	0	0	0	0	0	1700.26	0
V	614.17	0	97.48	384.7	0	0	76.06	0
Zn	(*)6.28	0	0	0	0	0	0	0
Zr	0	0	920.29	3226.31	0	0	(*)22.03	0

(\*) implies net import of heavy metals to the estuary  
ST=Spring Tide NT=Neap Tide  
Zeros indicate either the absence of the heavy metal or concentration levels below the detection limit

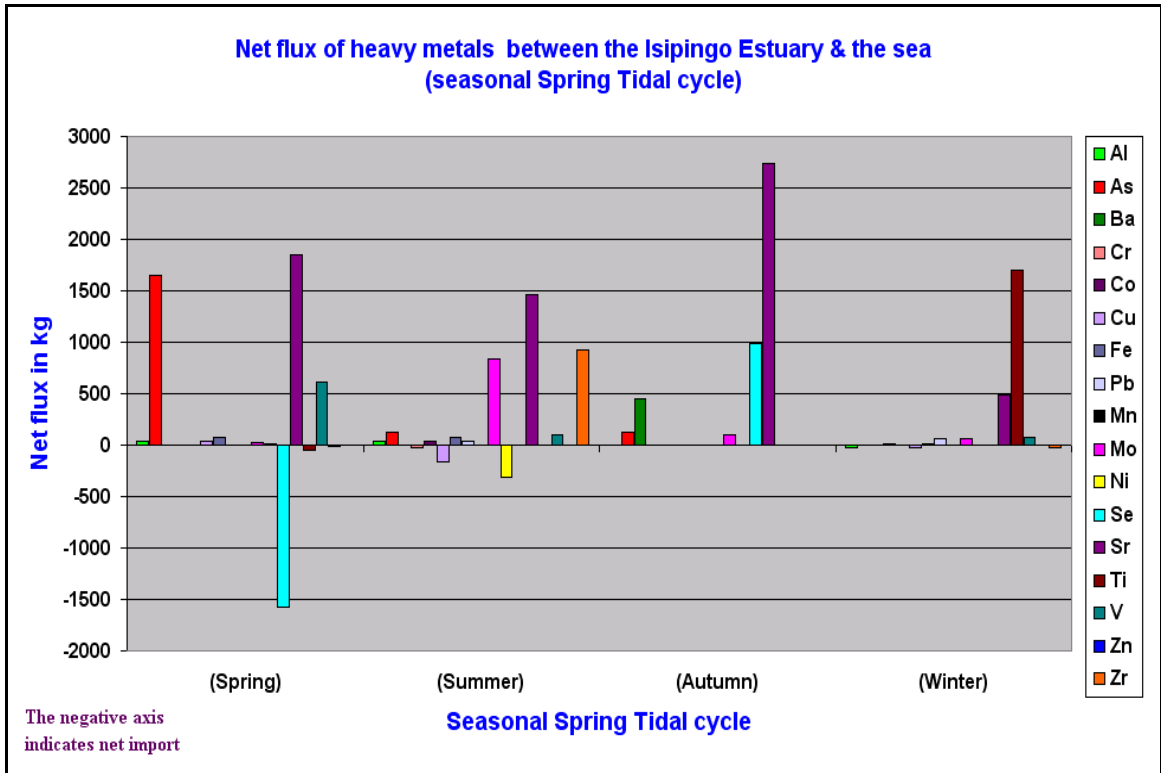


Figure 4.20: Net flux of heavy metals (seasonal Spring Tidal cycle)

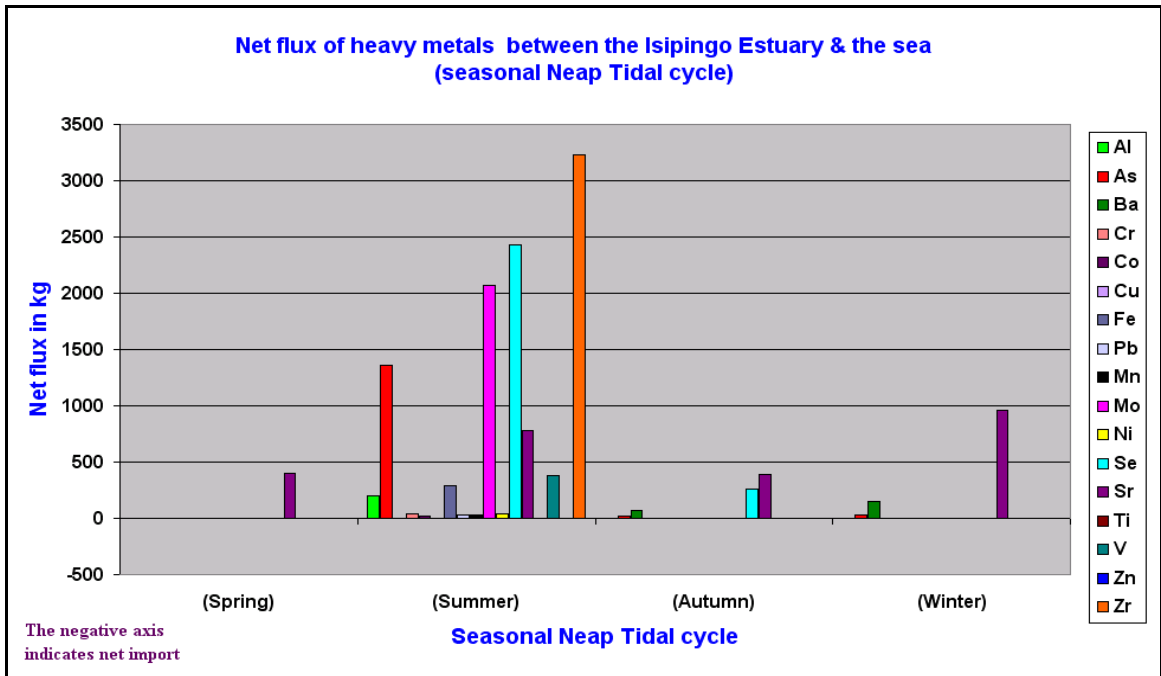


Figure 4.21: Net flux of heavy metals (seasonal Neap Tidal cycle)



On an annual basis (Table 4.16 together with Figures 4.22, 4.23 and 4.24) all metals sampled for are exported with the exception of Cu, Ni and Zn. Hence, this demonstrates the flushing capabilities of the Isipingo Estuary. However, the import of Cu, Ni and Zn may be adsorbed onto estuarine sediments resulting in the Isipingo estuary serving as a sink for these heavy metals. Cu, Ni and Zn can have deleterious effects on aquatic organisms depending on the physical and chemical conditions of the estuarine body, although the toxicity of Cu is reduced in the presence of Zn (Dallas and Day, 1993). Across all seasons and tidal events, the ebb flow is more dominant; however, Spring tides do result in a tidal prism entering the system.

Table 4.16: Estimated total seasonal and annual net heavy metal flux in kilograms (kg) (Data extrapolated from Table 4.15)

	<b>Total seasonal and annual net flux (kg)</b>				
<b>Heavy metals</b>	<b>spring</b>	<b>summer</b>	<b>autumn</b>	<b>winter</b>	<b>Total per annum</b>
<b>Al</b>	3367.8	20979	0	(*)2385	21961.8
<b>As</b>	147964.5	133520.4	13152.6	2843.1	297480.6
<b>Ba</b>	378.9	0	47362.5	13689	61430.4
<b>Cr</b>	0	1355.4	0	884.7	2240.1
<b>Co</b>	0	5076	0	378.9	5454.9
<b>Cu</b>	3081.6	(*)14187.6	0	(*)1754.1	(*)12860.1
<b>Fe</b>	6471.9	32391.9	0	780.3	39644.1
<b>Pb</b>	0	6073.2	0	5112.9	11186.1
<b>Mn</b>	0	2754	0	315.9	3069.9
<b>Mo</b>	2568.6	262458.9	8457.3	5251.5	278736.3
<b>Ni</b>	1415.7	(*)23943.6	0	0	(*)22527.9
<b>Se</b>	(*)141348.6	218782.8	111539.7	(*)397.8	188576.1
<b>Sr</b>	202322.7	201351.6	281534.4	129386.7	814595.4
<b>Ti</b>	(*)4022.1	0	0	153023.4	149001.3
<b>V</b>	55275.3	43396.2	0	6845.4	105516.9
<b>Zn</b>	(*)565.2	0	0	0	(*)565.2
<b>Zr</b>	0	373194	0	(*)1982.7	371211.3
<b>(*) implies net import of heavy metals to the estuary</b>					
<b>ST=Spring Tide NT=Neap Tide</b>					
<b>Zeros indicate either the absence of the heavy metal or concentration levels below the detection limit</b>					

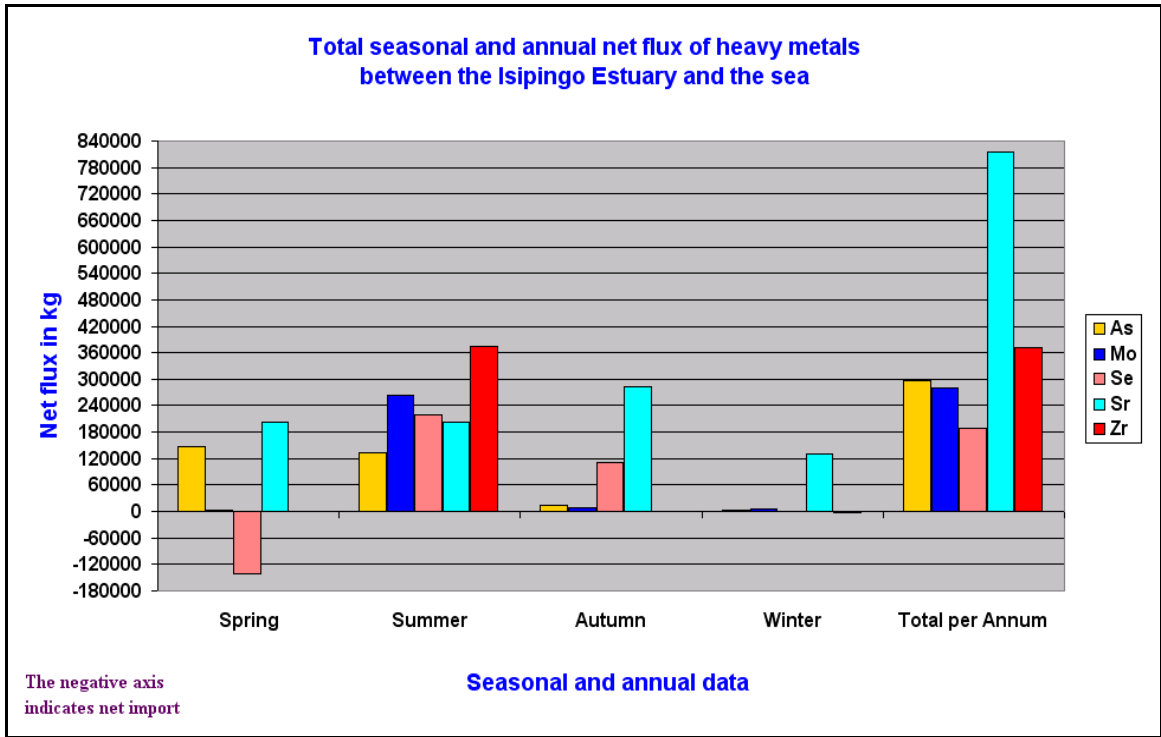


Figure 4.22: Total seasonal and annual net flux of As, Mo, Se, Sr and Zr

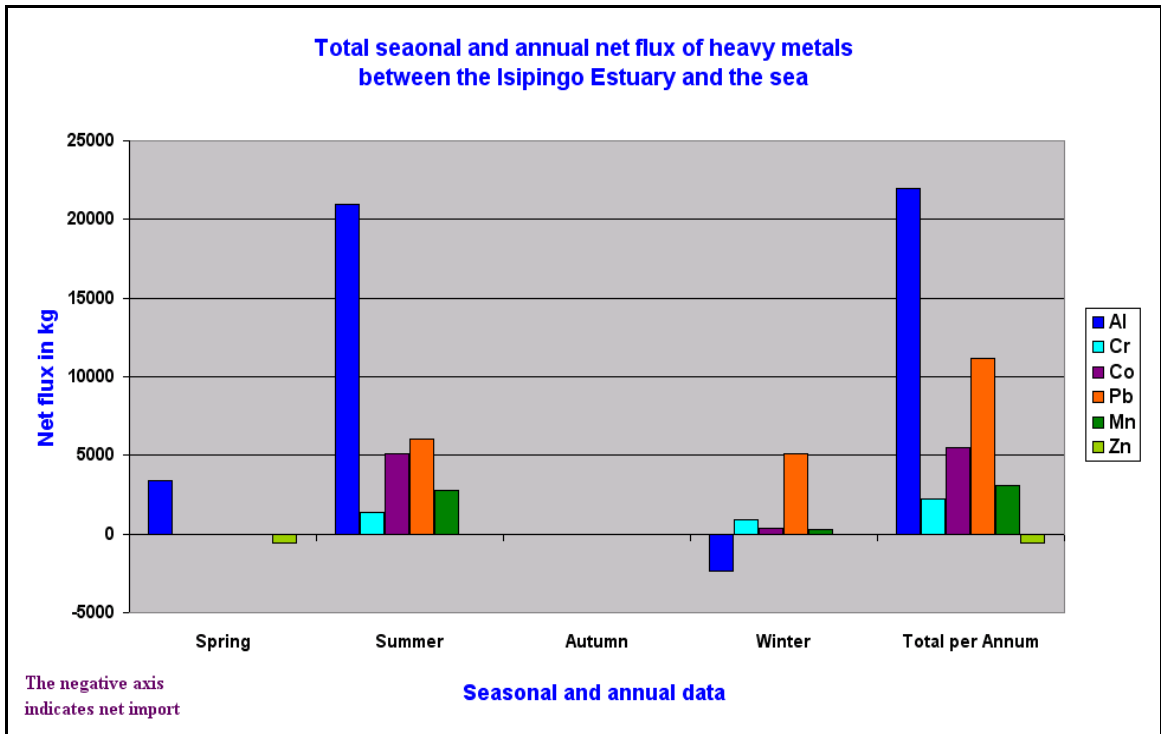


Figure 4.23: Total seasonal and annual net flux of Al, Cr, Co, Pb, Mn and Zn

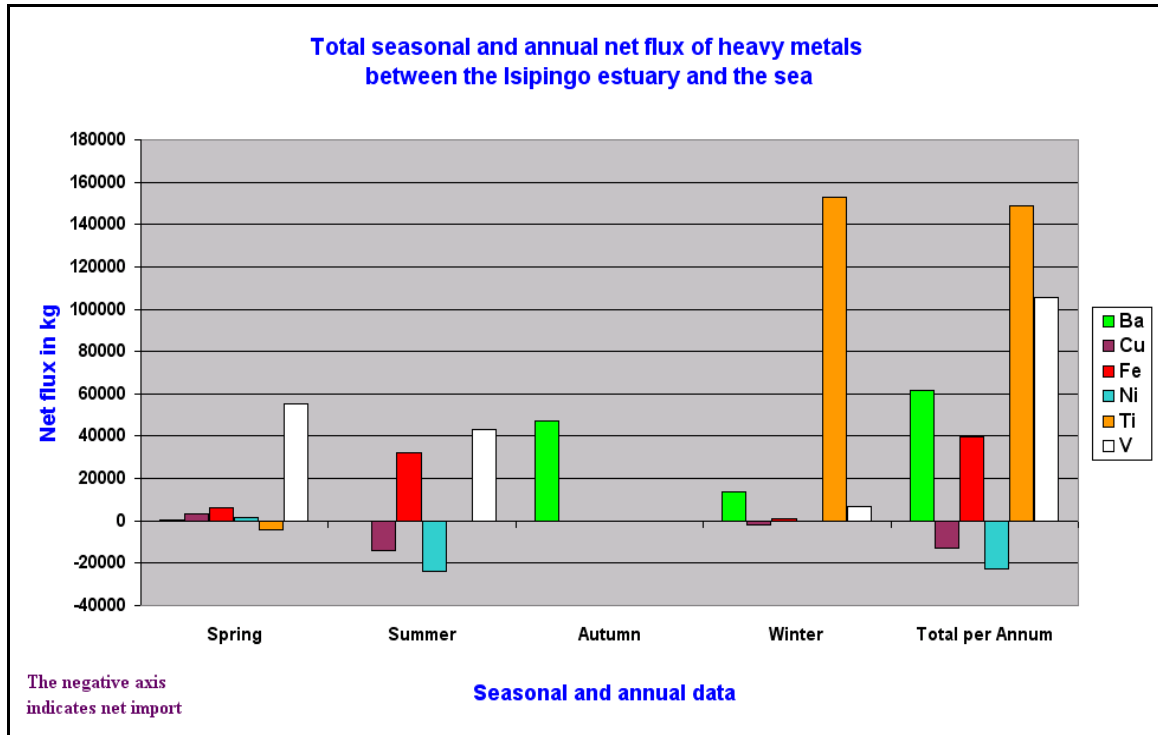


Figure 4.24: Total seasonal and annual net flux of Ba, Cu, Fe, Ni, Ti and V

During the spring, summer and winter spring tide as well as the winter neap tide, there was a net import of a number of heavy metals into the estuary (Table 4.15). During these periods, the concentrations of the heavy metals recorded during the flood flows were greater than those recorded during the ebb flows. This may be attributed to higher concentrations of these heavy metals in the nearshore environment. The actual source of these higher concentrations did not form part of this study but it is noteworthy to mention that possible anthropogenic sources such as marine outfalls of industrial and sewage effluent are located to the south of the Isipingo Estuary at Amanzimtoti. Estuaries located to the south of the study site could also serve as potential sources. It is also important to mention that a change in wind direction and wave approach from north-easterly to south-westerly could point to anthropogenic sources north of the study area.

During the periods when the estuary served to export material, the longer duration of the ebb flow together with higher heavy metal concentrations resulted in there being no net import of material. Generally, the flood velocities recorded were higher than the ebb velocities although the duration of the former was much shorter. On average, the ebb flow was dominant during 75% of the tidal cycle duration. The higher export of metals during the summer period, both in terms of concentration and variety of metals may be attributed to

increased industrial pollution, typical higher precipitation and surface flow. The drier months typically reduces the flushing capabilities of the system with a reduction in the volume of material exported. The variation in heavy metal concentrations indicates that there are conditions occurring within the Isipingo Estuary system which may at various times in the year result in the system acting as a sink and/or a source of heavy metals. In addition, this allows indicates the degree of impact from anthropogenic sources in the catchment.

The estuarine morphodynamics, hydrological conditions, material loading, physical-chemical conditions and nearshore processes influence the ability of the estuary to import or export material. This study shows that under certain conditions the import of some heavy metals occurs from the marine environment under favourable conditions.

#### 4.4.2 Analysis of variance

Results of the ANOVA of the seasonal net flux over the neap and spring tides are presented in Table 4.17. There is no significant flux differences for heavy metals concentrations displayed seasonally ( $p > 0.05$  and  $F < F_{crit}$ ), however a statistically significant difference between the spring and neap tide fluxes exist ( $p < 0.05$  and  $F > F_{crit}$ ). This is expected because of the higher tidal prism experienced on the spring tide and hence the greater volume of material exchanged.

Table 4.17: Results of ANOVA of heavy metals between seasons and tides (spring and neap)

Source of Variation	SS	df	MS	F	p-value	F <sub>crit</sub>
Tides	5.01E+06	7	7.16E+05	2.43	0.02	2.08
Seasons	3.75E+10	3	1.25E+10	2.03	0.12	2.75
<b>SS = Sum of squares      df = Degrees of Freedom      MS = Mean squares</b>						

The highest flux variance occurred in the summer season with winter displaying the lowest variance of all the seasons. During summer, the larger tidal prism concomitant with larger fluvial flows is responsible for the higher flux variations. The greatest variance was displayed for the summer Neap Tides (Table 4.18). During the summer months, higher fluvial flows result in more heavy metals being flushed through the system accounting for part or all of the higher variance display during the summer Neap Tide. Many heavy metals were not

present in the water column or were below the detection limit in the spring and autumn Neap Tides contributing to lower variance at this time.

Table 4.18: Variance of heavy metal concentrations over seasonal and tidal cycles (in order of increasing variance)

Seasonal Spring and Neap Tides	Variance	Season	Variance
spring Neap Tide	9388	Winter	2.14E+09
autumn Neap Tide	11830	Spring	4.18E+09
winter Neap Tide	53862	Autumn	5.1E+09
winter Spring Tide	173620	Summer	1.32E+10
summer Spring Tide	177400		
spring Spring Tide	432054		
autumn Spring Tide	473386		
summer Neap Tide	1023145		

#### 4.4.3 Conclusion

This study demonstrates that significant quantities of the suite of heavy metals analysed for are being exported on an annual basis from the Isipingo Estuary with the exception of Cu, Ni and Zn. Although the Isipingo Estuary is a net exporter of heavy metals, there is a net import of certain heavy metals (Al, Cr, Cu, Ni, Se, Ti, Zn and Zr) into the estuary during certain seasonal tidal cycles. The ebb flow has a much longer duration than the flood flow throughout the seasonal tidal cycles although the flood velocities are greater than the ebb velocities. There are certain periods during which the estuary serves as a net importer of certain heavy metals which is attributed to longshore drift and nearshore cell circulation. These processes result in heavy metals deposited into the sea from various sources being transported back in the Isipingo estuary. There are also periods during which heavy metals are absent from the water column or below the detection limit and hence heavy metals are neither imported nor exported. The absence or non-detection of a number of heavy metals in the water column during certain periods of the year indicates the need to do further research on the retention times and the heavy metal budget for the system. These factors would need to be considered in the overall management of the estuarine system. Statistically significant differences in heavy metal concentrations occur between spring and neap tides, although variations in the seasonal concentrations were found to not be statistically significant.

#### 4.4.4 Nutrient fluxes

The nutrient concentration and discharge for each seasonal Spring and Neap tide is displayed in Appendix 7. The Isipingo estuary experiences tidal asymmetry throughout the year with the ebb dominance due to the perched nature of the estuary however, flood velocities tend to be greater than the ebb velocities. There are occasions when higher concentrations of nutrients are received during the flood flow resulting in nutrients being imported. The Spring tides of the spring, summer and autumn seasons recorded higher flood velocities during this study although the ebb flow has a longer duration. During all seasonal Neap tides, there was an export of macro-nutrients ( $\text{NH}_3$ ,  $\text{NO}_3$  and P) (Table 4.19 and Figure 4.25) and micro-nutrients (Ca, Mg, K and Na) except for K during the summer Neap tide where this variable was absent from the water column or at a concentration below the detection limit (Table 4.19 and Figure 4.26).

The highest amount of  $\text{NO}_3$  exported from the estuary was recorded in the summer Spring and Neap tides while the spring Spring tide recorded an import of  $\text{NO}_3$ . This corroborated the findings by Fernandes (2011) and Fernandes and Pillay (2012) in the study on the Isipingo estuary which concluded that the estuary imported  $\text{NO}_3$  during the spring Spring tide. However, although the aforementioned study also demonstrated that the system imported nitrates during the summer and autumn Spring tides, the findings of this study illustrated that the estuary tended to export nitrates during these seasonal tidal cycles. The sampling frequency in the study by Fernandes (2011) and, Fernandes and Pillay (2012) was every 2 hours compared to the more rigorous hourly sampling conducted during this study and could account for the observed differences.

$\text{NH}_3$  was exported during all seasonal tidal cycles except the summer Spring tide during which the estuary imported 24510 kg (Table 4.19). The autumn Spring tide exported the highest amount of  $\text{NH}_3$  (17980 kg). The spring, summer and winter Spring tides resulted in the import of P with the highest import (3133 kg) occurring during the spring Spring tide. The estuary served as a net importer of Ca, K and Mg during the summer Spring tide and of K during the winter Spring tide. Na was the only cation (micronutrient) exported during all seasonal tidal cycles. The estuary served as a net importer for all nutrients with the exception of Na and  $\text{NO}_3$  during the summer Spring tide. During these periods, the concentrations of some of nutrients recorded during the flood flows were greater than those recorded during the ebb flows. This together with the higher flood velocities experienced resulted in large amounts of material being imported during this period. A similar situation

exists during the spring and winter Spring tides for the variables indicated in Table 4.19. This may be attributed to higher concentrations of these nutrients in the nearshore environment adjacent to the Isipingo Estuary.

Table 4.19: Net flux of nutrients over a tidal cycle in kilograms (kg)

Variables	Net flux (kg)							
	ST (Spring)	NT (Spring)	ST (Summer)	NT (Summer)	ST (Autumn)	NT (Autumn)	ST (Winter)	NT (Winter)
NH <sub>3</sub>	0	5411	(*)24510	8087	17980	3036	5412	6252
NO <sub>3</sub>	(*)2385	5418	21495	18055	5672	3657	11587	5652
P	(*)3133	168	(*)375	584	0	634	(*)37	3.78
Ca	33095	45765	(*)210826	57548	36560	6719	17834	15070
K	166970	84013	(*)257608	0	19418	2388	(*)56702	6430
Mg	58020	91750	(*)779083	51077	99198	11280	72638	31224
Na	901897	115245	324332	83670	1131604	124095	661174	359782

(\*) implies net import of nutrients to the estuary  
 ST=Spring Tide NT=Neap Tide  
 Zeros indicate either the absence of the heavy metal or concentration levels below the detection limit

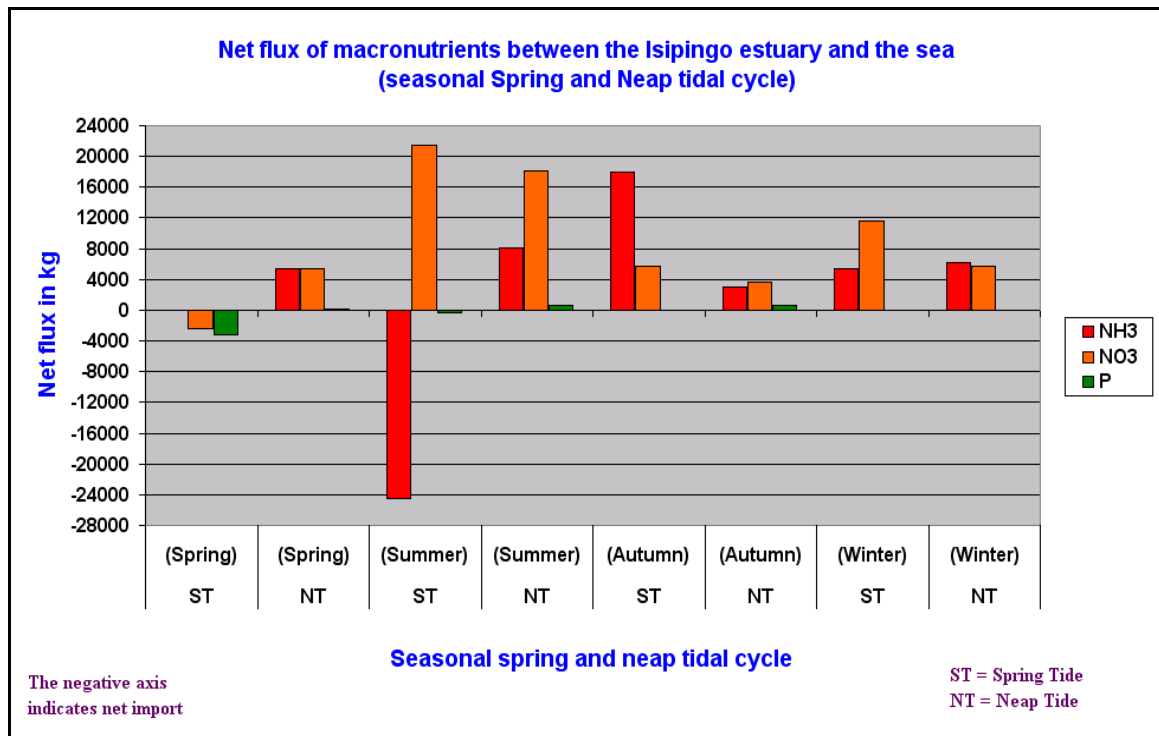


Figure 4.25: Net flux of macronutrients: seasonal Spring and Neap tidal cycle

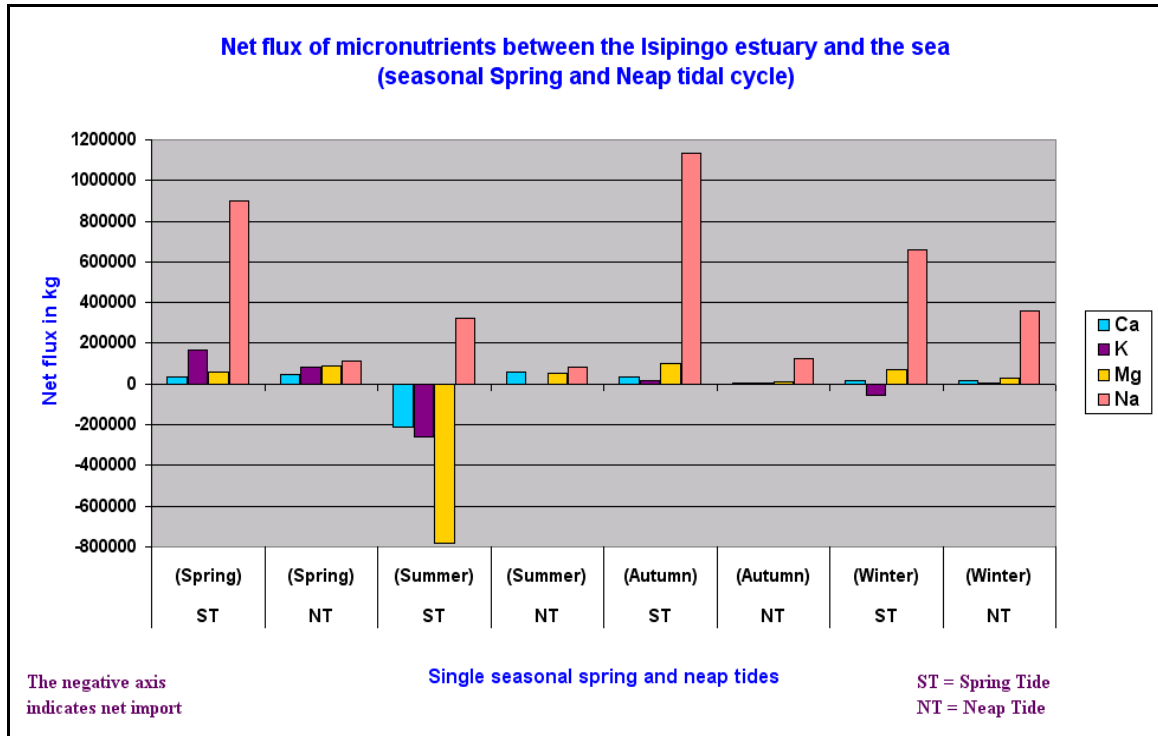


Figure 4.26: Net flux of micronutrients: seasonal Spring and Neap tidal cycle

Determining the sources of these nutrients has not been the focus of this study but Fernandes (2011) and Fernandes and Pillay (2012) suggested potential anthropogenic sources of nitrates such as sewage and industrial effluent from marine outfalls located to the south of the study area. Another potential source could emanate from other estuaries located to the south of the study site, which may result in material being transported in a northerly direction and injected into the Isipingo Estuary on the flooding episodes of spring tides.

Further extrapolation of the data yielded a net import of P, K and Mg on an annual basis (Table 4.20). This is also illustrated in Figures 4.27 and 4.28. Phosphorous is regarded as the limiting factor with respect to eutrophication. The import of P is of concern from an estuarine management perspective as conditions could lead to an accumulation of P eventually giving rise to a highly eutrophic system. The northern arm of the estuary is periodically covered by water hyacinth which is manually removed by the eThekweni Municipality.



Table 4.20: Estimated total seasonal and annual net nutrient flux in metric tons (T) (Data extrapolated from Table 4.19)

Variables	Net flux (T)				
	Spring	Summer	Autumn	Winter	Total per annum
NH <sub>3</sub>	487	-1478	1891	1050	1950
NO <sub>3</sub>	273	3560	840	1552	6225
P	-267	19	57	-3	-194
Ca	7097	-13795	3895	2961	159
K	22588	-23185	1963	-4524	-3158
Mg	13479	-65521	9943	9348	-32751
Na	91543	36720	113013	91886	333162

(\*) implies net import of nutrients to the estuary

Zeros indicate either the absence of the heavy metal or concentration levels below the detection limit

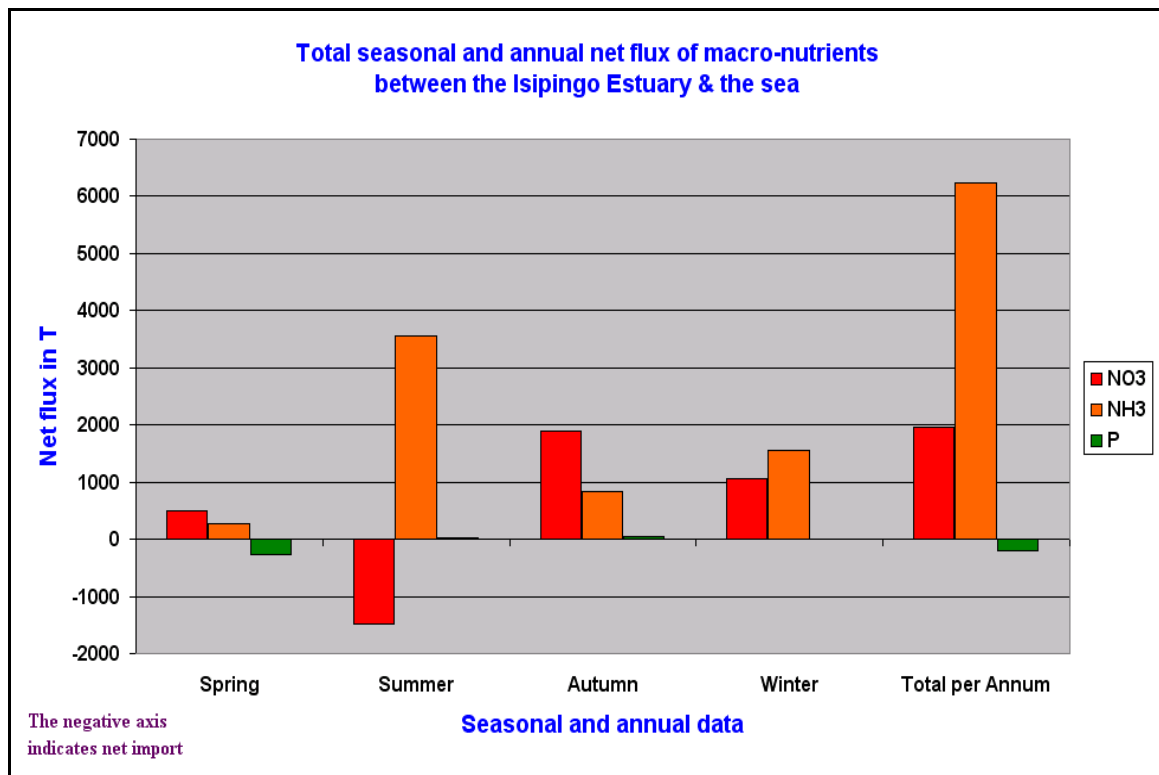


Figure 4.27: Total seasonal and annual net flux of macronutrients

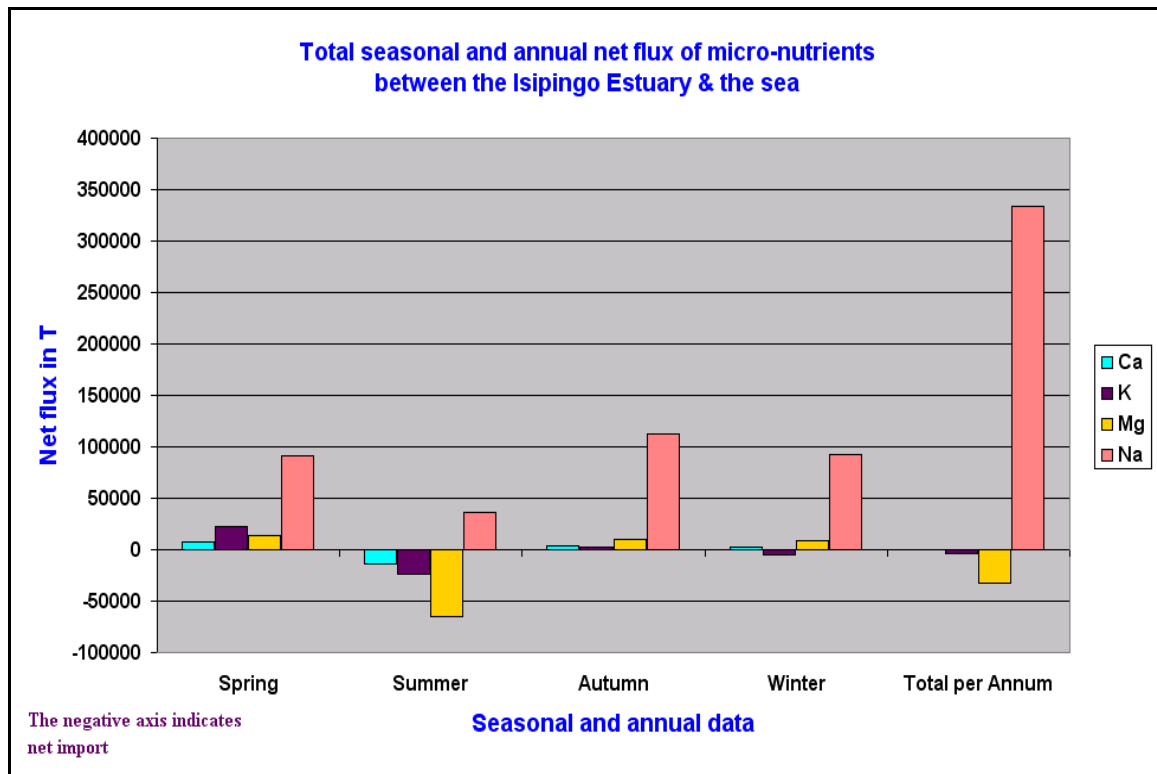


Figure 4.28: Total seasonal and annual net flux of micronutrients

The reduced fluvial flows have reduced the flushing capabilities of the system leading to the accumulation and sequestration of material. For the majority of the seasonal tidal cycles, the system exports nutrients. The Isipingo estuary showed some variation in nutrient concentrations indicating a degree of impact arising from anthropogenic sources within the catchment. However, the summer season spring tide event resulted in the import of a majority of nutrients. The summer season is typically a wet season in fluvial flow in KwaZulu-Natal but this does not drive the export of nutrients during this season spring tide. This makes the Isipingo estuary system susceptible to a greater risk of eutrophication during the summer spring tide and would require careful consideration in terms of the development of a management strategy for this system. This study also demonstrates that estuarine morphodynamics, hydrological conditions, material loading and nearshore processes influence the ability of an estuary to import or export material.

#### 4.4.5 Analysis of variance

Results of the ANOVA indicated there is no significant differences of the nutrient concentrations across the seasons as well as during the spring and neap tides as tabulated

in Table 4.21 ( $p > 0.05$  and  $F < F_{crit}$ ). The greatest nutrient flux variance occurred in autumn season while greater variance in fluxes was displayed for the Spring Tides than the Neap Tides (Table 4.22). The variance experienced in autumn may be an expression of a lag effect arising from the introduction of nutrients to the system in summer which are trapped in sediment and expressed during autumn following greater turbulence in the water column during this windy season.

Table 4.21: Results of ANOVA of nutrients between seasons and tides (spring and neap)

Source of Variation	SS	df	MS	F	p-value	F <sub>crit</sub>
Tides	2.49E+15	7	3.56E+14	0.80	0.59	2.21
Seasons	2.05E+14	3	6.83E+13	0.06	0.98	3.01
<b>SS = Sum of squares      df = Degrees of Freedom      MS = Mean squares</b>						

Table 4.22: Variance of nutrient concentrations over seasonal and tidal cycles (in order of increasing variance)

Seasonal Spring and Neap Tides	Variance	Season	Variance
summer Neap Tide	1.08E+09	Summer	6.94E+14
autumn Neap Tide	2.05E+09	Spring	1.08E+15
spring Neap Tide	2.27E+09	Winter	1.13E+15
winter Neap Tide	1.75E+10	Autumn	1.74E+15
winter Spring Tide	5.81E+10		
summer Spring Tide	7.5E+10		
spring Spring Tide	1.09E+11		
autumn Spring Tide	1.75E+11		

#### 4.4.6 Conclusion

This study demonstrates that while significant quantities of nutrients ( $\text{NH}_3$ ,  $\text{NO}_3$ , Ca and Na) are exported annually from Isipingo Estuary, the system record a net annual import of P, K and Mg. Although the system functions as a net exporter of nutrients over certain seasonal tidal cycles, the summer Spring tide displayed the highest net import of  $\text{NH}_3$ , P, Ca, K and Mg. The estuary acted as a net importer of  $\text{NO}_3$  and P during the spring Spring tide with P and K being imported during the winter Spring tide. The ebb flow has a much longer duration than the flood flow throughout the seasonal tidal cycles although the flood velocities are greater than the ebb velocities. The neap tides of all seasons yielded high exported values

which may be attributed to the lower flooding experienced during the neap tides. The variation in the quantity and concentration of nutrients exported during the seasons may be attributed to anthropogenic sources such as pollution emanating from industries, sewage and agricultural activities as well as the variation in precipitation and surface flow.

There are certain periods during which the estuary imported nutrient which is attributed to longshore drift and nearshore cell circulation. These processes result in material deposited into the sea from various sources being transported back in the Isipingo estuary. Nutrients gained from marine sources can compound eutrophication problems in the Isipingo estuary which already receives nutrients from anthropogenic sources in the catchment. It is important that sources of nutrients identified in the catchment are addressed and that a strategy to address this problem is developed and implemented in collaboration with regulators, non-governmental organizations (NGO's) and the public. The results indicate seasonal variability of nutrient concentrations; however these are not statistically significant.

**CHAPTER FIVE**  
**THE DEVELOPMENT**  
**OF A WATER QUALITY MANAGEMENT PLAN**  
**FOR THE ISIPINGO CATCHMENT**

**5.1 Introduction**

A river catchment is the land area that contributes water, sediment and other surface derived material to a river (Rowntree, 2006). The majority of urban areas in South Africa are located on watersheds of river catchments (CSIR, 2010a). These rivers generally provide a dual service of transporting waste material and supplying water to urban and rural areas. Water Quality Plans (WQPs) are an integral part of the Department of Water Affairs (previously known as the Department of Water Affairs and Forestry) water quality management strategy to afford adequate protection to water resources (DWAF, 2000). The development and execution of such a plan requires the involvement of all role players in a particular catchment. It requires the acceptance of responsibility by Government at a national, provincial and local level, industry, communities and non governmental organizations to implement agreed upon actions (DWAF, 2000). The basis for developing any sound water quality management plan is to understand land use activities within the catchment of concern and to be able to identify the sources of pollution concomitant with the economic and political constraints that may limit possible solutions (DWAF, 1999). The plan needs to culminate with key strategies and objectives that need to be achieved together with timeframes, resources and responsible organizations/roleplayers required to undertake the necessary action.

The rehabilitation and management plan proposed by Kalicharran and Diab (1993) required collaborative efforts amongst the previous regulatory entities known as the Borough of Isipingo, Borough of Amanzimtoti and the Municipality of Durban. This plan focused solely on the Isipingo Estuary with limited attention assigned to the overall management of contributing factors within the Isipingo catchment.

Since 1994 there has been the amalgamation of the boroughs to form the eThekweni Municipality as well as new integrated and holistic legislation such as the National Environmental Management Act, 1998 (Act 107 of 1998), National Water Act, 1998 (Act 36 of 1998) and the National Environmental Management: Integrated Coastal Management Act,

2008 (Act 24 of 2008). The advent of the National Environmental Management: Integrated Coastal Management Act makes provision for the development of an Estuary Management Plan. The eThekweni Municipality have recently prepared an Estuary Management Plan for the estuary (SSI, 2011), but this plan focuses specifically on the estuary without providing management strategies and objectives at a catchment level. The current state of the catchment is likely to deteriorate without a proper management plan coupled with effective regulatory enforcement.

## **5.2 Current Environmental Issues**

The Isipingo Catchment, in particular the lower reaches of the Isipingo River and its Estuary has been subjected to progressive land use changes which have, in turn, had a profound effect on the functioning of the system. Intensive industrialization and the expansion of high density residential development have infringed the systems floodplain, reducing its functional capacity of attenuating flood events and performing purification functions. The manipulation of the hydrology *via* canalization of a portion of the river has further compounded water quality, flow and the overall health of the Isipingo River and Estuary system.

The following major issues of concern have lead to the decline of the health status of the lower Isipingo River and its Estuary. These are summarized and include some of the pertinent historic findings as well as that of this current study.

### **5.2.1 Water quantity**

The reduction in the mean annual flow (MAR) from approximately 102 million m<sup>3</sup>/year to 3 million m<sup>3</sup>/year is the main contribution to the poor functioning of the estuarine system (Swart, 1987; Kalicharran and Diab, 1993). The insufficient flow of water to the Isipingo River and Estuary has limited the assimilative capacity of the system, and has further reduced the flushing and scouring capability of the estuary. The limited tidal exchange has done little to improve water quality of the estuary (Forbes and Demetriades, 2008).

The irregular maintenance and management of the Diversion Works System (DWS), constructed ahead of the Prospecton Canal System (PCS) to regulate and permit a controlled flow received from the upper catchment to the PCS, has further compounded the supply of freshwater to the estuary. During prolonged periods of non-operation of the DWS the Isipingo River flows to the Mbokodwini River, with the Isipingo Estuary no longer being the recipient of water received from the upper catchment.

If fluvial discharge is insufficient, then the dilution and flushing potential of the system is reduced which can have severe consequences for biota (MacKay *et al.*, 2000). The wastewater treatment works discharges treated effluent to the Isipingo River which augments supply during the dry periods; however, this is located above the DWS which results in the Mbokodweni River being the recipient of this flow. Modifications and development within the floodplain of the river and the transformation of wetland areas have further reduced the ability of the system to attenuate floods and perform purification processes. The reduction in flow has also reduced the assimilative capacity of the system which is corroborated by some of the water quality results undertaken as part of this study. The DWS was non-functional over 75% of the study period, resulting in a restriction of fluvial flow to the estuary. The conclusion by Grobler (1992) that there is insufficient freshwater inflow and tidal exchange still remains valid after twenty years with very little work conducted by authorities to improve these conditions.

Apart from the reduced flow into the estuary, is the reduction in the exchange of freshwater and seawater. According to SSI (2011), the stagnant estuarine conditions are attributed to the reduced tidal exchange, which is currently prevented by the semi-permanent closed mouth state and the limited connectivity to the sea provided by the two concrete pipes. Benefits from the backwash effect of the sea only occur during spring tides (Kalicharran and Diab, 1993). During this study, the estuary functioned as a net exporter for most heavy metals and nutrients during the seasonal tidal cycles. However, annually the heavy metals Cu, Ni and Zn as well as the nutrients P, K and Mg were imported into the estuary. If there is adequate flow provided to the estuarine system *via* the DWS, then there exists a possibility for the imported variables to be successfully flushed out instead of accumulating within the estuary. The implications of the accumulation of these nutrients within the estuary can lead to a system that may experience bouts of eutrophication. Furthermore, the toxicity of Cu can increase as the dissolved oxygen and pH of the water system decreases. Although, the toxicity of Cu decreases in the presence of Mg and Zn, its toxicity can increase in the presence of other heavy metals (DWAF, 1996c). Therefore regular monitoring of these key variables is required by the authorities.

### **5.2.2 Water quality**

The water quality of the Isipingo Estuary has been described as poor and unacceptable (Begg, 1978; Brand *et al.*, 1964; Furness, 1988; Griffiths, 1987; Grobler, 1992; Kalicharran and Diab, 1993; Forbes and Demetriades, 2008). Furthermore, both Grober (1992) and

Ramn (1986) described the system *–as showing a severe degree of degradation*” and it being *–presently impossible for the river portion of this system to support aquatic fauna to any degree.*” Decades later, there appears to be little improvement to water quality conditions (Forbes and Demetriades, 2008; Moodley, 2010; SSI, 2011 and this study). The water quality upstream of the sluice gates is also considered unacceptable (Forbes and Demetriades, 2008). The Isipingo River and Estuary have historically suffered from faecal contamination (Begg, 1978; Griffiths, 1987). This can be corroborated by this study which recorded extremely high levels of faecal contamination along the river and the estuary. Reconnaissance surveys of the catchment and engagement with members of the Isipingo Catchment Management Forum (ICMF) (forum that manages impacts to the Isipingo River) drew attention to raw sewage stemming from pump station failures, surcharging sewer manholes, breakages in sewerage lines as well as the poor management of sanitation facilities provided to the transit camps located within the floodplain of the lower reaches of the Isipingo River. The high faecal contamination poses a health risk to communities who utilize the river system and requires urgent intervention from the local government in conjunction with regulatory enforcement from national government.

The Isipingo Estuary and Lagoon have previously been categorized by low dissolved oxygen (Begg, 1978; Griffiths, 1987; Forbes and Demetriades, 2008). Begg (1978) highlighted that the dissolved oxygen levels at the bottom of the northern arm of the estuary was devoid of oxygen while the lagoon always has dissolved oxygen present in surface and bottom water. As part of this research study, the average surface dissolved oxygen levels recorded in the lagoon and estuary were greater than 5 mg/l, which is regarded as an improvement to the previous anoxic condition of the system.

This research study further demonstrated that the phosphorus levels at the estuary and lower sections of the river in both seasons exceeded the limit which is deemed sufficient to control plant growth while the nitrate levels at most of the sites were above the limit of 2.5 mg/l implying that the system is experiencing eutrophic conditions as witnessed by the excessive growth of water hyacinth particularly in sections of the system experiencing reduced flow. The Umlazi Wastewater Treatment Works discharges treated effluent into the Isipingo River and the final discharge is audited on a monthly basis by Department of Water Affairs. Based on correspondence with the Department of Water Affairs during this study period, the works was generally compliant. It must however be remembered that this is based on a monthly grab sample and a scenario could exist whereby effluent exceeding the



prescribed water quality standards may have been discharged to the Isipingo River. In addition, the management of greywater (water arising from washing of laundry and dishes) from the transit camps is problematic (Figure 5.1). The river is also used for the washing of clothing which results in detergents being introduced directly into the system (Figure 5.2). The market gardening area located to the north of the Bamboo Drain (next to old Durban Airport) could also be a likely source of phosphates and nitrates arising from the runoff of agrichemicals such as fertilizers.

An analysis of heavy metals was conducted along the Isipingo River and Estuary as part of this study. The results generally complied with the South African Water Quality Guideline (SAWQG) for domestic use purposes. However, a number of heavy metals including Al, As, Cu, Cr, Pb Se and Zn exceeded the SAWQG for the aquatic ecosystem. Although heavy metals do not pose a direct risk to human health from the consumption of water, there is a potential risk arising from the consumption of contaminated fish. A study of the state of fish in the estuary conducted in 2007 showed that aquatic life was being negatively affected by the state of the estuary (Forbes and Demetriades, 2008) (Figure 5.3).



Figure 5.1: Photograph of uncontrolled greywater from the transit camps along the Isipingo River (Taken on 23 June 2010)



Figure 5.2: Photograph demonstrating use of the Isipingo River for the washing of clothing (Taken on 26 May 2010)



Figure 5.3: Fish samples taken 27 July 2007 from the Isipingo estuary showing the effects of pollution (after Forbes and Demetriades as cited in SSI, 2011, p. 46)

The report by Grobler (1992) which looked at the water quality of the Isipingo River and Estuary concluded the following:

- *„The water quality is unfit for human contact and for the environment;*
- *Rehabilitation to a 1939 condition “will never be possible” although it may be possible to restore an aesthetically acceptable, functional biological system;*
- *Freshwater inflow and tidal exchange are insufficient to maintain a functional system;*
- *Industrial areas in the catchment are a “significant source of metal and toxic organic contaminants”;*
- *The industrial areas and the Umlazi township both contribute to bacteriological contamination;*
- *Metal and phenolic contamination pose a risk for aquatic organisms and a possible health hazard to humans if consumed; and*
- *There should be notice boards prohibiting swimming and warning of the dangers of consuming of fish or filterfeeding organism from the system’*

In comparing the overall findings of this research study to that of Grobler (1992) and others, the water quality of the Isipingo River and Estuary system still remains unfit for human contact due to the high levels of faecal contamination while aquatic organisms in the estuary remain exposed to heavy metals concentrations that exceed the SAWQG for aquatic ecosystems. This study did not analyse for organic and phenol contaminants and recommends that further work be conducted in this area. There is agreement with Grobler (1992) that rehabilitation of the Isipingo River and Estuary system to its origin state is unattainable due to the major modifications to the hydrology of the system, however this does not preclude relevant roleplayers from investigating options to improve the overall health and functioning of the system. This is captured as part of the Water Quality Improvement Plan presented further in this chapter.

### **5.2.3 Sediment quality**

According to Begg (1984), the northern arm (mangrove area) of the estuary regularly suffered from the brunt of pollution and other waste material entering the estuary. The bottom materials comprised of anaerobic black sludge which was attributed to excessive sewage spillages. The bed of the lagoon (commonly referred to as the southern arm) however, is comprised largely of silt, with sludge only being detected in the deepest part of the lagoon (Begg, 1984). The work conducted as part of this study has indicated that

although several metals were absent at certain river sites, the concentrations of heavy metals increased in a longitudinal direction from the upper catchment to the estuary. The river and estuary showed signs of moderate to high enrichment respectively with selenium being the metal of main concern. This may be attributed to historical contamination arising from uncontrolled discharges of industrial effluent from the PIA. Other heavy metals showing signs of enrichment in the estuarine environment are As, Cr, Pb and Zn. The overall degree of contamination for both the river and estuary was considered low only when selenium was omitted from the calculation. However, if physico-chemical conditions of the water body changes, then metals can be released back into the water column posing further risk to aquatic ecosystems and possibly human health. Conditions of the water body must be monitored to ensure proactive management and timeous intervention.

#### **5.2.4 Solid waste**

Solid waste in the form of paper and plastic are widespread in this catchment (Figures 5.4). At various points along the lower Isipingo River and Estuary during this study, there was visible evidence of litter. According to (Forbes and Demetriades, 2008), sampling of the estuary during their surveys revealed that the bottom of the estuary is littered with full black refuse bags as well as other dumped items such as tyres, plastic bottles and household appliances. Kalicharran and Diab (1993) also made reference to the reclaiming of wetlands by the dumping of builders rubble and other material to create a platform to build on. The issue of solid waste pollution still remains and, education of communities on the consequences of improper waste disposal is required.



Figure 5.4: Photographs illustrating the problem of litter in the catchment (Taken on 16 November 2010 and 17 January 2011)

### 5.2.5 Habitat Integrity and Species Diversity

Any decrease in habitat availability will almost certainly result in a decrease of species diversity (DWAF, 1999). The reduced river flow and poor water quality (particularly with reference to nutrient levels and faecal contamination) have also contributed to a decrease in diversity of the estuary and lagoon. The original vegetation consisted of mangroves, low lying woodlands, marsh and scrub in the vicinity of the estuary (Forbes and Demetriades, 2008). The development of housing around the lagoon and estuary has removed much of the indigenous vegetation. The northern bank of the estuary still remains fairly well vegetated with mangroves (Forbes and Demetriades, 2008).

Forbes and Demetriades (2008) concluded that the number of species and total densities declined rapidly in the upper reaches of the estuary which has resulted in the benthic community being rated as poor. There has also been a decline in the fish population of the estuary. During the field work component of this study, there was notable destruction of the riparian vegetation during the June 2010 to July 2010 period above the area of the DWS (Figures 5.5(a) and 5.5(b)). The removal of riparian vegetation has also led to the collapse of the river bank and widening of the river channel, reduction in attenuation ability and increased sedimentation (Figures 5.5(a) and 5.5(b)).



Figure 5.5(a) Isipingo River prior to removal of riparian vegetation and Figure 5.5(b). Same section of the Isipingo River post removal of riparian vegetation (Taken on 23 June 2010 and 23 July 2010 respectively)

### 5.2.6 Alien Vegetation

Riparian vegetation plays a vital role in maintaining the channel form, stabilizing banks, minimizing erosion and providing a habitat for biota (Sukdeo, 2010). Along the lower Isipingo river, the riparian zone has been modified to a fair degree and is attributed to the disposal of rubble on the wetland and river floodplain in order to reclaim land for development. The riparian zone is dominated by alien vegetation such as *Chromolaena odorata* (triffid weed) and *Lantana camara* (lantana) while the lower section of the northern arm of the estuary as far as the Isipingo Island Hotel is home to the common reed *Phragmites australis* (Forbes and Demetriades, 2008) (Figure 5.6). There is also aquatic weed infestation of the surface water by water hyacinth (*Eichhornia crassipes*). Alien vegetation was visible at all sample sites forming part of this study while sections of the river and estuary where flow is restricted were infested by water hyacinth.



Figure 5.6: Photographs illustrating the problem of water hyacinth and alien vegetation in the catchment (Taken on 11 March 2010 and 29 April 2010).

### 5.3 Development of a Water Quality Management Plan

The development and execution of water quality management plans are an integral part of the Department water quality management strategy (DWA, 2000). The basic geographical unit for water resources management is the catchment (DWA, 2000). The Department of Water Affairs refers to a collective grouping of catchments as water management areas. There are three water management areas in the province of KwaZulu-Natal and the Isipingo

catchment falls within the Mvoti-Mzimkhulu water management area in the quaternary catchment U60E.

The development of a water quality management plan (WQMP) starts with the formulation of a vision and subsequently objectives for the catchment (Figure 5.7). Management strategies are developed to meet the objectives. In some instances, management strategies can be further broken into management actions which assign specific tasks to specific role players. Management actions need to be implemented in order to achieve the management strategies and objectives. Success of this WQMP is determined via a process of monitoring, assessment and evaluation. The WQMP should be viewed as a *living* document and therefore it is important that it is reviewed and updated regularly in a transparent manner through public participation.

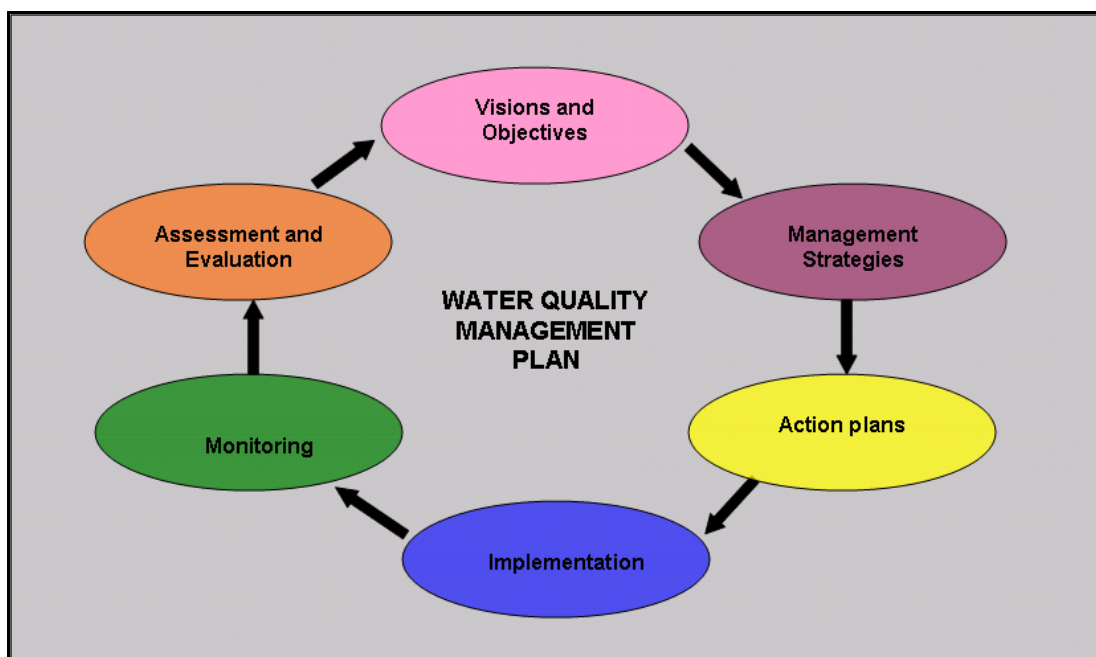


Figure 5.7: Components of a Water Quality Management Plan (concept adapted from DWAF, 2000)

### 5.3.1 Vision statement for the Isipingo Catchment

The vision statement represents the main focus of the plan and is developed together with relevant stakeholders (Dent and Breen, 2001). For the purpose of this study, a preliminary vision statement was developed.

***A healthy and functional River and Estuary  
through effective and sustainable management of activities  
in the Isipingo catchment***

### 5.3.2 Management objectives

Management objectives are viewed as the foundation to achieving the vision set for the catchment. The following management objectives have been identified as potential objectives and have been adapted from SSI (2011) and included as Table 5.1:

Table 5.1: Management Objectives: Isipingo catchment

Management Objectives	Description
1. Improvement to river and estuary (water quality and quantity)	Enhance the current functioning of the system through improvement to water quality in the system and to increase water quantity without increasing the risk of flooding to downstream users.
2. Conservation of biodiversity	Afford protection to and enhance biodiversity in the catchment.
3. Public awareness and education	Empower public with respect to the ecological, social and economic importance of the Isipingo river and estuary system. Enhance public awareness of the good and services provided by the system, the threats to the system and their role in preventing further degradation to the system.
4. Land use zonation, planning and management	Ensure that all developments or activities (housing, infrastructure, etc) are properly managed to prevent further impacts to the system. This includes regulation of existing and future developments or activities.
5. Institutional arrangements	Identify and clearly define the roles and responsibility of Government, civil society and business. Ensure effective management through transparency and co-operative governance
6. Develop eco-tourism and recreational potential of estuary	Explore opportunities to generate revenue through eco-tourism which can be used to run the educational center at the Isipingo Island Institute

### 5.3.3 Management strategies and action plans

The vision and objectives can be achieved through management strategies. Management strategies can be further broken down into action plans which when implemented would achieve the overall objectives. It is also important to include key performance indicators which serve as measures of success of implementation of the strategies and action plans. A basic management strategy (Figure 5.8), action plan, measures of success and responsible



roleplayers is presented in Appendix 8 which has been adopted from the proposed Isipingo Estuary Management Plan and modified to include the entire Isipingo catchment. In addition, the development of a water quality monitoring programme for the Isipingo River and Estuary would be a key measure in determining whether the implementation of the strategies and action plans have resulted in improvements to the system. A proposed water quality monitoring programme is presented in Appendix 9. The adoption of any water quality improvement plan would require further elaboration by roleplayers with respect to proposed time frames as well as financial and human resources required to execute the management strategies and action plans.

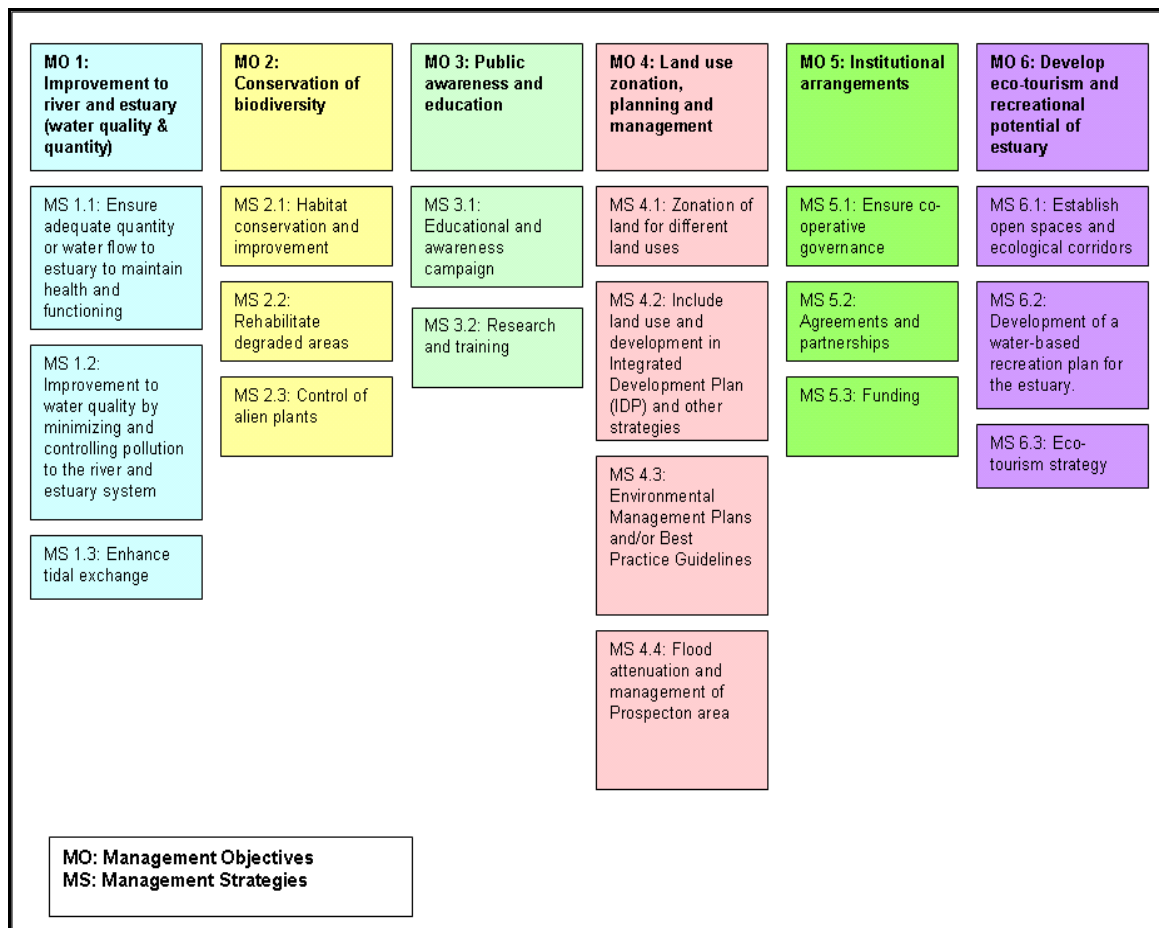


Figure 5.8: Management Objectives and Strategies (Developed by author, 2012)

#### 5.4. Implementation

The WQMP should be implemented under the guidance of the Department of Water Affairs and the eThekweni Municipality. The Isipingo Catchment Management Forum (ICMF) would be the ideal platform to implement the plan as all relevant stakeholders in the form of: civil

society, industry and spheres of government are represented at this forum. One of the objectives of this catchment forum is to table issues and problems that impact on the Isipingo River system as well as other related issues in the catchment as experienced by various stakeholders in the area; and to find solutions to these problems. The forum also looks at the protection, use, development, conservation, management and control of water resources within the area. The WQMP can be ratified by this forum with a view to broadening the plan into a Catchment Management Plan to incorporate other aspects such as geohydrology and the development of a groundwater management plan for the area. Maintaining and improving communication and coordination amongst roleplayers including research and educational institutions, and other interested and affected parties is important during implementation.

### **5.5 Monitoring and evaluation**

It is important that the progress made in implementing the plan is properly monitored, evaluated and documented. Evaluation is key as it assess the appropriateness and effectiveness of the activities performed against achieving the key deliverables (Sukdeo, 2010; King *et al.*, 2003). It is also vital that the plan is reviewed on a regular basis (generally this conducted every five years) to incorporate accomplishments and to include new commitments, management actions or strategies that need to be adopted. This allows government to monitor achievement of milestones and to identify gaps and areas of improvement.

### **5.6 Conclusion**

The development of a WQMP for the Isipingo catchment also encompasses issues which contribute directly and indirectly to deteriorating water quality. There is currently a draft Estuarine Management Plan for the Isipingo Estuary but this plan focuses specifically on the estuary. The scope of the proposed WQMP can be widened to incorporate other aspects such as groundwater monitoring plan and with a view to consolidating this into a Catchment Management Plan for the Isipingo area. It is important that resources are secured (financial and human) to ensure that activities and management interventions identified can be successfully implemented. Monitoring and evaluation are viewed as key aspects in measuring achievement of implementation of the plan.

## CHAPTER SIX

### CONCLUSION AND RECOMMENDATIONS

#### 6.1 Introduction

This chapter presents the conclusions and recommendations of this study. This chapter therefore is a distillation of the main findings of this research.

#### 6.2 Conclusion

The aim of this study was to holistically evaluate the water and sediment quality along the Isipingo River and Estuary, to quantify the net material (i.e. heavy metals and nutrients) exchange between the Isipingo estuarine system and the adjacent marine environment and, develop a water quality management plan for the Isipingo River and Estuary

The results of the water quality monitoring of the Isipingo River and Estuary demonstrated a system that exhibits extremely poor water quality from a microbiological perspective. This is evident from the extremely high levels of faecal contamination present during this study period and points towards anthropogenic sources. Furthermore, a comparison of the microbial results to the South African Water Quality Guidelines (SAWQG) categorized the water as being unfit for domestic and recreational usage and also presents a negative impact on the aquatic organisms. The nutrient levels indicate a system that is prone to eutrophic conditions as exhibited by the excessive growth of water hyacinth along the river system. In addition, the phosphorous levels during this study exceeded the limit required to control plant growth while the levels of ammonia and nitrate at most of the sites recorded values greater than 2.5 mg/l. Heavy metals are present in lower concentrations within the water column. Although these levels comply with the domestic use water quality guidelines, a vast number of these heavy metals are at concentrations that present a negative effect on the health of aquatic organisms.

One of the objectives of this study was to determine the quantity of selected nutrients and heavy metals that are imported or exported through tidal interchange between the Isipingo Estuary and the marine environment. It was concluded that although the estuary exports a variety of heavy metals as well as nutrients (NH<sub>3</sub> and NO<sub>3</sub>) annually, some variables namely Cu, Ni, Zn, P, K and Mg are imported into the estuary on an annual basis. The study also demonstrated that there are some seasonal tidal cycles during which there is a net import of

certain heavy metals (Al, Cr, Cu, Ni, Se, Ti, Zn and Zr) into the estuary. Furthermore, the Isipingo Estuary exhibits tidal asymmetry throughout the year with the ebb flow being dominant, although the flood velocities are greater than the ebb velocities. This study shows that although it is generally assumed that estuaries export considerable quantities of material to coastal waters, there are certain coastal process and estuarine morphodynamics which result in estuaries functioning as net importers of certain materials.

A further objective of this study was to quantify and assess heavy metal concentrations in sediment at selected sites along the Isipingo River and Estuary. The results indicated that with the exception of Selenium the enrichment factor of the majority of heavy metals was generally low. The riverine sites yielded moderate enrichment while E1 exhibited enrichment for As, Cr, Pb, Se and Zn and, is attributed to the fine grained sediment acting as both a contamination source and sink. The lagoon recorded a significantly high enrichment factor for As, Pb and Se while a slightly significant enrichment factor was recorded for V and Zn. This study also demonstrated that the concentrations of heavy metals increased longitudinally from the river to the estuary.

Other stresses imposed on the Isipingo system stem from increased alien vegetation, reduced riparian vegetation, development on the floodplain as well as improper waste disposal. In order to prevent further deterioration of the system and to improve current conditions, it is appropriate to develop and adopt a water quality management plan for the Isipingo catchment. Such a plan has been developed by the author and presented in Chapter 5 and Appendix 8.

In summary, it is evident that anthropogenic conditions are overall responsible for the deteriorating condition of the Isipingo River and Estuary. Faecal and nutrient contamination is considered to be the main constituents contributing to deteriorating health and functioning of the system. Heavy metal accumulation in the sediment of the estuary is of concern particularly with respect to As, Cr, Pb, Se and Zn. Human intervention is a necessity in preventing further degradation of the Isipingo system.

### **6.3 Recommendations**

Previous studies of the Isipingo system, in particular of the estuary have put forward several recommendations intended to improve the overall water quality, hydrological functioning and health of estuarine environment (Begg, 1978; Begg, 1984; Ramm *et al.*, 1985; Furness,

1988; Umgeni Water (1989); Anderson, 1992; Grobler, 1992; Kalicharran and Diab, 1993; Harrison *et al.*, 2000; Forbes and Demetriades, 2008; Moodley, 2010; Fernandes, 2011; Fernandes and Pillay, 2012). However, the current water quality data demonstrates that the Isipingo River and Estuary is still chemically and microbiologically poor. Furthermore, the system still suffers from reduced flow which magnifies the problems experienced with water quality of the system. The proposed development of a dug-out port immediately north of the estuary is earmarked to take place within the next few years and studies are to be initiated to assess amongst others impacts to the estuary.

This study proposes that the water quality management plan as presented in chapter five is implemented. It is of utmost importance that there is co-operation amongst all institutional roleplayers namely; national, provincial and local government as well as the non-governmental organizations. Furthermore, local communities must be mobilized and included as part of any management plan. It is further recommended that there is active continuence of the Isipingo Catchment Management Forum as this forum provides a platform for the interaction of various roleplayers and for the voices of local communities to be heard. This forum can also be utilized to develop an intergovernmental emergency protocol for pollution incidents.

It is imperative that legislative requirements which provide environmental protection, regulate wastewater discharges and control development are effectively implemented. Regulatory requirements must also be incorporated when implementing proper land use planning and management for future developments. This must also be coupled with rigorous enforcement and prosecution of any transgressions of environmental legislation.

Governmental authorities and non-governmental organizations including the Isipingo business sector must also develop and maintain education campaigns and environmental awareness programmes as mentioned in Chapter five. The Isipingo River and Estuary has a vast history and this can be used for further academic research by tertiary institutions.

It is further recommended that the Department of Water Affairs needs to undertake the following: investigate options to introduce more flow into the catchment; undertake a Reserve Determination; set resource water quality objectives for the Isipingo River and Estuary; implement the waste discharge charge system and develop Estuarine Water Quality Guidelines for selected user groups (i.e. aquatic ecosystems, recreational and domestic use).

In turn, it is recommended that the eThekweni Municipality undertake the following actions: repair and develop a maintenance plan for the Diversion Works System (DWS); develop a maintenance program to ensure the continuous removal of water hyacinth from the river and estuary as well as sediment removal from the canal system; re-instate riparian vegetation along river banks using indigenous vegetation; improve wetland functionality; maintain an industrial inventory; develop a sewerage infrastructure and maintenance plan; investigate options to improve tidal exchange, employ the services of Adopt-a-River (poverty alleviation and river improvement program which employs of local women to undertake litter and alien vegetation removal) and initiate further investigation of pollutants emanating from the Bamboo Drain.

Finally, the eThekweni Municipality and the Department of Water Affairs should in collaboration with one another, institute a River Health Monitoring Programme and regular monitoring of the system to ensure improvement as presented in proposed water quality monitoring programme presented in Appendix 9.

## REFERENCES

- Abed, R. (2009). An investigation into the suspended sediment flux and dynamics of the Mgeni Estuary, Durban. Unpublished Masters Dissertation, University of KwaZulu-Natal, Durban, South Africa.
- Addiscott, T.M., Whitmore, A.P., and Powlson, D.S. (1991). *Farming, fertilizer and the nitrate problem*. C.A.B International, Wallingford, Oxford.
- Aderinola, O.J., Clarke, E.O., Olarinmoye, O.M., Kusemiju, V. and Anatekhai, M.A. (2009). Heavy Metals in Surface Water, Sediments, Fish and Perwinklesof Lagos Lagoon. *American-Eurasian Journal of Agricultural and Environmental Science*, 5(5), 609-617.
- Allanson, B.R. and Baird, D. (eds). (1999). *Estuaries of South Africa*. Cambridge University Press, Cambridge.
- Allanson, B.R. (2001). Some factors governing the water quality of microtidal estuaries in South Africa. *Water SA*, 27(3), 373-386.
- Andersen, D.G. (1970). Effects of urban development of floods in Northern Virginia. United States Geological Survey Water Supply Paper No. 2001/C/26.
- Anderson, J.B. (1992). Isipingo Estuary: management of river flow. Unpublished memorandum to Estuarine Action Committee, Durban. pp 1-3.
- Archer, D. (1996). Suspended sediment yields in the Nairobi area of Kenya and environmental controls. In: *Erosion and Sediment Yield: Global and Regional Perspectives - proceedings of the Exeter Symposium, July 1996*. Wiltshire, United Kingdom. pp 37-47.
- Ashton, P.J., Hardwick, D. and Breen, C.M. (2008). Changes in water availability and demand within South Africa's shared river basins as determinants of regional social-ecological resilience. In: Burns, M.J. & Weaver, A. (eds). *Exploring sustainability science: A Southern African perspective*. Stellenbosch University Press, Stellenbosch, South Africa. pp 279-310.
- Awofolu, O.R., Mbolekwa, Z., Mtshemla, V. and Fatoki, O.S. (2005). Levels of trace metals in water and sediments from Tyume River and its effects on an irrigated farmland. *Water SA*, 31(1), 87-94.
- Baird, D. and Winter, P.E.D. (1989). Annual flux budget of dissolved inorganic nutrients through a well mixed estuary. In: Michaelis, W. (ed). (1989). *Coastal and Estuarine Studies: Estuarine Water Quality Management: Monitoring, Modelling and Research*. Springer-Verlag, New York. pp 335-340.
- Baird, D. and Winter, P.E.D. (1992). Flux of inorganic nutrients and particulate carbon between a *Spartina maritime* salt marsh and the Swartkops estuary, Eastern Cape. *Southern African Journal of Aquatic Sciences*, 18, 64-73.
- Baird, D., Winter, P.E.D. and Wendt, G. (1987). The flux of particulate material through a well mixed estuary. *Continental Shelf Research*, 7, 1399-1403.

- Balls, P.W. (1994). Nutrient inputs to estuaries from nine Scottish east coast rivers, influence of estuarine processes on inputs to the North Sea. *Estuary Coast Marine Science*, 39, 329-352.
- Bate, G.C., Whitfield, A.K., Adams, J.B., Huizinga, P. and Wooldridge, T.H. (2002). The importance of the River Estuary Interface zone in estuaries. *Water SA*, 28(3), 271-279.
- Beck, J.S., Theron, A.T., Kemp, A., Huizinga, P. and Basson, G. R. (2004). *Hydraulics of Estuarine Sediment Dynamics in South Africa – Implications for Estuarine Reserve Determination and the Development of Management Guidelines*. WRC Report No. 1257/1/04. Water Research Commission, Pretoria, South Africa.
- Beer, T. (1983). *Environmental Oceanography: An Introduction to the Behaviour of Coastal Waters*. A. Wheaton and Co. Ltd, Exeter, Great Britain.
- Begg, G.W. (1978). *The Estuaries of Natal: Part 1*. Natal Town and Regional Planning Report, Volume 41. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.
- Begg, G.W. (1984). *The Estuaries of Natal: Part 2*. Natal Town and Regional Planning Report, Volume 55. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.
- Biney, C., Amazu, A.T., Calamari, D., Kaba, N., Mbome, I.L., Naeve, H., Ochumba, P.B.O., Osibanjo, O., Radegonde, V. and Saad, M.A.H. (1994). Review of heavy metals in African aquatic environment. *Ecotoxicology and Environmental Safety*, 31, 134-159.
- Binning, K. and Baird, D. (2001). Survey of heavy metal in the sediments of the Swartkops Rivers Estuary, Port Elizabeth South Africa. *Water SA*, 27, 461-466.
- Bird, E. (2000). *Coastal Geomorphology: An Introduction*. John Wiley and Sons Ltd, England.
- Boyle, E., Collier, R., Dengler, A., Edmond, J., Ng, A. and Stallards, R. (1974). On the chemical mass balance in estuaries. *Geochemical et Cosmochemica Acta*, 38(2), 1719-1728.
- Brand, P.A. (1967). *Water quality and abatement of pollution in Natal Rivers: Survey of the Three Rivers Region*. Natal Town and Regional Planning Report, Volume 13. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.
- Brezonik, P.L., King, S.O. and Mach, C.E. (1991). The influence of water chemistry on trace metal bioavailability and toxicity to aquatic organisms. In: Newman, M.C. and McIntosh (eds). (1991). *Metal ecotoxicology: Concepts and applications*. A.W. Lewis Publishers, Michigan. pp 87-94.
- Brijlal, N. (2005). The environmental and health status of the Mgeni Estuary in KwaZulu-Natal, South Africa. Unpublished Masters Dissertation, University of KwaZulu-Natal, Durban, South Africa.



- Bucas, K. (2006). Natural and anthropogenic influences on the water quality of the Orange River, South Africa. Masters Dissertation, Department of Geography, University of KwaZulu-Natal, Durban, South Africa.
- Calder, I.R., Hall, R.L., Bastable, H.G., Gunston, H.M., Shela, O., Chirwa, A. and Kafundu, R. (1995). The impact of land use change on water resources in sub-Saharan Africa: a modelling study of Lake Malawi. *Journal of Hydrology*, 170(1–4), 123–135.
- Callow, S. (1994). Aspects of Heavy Metal Concentrations in Natal Estuarine Sediments, Kwazulu-Natal. Masters Dissertation, Department of Geography – School of Environmental Science, University of Natal, Durban, South Africa.
- Caraco, N.F. (1995). Influence of human populations on phosphorus transfers to aquatic systems: a regional scale studying using large rivers. In Tiessen, H. (ed). *Phosphorus in the Global Environment*. John Wiley and Sons, London. pp 235-244.
- Carbiener, R. Trémolières, M. Mercier, J.L. and Ortscheit, A. (1990). Aquatic macrophyte communities as bioindicators of eutrophication in calcareous oligosaprobe stream waters (Upper Rhine plain, Alsacc). *Vegetatio*, 86, 71-88.
- Carrasco, M., Ramirez, J.A.L., Benavente, J., Aguayo, F.L. and Sales, D. (2003). Assessment of urban and industrial contamination levels in the bay of cádiz, SW Spain. *Marine Pollution Bulletin*, 46, 335-345.
- CERM (Corporate Environmental Risk Management). (1995). A co-ordinated research programme on decision-support for the conservation and management of estuaries. Progress Report prepared for Consortium for Estuarine Research and Management, University of Natal, Pietermaritzburg.
- Chakravarty, M. and Patgiri, A.D. (2009). Metal Pollution Assessment in Sediments of the Dikrong River, N. E. India. *Journal of Human Ecology*, 27(1), 63-67.
- Chapman, D. (ed). (1992). *Water Quality Assessments: A guide to the use of biota, sediments and water in environmental monitoring* (2<sup>nd</sup> edition). E and FN Spon, London.
- Chapman, P.M. (1989). Current approaches to developing sediment quality criteria. *Environmental Toxicology and Chemistry*, 8, 589-599.
- Chetty, S. (2010). Personal communication. (12 August 2010, University of KwaZulu-Natal, Durban).
- Chiaudani, G. and Premazzi, G. (1988). Appraisal of the possible methods of combating the threat of eutrophication in Community waters. Commission of the European Communities (CEC), Brussels.
- Christian, G.D. (2007). *Analytical Chemistry* (6<sup>th</sup> edition). John Wiley and Sons, New York.
- Chust, G., Borja, A., Liria, P., Galparsoro, I., Marcos, M., Caballero, A. and Castro, R.I. (2009). Human impacts overwhelm the effects of sea-level rise on Basque coastal habitats (N Spain) between 1954 and 2004. *Estuarine, Coastal and Shelf Science*, 84, 453-462.

- Cobelo-Garcia, A., Prego, R. and Labandeira, A. (2004). Land inputs of trace metals, major elements, particulate organic carbon and suspended solids to an industrial coastal bay of the NE Atlantic. *Water Research*, 38, 1753–1764.
- Cole, J.A. and Whitelaw, K. (2001). Metal fluxes in the Mersey Narrows. *Hydrology and Earth System Sciences*, 5, 103-118.
- Constitution of the Republic of South Africa (Act 108 of 1996).
- Cooper, J.A.G. (1991). *Shoreline changes on the Natal Coast: Mkomazi River Mouth to Tugela River Mouth*. Natal Town and Regional Planning Report, Volume 77. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.
- Cooper, J.A.G. (1993a). Sedimentation in a river dominated estuary. *Geomorphology*, 40, 979-1017.
- Cooper, C.M. (1993b). Biological effects of agriculturally derived surface water pollutants on aquatic systems - a review. *Journal of Environmental Quality*. 22, 402–408.
- Cooper, J.A.G. (1994). Sedimentary processes in the river-dominated Mvoti Estuary, South Africa. *Geomorphology*, 9(4), 271-300.
- Cooper, J.A.G. (2001). Geomorphological variability among the microtidal estuaries from the wave dominated South African coastline. *Geomorphology*, 40, 99-122.
- Costanza, R., D'arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387, 253-259.
- Crosa, G., Froebrich, J., Nikolayenko, V., Stefani, F., Galli, P. and Calamari, D. (2006). Spatial and seasonal variations in the water quality of the Amu Darya Ricer (Central Asia). *Water Research*, 40, 2237-2245.
- Crossland, C.J., Baird, D., Ducrottoy, J.P. and Lindeboom, H. (2005). The coastal zone – a domain of global interactions. In: Crossland, C.J., Kremer, H.H., Lindeboom, H.J., Marshall Crossland, J.I. and Le Tissier, M.D.A. (eds). *Coastal fluxes in the anthropocene*. International Geosphere – Biosphere Programme Series, Springer.
- CSIR (Council for Scientific and Industrial Research). (2003). *The Great Brak management programme*. CSIR Report No. ENV/S/C/2003/092. Stellenbosch, South Africa.
- CSIR (Council for Scientific and Industrial Research). (2010a). *A CSIR perspective on Water in South Africa: 2010*. CSIR Report No. CSIR/NRE/PW/IR/2011/0012/A. Pretoria, South Africa.
- CSIR (Council for Scientific and Industrial Research). (2010b). *Sea Disposal of Sewage: Environmental Surveys in the Durban Outfalls: 2009*. CSIR Regional Report No. 28. Durban, South Africa.
- Cullis, B. (2012). Personal communication. (12 July 2012 and 20 August 2012, Department of Water Affairs, Durban)

- Cyrus, D.P., MacKay, C.F. and Weerts, S.P. (2008). Intrusion of beach-disposed dredger spoil into the Mhlathuze Estuary, South Africa, and its impact on *Zostera capensis*. *African Journal of Aquatic Science*, 33(3), 223-231.
- Cyrus, D.P., Vivier, L., Owen, R.K. and Jerling, H.L. (2011). Ecological status and role of the Mfolozi-Msunduzi estuarine system within the iSimangaliso Wetland Park, a World Heritage Site on the south-east coast of South Africa. *African Journal of Aquatic Science*, 35(2), 109-116.
- Dairymple, R.W., Zaitlin, B.A. and Boyd, R. (1992). Estuarine facies models: Conceptual basis and stratigraphic implications. *Journal of Sedimentary Petrology*, 62, 130-146.
- Dallas, H.F. and Day, J.A. (1993). *The Effect of Water Quality Variables on riverine Ecosystems: A Review*. WRC Report No. TT 61/93. Water Research Commission, Pretoria, South Africa.
- Dallas, H.F. and Day, J.A. (2004). *The Effects of Water Quality Variables on riverine biotas*. WRC Report No. TT 224/04. Water Research Commission, Pretoria, South Africa.
- Dame, R.F. and Allen, D.M. (1996). Between estuaries and the sea. *Journal of Experimental Marine Biology and Ecology*, 200, 169-185.
- David, R.A. (2006). A study of trace metals in estuarine sediment on the KwaZulu-Natal coast. Unpublished Masters Dissertation, University of KwaZulu-Natal, Durban. South Africa.
- Davies, B.R. and Day, J.A. (1998). *Vanishing Water*. University of Cape Town Press, Cape Town.
- Davies, C.A., Tomlinson, K. and Stephenson, T. (1991). Heavy metals in River tees estuary sediments. *Environmental Technology*, 12, 961-972.
- Day, J.H. (ed). (1981). *Estuarine ecology with special reference to Southern Africa*. AA Belkema, Cape Town.
- Deacon, J.R., Soule, S.A. and Smith, T.E. (2005). Effects of urbanization on stream quality at selected sites in the Seacoast region in New Hampshire. United States Geological Survey Scientific Investigations Report No. 2005/5103.
- DEAT (Department of Environmental Affairs and Tourism). (2005). *Background research paper: Inland Water, South Africa Environment Outlook*. Department of Environmental Affairs and Tourism, Pretoria, South Africa.
- DEAT (Department of Environmental Affairs and Tourism). (2006). *South Africa Environment Outlook. A report on the state of the environment*. Department of Environmental Affairs and Tourism, Pretoria, South Africa.
- DeBusk, W.F. (1999). Document SL170. Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida.
- Dent, M and Breen, C.M. (2001). Becoming involved in estuary management. In: Breen, C.M. and McKenzie M. (eds). *Managing Estuaries in South Africa: An Introduction*. Institute of Natural Resources, Pietermaritzburg. pp 32-39.

Devesa-Ray, R., Diaz-Fierrosa, F. and Barrala, M.T. (2009). Normalisation strategies for river bed sediments: a graphical approach. *Microchemical Journal*, 91(2), 253-265.

Devesa-Rey, R., Barral, M.T., Jouanneau, J.M. and Díaz-Fierros, F. (2010). Analysis of the degree of contamination and evolution in the last 100 years of the composition of the bed sediments of the Anillo's Basin. *Environmental Earth Sciences*, 61, 1401-1417.

De Villiers, S. and de Wit, M. (2010). H<sub>2</sub>O-CO<sub>2</sub>-Energy Equations for South Africa. Present Status, Future Scenarios and Proposed Solutions. AEON Report Series No. 2.

Diab, R.D. and Scott, D. (1989). Inanda Dam: A case study of estuarine impacts. *International Journal of Environmental Studies*, 34, 271-278.

Durubibe, J.O., Ogwuegbu, M.O.C. and Egwurugwu, J.N. (2007). Heavy metal pollution and human biotoxic effects. *International Journal of Physical Science*, 2(5), 112-118.

DWA (Department of Water Affairs). (2010). *Resource Directed Management of Water Quality: Planning Level Review of Water Quality in South Africa*. Sub-series No. WQP 2.0. Pretoria, South Africa.

DWA (Department of Water Affairs). (2011). *The 2010/2011 audit results for the Umlazi Wastewater Treatment Works*. Durban, South Africa.

DWAF (Department of Water Affairs and Forestry). (1996a). *South African Water Quality Guideline for Fresh Waters, Volume 1: Domestic Use*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (1996b). *South African Water Quality Guidelines for Fresh Waters, Volume 2: Recreational use*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (1996c). *South African Water Quality Guidelines for Fresh Waters, Volume 7: Aquatic Ecosystems*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (1997). *Water Quality Management Orientation Course: The Why, When, What and How of Inspections*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (1999). *Resource Directed Measures for the protection of water resources*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (2000). *Water Quality Management Orientation Course: Water Quality Management within a Catchment Context*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (2001a). *Water Quality Management Orientation Course: The Bigger Picture: Introduction to Sustainability, Environmental Management and Water Quality*. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). (2001b). *Water Quality Management Orientation Course: Legal Tools for the Water Quality Manager in the Department of Water Affairs and Forestry*. Pretoria, South Africa.

- DWAF (Department of Water Affairs and Forestry). (2002). *Water Quality Management*. [Accessed May 2010] <http://www.dwaf.gov.za>.
- DWAF (Department of Water Affairs and Forestry). (2004a). *National Water Conservation and Water Demand Management Strategy*. Pretoria, South Africa.
- DWAF (Department of Water Affairs and Forestry). (2004b). *Eastern Region Internal Strategic Perspectives Mvoti to Mzimkhulu Water Management Areas*. Pretoria, South Africa.
- DWAF (Department of Water Affairs and Forestry). (2005). *Kromme/Seekoei Catchments Reserve Determination Study – Technical Component*. Pretoria, South Africa.
- DWAF (Department of Water Affairs and Forestry). (2007). *Strategy for the Waste Discharge Charge System*. Pretoria, South Africa.
- DWAF (Department of Water Affairs and Forestry). (2009). *First Order Assessment of Wastewater Treatment Works in KwaZulu-Natal*. Pretoria, South Africa.
- Dyer K.R., (1997). *Tides in Estuaries*. In: Dyer, K.R. (ed). *A Physical Introduction* (2nd edition). John Wiley and Sons Ltd, London. pp 31-40.
- Fernandes, S. (2011). A Study of the net flux of nitrates from three estuaries of the eThekweni Municipality of Durban, KwaZulu-Natal. Unpublished Masters Dissertation, School of Environmental Science, University of KwaZulu-Natal, Durban, South Africa.
- Fernandes, S. and Pillay, S. (2012). A study of the net flux of nitrates from estuaries of the eThekweni Municipality of Durban, KwaZulu-Natal, South Africa. *Environmental Earth Sciences*, 67(8), 2193-2203.
- Finney, B.P. and Huh, C.A. (1989). Heavy metal pollution in the Southern California Bight: an update, *Environmental Science and Technology*, 23, 294-303.
- Forbes, A.T. and Demetriades, N.T. (2008). Estuaries of Durban, KwaZulu-Natal, South Africa. Report prepared for the Environmental Management Department, eThekweni Municipality.
- Fratini, S., Zane, L., Ragionieri, L., Vannini, M. and Cannicci, S. (2008). Relationship between heavy metal accumulation and genetic variability decrease in the intertidal crab *Pachygrapsus marmoratus* (Decapoda; Grapsidae). *Estuarine, Coastal and Shelf Science*, 79, 679–686.
- Fuggle, R.F. and Rabie, M.A. (1994). *Environmental Management in South Africa* (2<sup>nd</sup> edition). Juta, Cape Town.
- Furness, H. (1988). Pollution of the Lower Isipingo River. Unpublished report. Umgeni Water, Pietermaritzburg. pp 1-9.
- Garbarino, J.R., Hayes, H., Roth, D., Antwelder, R., Brinton, T.I. and Taylor, H. (1995). Contaminants in the Mississippi River. United States Geological Survey Circular 1133. Virginia, United States of America.

- Garland, G. and Moleko, L. (2000). Geomorphological impacts of Inanda Dam on the Mgeni estuary, north of Durban, South Africa. *Bulletin of Engineering Geology and the Environment*, 59, 119-126.
- Garcia-Armisen, T., Lebaron P. and Sevais P. (2005).  $\beta$ -D-glucuronidase activity assay to assess viable *Escherichia coli* abundance in freshwaters. *Letters in Applied Microbiology*, 40, 278-282.
- George, I., Crop, P. and Servais, P. (2002). Faecal coliforms removal in wastewater treatment plants studied by plate counts and enzymatic methods. *Water Research*, 36, 2607–2617.
- Gove, N.E., Edwards, R.T. and Conquest, L.L. (2001). Effects of scale on land use and water quality relationships, *Journal of American Water Resource Association*, 37(6), 1721–1734.
- Govender, S. (2009). An Investigation of the Natural and Human Induced Impacts on the Umdloti Catchment. Masters Dissertation, University of KwaZulu-Natal, Durban, South Africa.
- Gravelet-Blondin, L.R. (2010). Personal communication. (12 April 2010, Durban).
- Griffiths, D. (1987). *Rehabilitation of the Isipingo Estuary and Lagoon: River Pollution with special reference to Prospecton Industrial Estate*. Natal Town and Regional Planning Supplementary Report, Volume 25. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.
- Grindley, J.R. (1970). The role of fresh water in the conservation of South African estuaries. *Convention on water for the future for water year 1970*. Pretoria, South Africa. pp 16-20.
- Grobler, D.F. (1992). A water quality investigation of the Isipingo River and Estuary, Natal. Hydrological Research Institute Report No. N/U600/REQ/3291 prepared for the Department of Water Affairs and Forestry. Pretoria, South Africa.
- Guo, H., Hu, Q. and Jiang, T. (2008). Annual and seasonal streamflow responses to climate and land-cover changes in the Poyang Lake basin, China, *Journal of Hydrology*, 355, 106-122.
- Håkanson, L. (1980). An ecological risk index for aquatic pollution control—a sedimentological approach. *Water Resources*, 14, 975-1001.
- Hanson, P.J., Evans, D.W., Colby, D.R. and Zdanowicz, V.S. (1983). Assessment of elemental contamination in estuarine and coastal environments based on geochemical and statistical modeling of sediments. *Marine Environmental Research*, 36, 237-266.
- Hardman, D.J., McEldowney, S. and Waite, S. (1993). *Pollution: ecology and biotreatment*. Longman Group UK Limited, England.
- Harris, D.V. (1987). *Rehabilitation of the Isipingo Estuary and Lagoon: Welcome*. Natal Town and Regional Planning Supplementary Report, Volume 25. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.

- Harris, T.F.W. (1953). A survey of wastewater disposal on the South Coast of Natal. Council for Scientific and Industrial Research/National Institute of Water Research, Durban, South Africa. pp 1-62.
- Harrison, T.D., Cooper, J.A.G. and Ramm, A.E.L. (2000). State of the Environment Series: State of South African Estuaries. Report No. 2 prepared for the Department of Environmental Affairs and Tourism. Council for Scientific and Industrial Research, Pretoria, South Africa. pp 1-14.
- Harrison, T.D. (2004). Physico-chemical characteristics of South African estuaries in relation to the zoogeography of the region. *Estuarine Coastal and Shelf Science*, 61, 73- 87.
- Hart, B.T., Angehrn-Bettinazzi, C., Campbell, I.C. and Jones, M.J. (1992). *Australian water quality guidelines*. Australian and New Zealand Environment and Conservation Council.
- Hawkes, J.S. (1997). Heavy metals. *Journal of Chemical Education*, 74(11), 1374.
- Hayes, M.O. (1979). *Barrier island morphology as a function of tidal and wave regime*. In: Leatherman, S.P. (ed). *Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico*. Academic Press, New York. pp 1-27.
- Heydorn, A.E.F. (1985). *Short course for Planning in the Coastal Zone: Natal*. National Research Institute for Oceanography, Stellenbosch, South Africa.
- Hounslow, W. (1995). *Water quality data: analysis and interpretation*. Lewis Publishers, New York.
- Huizinga, P. and van Niekerk, L. (2005). Coastal Engineering Course - Mouth dynamics and hydrodynamics of Estuaries. Unpublished notes. University of Stellenbosch, South Africa.
- Huu, H.H., Rudy, S. and Van Damme, A.N. (2010). Distribution and contamination status of heavy metals in estuarine sediments near Cau Ong harbour, Ha Long Bay, Vietnam. *Geology Belgica*, 13(1-2), 37-47.
- Indrees, F.A. (2009). Assessment of trace metal distribution and contamination in surface soils of Amman, Jordan. *Journal of Chemistry*, 4(1), 77-87.
- IPCC (Intergovernmental Panel on Climate Change). (2007). Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability. Fourth Assessment Report.
- James, R., Sampath, K. and Selvamani, P. (1998). Effect of EDTA on reduction of copper toxicity in *Oreochromis mossambicus* (Peters). *Bulletin of Environmental Contamination and Toxicology*, 60, 487-493.
- Jarvie, H.P., Wade, A.J., Butterfield, D., Whitehead, P.G., Tindall, C.I., Virtue, W.A., Dryburgh, W. and McGraw, W. (2002). Modelling nitrogen dynamics and distributions in the River Tweed, Scotland: an application of the INCA model. *Hydrology and Earth System Science*, 6, 433-453.
- Jennings, M.E. (2005). Nutrient Dynamics in and offshore of two permanently open South Africa Estuaries with contrasting fresh water inflow. Masters Dissertion, University of Rhodes, South Africa.

- Johnson, L.B., Richards, C., Host, G.E. and Arthur, J.W. (1997). Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology*, 37, 193–208.
- Jumbe, A.S. and Nandini, N. (2009). Heavy metals assessment of wetlands around Peenya industrial area, Bangalore, India. *Journal of Research in Environmental and Life Sciences*, 2, 23-30.
- Kalicharran, S. (1990). Proposals for the Rehabilitation and Management of Isipingo Lagoon and Estuary, South Africa. Masters Dissertaion, Department of Geographical and Environmental Sciences, University of Natal, Durban, South Africa.
- Kalicharran, S. and Diab, R. (1993). Proposals for Rehabilitation and Management of Isipingo Lagoon and Estuary, South Africa. *Environmental Management*, 17, 759-763.
- Kamaruzzaman, B.Y., Ong, M.C., Noor Azhar, M.S., Shahbudin, S. and Jalal, K.C.Z. (2008). Geochemistry of Sediment in the Major Estuarine Mangrove Forest of Terengganu Region, Malaysia. *American Journal of Applied Sciences*, 5(12), 1707-1712.
- Kamau, J.N. (2002). Heavy metal distribution and enrichment at Port-Reitz Creek, Mombasa. *Western Indian Ocean Journal of Marine Science*, 1(1), 15-25.
- Kansiime, F., Kateyo, E., and Okot-okumu, J. (1995). Effects of pollution on Inner Murchison bay (Lake Victoria-Uganda) on the distribution and abundance of plankton. A Report by Makerere Institute of Environment and Natural Resources.
- Karbassi, A., Saeedi, M. and Amirnejad, R. (2008). Historical changes of heavy metal content and sequential extraction in a sediment core from the Gorgan Bay SW Caspian Sea. *Indian Journal of Marine Sciences*, 27(3), 267-272.
- Keller, E.A. (1992). *Environmental Geology* (6<sup>th</sup> edition). MacMillan, New York.
- Kersten, M. and Smedes, F. (2002). Normalization procedures for sediments contaminants in spatial and temporal trend monitoring. *Journal of Environmental Monitoring*, 4, 109-115.
- Khan, F.A. and Ansari, A.A. (2005). Eutrophication: An Ecological Vision. *The Botanical Review*, 71(4), 449-482.
- King, J.M., Scheepers, A.C.T., Fisher, R.C., Reinecke, M.K and Smith, L.B. (2003). *River rehabilitation: Literature review, case studies and emerging principles*. WRC Report No. 1161/1/03. Water Research Commission, Pretoria, South Africa.
- Kjerfve, B. and McKellar Jr, H.N. (1980). *Time Series Measurements of Material Fluxes: Estuarine Perspectives*. pp 341-357.
- Krantz, D. and Kifferstein, B. (1996). *Water Pollution and Society*. The Ecosystem Island Press, California, United States of America.
- Lawrie, R. A. (2007). Modelling of the Water Balance and Nutrient Dynamics of Mhlanga Estuary. Masters Dissertation, Department of Engineering: Civil Engineering Programme, University of KwaZulu-Natal, Durban, South Africa.



- Lazaro, T.R. (1990). *Urban Hydrology, a Multidisciplinary Perspective*. Technomic publishing company, Lancaster.
- Lemly, A.D. and Smith, G.J. (1987). Aquatic Cycling of Selenium: Implications for Fish and Wildlife. United States Department of the Interior, Fish and Wildlife Service, Fish and Wildlife Leaflet 12. Washington, D.C.
- Lenntech Water Treatment and Air Purification. (2004). Water Treatment. Published by Lenntech, Rotterdamseweg, Netherlands. [Accessed 8 August 2011] [www.excelwater.com/thp/filters/Water-Purification.htm](http://www.excelwater.com/thp/filters/Water-Purification.htm).
- Lewis, D.A. and McConchie, D. (1994). *Practical Sedimentology* (2<sup>nd</sup> edition). Chapman and Halls, London.
- Lindsay, P., Mason, T.R., Pillay, S. and Wright, C.I. (1996). Sedimentology and dynamics of the Mfolozi Estuary, north KwaZulu-Natal, South Africa. *South African Journal of Geology*, 99(3), 327-336.
- Lindsay, P., Mason, T.R., Pillay, S. and Wright, C.I. (1996). Suspended particulate matter and dynamics of the Mfolozi Estuary, KwaZulu-Natal: Implications for Management. *Environmental Geology*, 28(1), 1-12.
- Linnik, P.M. and Zubenko, I.B. (2000). Role of bottom sediments in the secondary pollution of aquatic environments by heavy metal compounds, lakes and reservoirs. *Resource Management*, 5 (1), 11-21.
- Lwanga, M.S., Kansiime, F., Denny, P. and Scullion, J. (2003). Heavy metals in Lake George, Uganda with relation to metal concentrations in tissues of common fish species. *Hydrobiologia*, 499(1-3), 83-93.
- Mackay, C.F., Weerts, S.P., and Cyrus, D.P. (2000). *Ecological Evaluation of the lower Mvoti River and Estuary*. CRUZ Environmental Report No. Coastal Research Unit of Zululand, University of Zululand, Empangeni, South Africa.
- Madsen, T., O'Malley, D. and Mottola, D. (2003). Rivers in Danger: The impact of development on water quality in New Jersey. New Jersey Public Interest Research Group, Law and Policy Center.
- Marine and Estuarine Research (MER). (2007). An Inventory of sandmining operations in KwaZulu-Natal Estuaries: Thukela to Mtamvuna. Report prepared for Coastwatch and Ezemvelo KZN Wildlife. Durban, South Africa.
- Martinez, J., Llamas, J., de Miguel, E., Rey, J. and Hildago, M.C. (2007). Determination of the geochemical background in a metal mining site: example of the mining district of Linares (South Spain). *Journal of Geochemical Exploration*, 94, 19-29.
- Mason, T.R. and Wright, C.I. (1993). Management and sediment dynamics of the St. Lucia Estuary mouth, Zululand, South Africa. *Journal of Environmental Geology*, 22(3), 227-241.
- Masselink, G. and Hughes, M. (2003). *An Introduction to Coastal Process and Geomorphology*. Hodder Arnold, United Kingdom.

- Meyer, J.H. and van Antwerpen, R. (1995). Trends in water quality of selected rivers in the South African sugar industry. *Proceeding of the South African Sugar Technology Association*, 69, 60-68.
- Mhlongo, M. (2010). Personal communication. (20 April 2010, eThekweni Municipality, Durban).
- Milenkovic, N., Damjanovic, M. and Ristic, M. (2005). Study of Heavy Metal Pollution in Sediments from Iron Gate (Danube River), Serbia and Montenegro. *Polish Journal of Environmental Studies*, 14(6), 781-787.
- Moodley, D. (2010). An Assessment of Water Quality and Health Status of the Isipingo Estuary with particular reference to Physical and Chemical Indicators, South Africa. Honours Dissertation, Department of Geography, School of Environmental Sciences, University of KwaZulu-Natal, Durban, South Africa.
- Moscrip, A.L. and Montgomery, D.R. (1997). Urbanization flood, frequency and salmon abundance in Puget Lowland Streams. *Journal of the American Water Resources Association*, 33(6), 1289–1297.
- Muller, G. (1979). Heavy metal Anomalies in Lagoon Sediments related to Intensive Agriculture in Altata-Ensenada del PabelloÂn coastal system (SE Gulf of California). *Environmental International*, 26, 265-273.
- Naicker, R. (2010) Personal communication. (2 July 2010 and 2 December 2010, eThekweni Municipality, Durban).
- Naidoo, K. (2005). The anthropogenic impacts of urbanisation and industrialization on the water quality, ecology and health status of the Palmiet River Catchment, Durban, Kwazulu-Natal. Unpublished Masters Dissertation, Department of Geography, University of KwaZulu-Natal, Durban, South Africa.
- National Environmental Management Act (Act 107 of 1998).
- National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008).
- National Environmental Management: Waste Act (Act 59 of 2008).
- National Health Act (Act 61 of 2004).
- National Water Act (Act 36 of 1998).
- Nedwell, D.B. and Trimmer, M. (1996). Nitrogen fluxes through the upper estuary of the Great Ouse, England: the role of bottom sediments. *Marine Ecology Progress Series*, 142, 273-286.
- Ngila, J.C. (2008). *Environmental Chemistry Practical Manual*. School of Pure and Applied Chemistry, University of KwaZulu-Natal, Durban.
- Nixon, S.W. (1980). Between coastal marshes and coastal water—a review of twenty years of speculation and research in the role of salt marshes in estuarine productivity and water

chemistry. In: Hamilton, P. and MacDonald, K. B. (eds). *Wetland processes with emphasis on modeling*. Plenum Press, New York. pp. 437-525.

North Sea Task Force (1993). North Sea quality status report 1993. Oslo and Paris commission.

Nussey, G. (1998). Metal Ecotoxicology of the Upper Olifants River at Selected Localities and the Effect of Copper and Zinc on Fish Blood Physiology. Doctorate Dissertation, Rand Afrikaans University, South Africa.

Oberholster, P.J. and Ashton, P.J. (2008). An overview of the current status of water quality and eutrophication in South African rivers and reservoirs. SA Parliamentary State of the Nation Report.

Odum, E.P. (2002). Tidal marshes as outwelling/pulsing systems. In: Weinstein, M.P. and Kreeger, D.A. (eds). *Concepts and controversies in tidal marsh ecology*. Kluwer Academic Publishers, New York. pp 44-58.

Officer, C. and Lynch, D. (1981). Dynamics of mixing in estuaries. *Estuarine, Coastal and Shelf Science*, 12, 525-533.

Olubunmi, F.E. and Olorunsola, O.E. (2010). Evaluation of the Status of Heavy Metal Pollution of Sediment of Agbabu Bitumen Deposit Area, Nigeria. *European Journal of Scientific Research*, 41(3), 373-382.

Omernik, J.M., Abernathy, A.R. and Male, L.M. (1981). Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. *Journal of Soil and Water Conservation*, 36, 227-231.

Orme, A.R. (1974). Estuarine sedimentation along the Natal coast, South Africa. *Office of naval research*, 5, 1-53.

Ouattara, N.K., Passerat, J. and Servais, P. (2009). Microbiological water quality in rivers of the Scheldt drainage network (Belgium): impact of urban wastewater release. *8th World Wide Workshop for Young Environmental Scientists*.

Ouyang, Y., Nkedi-Kizza, P., Wu, Q.T., Shinde, D. and Huang, C.H. (2006). Assessment of seasonal variations in surface water quality. *Water Research*, 40, 3800-3810.

Partridge, T.C. and Maud, R.R. (1987). Geomorphic evolution of Southern Africa since the Mesozoic South African. *Journal of Geology*, 90, 179-208.

Partridge, T.C. and Maud, R.R. (2000). *The Cenozoic of Southern Africa*. Oxford, New York.

Perry, J.E. (1989). *The impact of the 1987 floods on the estuaries of Natal: a hydro-photographic perspective*. CSIR Report Number 640. Council for Scientific and Industrial Research, Durban, South Africa.

Pethick, J. (1984). *Introduction to coastal geomorphology*. Edward Arnold, London.

- Philip, R.A. (2010). Personal communication. (20 February 2010 and 18 August 2010, Department of Water Affairs, Durban).
- Pillay, S. (1996). Sedimentology and dynamics of the Mfolozi and St Lucia Estuaries, KwaZulu-Natal, South Africa. Doctorate Dissertation, Department of Geology and Applied Geology, University of Natal, Durban, South Africa.
- Pillay, S., Lutchmiah, J., Gengan, R.M. and Lindsay, P. (2003). Morphology and sediment dynamics of the ephemeral Mfolozi Estuary, KwaZulu-Natal, South Africa. *South African Geographical Journal*, 85(2), 158-163.
- Pillay, S. (2013). Personal communication. (18 January 2013, University of KwaZulu-Natal, Durban).
- Prego, R. and Cobelo-García, A. (2003). 20th Century overview of Heavy Metals in the Galician Rias (NW Iberian Peninsula). *Environmental Pollution*, 121, 425-452.
- Pritchard, D.W. (1967). What is an estuary: physical viewpoint. In: Lauff, G.H. (ed). *Estuaries*. American Association for the Advancement of Science, Washington DC. pp 3-5.
- Rajharen, A. and Adams, J. (2006). Review of Mangrove Communities in Various KwaZulu-Natal Estuaries. Department of Botany, NMMU Paper, Port Elizabeth.
- Ram, A., Rokade, M.A. and Zingde, M.D. (2009). Mercury enrichment in sediments of Amba estuary. *Indian Journal of Marine Sciences*, 38(1), 89-96.
- Ramm, A., Cerff, E.C. and Harrison, T.D. (1985). *The Isipingo Estuary*. Natal Estuary Status Report No. 21. Estuaries and Coastal Process Division, National Institute for Water Research, Council for Scientific and Industrial Research, Durban, South Africa.
- Ramm, A. (1987). *Rehabilitation of the Isipingo Estuary and Lagoon: Isipingo Estuary and Lagoon*. Natal Town and Regional Planning Supplementary Report, Volume 25. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.
- Rankin, A. (1992). *Filenote: Sewage pollution from the Umlazi Wastewater Treatment Works*. Department of Water Affairs, Durban, South Africa.
- Ravelonandro, P.H., Rajoelisoa, A., Mong, Y., Rajaonarivony, M., Ravonizafy, C. and Nirilalaina, A. (2010). Assessment of heavy metals concentrations in coastal sediments in north-western cities of Madagascar. *African Journal of Environmental Science and Technology*, 4(2), 51-60.
- Richards, C., Johnson, L.B. and Host, G.E. (1996). Landscape-scale influences on stream habitats and biota. *Canadian Journal of Fisheries and Aquatic Sciences*, 53, 295–311.
- Robin, J. (1988). Analysis of water by emission spectrometry with an Inductively-coupled Plasma Source. In: West, T.S. and Nurnberg, H.W. (eds). *The determination of trace metals in natural waters*. Blackwell Scientific Publications, Oxford, London. pp 72-84.
- Rooseboom, A. (1992). *Sediment transport in rivers and reservoirs – a South African Perspective*. WRC Report No. 297/1/92. Water Research Commission, Pretoria, South Africa.

Rosales-Hoz, L., Cundy A.B. and Bahena-Manjarrez, J.L. (2003). Heavy metals in sediment cores from a tropical estuary affected by anthropogenic discharges: Coatzacoalcos estuary, Mexico. *Estuarine Coastal and Shelf Science*, 58, 117-126.

Rösler, J.H. and Lange, H. (1972). *Geochemical Tables*. University of Michigan Elsevier, Russia.

Roussouw, J.N. and Forster, L. (2008). *Guide to the Visual Assessment of Eutrophication Problems*. Department of Water Affairs and Forestry, Pretoria, South Africa.

Rowntree, K. (2006). *Integrated Water Resources Management (IWRM): Environmental Guidelines for South Africa*. Water Research Commission, Pretoria, South Africa.

Sager, M. (1992). Chemical speciation and environmental mobility of heavy metals in sediments. In: Stoeppler, M. (ed), *Hazardous Metals in the Environment*. Elsevier Science Publications, Amsterdam. pp 133-174.

Santos Bermejo, J.C., Beltran, R. and Gomes Ariza, J.L. (2003). Spatial variation of heavy metals contamination in sediments from Odiel River (Southwest Spain). *Environment International*, 29, 69-77.

Scharler, U.M. and Baird, D. (2005). The filtering capacity of selected Eastern Cape estuaries, South Africa. *Water SA*, 31(4), 483- 490.

Schueler, T. (1995). *Environmental Land Planning Series: Site Planning for Urban Streams Protection*. Center for Watershed Protection Publication No. 95708. Metropolitan Washington Council of Governments, Washington DC.

Schumann, E., Largier, J. L. and Slinger, J. (1999). Estuarine hydrodynamics. In: Allanson, B. R. and Baird, D. (eds). (1999). *Estuaries of South Africa*. Cambridge University Press, South Africa. pp 289-321.

Shinn, C., Dauba, F., Grenouillet, G., Guenard, G. and Lek, S. (2009). Temporal variation of heavy metal contamination in fish of the River Lot in southern France. *Ecotoxicology and Environmental Safety*, 72, 1957-1965.

Singh, L (2012). Personal communication. (21 August 2012, Isipingo).

Skoog, D.A. and West, D.M. (1982). *Fundamentals of Analytical Chemistry* (4<sup>th</sup> edition). Saunders Publishing, Philadelphia.

Snow, G. and Taljaard, S. (2007). *Water Quality: A review of information on temporarily open/closed estuaries in the Warm and Cool Temperature Biogeographic Regions of South Africa, with particular emphasis on the influence of River flow on these systems*. WRC Report No. 1581/1/07. Water Research Commission, Pretoria. South Africa.

Sooklall, R. (2010). Personal communication. (12 May 2010, eThekweni Municipality, Durban)

Sousa, A.I., Lillebø A.I., Pardal, M.A. and Caçador, I. (2010). Productivity and nutrient cycling in salt marshes: Contribution to ecosystem health. *Estuarine, Coastal and Shelf Science*, 87, 640-646.

SSI (Stewart Scott International Engineers and Environmental Consultants). (2011). *Isipingo Estuary Management Plan Part 1: Situation Analysis*. Report for the Coastal, Stormwater and Catchment Management Department, eThekweni Municipality.

Strady, E., Blanc, G., Schäfer, J. and Coynel, A. (2009). Dissolved uranium, vanadium and molybdenum behaviours during contrasting freshwater discharges in the Gironde Estuary (SW France). *Estuarine Coastal and Shelf Science*, 83, 550-560.

Sukdeo, P. (2010). A Study of Natural and Anthropogenic impacts on the sediment and water quality of the middle and lower Mvoti River system, KwaZulu-Natal, South Africa. Masters Dissertation, School of Environmental Science, University of KwaZulu-Natal-Westville Campus.

Sukdeo, P., Pillay, S. and Bissessur, A. (2010), An assessment of the presence of heavy metals in the sediments of the lower Mvoti river system, KwaZulu-Natal, South Africa. *African Journal of Science and Technology*, 11(2), 103-109.

Sukdeo, P., Pillay, S. and Bissessur, A. (2011), A geochemical assessment of the middle and lower Mvoti river system, KwaZulu-Natal, South Africa. *Environmental Earth Sciences*, 66, 481-487.

Sutherland, R. A., (2000). Bed sediment associated trace metals in an urban stream Oahu. Hawaii. *Environmental Geology*, 39(6), 611-627.

Swart, H. (1987). *Rehabilitation of the Isipingo Estuary and Lagoon: Engineering remedies*. Natal Town and Regional Planning Supplementary Report, Volume 45. The Natal Town and Regional Planning Commission, Pietermaritzburg, South Africa.

Tabayashi, Y. and Yamamuro, M. (2009). Changes in the impact of anthropogenic effects on river water quality during the last 50 years in Japan. *Wetlands Ecology and Management*, 17, 409-415.

Taghinia H, A., Basavarajappa, H.T. and Qaid Saeed, A.M. (2010). Heavy Metal Pollution in Kabini River Sediments. *International Journal of Environmental Research*, 4(4), 629-636.

Talbot, B. (2012). Personal communication. (25 September 2012, Pietermaritzburg).

Taljaard, S., Slinger, J.H., van Niekerk, L. and Huizinga, P. (1997). *Topographic and physicochemical surveys of three Eastern Cape estuaries during August 1996: Mngazi river estuary, Mzimvubu river estuary, Mntafufu river estuary*. CSIR Report No. ENV/S 97003. Council for Scientific and Industrial Research, Pretoria, South Africa.

Tang, Z., Engel, B.A., Pijanowski, B.C. and Lim, K.L. (2005). Forecasting land use change and its environmental impact at a watershed scale. *Journal of Environmental Management*, 76, 35-45.

- Taylor, D.I. and Allanson, B.R. (1995). Organic carbon fluxes between a high marsh and estuary, and the inapplicability of the Outwelling Hypothesis. *Marine Ecology Progress Series*, 120, 263-270.
- Taylor, L. (2012). Personal communication. (21 August 2012, Isipingo).
- Theron, A. (2003). *Setbackline for the coastal zone: Cave Rock to Msimbazi River Mouth*. Prepared for eThekweni Municipality City Engineers Unit, Rivers and Coastal Engineering Department by the Council for Scientific and Industrial Research. CSIR, Pretoria, South Africa.
- Turner, W.D. and Livingstone, D.J. (1974). National marine pollution monitoring programme-East coast impact area surveys. *Progress report*, 2, 1-10.
- Turpie, J.K., Adams, J.B., Colloty, B.M., Joubert, A., Harrison, T.D., Maree, R.C., Taljaard, S., van Niekerk, L., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taylor, R., Morant, P., Awad, A., Weston, B. and Mackay, H. (2002). *Classification and prioritization of South African estuaries on the basis of health and conservation priority status for determination of the estuarine water reserve*. Department of Water Affairs and Forestry, Pretoria, South Africa.
- Tyler, M.A. and Seliger, H.H. (1989). Time Scale Variations of Estuarine Stratification Parameters and Impact on the Food chains of the Chesapeake Bay. In: Neilson, K. and Brubaker (eds). *Estuarine Circulation*. Humana Press, Clifton, New Jersey.
- Tyson, P.D. and Preston-Whyte, R.A. (2000). *The weather and climate of Southern Africa*. Oxford University Press, Southern Africa, Cape Town.
- Ujević, I., Odžak, N. and Barić, A. (2000). Trace metal accumulation in different grain size fractions of the sediments from a semi-enclosed bay heavily contaminated by urban and industrial wastewaters. *Water Research*, 34, 3055–3061.
- Umgeni Water (1989). *Report on the Pollution of the Isipingo River*. Umgeni Water, Pietermaritzburg.
- United Nations Environment Programme (UNEP). (1996). Water Quality for ecosystems and human health. United Nations Environment Programme Global Environment Monitoring System (GEMS) / Water Programme.
- United Nations Environment Programme and the World Health Organisation (UNEP/WHO). (1996). Hydrological Measurements: Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes.
- United States Environmental Protection Agency (USEPA). (2006). Nutrients – Nitrogen and Phosphorus. Voluntary Estuary Monitoring: A Methods Manual.
- Van Aardt, W.J. and Booyesen, J. (2004). Water hardness and the effects of Cd on oxygen consumption, plasma chlorides and bioaccumulation in *Tilapia sparrmanii*. *Water SA*, 30, 57-64.

- Van der Laan, M., Van Antwerpen, R. and Bristow, K.L. (2012). River water quality in the northern sugarcane producing regions of South Africa and implications for irrigation: a scoping study. *Water SA*, 38(1), 1816-7950.
- Van Niekerk, L., Van der Merwe, J.H. and Huizinga, P. (2005). The hydrodynamics of the Bot River estuary revisited. *Water SA*, 31(1), 73-86.
- Van Niekerk, L. (2007). A framework for regional estuarine management: A South African case study. Unpublished Masters Dissertation, University of Stellenbosch, South Africa.
- Viljoen, A. (1999). Effects of zinc and copper on the post ovulatory reproductive potential of the sharptooth catfish *Clarias gariepinus*. Masters Dissertation, Rand Afrikaans University, South Africa.
- Villars, M.T. and Delvigne, G.A.L. (2001). *Estuarine Processes: Literature review*. Research conducted as part of the Long-range Research Initiative (LRI). Chemical associations of American Chemistry Council (US), JCIA (Japan) and the European Chemical Industry Council (CEFIC).
- Waeles, M., Tanguy, V., Lespes, G and Riso, R.D. (2008). Behaviour of colloidal trace metals (Cu, Pb and Cd) in estuarine waters: An approach using frontal ultrafiltration (UF) and stripping chronopotentiometric methods (SCP). *Estuarine, Coastal and Shelf Science*, 80, 538–544.
- Walmsley, R.D. (2000). *A review and Discussion Document: Perspective on Eutrophication of Surface Waters: Policy/research Needs in South Africa*. WRC Report No. KV129/00. Water Research Report, Pretoria, South Africa.
- Ward, C.J. (1980). The plant ecology of the Isipingo Beach area, Natal, South Africa. *Memoirs of the Botanical Survey of South Africa*, 45, 1-147.
- Ward, C.J. (2010). Personal communication. (8 February 2010, Durban).
- Wasson, R.J. (1992). Land Use and Climate Impacts on Fluvial Systems during the Period of Agriculture: Recommendations for a Research Project and its Implementations. PAGES Workshop Report, Series 96-2.
- Water Services Act (Act 108 of 1997).
- Wen, L.S., Santschi, P., Gill, G. and Paternostro, C. (1999). Estuarine trace metal distributions in Galveston Bay: Importance of colloidal forms in dissolved phase speciation. *Marine Chemistry*, 63, 185-212.
- Wepener, V., Van Vuren, J.H.J and Du Preez, H.H. (2001). Uptake and distribution of a copper, iron and zinc mixture in gill, liver and plasma of a freshwater teleost, *Tilapia sparmanii*. *Water SA*, 21(1), 990-1018.
- Whitfield, A. and Bate, G. (2007). *A review of information on temporarily open/closed estuaries in the warm and cool temperate biogeographic regions of South Africa, with particular emphasis on the influence of river flow on these systems*. WRC Report No. 1581/1/07. Water Research Commission, Pretoria, South Africa.



Whitmore, G., Meth, D. and Uken, R. (2006). Geology of KwaZulu-Natal, Geological Sciences, University of KwaZulu-Natal. [Accessed 18 March 2012] <http://www.geology.ukzn.ac.za>.

Wiley, D., Root, C.E., Peek, S. and Ramurath, S. (1996). *Negotiating Environment and Development in Durban's South Basin: Communities, Industries and Authorities*. Report by Institute for Social and Economic Research, University of Durban-Westville, South Africa.

Winter, P.E.D. and Baird, D. (1991). The exchange of phosphate between the Swartkops estuary and Algoa Bay. *South African Journal of Science*, 87, 192-197.

Wright, L.D. (1995). *Morphodynamics of Inner Continental Shelves*. CRC Press, Boca Raton.

World Health Organisation (WHO). (2009). Weekly Epidemiological Record. *Health Cluster Bulletin No. 8*, 84(31), 309-324.

WSP, NBI (National Business Initiative) and CDP (Carbon Disclosure Project). (2012). *Water Disclosure South Africa Report 2011: Assessing the value of water*. CDP, United Kingdom.

Yin, K. and Harrison, P.J. (2000). Influences of flood and ebb tides on nutrient fluxes and chlorophyll on an intertidal flat. *Marine Ecology Progress Series*, 196, 75-80.

Zhang, Y., Wang, Y. and Xi, H. (2009). Investigating the Impacts of Landuse-landcover (LULC) change in the Pearl River Delta Region on Water Quality in the Pearl River Estuary and Hong Kong's Coast. *Remote Sensing*, 1, 1055-1064.



## APPENDIX 2

Summary of the effects of selected microbiological indicators (Adapted from the Water Quality Guidelines for Fresh Water Resources) (DWAF, 1996a) (Where other sources are used, they are referenced in text)

Pathogens	Description	Interaction in environment	Environmental effects
Total coliforms	These bacteria comprise microorganisms that live in the intestines of both warm and cold-blooded animals and are used to give a general sanitary quality of the water body as this group includes bacteria of faecal origin. Total coliforms can include bacteria that could originate from growth in aquatic organisms	The activities of coliform bacteria are dependent on all the physical, chemical and biological interactions of the aquatic environment, which determine their growth rate and survival.	The total coliform group includes bacteria of faecal origin and indicates the possible presence of bacterial pathogens such as <i>Salmonella spp.</i> , <i>Shigella spp.</i> , <i>Vibrio cholerae</i> , <i>Campylobacter jejuni</i> , <i>C. coli</i> , <i>Yersinia enterocolitica</i> and pathogenic <i>E. coli</i> , especially when detected in conjunction with other faecal coliforms. These organisms can cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever
Faecal coliforms	A specific subgroup of this collection is the faecal coliform bacteria which a better indicator of faecal pollution than the broader total coliform bacteria. Used to evaluate the quality of wastewater effluents, river water, sea water at bathing beaches, raw water for drinking water supply, recreational waters as well as water used for irrigation, livestock watering	The activities of coliform bacteria are dependent on all the physical, chemical and biological interactions of the aquatic environment, which determine their growth rate and survival.	Faecal coliforms are primarily used to indicate the presence of bacterial pathogens such as <i>Salmonella spp.</i> , <i>Shigella spp.</i> , <i>Vibrio cholerae</i> , <i>Campylobacter jejuni</i> , <i>Campylobacter coli</i> , <i>Yersinia enterocolitica</i> and pathogenic <i>E. coli</i> . These organisms can be transmitted via the faecal/oral route by contaminated or poorly-treated drinking water and may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever. The risk of being infected by microbial pathogens correlates with the level of contamination of the water and the amount of contaminated water consumed. Higher concentrations of faecal coliforms in water will indicate a higher risk of contracting waterborne disease, even if small amounts of water are consumed.

	and aquaculture well as water used for irrigation, livestock watering and aquaculture.		
<i>Escherichia coli</i> (E. coli)	<i>Escherichia coli</i> (E. coli) is a highly specific indicator of faecal pollution and the difference between E. coli and other coliforms is that E. coli is found exclusively in the faeces of humans and warm-blooded animals while other coliforms are naturally found in vegetation, soil, water and faeces. For these reasons, E. coli is considered to be the species of coliform bacteria that is the best indicator of human faecal pollution and the possible presence of pathogens (Keller, 1960).	The activities of coliform bacteria are dependent on all the physical, chemical and biological interactions of the aquatic environment, which determine their growth rate and survival.	Same as faecal coliforms

### APPENDIX 3

Summary of the effects and interaction of heavy metals in the environment (Adapted from the Water Quality Guidelines for Fresh Water Resources) (DWAF, 1996c) (Where other sources are used, they are referenced in text)

Variables (Metals)	Description	Interaction in environment	Toxicity & Environmental effects
Aluminium (Al)	Al is the 3 <sup>rd</sup> most abundant element in the earth's crust and occurs primarily as aluminosilicate minerals which are too insoluble to participate readily in biogeochemical reactions (DWAF, 1996). One of the particulates emitted from combustion of coal and from aluminium smelters. Alum or aluminium sulphate is used in water treatment processes. Also used in processes by the paper, metal construction, leather and textile industry. Is one of the more toxic trace metals (Dallas & Day, 1993).	Speciation (as such solubility and bioavailability) is strongly pH dependent. It is relatively insoluble at a neutral pH (6.5-7.5). At pH<4, Al is the Al <sup>3+</sup> form which is very soluble. Between pH 4.5-6.5, Al undergoes hydrolysis and decreases in solubility. At pH >8 it is present as soluble but biological unavailable hydroxide complexes or as colloids or flocculants (DWAF, 1996c). At low pH, Al can form complexes with ions, Si and other organic solutes (e.g. humic substances). Through adsorption and coagulation reactions, Al may alter the cycling and availability of elements such as phosphorous.	Toxicity of Al depends on the chemical species involved (DWAF, 1996c). The Al <sup>3+</sup> form is also very toxic. In a complex form, Al becomes unavailable and hence non-toxic. High concentrations of Al in water are toxic to a number of organisms. The toxic effects are dependent on the species and life stage of the organism, the concentration of calcium in the water and pH. In acidic waters, Al is more toxic between pH 4.4-5.4 with maximum toxicity occurring at pH 5.0-5.2. In fish, it interferes with osmotic balance respiratory problems as a result of coagulation of mucus on gills. South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.15 mg/l, aquatic ecosystem is 0.005 mg/l and the ecological environment is 0.02 mg/l.
Arsenic (As)	It is a metalloid element. Most common forms are III and V.	Elemental As is insoluble in water but many of its compounds are very soluble. Occurs in many oxidation states (namely III, IV, V and <sup>-</sup> III) – depending on pH and redox potential of the water. Elemental As combines with many metals to form arsenide salts. As adsorbs onto sediments and suspended solids is	Is toxic to marine and freshwater aquatic organisms and is a known carcinogen. Arsenide salts are toxic. Organic arsenal compounds have been shown to be less toxic than inorganic forms of arsenic. Inorganic As does not accumulate in aquatic organisms but some forms of As is lipid soluble and can accumulate in fatty tissue. South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.01 mg/l, aquatic ecosystem is

		lipid soluble.	0.01 mg/l and the ecological environment is 0.02 mg/l.
Barium (Ba)	Barium is one of the trace metals classified by the USEPA as a 'hazardous candidate' because of its potential as an environmental contaminant		It causes vomiting and diarrhea, bleeding of the kidneys and affects the central nervous system (Dallas & Day, 1993). The World Health Organisation (WHO) drinking water limit for Ba is 0.7 mg/l. There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.
Chromium (Cr)	Chromium ions can exist in the following forms: II, III & VI. Chromium is a relatively scarce metal and should therefore be present at low concentrations in the natural environment. Increased concentrations in the aquatic environment are a result of industrial activities. Cr <sup>6+</sup> salts are used in the leather industry, metal pickling and plating and in the manufacture of paints, dye, ceramics and paper while trivalent chromium is used to a lesser extent in photography, ceramic and glass industry and as a fixative in textile dye manufacturing.	Cr <sup>6+</sup> is a highly oxidized state and occurs as the yellow dichromate salt in neutral or alkaline media and an orange dichromate salt in acid media. Cr <sup>6+</sup> is highly soluble at all pH values. In the aquatic environment, chromous compounds are oxidized to chromic forms while Cr <sup>6+</sup> is reduced to Cr <sup>3+</sup> by heat, in the presence of organic matter and reducing agents. Trivalent Cr salts (e.g. chloride, nitrate and sulphate salts) are soluble but the hydroxide and carbonate salts are relatively insoluble. Sodium, potassium and ammonium chromate and dichromates (i.e. hexavalent salts) are soluble). The equilibrium between Cr <sup>6+</sup> and Cr <sup>3+</sup> is influenced by pH and redox potential.	The reduced forms of Cr <sup>2+</sup> and Cr <sup>3+</sup> are less toxic than Cr <sup>6+</sup> . The presence of oxidisable material with result in the reduction to less toxic oxidation states. Chromium exerts toxic effects at different concentrations to different groups of aquatic organisms. South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.05 mg/l, aquatic ecosystem is 0.007 mg/l and the ecological environment is 0.024 mg/l.
Copper (Cu)	Copper is an essential trace element to plants, animals and even humans (DWAf, 1996c). It is a	Organic and inorganic substances form complexes with Cu <sup>2+</sup> and the free ion is rarely found except in	It is toxic at elevated levels and even found in natural waters, the ionic form is very poisonous towards photosynthesis (Steemann

	<p>micronutrient. It is a widely used metal particularly in the electrical industry. Other anthropogenic sources include mining, electroplating operations, sewage treatment plant effluent or industrial effluent. Occurs in four oxidation states namely 0, I, II &amp; III.</p>	<p>pure acidic soft water In waters with a high pH, copper precipitates while at low pH, it is soluble and more toxic (Nussey, 1998). Copper can be present as cupric ions, complexed with inorganic or organic ligands, attached to suspended or be sediments and as precipitates of hydroxides, phosphates or sulphides. The speciation is dependent on pH and the presence of ligands such as sulphate, chloride and nitrate in the water. Cu is more soluble in acidic waters while it precipitates as <math>\text{Cu}(\text{OH})_2</math> at pH above 6.5. <math>\text{Cu}^{2+}</math> is very soluble in water while copper carbonate, hydroxide and sulphide are insoluble. Cu is easily adsorbed and precipitated in sediments at alkaline pH.</p>	<p>The toxicity of copper is largely attributed to its <math>^{2+}</math> form which combines with other ions (Nussey, 1998). The toxicity of <math>\text{Cu}^{2+}</math> increases when a decrease in dissolved oxygen, water hardness, temperature, pH and in the presence of other metals (Nussey, 1998). Cu toxicity decreases in the presence of humic acids, amino acids and suspended solids, with an increase in alkalinity, in the presence of zinc, sulphate, calcium or magnesium. The toxicity of Cu in waters rich in organic matter is less. It toxicity is also reduced in the presence of zinc, molybdenum and sulphate (Dallas &amp; Day, 1993). South African Water Quality Guidelines (SAWQG) target value for domestic use is 1 mg/l, aquatic ecosystem is 0.0003 mg/l and the ecological environment is 0.0005 mg/l.</p>
Cobalt (Co)	<p>The elemental form of cobalt is not found in nature. It is an essential micronutrient and is also fairly toxic in small quantities.</p>	<p>Cobalt is strongly adsorbed by soil/sediment.</p>	<p>Insoluble inorganic cobalt compound are carcinogenic while the soluble inorganic compounds are toxic. There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.</p>

Iron (Fe)	Fe is an essential micronutrient for all organisms. Iron is released naturally from weathering of sulphide ores and igneous, sedimentary and metamorphic rocks. Human activities arising from mining, sewage effluent, landfill leachates and some industrial effluents	Two most common states in water are the reduced ferrous ( $\text{Fe}^{2+}$ ) form and the oxidized ferric ( $\text{Fe}^{3+}$ ) state. The chemical behaviour of Fe in the aquatic environment is determined by oxidation-reduction reactions, pH and coexisting organic and inorganic complexing agents. At low pH, $\text{Fe}^{2+}$ will predominate in the absence of oxygen while $\text{Fe}^{3+}$ will prevail in oxygenated waters. Water hardness also affects the concentration of Fe. Soft water usually contains higher Fe concentrations. The amount of Fe in solution can be affected by biological interactions. Fungi and micro-organisms can mobilize flocculent materials and bring iron back into solution. In anaerobic sediments, ferric oxide and hydroxides may be reduced. Algal growth can reduce iron concentrations in the water column while iron is released when the plants decay.	The toxicity depends on the form it is in. Although Fe has toxic properties at high concentrations, it is not easily absorbed in the gastrointestinal tract. South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.5 mg/l. The SAWQG do not have any values for the aquatic ecosystem or ecological environment.
Lead (Pb)	Exists in different oxidation states (0, I, II & IV). Released naturally to the environment through weathering of sulphide ores and is generally low in aquatic systems. Main anthropogenic sources include dust fallout, industrial and municipal wastewater, mining, milling and smelting activities and the combustion of fossil fuels.	The divalent form is said to be the form that is bioaccumulated in aquatic organisms. A decrease in pH increases the bioavailability of $\text{Pb}^{2+}$ . Solubility increases with increasing alkalinity. Soluble lead is removed from solution by attachment to sediment and suspended particulates of inorganic and organic material.	The uptake of lead by aquatic organisms is dependent on the action of calcium. Water hardness is thus an important factor determining the toxicity of Pb. Calcium at around 50mg/l can prevent the toxic effects of Pb at 1mg/l. Lead is therefore more toxic in soft water than hard water. Lead toxicity also increases with decreasing concentrations of dissolved oxygen. Pb accumulates in living tissue. It reacts metabolically with iron and can interfere with



		Adsorption is the primary factor responsible for low lead concentrations in the aquatic environment. In the presence of clay at pH 5-7, Pb is precipitated and adsorbed.	haemoglobin synthesis. Low levels of Pb can affect fish by forming a film of mucous over their gills. Pb is also bioaccumulated benthic bacteria, freshwater plants, invertebrates and fish. The South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.01 mg/l, aquatic ecosystem is 0.0002 mg/l and the ecological environment is 0.0005 mg/l.
Manganese (Mn)	Mn is an essential micronutrient for plants and animals. It is a functional component of nitrate assimilation (DWAF, 1996c). Industrial effluent can contribute to elevated Mn concentrations in water. Industries such as steel, fertilizer and chemical (paint, dyes, glass, ceramics) use Mn in their processes or products.	In the aquatic environment, Mn does not occur naturally as a metal but is found in various salts and minerals and is frequently in association with iron compounds. Can exist as $Mn^{2+}$ but is oxidized to insoluble $Mn^{4+}$ form. $Mn^{2+}$ ion occurs at low redox potential and low pH. Permanganates ( $Mn^{7+}$ ) do not persist in the environment as it oxidizes organic material and is therefore reduced. Nitrate, sulphate and chloride salts of Mn are fairly soluble in water whereas oxides, carbonates, phosphates, sulphides and hydroxides are less soluble. Large portion of Mn is present in suspended and adsorbed forms. Concentration of dissolved Mn is influenced by redox potential, dissolved oxygen, pH and organic matter. Organic and inorganic complexing compounds stabilize Mn oxides. Under anaerobic conditions with low pH, soluble Mn forms can be	High concentrations of Mn are toxic. Limited information on toxicity effects of Mn to algae, invertebrates and vertebrates. An excess of Mn has been implicated in causing disturbances to the central nervous system (Dallas & Day, 1993).

		present. Increased carbon activity decreases Mn solubility and at high concentration of carbon, the oxidation rate of Mn is reduced.	
Molybdenum (Mo)	Is a trace metal essential for nitrogen fixation by bacteria (Dallas & Day, 1993).		It is not accumulated in tissues of organisms nor is it toxic, except at high concentrations. The presence of Molybdenum has been shown to induce symptoms of copper deficiency in animals (Dallas & Day, 1993). There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.
Nickel (Ni)	Nickel may be present at naturally high levels in the environment David (2006). Its anthropogenic sources include mining, refineries, nickel-cadmium battery manufacturing and fossil fuel industries (David, 2006).	Nickel ions tend to be soluble as pH values < 6.5 while above a pH of 6.7, they mostly form insoluble nickel hydroxides (Dallas & Day, 1993). Also forms complexes which adhere to clay particles.	It is toxic even in small amounts and has been shown to be carcinogenic in mammals (Dallas & Day, 1993). It can diminish the growth rates of algae in surface waters while micro-organisms can suffer from a decline in growth, although they may develop a resistance with time (Pather, 2010). There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.
Selenium (Se)	Se is a non-metallic element but behaves like a metal. Increased concentrations occur as a result of industrial activity (used in process or discharged through effluent). Some industries include paint, food processing, steel, vehicle plating, glass and ceramics, dye manufacturing, rubber metal alloy industry.	Present as $\text{II}$ , 0, $\text{II}$ , $\text{IV}$ and $\text{VI}$ . A decrease in pH decreases the solubility of Se. Some chemical similarities between Se and sulphur which leads to situations where Se can replace sulphur in biological important substances. Se can undergo biological methylation in sediments into selenomethionine.	The toxicity of Se to fish species depends on water temperature. Decreases in pH have little impact on toxicity. Se is antagonistic to the toxic effects caused by mercury, thallium and silver. It is also antagonistic to cadmium toxicity to green algae. Se can accumulate in liver of mammals and fish. Selenomethionine is 10 times more toxic than inorganic selenium. The South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.02 mg/l and

			the aquatic ecosystem is 0.002 mg/l. There are no values available for the ecological environment.
Strontium (Sr)	Occurs in various rocks and minerals in the Earth's crust but is usually found in low concentrations in water (Moodley, 2010). Sr can be transported with atmospheric aerosols and can be found in atmospheric fallout (Moodley, 2010).		There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.
Titanium (Ti)	Ti is the 9 <sup>th</sup> most abundant element in the Earth's crust and is present in most igneous rocks (Lenntech, 2004).		There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.
Vanadium (V)	Metallic V does not occur in nature. Vanadium compounds have various industrial applications and are used as catalysts in the chemical industry, in certain glassware and ceramic products, in the textile industry and in the manufacture of dyes.	Occurs in oxidation states II, III, IV & V. Vanadium IV and V salts are soluble in water and are not strongly adsorbed onto soil particles (therefore stays in solution). Compounds of vanadium such as trifluoride, trioxide and trisulphide are insoluble in water and are associated with sediments. Metabolically, vanadium interacts with chromium and iron.	High levels of V inhibit tissue oxidation and can also inhibit the synthesis of cholesterol, phospholipids, other lipids and amino acids (Dallas & Day, 1993). The South African Water Quality Guidelines (SAWQG) target value for domestic use is 0.1 mg/l. There are no values available for the aquatic ecosystem and the ecological environment.
Zinc (Zn)	Zinc is an essential trace element/micronutrient. Can enter the aquatic system through natural and anthropogenic activities. Used in metal galvanizing, dye manufacturing and processing, paint and cosmetic pigments, pharmaceuticals, fertilizers and insecticides.	Zinc has an antagonistic and protective action in the uptake and toxic action of other metals e.g. cadmium. Occurs in 2 oxidation states namely as the metal and Zn <sup>2+</sup> . In aqueous solutions, zinc is amphoteric (i.e. dissolves in acids to form hydrated cations Zn <sup>2+</sup> and in bases to form Zn(OH) <sub>4</sub> <sup>2-</sup> ). In	The toxicity of zinc is affected by the levels of dissolved oxygen, hardness, pH and temperature of the water (Nusse, 1998). High temperatures results in an increase in zinc toxicity while increases in water hardness, alkalinity and organic chelators can reduce its acuteness. Low dissolved oxygen levels on the other hand results in an increase in zinc toxicity. Zn <sup>2+</sup> is toxic to fish and aquatic organisms at relatively low

		<p>most natural waters, zinc is found in the divalent form. Water with a low pH, low alkalinity and high ionic strength will have the greatest amount of dissolved Zn concentration. There is adsorption of Zn by hydrous metal oxides, clay minerals and organic materials.</p>	<p>concentrations. Zn reduces the toxicity of cadmium while its toxicity increases in the presence of copper in soft water, not hard water. Zn toxicity also increases at lower oxygen concentrations. Zn is synergistically toxic with cyanide. Zn can form insoluble compounds in the mucus covering the gills. The South African Water Quality Guidelines (SAWQG) target value for domestic use is 20 mg/l and the aquatic ecosystem is 0.002 mg/l. There are no values available for the ecological environment.</p>
Zirconium (Zr)			<p>There are no guideline values available in the South African Water Quality Guidelines (SAWQG) for domestic use, the aquatic or ecological environment.</p>

**APPENDIX 4**

Average wet and dry season results of physical water quality variables and cations along the Ispingo River and Estuary for the period February 2010 to January 2011. Results are presented in mg/l except pH which is displayed in pH units and EC which is displayed in mS/m

Physical water quality variables and cations																								
Sample sites	Wet season average concentrations (Diversion works non-operational)								Wet season average concentrations (Diversion works operational)								Dry season average concentrations (Diversion works non-operational)							
	pH	DO	EC	TDS	Ca	K	Mg	Na	pH	DO	EC	TDS	Ca	K	Mg	Na	pH	DO	EC	TDS	Ca	K	Mg	Na
R1	8.48	8.38	51.14	301.50	8.22	17.16	3.93	32.69	8.48	8.38	51.14	301.50	8.22	17.16	3.93	32.69	7.62	7.87	85.40	488.33	12.77	28.03	8.58	23.74
R2	7.61	8.72	61.73	303.33	8.11	6.57	7.72	36.72	7.61	8.72	61.73	303.33	8.11	6.57	7.72	36.72	7.86	7.83	105.03	610.00	13.20	32.17	6.93	29.90
R3	#	#	#	#	#	#	#	#	7.89	9.00	44.23	316.67	5.45	4.95	3.25	23.19	#	#	#	#	#	#	#	#
R4	8.99	7.83	95.10	506.67	10.51	4.32	5.33	95.02	8.19	7.47	58.27	300.00	5.18	6.96	5.43	68.10	7.54	7.55	98.26	526.67	7.77	7.52	12.22	47.04
E1	8.82	5.93	87.81	550.00	9.04	4.09	12.67	115.05	8.32	5.93	85.57	550.00	5.99	2.55	14.40	69.32	8.04	5.86	100.25	727.83	7.38	5.98	14.68	104.89
E2	8.10	6.33	5330.00	27566.67	187.33	152.43	491.00	4123.99	7.22	7.27	3541.00	21030.00	123.01	229.67	333.5	2681.98	7.71	6.39	5046.2	29406.67	299.37	298.03	614.5	4333.66
E3	8.13	6.16	625.33	3013.33	22.16	17.03	58.00	418.04	7.40	7.48	366.20	2094.67	13.88	23.57	34.24	150.23	7.98	6.00	600.78	2958.33	21.53	23.42	78.75	211.63
E4	8.32	7.71	389.33	1970.00	34.42	14.22	28.27	248.35	8.04	7.88	295.00	1510.00	27.41	16.57	35.52	146.06	7.62	8.10	342.58	1816.33	15.62	30.25	34.05	242.41
TWQR DUI	5-9.5	na	70	450	10	25	70	100	5-9.5	na	70	450	10	25	70	100	5-9.5	na	70	450	10	25	70	100
TWQR AQI	6.5-8	6	30	*	na	na	na	na	6.5-8	6	30	*	na	na	na	na	6.5-8	6	30	*	na	na	na	na
TWQR ECI	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
TWQR RFCI	6.5-	na	na	na	na	na	na	na	6.5-	na	na	na	na	na	na	na	6.5-	na	na	na	na	na	na	na
TWQR: Target Water Quality Range #: Diversion works non-operational *: TDS should not vary more than 15% of normal cycles DUI: Domestic use – Ideal AQI: Aquatic ecosystems – Ideal ECI: Ecological environment – Ideal RFCI: Recreational use full contact - Ideal																								

**APPENDIX 5**

Average wet and dry season results of nutrient concentrations along the Isipingo River and Estuary for the period February 2010 to January 2011. Results are presented in mg/l

Nutrient concentrations in mg/l											
Sample sites	Average wet (Diversion works non-operational)				Average wet (Diversion works operational)				Average dry (Diversion works non-operational)		
	NH <sub>3</sub>	NO <sub>3</sub> <sup>-</sup>	P		NH <sub>3</sub>	NO <sub>3</sub> <sup>-</sup>	P		NH <sub>3</sub>	NO <sub>3</sub> <sup>-</sup>	P
<b>R1</b>	0.773	4.113	0.017		0.773	4.113	0.017		1.827	4.976	0.460
<b>R2</b>	0.897	3.031	0.179		0.897	3.031	0.179		1.027	3.633	0.386
<b>R3</b>	#	#	#		0.000	3.140	0.103		#	#	#
<b>R4</b>	1.805	2.280	0.030		2.173	3.535	0.134		1.671	8.686	0.016
<b>E1</b>	1.419	1.785	0.000		0.040	5.872	0.118		1.252	5.769	0.239
<b>E2</b>	5.369	2.080	0.171		0.795	0.662	0.030		2.896	0.754	0.208
<b>E3</b>	4.076	0.847	0.040		0.587	1.870	0.130		1.873	1.303	0.082
<b>E4</b>	2.413	1.286	0.000		1.617	3.932	0.045		1.797	2.122	0.474
<b>TWQR DUI</b>	1	6	na		1	6	na		1	6	na
<b>TWQR AQI</b>	0.007	na	na		0.007	na	na		0.007	na	na
<b>TWQR ECI</b>	0.015	na	0.005		0.015	na	0.005		0.015	na	0.005
<b>TWQR: Target Water Quality Range</b>						<b>DUI: Domestic use – Ideal</b>					
<b>#: Diversion works non-operational</b>						<b>AQI: Aquatic ecosystems – Ideal</b>					
						<b>ECI: Ecological environment – Ideal</b>					

**APPENDIX 6**

Appendix 6.1: *E. coli* levels (in cfu/100ml) present along the Isipingo River and Estuary for the period February 2010 to January 2011

<i>E. coli</i> in counts per 100 ml												
Sample sites	February	March	April	May	June	July	August	September	October	November	December	January
R1	1364	4300	3100	1400	4200	290	490	na	3600	700	19000	37000
R2	144	700	2200	8400	4400	80	110	7	500	1500	23000	2900
R3	#	#	#	#	#	#	#	#	#	2300	1500	580
R4	166	140	4000	14000	2800	1600	220	1900	260	7000	80	22000
E1	114	40	4400	4300	1600	2800	150	2200	4100	5000	2000	0
E2	12	47	19	5	39	21	3	0	170	1150	3300	15
E3	14	840	66	220	1000	420	10	3	290	1800	2400	290
E4	126	300	103	6200	800	900	500	0	1200	700	1600	580
TWQR DUI	0	0	0	0	0	0	0	0	0	0	0	0
TWQR RFCI	130	130	130	130	130	130	130	130	130	130	130	130
TWQR RICl	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
TWQR: Target Water Quality Range				DUI: Domestic use – Ideal								
na: not available				RFCI: Recreational full contact – Ideal								
#: Diversion works not operational				RICl: Recreational intermediate contact – Ideal								

Appendix 6.2: Faecal coliform levels (in cu/100ml) present along the Isipingo River and Estuary for the period February 2010 to January 2011

Faecal coliforms in counts per 100 ml												
Sample sites	February	March	April	May	June	July	August	September	October	November	December	January
R1	10000	4300	6100	3800	7200	1100	680	na	4700	1900	55000	48000
R2	10000	1240	3000	12400	5300	190	390	7	1680	2900	48000	3600
R3	#	#	#	#	#	#	#	#	#	4800	4800	640
R4	10000	960	14000	20000	11600	14000	880	1900	340	11000	120	26000
E1	536	80	9900	9700	4900	2900	240	2000	6500	13000	3500	0
E2	38	58	36	5	40	36	10	0	260	1600	5800	15
E3	564	1040	99	540	1700	600	40	3	420	2700	3900	480
E4	974	340	166	8900	1900	3400	850	0	3500	5200	4600	620
TWQR DUI	0	0	0	0	0	0	0	0	0	0	0	0
TWQR RFCI	130	130	130	130	130	130	130	130	130	130	130	130
TWQR RICl	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
TWQR: Target Water Quality Range						DUI: Domestic use – Ideal						
na: not available						RFCI: Recreational full contact – Ideal						
#: Diversion works not operational						RICl: Recreational intermediate contact – Ideal						



Appendix 6.3: Total coliform levels (in cufl/100ml) present along the Isipingo River and Estuary for the period February 2010 to January 2011

Total coliforms in counts per 100 ml												
Sample sites	February	March	April	May	June	July	August	September	October	November	December	January
R1	10000	5300	12400	9200	12400	1520	1860	na	8000	3000	71000	52000
R2	10000	1320	9700	16300	6500	550	1690	9	1830	3200	76000	4100
R3	#	#	#	#	#	#	#	#	#	6200	6100	730
R4	10000	1080	63000	69000	17300	14400	1250	2000	690	42000	310	29000
E1	10000	270	13300	14900	9300	9900	820	2800	8200	28000	4600	0
E2	38	65	48	16	85	53	160	0	580	3750	6800	17
E3	564	1150	115	760	8200	1030	150	5	710	5300	6900	510
E4	10000	620	189	10200	7800	4800	1230	0	4500	6600	7300	720
TWQR DUI	0	0	0	0	0	0	0	0	0	0	0	0
TWQR RFCI	na	na	na	na	na	na	na	na	na	na	na	na
TWQR RICl	na	na	na	na	na	na	na	na	na	na	na	na
TWQR: Target Water Quality Range						DUI: Domestic use – Ideal						
na: not available						RFCI: Recreational full contact – Ideal						
#: Diversion works not operational						RICI: Recreational intermediate contact – Ideal						

**APPENDIX 7**

Appendix 7.1: Heavy metal concentrations and flux over each seasonal spring and neap tide (negative values correspond to flood velocities and net import)

<b>Spring - Spring Tide (SST)</b>														
<b>Variables</b>	<b>Units</b>	<b>SST 1</b>	<b>SST 2</b>	<b>SST 3</b>	<b>SST 4</b>	<b>SST 5</b>	<b>SST 6</b>	<b>SST 7</b>	<b>SST 8</b>	<b>SST 9</b>	<b>SST 10</b>	<b>SST 11</b>	<b>SST 12</b>	<b>Flux (kg) over tidal cycle</b>
Aluminium	mg/l	0.20	0.00	0.20	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	37.42
Arsenic	mg/l	0.26	0.00	0.45	0.24	0.00	0.24	0.10	0.19	0.09	0.00	0.00	0.00	1644.05
Barium	mg/l	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.21
Boron	mg/l	0.05	0.01	0.10	0.26	0.04	0.02	0.00	0.02	0.04	0.01	0.07	0.02	65.14
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper	mg/l	0.07	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	34.24
Iron	mg/l	0.13	0.00	0.12	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	71.91
Lead	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum	mg/l	0.07	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	28.54
Nickel	mg/l	0.05	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	15.73
Selenium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	-1570.54
Silicon	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-9.40
Strontium	mg/l	0.31	0.05	0.55	1.46	0.00	0.02	0.00	0.00	0.00	0.03	0.06	0.20	1848.57
Titanium	mg/l	0.04	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	-44.69
Vanadium	mg/l	0.06	0.00	0.14	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	614.17
Zinc	mg/l	0.03	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	-6.28
Zirconium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.36</b>	<b>0.42</b>	<b>0.39</b>	<b>0.36</b>	<b>0.31</b>	<b>0.29</b>	<b>0.31</b>	<b>0.3</b>	<b>0.17</b>	<b>-0.97</b>	<b>-2.16</b>	<b>-1.32</b>	

<b>Spring – Neap Tide (SNT)</b>														
<b>Variables</b>	<b>Units</b>	<b>SNT 1</b>	<b>SNT 2</b>	<b>SNT 3</b>	<b>SNT 4</b>	<b>SNT 5</b>	<b>SNT 6</b>	<b>SNT 7</b>	<b>SNT 8</b>	<b>SNT 9</b>	<b>SNT 10</b>	<b>SNT 11</b>	<b>SNT 12</b>	<b>Flux (kg) over tidal cycle</b>
Aluminium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Arsenic	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Barium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Boron	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Iron	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Lead	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Molybdenum	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Nickel	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Selenium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Silicon	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Strontium	mg/l	0.17	0.14	0.15	0.14	0.08	0.36	0.31	0.25	0.16	0.14	0.15	0.13	399.501
Titanium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	mg/l	0.00	0.00	0.00	0.00	0.00	0.40	0.44	0.00	0.00	0.00	0.00	0.00	0
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.14</b>	<b>0.13</b>	<b>0.11</b>	<b>0.11</b>	<b>-0.11</b>	<b>-0.11</b>	<b>0.11</b>	<b>0.09</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	

Summer – Spring Tide (SUST)														
Variables	Units	SUST 1	SUST 2	SUST 3	SUST 4	SUST 5	SUST 6	SUST 7	SUST 8	SUST 9	SUST 10	SUST 11	SUST 12	Flux (kg) over tidal cycle
Aluminium	mg/l	0.02	0.01	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	37.926
Arsenic	mg/l	0.01	0.00	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.00	121.1535
Barium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Boron	mg/l	0.04	0.12	0.08	0.10	0.11	0.11	0.10	0.11	0.09	0.06	0.80	0.73	-3084.12
Chromium	mg/l	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	-26.361
Cobalt	mg/l	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	33.174
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	-157.644
Iron	mg/l	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	72.639
Lead	mg/l	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	36.972
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.256
Molybdenum	mg/l	0.22	0.23	0.28	0.19	0.22	0.29	0.20	0.22	0.19	0.23	0.19	0.17	841.77
Nickel	mg/l	0.00	0.03	0.01	0.00	0.02	0.00	0.00	0.00	0.06	0.03	0.06	0.06	-309.951
Selenium	mg/l	0.40	0.32	0.09	0.36	0.39	0.50	0.43	0.39	0.32	0.42	0.46	0.65	-1.665
Silicon	mg/l	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.796
Strontium	mg/l	0.13	0.36	0.24	0.27	0.30	0.32	0.30	0.32	0.24	0.16	0.23	0.21	1458.3114
Titanium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	mg/l	0.04	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.04	0.05	0.04	0.04	97.479
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	920.286
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.44</b>	<b>0.39</b>	<b>0.35</b>	<b>0.34</b>	<b>0.37</b>	<b>0.41</b>	<b>0.39</b>	<b>0.39</b>	<b>0.39</b>	<b>0.39</b>	<b>-1.08</b>	<b>-1.15</b>	<b>-0.58</b>

Summer – Neap Tide (SUNT)														
Variables	Units	SUNT 1	SUNT 2	SUNT 3	SUNT 4	SUNT 5	SUNT 6	SUNT 7	SUNT 8	SUNT 9	SUNT 10	SUNT 11	SUNT 12	Flux (kg) over tidal cycle
Aluminium	mg/l	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.04	0.02	0.04	195.165
Arsenic	mg/l	0.15	0.00	0.34	0.00	0.00	0.12	0.17	0.36	0.02	0.00	0.33	0.00	1362.411
Barium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Boron	mg/l	0.04	0.03	0.03	0.02	0.03	0.04	0.02	0.02	0.02	0.03	0.02	0.02	228.951
Chromium	mg/l	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	41.418
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	23.229
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Iron	mg/l	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	287.271
Lead	mg/l	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.51
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.344
Molybdenum	mg/l	0.31	0.28	0.22	0.22	0.22	0.23	0.20	0.26	0.22	0.20	0.22	0.18	2074.437
Nickel	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.06	43.911
Selenium	mg/l	0.34	0.36	0.31	0.43	0.16	0.46	0.41	0.03	0.09	0.26	0.35	0.36	2432.592
Silicon	mg/l	0.46	0.25	0.28	0.19	0.32	0.22	0.00	0.05	0.17	0.00	0.00	0.00	1141.029
Strontium	mg/l	0.12	0.09	0.26	0.08	0.05	0.10	0.06	0.05	0.06	0.06	0.06	0.04	778.932
Titanium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	mg/l	0.05	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.05	0.05	0.04	0.05	384.696
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	3226.311
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.35</b>	<b>0.29</b>	<b>0.29</b>	<b>0.26</b>	<b>-0.12</b>	<b>-0.15</b>	<b>0.34</b>	<b>0.33</b>	<b>0.32</b>	<b>0.31</b>	<b>0.31</b>	<b>0.28</b>	

<b>Autumn – Spring Tide (AST)</b>														
<b>Variables</b>	<b>Units</b>	<b>AST 1</b>	<b>AST 2</b>	<b>AST 3</b>	<b>AST 4</b>	<b>AST 5</b>	<b>AST 6</b>	<b>AST 7</b>	<b>AST 8</b>	<b>AST 9</b>	<b>AST 10</b>	<b>AST 11</b>	<b>AST 12</b>	<b>Flux (kg) over tidal cycle</b>
Aluminium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Arsenic	mg/l	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.09	0.00	0.00	125.649
Barium	mg/l	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.09	0.09	451.647
Boron	mg/l	0.25	0.32	0.25	0.37	0.17	0.23	0.26	0.26	0.26	0.29	0.28	0.30	1123.461
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Iron	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Lead	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Molybdenum	mg/l	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.00	0.00	0.01	93.9654
Nickel	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Selenium	mg/l	0.00	0.14	0.35	0.00	0.37	0.00	0.00	0.00	0.32	0.40	0.08	0.00	982.305
Silicon	mg/l	2.10	2.34	2.34	2.33	2.40	2.34	2.41	2.38	2.41	2.48	2.30	2.27	11781.216
Strontium	mg/l	0.87	0.79	0.64	1.07	0.45	0.70	0.87	0.76	0.56	0.81	0.86	1.03	2741.715
Titanium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>-0.36</b>	<b>0.22</b>	<b>0.32</b>	<b>0.36</b>	<b>0.42</b>	<b>0.41</b>	<b>0.34</b>	<b>0.31</b>	<b>0.26</b>	<b>0.11</b>	<b>-0.73</b>	<b>-0.99</b>	

<b>Autumn – Neap Tide (ANT)</b>														
<b>Variables</b>	<b>Units</b>	<b>ANT 1</b>	<b>ANT 2</b>	<b>ANT 3</b>	<b>ANT 4</b>	<b>ANT 5</b>	<b>ANT 6</b>	<b>ANT 7</b>	<b>ANT 8</b>	<b>ANT 9</b>	<b>ANT 10</b>	<b>ANT 11</b>	<b>ANT 12</b>	<b>Flux (kg) over tidal cycle</b>
Aluminium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Arsenic	mg/l	0.19	0.09	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.05	0.00	20.493
Barium	mg/l	0.11	0.09	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.10	0.10	74.601
Boron	mg/l	0.16	0.17	0.17	0.19	0.25	0.20	0.28	0.18	0.16	0.21	0.21	0.26	145.17
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Iron	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Lead	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Molybdenum	mg/l	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.03	0.00	0.05	-5.13
Nickel	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Selenium	mg/l	0.00	0.37	0.00	0.00	0.57	0.00	0.00	0.18	0.00	0.30	0.11	0.06	257.022
Silicon	mg/l	2.84	2.66	2.63	2.65	2.67	2.64	2.66	2.59	2.32	2.72	2.76	2.59	2154.024
Strontium	mg/l	0.57	0.37	0.40	0.41	0.92	0.55	0.64	0.43	0.76	0.51	0.68	0.54	386.442
Titanium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.06</b>	<b>-0.15</b>	<b>-0.23</b>	<b>-0.1</b>	<b>0.11</b>	<b>0.12</b>	<b>0.09</b>	

Winter – Spring Tide (WST)														
Variables	Units	WST 1	WST 2	WST 3	WST 4	WST 5	WST 6	WST 7	WST 8	WST 9	WST 10	WST 11	WST 12	Flux (kg) over tidal cycle
Aluminium	mg/l	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.04	-26.496
Arsenic	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.808
Barium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Boron	mg/l	0.15	0.16	0.17	0.15	0.16	0.16	0.15	0.15	0.23	0.13	0.36	0.43	99.378
Chromium	mg/l	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.828
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.212
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	-19.494
Iron	mg/l	0.02	0.05	0.01	0.02	0.00	0.02	0.04	0.02	0.05	0.09	0.06	0.00	8.667
Lead	mg/l	0.00	0.00	0.04	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.00	56.817
Manganese	mg/l	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.51
Molybdenum	mg/l	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.07	0.15	0.10	58.347
Nickel	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Selenium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Silicon	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	37.485
Strontium	mg/l	0.49	0.57	0.59	0.55	0.58	0.58	0.54	0.54	0.78	0.47	1.26	1.35	481.347
Titanium	mg/l	0.60	0.60	0.61	0.60	0.60	0.64	0.61	0.59	0.62	0.66	0.61	0.67	1700.262
Vanadium	mg/l	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.02	76.059
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	-22.032
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>-0.23</b>	<b>0.25</b>	<b>0.23</b>	<b>0.2</b>	<b>0.18</b>	<b>0.22</b>	<b>0.18</b>	<b>0.17</b>	<b>0.17</b>	<b>-0.16</b>	<b>-0.32</b>	<b>-0.4</b>	
Winter – Neap Tide (WNT)														
Variables	Units	WNT 1	WNT 2	WNT 3	WNT 4	WNT 5	WNT 6	WNT 7	WNT 8	WNT 9	WNT 10	WNT 11	WNT 12	Flux (kg) over tidal cycle
Aluminium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Arsenic	mg/l	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	28.782
Barium	mg/l	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	152.1
Boron	mg/l	0.14	0.22	0.27	0.26	0.24	0.31	0.22	0.25	0.17	0.22	0.21	0.15	287.199
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Cobalt	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Copper	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Iron	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Lead	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Manganese	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Molybdenum	mg/l	0.04	0.03	0.00	0.14	0.02	0.03	0.01	0.00	0.01	0.03	0.00	0.03	42.822
Nickel	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Selenium	mg/l	0.00	0.19	0.00	0.02	0.00	0.41	0.26	0.14	0.23	0.14	0.00	0.07	-4.419
Silicon	mg/l	7.12	6.91	7.00	6.96	6.86	6.90	6.86	6.75	6.79	6.83	6.84	6.80	10896.363
Strontium	mg/l	0.55	0.72	0.56	0.58	0.65	0.65	0.69	0.74	0.65	0.61	0.61	0.60	956.277
Titanium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Vanadium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zinc	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Zirconium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.09</b>	<b>0.08</b>	<b>0.09</b>	<b>0.09</b>	<b>-0.06</b>	<b>-0.15</b>	<b>-0.11</b>	<b>0.09</b>	<b>0.1</b>	<b>0.11</b>	<b>0.11</b>	<b>0.09</b>	

Appendix 7.2: Nutrient concentrations and flux over each seasonal spring and neap tide (negative values corresponds to flood velocities and net import)

<b>Spring - Spring Tide (SST)</b>														
Variables	Units	SST 1	SST 2	SST 3	SST 4	SST 5	SST 6	SST 7	SST 8	SST 9	SST 10	SST 11	SST 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium	mg/l	7.14	3.86	13.66	33.22	2.01	3.50	1.92	2.40	2.39	3.54	5.14	1.84	33095.00
Magnesium	mg/l	13.07	12.42	34.44	99.46	7.01	10.58	6.13	7.75	7.52	10.83	15.71	14.06	58020.01
Nitrates	mg/l	0.41	0.49	0.62	0.61	0.79	0.67	0.59	0.60	0.64	0.50	0.67	0.60	-2384.82
Phosphorus	mg/l	0.04	0.97	0.02	0.01	0.69	0.80	0.98	1.32	0.59	0.91	0.86	0.01	-3133.24
Potassium	mg/l	0.00	0.00	18.14	0.00	23.40	46.19	43.85	21.65	12.89	0.03	0.00	0.00	166970.08
Sodium	mg/l	148.65	0.00	522.28	255.46	462.80	536.94	139.01	40.16	192.63	163.31	155.77	0.00	901896.77
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.36</b>	<b>0.42</b>	<b>0.39</b>	<b>0.36</b>	<b>0.31</b>	<b>0.29</b>	<b>0.31</b>	<b>0.3</b>	<b>0.17</b>	<b>-0.97</b>	<b>-2.16</b>	<b>-1.32</b>	
<b>Spring – Neap Tide (SNT)</b>														
Variables	Units	SNT 1	SNT 2	SNT 3	SNT 4	SNT 5	SNT 6	SNT 7	SNT 8	SNT 9	SNT 10	SNT 11	SNT 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	2.11	1.54	1.58	2.81	2.69	1.88	1.32	3.28	1.76	2.75	2.87	2.87	5410.728
Calcium	mg/l	17.57	16.72	17.74	16.21	9.59	33.25	34.30	24.50	18.99	16.86	15.91	16.24	45764.784
Magnesium	mg/l	33.40	33.23	34.49	31.08	18.36	64.64	65.97	48.36	37.58	36.44	34.07	34.27	91750.428
Nitrates	mg/l	2.17	2.34	2.13	2.57	2.63	0.83	0.77	1.45	1.89	2.44	3.03	2.47	5418.18
Phosphorus	mg/l	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	167.67
Potassium	mg/l	35.87	32.93	35.43	32.58	29.82	34.09	32.22	33.38	30.44	35.96	35.78	35.43	84013.362
Sodium	mg/l	51.76	43.77	43.39	43.47	45.21	49.69	46.62	48.11	41.73	52.50	52.83	53.17	115244.946
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.14</b>	<b>0.13</b>	<b>0.11</b>	<b>0.11</b>	<b>-0.11</b>	<b>-0.11</b>	<b>0.11</b>	<b>0.09</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	
<b>Summer – Spring Tide (SUST)</b>														
Variables	Units	SUST 1	SUST 2	SUST 3	SUST 4	SUST 5	SUST 6	SUST 7	SUST 8	SUST 9	SUST 10	SUST 11	SUST 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	1.66	1.35	1.42	1.54	1.58	1.50	1.50	1.32	1.28	1.07	8.39	4.53	-24509.88
Calcium	mg/l	6.76	12.54	9.39	9.93	10.62	11.17	11.34	11.24	9.42	7.12	60.76	55.05	-210825.594
Magnesium	mg/l	12.33	33.03	22.73	25.42	28.86	30.15	28.25	29.98	23.07	15.49	205.20	186.20	-779082.66
Nitrates	mg/l	9.08	3.21	4.66	3.86	3.32	3.86	4.26	2.94	4.89	6.95	0.56	0.62	21495.195
Phosphorus	mg/l	0.08	0.04	0.02	0.00	0.07	0.06	0.09	0.03	0.05	0.00	0.06	0.41	-374.751
Potassium	mg/l	0.00	5.50	3.35	4.14	6.07	4.37	3.91	4.71	2.44	0.00	58.49	59.85	-257607.909
Sodium	mg/l	60.32	132.19	117.07	126.77	139.63	131.85	125.42	127.56	111.65	83.90	146.74	138.50	324332.406
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.44</b>	<b>0.39</b>	<b>0.35</b>	<b>0.34</b>	<b>0.37</b>	<b>0.41</b>	<b>0.39</b>	<b>0.39</b>	<b>0.39</b>	<b>-1.08</b>	<b>-1.15</b>	<b>-0.58</b>	
<b>Summer – Neap Tide (SUNT)</b>														
Variables	Units	SUNT 1	SUNT 2	SUNT 3	SUNT 4	SUNT 5	SUNT 6	SUNT 7	SUNT 8	SUNT 9	SUNT 10	SUNT 11	SUNT 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	0.81	0.73	0.62	1.16	1.16	1.28	1.42	0.79	0.59	0.89	1.25	1.16	8086.86
Calcium	mg/l	7.47	6.45	9.87	6.31	5.27	7.30	6.37	5.06	5.64	6.49	5.48	4.99	57547.719
Magnesium	mg/l	8.22	7.36	8.58	4.77	4.65	8.37	5.70	4.12	4.23	5.49	4.82	4.01	51076.521
Nitrates	mg/l	1.75	1.86	1.84	1.93	2.12	1.18	2.32	2.12	2.17	2.43	1.73	1.57	18055.458
Phosphorus	mg/l	0.09	0.06	0.11	0.03	0.06	0.04	0.04	0.09	0.00	0.03	0.13	0.07	584.451
Potassium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Sodium	mg/l	18.21	48.56	13.66	25.80	0.00	139.61	0.00	0.00	0.00	0.00	0.00	0.00	83669.94
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.35</b>	<b>0.29</b>	<b>0.29</b>	<b>0.26</b>	<b>-0.12</b>	<b>-0.15</b>	<b>0.34</b>	<b>0.33</b>	<b>0.32</b>	<b>0.31</b>	<b>0.31</b>	<b>0.28</b>	

Autumn – Spring Tide (AST)														
Variables	Units	AST 1	AST 2	AST 3	AST 4	AST 5	AST 6	AST 7	AST 8	AST 9	AST 10	AST 11	AST 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	2.23	2.56	2.46	2.56	1.14	2.89	2.51	2.78	0.15	0.24	0.21	0.22	17980.4844
Calcium	mg/l	14.78	11.93	8.74	17.76	4.84	10.08	13.44	11.24	7.38	12.48	13.19	16.21	36559.674
Magnesium	mg/l	40.04	35.05	25.07	52.84	12.47	28.68	39.14	31.94	19.33	35.17	38.67	48.82	99197.64
Nitrates	mg/l	0.36	0.54	0.73	0.72	0.94	0.86	1.31	0.87	1.73	1.33	0.67	0.74	5672.187
Phosphorus	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Potassium	mg/l	12.61	10.28	5.87	16.56	0.98	7.03	10.98	9.12	3.77	10.05	11.21	15.17	19417.698
Sodium	mg/l	365.62	333.07	264.14	423.13	170.28	290.36	351.67	313.62	226.93	335.18	349.56	397.76	1131603.993
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>-0.36</b>	<b>0.22</b>	<b>0.32</b>	<b>0.36</b>	<b>0.42</b>	<b>0.41</b>	<b>0.34</b>	<b>0.31</b>	<b>0.26</b>	<b>0.11</b>	<b>-0.73</b>	<b>-0.99</b>	

Autumn – Neap Tide (ANT)														
Variables	Units	ANT 1	ANT 2	ANT 3	ANT 4	ANT 5	ANT 6	ANT 7	ANT 8	ANT 9	ANT 10	ANT 11	ANT 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	3.40	1.34	5.87	3.01	2.84	2.67	3.40	1.86	0.30	1.82	2.01	1.78	3035.889
Calcium	mg/l	9.87	4.19	4.96	5.06	17.71	8.28	10.73	5.36	11.97	7.36	12.12	8.16	6719.319
Magnesium	mg/l	19.17	7.42	9.17	10.06	43.63	18.87	24.22	11.52	35.12	15.64	26.21	17.47	11280.276
Nitrates	mg/l	2.21	5.45	4.23	2.48	1.80	1.82	2.89	2.63	0.51	2.83	3.06	2.97	3657.195
Phosphorus	mg/l	0.00	0.00	0.00	2.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	633.6
Potassium	mg/l	4.01	0.00	0.00	0.00	13.77	4.01	6.33	0.28	9.35	2.38	6.80	3.07	2387.907
Sodium	mg/l	223.98	107.27	128.84	141.52	374.08	223.13	264.14	157.17	327.57	197.34	271.76	206.64	124094.7
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.08</b>	<b>0.06</b>	<b>-0.15</b>	<b>-0.23</b>	<b>-0.1</b>	<b>0.11</b>	<b>0.12</b>	<b>0.09</b>	

Winter – Spring Tide (WST)														
Variables	Units	WST 1	WST 2	WST 3	WST 4	WST 5	WST 6	WST 7	WST 8	WST 9	WST 10	WST 11	WST 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	3.00	3.24	3.08	3.08	2.92	2.85	2.64	3.41	2.09	2.15	4.89	5.15	5411.79
Calcium	mg/l	13.35	15.83	16.26	15.01	16.24	16.37	15.18	15.20	22.19	13.15	33.83	33.26	17834.13
Magnesium	mg/l	44.28	54.11	54.67	50.19	54.48	52.90	49.76	51.26	69.26	43.09	103.60	103.90	72637.83
Nitrates	mg/l	2.82	2.94	2.76	3.42	3.34	2.33	2.56	2.31	1.93	2.63	0.74	0.65	11586.951
Phosphorus	mg/l	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.01	0.06	0.03	-37.089
Potassium	mg/l	0.00	2.72	4.67	1.15	5.09	3.83	1.01	0.03	0.00	0.00	38.45	43.37	-56702.241
Sodium	mg/l	301.06	337.03	336.72	314.26	328.83	321.09	325.65	324.28	309.86	287.86	489.23	511.53	661173.849
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>-0.23</b>	<b>0.25</b>	<b>0.23</b>	<b>0.2</b>	<b>0.18</b>	<b>0.22</b>	<b>0.18</b>	<b>0.17</b>	<b>0.17</b>	<b>-0.16</b>	<b>-0.32</b>	<b>-0.4</b>	

Winter – Neap Tide (WNT)														
Variables	Units	WNT 1	WNT 2	WNT 3	WNT 4	WNT 5	WNT 6	WNT 7	WNT 8	WNT 9	WNT 10	WNT 11	WNT 12	Flux (kg) over tidal cycle
Ammonium ion	mg/l	6.23	6.36	3.14	3.76	3.40	3.33	3.61	3.47	3.07	3.01	3.20	2.84	6252.183
Calcium	mg/l	8.31	12.99	8.42	8.72	10.00	10.36	10.78	11.91	9.97	9.33	9.53	9.01	15070.266
Magnesium	mg/l	17.09	25.55	17.05	18.36	22.55	22.68	24.85	28.50	22.52	20.19	20.37	19.32	31223.61
Nitrate	mg/l	3.49	3.84	3.55	3.96	3.42	3.44	2.30	3.33	2.80	3.46	3.26	3.19	5652.108
Phosphorus	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	3.78
Potassium	mg/l	3.85	6.81	2.85	3.55	5.18	5.41	5.64	7.27	4.95	4.02	4.25	3.78	6429.69
Sodium	mg/l	205.10	267.68	207.16	219.93	249.57	250.39	264.80	284.97	247.92	233.10	236.39	224.04	359781.57
<b>Discharge</b>	<b>m<sup>3</sup>/s</b>	<b>0.09</b>	<b>0.08</b>	<b>0.09</b>	<b>0.09</b>	<b>-0.06</b>	<b>-0.15</b>	<b>-0.11</b>	<b>0.09</b>	<b>0.1</b>	<b>0.11</b>	<b>0.11</b>	<b>0.09</b>	

## APPENDIX 8

Management objectives, strategies and action plans (Adapted and modified from SSI, 2011)

### Management Objective 1: Improvement to river and estuary (water quality and quantity)

Management strategy	Action plan	Measures of success	Responsibility
Ensure adequate quantity or water flow to estuary to maintain health and functioning	Evaluate current design of Diversion Works System (DWS) and upgrade or repair in accordance to design specifications.	Continuous flow supply to estuary via the DWS	eThekweni Municipality (EM))
	Ensure maintenance of the DWS through the development of an Operational and Management Plan.	Continuous flow supply to estuary via the DWS	EM
	Explore options to supplement water supply.	Additional water supply introduced	EM and Department of Water Affairs (DWA)
	Implement flood risk and modeling as conducted by SSI (2011)	Flood attenuation measures constructed	EM
Improvement to water quality by minimizing and controlling pollution to the river and estuary system	Pinpoint sources of pollution and implement mitigation measures. Develop a management plan to regulate diffuse and point source pollution.	Sources identified and action/mitigation measures assigned – constantly reviewed. Management plan in place.	EM, DWA, Provincial Department of Agriculture, Environmental Affairs and Rural Development (DAEARD)
	Rigorous enforcement of legislation (fines, penalties or directives) to perpetrators.	Number of fines and non-compliance notifications issued.	EM, DWA, DAEARD



	Auditing of compliance of discharges to both the water resource and municipal sewer system through regular inspections.	Improved compliance levels. Adoption of pollution prevention strategies by municipalities, industry and others. Inspection reports available.	EM and DWA,
	Determine status quo of the integrity of all sewerage infrastructure (pump stations, sewer lines, etc) in the catchment. Institute upgrades and maintenance of said infrastructure.	Less frequent sewer breakages and infrastructure failures. Installation of proper sanitation facilities. Improvement to sewage and greywater management from transit camps. Fewer overflowing manholes arising from stormwater ingress.	EM
	Eradicate illegal stormwater-sewage connections and develop a stormwater management plan for the catchment.	Fewer illegal connections recorded. Integrated stormwater management plan developed. Site specific stormwater management places for industries available. Less ingress of stormwater to sewers.	EM

	Undertake regular awareness campaigns with reference to proper waste management.	Evidence of campaign and educational drives taking place. Reduction in litter and waste in the catchment.	EM, DWA, DAEARD
	Regular removal and maintenance of sediment and waste from the canal system.	Reduction in sediment levels and waste in canal system. Adherence to maintenance and removal schedule.	EM
	Regular removal of water hyacinth (this is treating the symptom where as the sources needed to be identified and eliminated).	Reduced growth in water hyacinth. Adherence to removal schedule.	EM
	Develop and institute an integrated water quality monitoring programme for the river and estuary which should include River Health Monitoring.	Water quality monitoring programme (Appendix 10 – proposed plan)	EM and DWA
	Initiate measures to undertake a Reserve Determination for the river and estuary with a view to establishing water quality objectives required to be achieved or maintained in the river and estuary.	Reserve undertaken Resource quality objective available for river and estuary (target water quality values available). Trend data showing continuing improvement in river and estuarine water quality (e.g. faecal coliform counts, nutrients, other compounds).	DWA

	Develop and undertaken sediment quality monitoring of the estuary.	Sediment quality monitoring programme (Appendix 1 – proposed plan). Improvement with time – implies source reduction.	EM and DWA
	Utilise the Adopt-a-River programme (funded by the Department of Water Affairs empowering local woman who assist with removal of solid waste along river reaches.	Implementation of Adopt-a-River programme in catchment. Reduction in solid waste and litter.	DWA
	Nutrient management programme	Programme developed. Less water hyacinth in system. Water quality monitoring data and trends.	EM and DWA
	Communication strategy and protocol to deal with emergency incidents (such as sewage overflows, spills)	Communication strategy available. Emergency incident protocol developed.	EM and DWA
	Identify areas for cultural and religious practices	Zonation of areas. Use of designated areas.	EM
Enhance tidal exchange	Investigate alternative options for improving tidal exchange without creating a risk to residential housing surrounding the estuary.	Improved tidal exchange	EM, DAEARD and KZN Wildlife
	Maintain the sand berm to a level that will allow natural breaching in times of flood events.	Sand berm level maintained	EM and KZN Wildlife

	Develop an agreement and attached conditions for artificial breaching with KZN Wildlife.	Written agreements/protocols in place	EM and KZN Wildlife
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**Management Objective 2: Conservation of biodiversity**

<b>Management strategy</b>	<b>Action plan</b>	<b>Measures of success</b>	<b>Responsibility</b>
Habitat conservation and improvement	Develop a habitat inventory: Identify and declare natural areas as protected and conservation areas. This should be linked to a Geographic Information System (GIS).	GIS map – demarcated areas zoned. By-law and legislation enforced	EM
	Identify and create additional habitat areas.	Number, quality and endurance of new habitats	EM
	Develop partnerships or incentives with industry, local organizations and individual citizens to protect identified habitats.	Number of partnerships entered into.	EM
	Institute River Health Monitoring (monitoring of the condition of biological communities of rivers (such as fish, aquatic invertebrates and riparian vegetation) as well as river habitats to provide and integrated measure or health of the river systems).	River Health Monitoring Report Implementation plan in accordance with report findings.	EM and DWA
	Maintain ecological corridors.	Number, quality and endurance of ecological corridors	EM
Rehabilitate degraded areas	Identify and map habitat areas that need to be rehabilitated. This must include the riparian	Number, quality and endurance of areas rehabilitated.	EM

	zone for the river.		
	Develop a rehabilitation management plan which must include a maintenance plan.	Rehabilitation and maintenance plan GIS map of wetland areas.	EM
	Identify and map wetland areas with a view to rehabilitation.	Improvement plan developed	EM
Control of alien plants	Regular removal of water hyacinth (sources contributing to eutrophication must be identified and eradicated.	Less water hyacinth in river and estuary system. Adherence to removal schedule	EM
	Develop an alien invasion removal programme. Investigation the option of using the Working for Water Programme (funded by Department of Environmental Affairs (DEA) to remove alien invasives)	Less infestation by alien plants. Alien removal programme developed.	EM and DEA

### Management Objective 3: Public awareness and education

Management strategy	Action plan	Measures of success	Responsibility
Educational and awareness campaigns	Conduct public awareness programmes (through workshops, presentations, articles, etc)	Number of workshops, presentations, articles conducted. Awareness programme established	EM and Isipingo Island Institute in collaboration with DWA and DAEARD
	Water quality monitoring programs database should be made web-accessible or accessible by other means.	Web page containing water quality information	EM in collaboration with DWA

	Install consistent signage along areas of significance. This could include historical information.	Signage installed	EM
	Develop an educational training programme for schools and other organizations (e.g. bird watchers)	Educational training programme in place. Number of organizations that attended training programme	EM and Isipingo Island Institute in collaboration with DWA and DAEARD
	Seek sponsorship from business and industry to maintain the Isipingo Island Institute	Number of sponsorships in place. Status of Isipingo Island Institute	Isipingo Island Institute
Research and training	Use of research and tertiary institutions to undertake research and monitoring.	Availability of monitoring data. Research publications.	EM, DWA, DAEARD and Isipingo Island Institute

#### Management Objective 4: Land use zonation, planning and management

Management strategy	Action plan	Measures of success	Responsibility
Zonation of land for different land uses	Ensure that land use demarcations/zones are clearly identified and mapped.	GIS database containing information.	EM
	Implement enforcement protocol to ensure that land use requirements are adhered to.	Reduction in number of illegally sited developments.	EM and DAEARD
Include land use and development in Integrated Development Plan (IDP) and other strategies	Update the IDP's to reflect all strategies and management requirements for the catchment	IDP's updated	EM
	Integrate strategies and management plans	IDP's updated to include strategies and management plans	EM

Environmental Management Plans and/or Best Practice Guidelines	Develop management plans for different land uses or best practice guidelines (e.g. for market gardeners)	Availability and implementation of best practice guidelines.	EM, DWA and DAEARD
Flood attenuation and management of Prospecton area	Design, management and maintenance of Diversion Works System (DWS) is required	Upgrades completed. Maintenance schedule adhered to. Continuous supply of flow to estuary.	EM
	Investigate possibility of the construction of attenuation structures	Feasibility Report containing alternatives available.	EM
	Canals to be kept free of litter and debris	Less litter and debris visible	EM
	Floodlines to be mapped on GIS and the public to be informed.	GIS map showing floodlines	EM
	Ensure that riparian vegetation remains intact to assist with flood attenuation. Improve wetland functioning.	Increase health and coverage of riparian zone. Wetland functionality improved – plans implemented	EM in collaboration with DWA and DAEARD
	Develop an emergency response procedure for flooding events which must include a communication strategy.	Emergency response plan – Flooding.	EM in collaboration with DWA and DAEARD

**Management Objective 5: Institutional arrangements**

Management strategy	Action plan	Measures of success	Responsibility
Ensure co-operative governance	Involve all spheres of government and other role players in the development of a management plan or improvement plan for the catchment.	Ratification of plan by roleplayers – minutes of meetings.	EM, DWA and DAEARD

	Utilize the Isipingo Catchment Management Forum to disseminate information.	Minutes of forum.	EM, DWA and DAEARD
	Government Department to work in unison – integrated management of issues in the catchment.	Joint operations and inspections by regulatory authorities.	EM, DWA and DAEARD
	Development of policies, regulation, by-laws, etc	Implementation of new policies and bylaws.	EM, DWA and DAEARD
Agreements and partnerships	Establish roles and responsibilities amongst all role players.	Action plan developed with clear roles and responsibilities	EM, DWA and DAEARD
Funding	Investigate avenues to obtain funding to improve current catchment conditions (e.g. municipal infrastructure grant (MIG) funding)	Effective use of funding – financial statements. Number of sponsorships received.	EM and Isipingo Island Institute

**Management Objective 6: Develop eco-tourism and recreational potential of estuary**

<b>Management strategy</b>	<b>Action plan</b>	<b>Measures of success</b>	<b>Responsibility</b>
Establish open spaces and ecological corridors	Use partnerships to acquire and protect land for both recreation and conservation purposes.	Number, quality and endurance of conservation and recreational land and habitats.	EM and KZN Wildlife
Development of a water-based recreation plan for the estuary.	Facilitate development of a water-based recreation plan for the estuary that incorporates issues around navigation, access to the estuary, public safety, and use of paddle boats (depends on improvement in water quality)	Recreational plan developed. Safety plan in place. Number of people accessing estuary. Water sport activities	EM



Eco-tourism strategy	Facilitate the development of nature or hiking trails, recreational water sports, etc.	Number of nature trails developed. Number of people utilizing natural trails. etc	EM
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## APPENDIX 9

Proposed Water Quality Monitoring Programme (Adapted and modified from SSI, 2011)

Water Quality Monitoring Parameters		Frequency*
<b>General</b>	Temperature, pH, dissolved oxygen (DO)	Daily
	Suspended solids (SS), Electrical conductivity (EC), salinity	Weekly
	Chlorophyll a, redox potential	Monthly
<b>Nutrients #</b>	Ammonia (NH <sub>3</sub> ), nitrate (NO <sub>3</sub> ), Orthophosphate (PO <sub>4</sub> <sup>3-</sup> ) (soluble reactive phosphorus), Total phosphorous (P)	Weekly
<b>Coliforms</b>	Faecal coliforms, <i>Escherichia coli</i> ( <i>E. coli</i> ), Faecal streptococci	Weekly
<b>Organic matter</b>	Chemical oxygen demand (COD)	Weekly
<b>Major ions</b>	Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Chloride (Cl <sup>-</sup> ), Sulphate(SO <sub>4</sub> <sup>2-</sup> )	Quarterly
<b>Inorganic variables</b>	Sulphide, cyanide	Quarterly
<b>Metals #</b>	Aluminium (Al), Arsenic (As), Barium (Ba), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Mercury (Hg) Molybdenum (Mo), Nickel (Ni), Lead (Pb), Selenium (Se), Strontium (Sr), Titanium (Ti), Vanadium (V), Zinc (Zn) and Zirconium (Zr),	Quarterly
<b>Others</b>	Polychlorinated Biphenyls (PCB's).	Bi-annually
<b>River Health Monitoring</b>	SASS (macro-invertebrates, Habitat Integrity, Fish and Riparian Vegetation Assessment and Di-atom assessment)	Bi-annually

\* Can be reduced if improvements are noted or increased if deterioration is occurring. Adhoc samples will need to be taken in the event of spillages into the river and estuary.

# Sediment should be analysed for metals and nutrients bi-annually (wet and dry season)

**1. Recording the flow rate at each sample point would be beneficial in terms of calculating load**  
**2. Location of sample sites must be agreed upon by relevant stakeholders and authorities**  
**although it is recommended that this is consistent with the research sites of the author for comparative purposes.**