A STUDY OF THE ENVIRONMENTAL IMPACTS (NATURAL AND ANTHROPOGENIC) ON THE ESTUARIES OF KWAZULU-NATAL, SOUTH AFRICA: IMPLICATIONS FOR MANAGEMENT

BY

Nsizwazikhona Simon Chili

Submitted in fulfillment of the requirements for the degree of Doctor of Philosophy, in the Department of Geography, School of Environmental Sciences,
University of KwaZulu-Natal, 2008

Supervisor ______________________

June 2008

DECLARATION

I Nsizwazikhona Simon Chili declare that

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

(ii) This thesis has not been submitted for any degree or examination at other university.

(iii) This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other researchers.

(iv) This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;
b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) Where I have reproduced publication of which I am an author, co-author or editor, I have indicated in detail which part of the publication was actually written by myself alone and have fully referenced such publications.

(vi) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: ------------------------------------

Preface

The research undertaken and described in this thesis was carried out in the Department of Geography and Environmental Studies, University of KwaZulu-Natal, Durban from April 2003 to June 2008, under the supervision of Dr Srinivasan Pillay.

This study represents original work by the researcher and has never been submitted in any institution including the university. Where reference was made from other researchers and sources, it has been duly acknowledged in the text.

ACKNOWLEDGEMENTS

Many individuals and organizations have made contributions and provided assistance for this work. The role of Dr Srinivasan Seeni Pillay as a supervisor for this work was highly appreciated. He promoted the work and provided the guidance, assurance, professionalism and expertise. He assisted in a variety of ways right from the beginning up to the finality of the project. He even assisted in the provisions of application forms for financial institutions that funded the project. My sincere thanks are also directed to Johnny who is also a lecturer in the department who assisted wholeheartedly in essuring that relevant maps were made available.

My gratitude also goes to the the following post graduate student of UKZN, Nitesh Poona, Deshni, Wallace and Shamaine who also played their role during data collection especially in St Lucia. Eddie who is also a lecturer in the Department of Geography and Environmental Studies assisted with relevant sources of information. Many thanks also deservedly go to R Gengan for water quality analysis. Mr A. Singh formerly of the CSIR, Durban, provided several photographs and maps used in the study.

I thank Simphiwe Memela from the Department of Water Affairs and Forestry for the provision of water quality policies and other relevant information. I also thank Thembelani Dlomo for computer assitance, Vincent Ramsan from Mngeni Water and Sandi Ngcobo who is now stationed at Pretoria and Zama Mabaso who once transported me to the campus during one of the fieldwork visits.

I also thank the University of KZN for awarding a Graduate scholarship for the project. The faculty also provided the financial assistance for this work. Johnny Lutchmiah who is the lecturer at UKZN also assisted in making the maps of the study area available.

DEDICATION

This thesis is dedicated to the late members of the family; Sesaba (father), Bangelani (father in law), Canukile (mother in law), Mbongwa and Delani (late brothers), and my living family members; Sthe (my wife), Thabsile, Yoliswa, Zakithi, Qophelo and my mother Ngethembi (Intomb'endala).

Abstract

This thesis documents eight estuaries that are situated on the northern coastline of KwaZulu-Natal viz.: St Lucia, Mfolozi, Zinkwazi, Mvoti, Mngeni and those of the South i.e. Isipingo, Manzimtoti and Mkomazi. The documentation is aimed at undertaking a holistic approach on estuaries of KwaZulu-Natal approximately 10% and determines the influence of anthropogenic and natural impacts upon their health status. The study has also analysed selected sample estuaries of KZN in terms of their general natural characteristics, looked at the morphological features, riparian vegetation and land use directly from site visits and from aerial photographys, and determined the influence of anthropogenic and natural impacts in the estuaries. It also assessed the health status of the estuaries, proposed appropriate management strategies and reviewed the current status of estuaries in KZN / southern Africa. The researcher employed quantitative approach as a viable and the most relevant method where a holistic approach has been used. This was achieved through the execution of various techniques. For instance, reconnaissance survey was conducted including the usage of aerial photographys and topographical maps. Data was also collected using the YSI 6920 model. The study was also undertaken in order to determine whether the KwaZulu-Natal estuaries were still having a nursery function, which appeared to be losing when considering both primary and secondary activities that took place in the catchment areas.

All of these estuaries were under a severe stress and pressure through natural and anthropogenic phenomenon. They were all suffering and gradually getting contaminated and depleted through anthropogenic activities that took place uncontrolled in their catchmenmt areas. Findings also show humans as the main culprits for estuarine contamination and degradation. It was discovered that about 84.2% of the catchment areas within the study area was human occupied. Their suffering differed as it depended on the extent in which catchment areas were utilized. Where anthropogenic activities took place alarmingly, estuaries also suffered a great deal. This posed a challenge to ecologists, hydrologist and environmentalists generally, and to physical geographers specifically since they regard estuaries as very important for their nursery functions and ecological balances.

Mfolozi and St Lucia estuaries were found to be little affected from direct anthropogenic effects. Pollutants accumulating in the systems may have come from farmlands in the north of the Mfolozi and from the town of St Lucia in the case of the St Lucia estuary. However, more negative effects were clearly due to excessive sedimentation.

The study has revealed that the Mfolozi mouth position had been artificially relocated on several occasions since 1952 by human intervention in the system. In these situations, the Mfolozi mouth may be located between one and two kilometres south of the St-Lucia mouth. Two estuaries, Mvoti in the north and Isipingo in the south were found to be the most affected water bodies by human activities occurring in the catchment areas and this has led to them having unhealthy water status.

It was found that through anthropogenic interference, there were changes in the nature of runoff and water quality that was attributed to industrial pollution, runoff from agricultural activities, sewage effluent and the runoff from urban areas.

There is evidence of extremely poor catchment management practices as proved by the poor state of many estuaries along the KwaZulu-Natal coast. The study recommended that for the important future well being of these estuaries, various tiers of catchment management authority must be put in place by the Department of Water Affairs and Forestry.

The local authorities must proactively manage land uses and anthropogenic activities on and around the estuaries in order to minimise potential impacts on the systems.

CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER ONE: INTRODUCTION

1.1 Introduction

It is generally recognised that human interference and utilization of river catchments can substantially impact negatively on the health status, water quality, and aesthetic value of estuaries (Kelbe, 1992). It is quite clear that it is not only the estuaries of KwaZulu-Natal (KZN) which are under severe stress and pressure but almost all the South African estuaries are affected both anthropogenically and naturally (Cooper, 1994). In fact, in South Africa and other regions quantitative and qualitative evaluation of such impacts are poorly researched, and consequently the management of the estuarine environment is largely ignored (Glavovic, 2000). It is therefore the researcher's intention to undertake a more holistic approach in order to examine the extent to which both physical and human impacts affect these life- supporting systems.

Two hundred and fifty estuaries occur along the South African coastline, and most of them (182 or 73%) are classed as ephemeral (Kelbe, 1992). Of the 74 estuaries that occur along the KZN coastline of South Africa, only the uThukela River, which has the largest catchment area maintains a constantly opened mouth (Begg, 1984). In the 1980's the Town and Regional Commission initiated the development of policy for the management of estuaries in KZN (DEAT, 2000). The thrust of this activity was focused on biological and physical characteristics. Since that time, the nature and intensity of use of estuaries by the people of KwaZulu- Natal, and importantly by visitors to this province, has changed substantially (Pillay, 1996). Numerous problems in estuaries have arisen through human impacts in river catchments and directly in estuaries themselves. However, the damages occurring to all species using these estuaries as their habitat through natural and most importantly anthropogenic factors are not exactly known.

This study on environmental and anthropogenic impacts on KZN estuaries also stems from the reality that there is one environmental issue that many environmentalists now believe surpasses all others in terms of long-term global impacts: the loss of the planet's ecological diversity. Animal and plant species around the world are disappearing fast (Whitfield, 1998). South Africa is therefore not exceptional, since its marine resources are also facing depletion. Estuaries of KZN as wetlands are also some of the most important life supporting ecological systems with a variety of biotic elements that are also under a severe stress and pressure, and that need to be well monitored and managed (Whitfield, 2000). Some scientists and environmentalists believe as many as 25% of the world's total complement of species could be lost over the next few decades (Barnes, 1996). The planet is clearly facing a wide and disconcerting array of environmental problems and biodiversity loss is only one of them. Attempts to identify appropriate action present a daunting task (Barnes, 1996). However, depletion of global biodiversity presents an urgent and unique set of concerns. The key feature of this problem is the irreversibility of the damage (Barnes, 1996). Whilst it might arguably be feasible to halt or even reverse other ecological problems by developing social and technological solutions, technological advances cannot mitigate the loss of species.

According to Begg (1978) and, Cooper and Mason (1987), development pressure and human impact has had, in many of the estuaries, a negative effect on the terrestrial environment immediately surrounding the water body, together with a detrimental effect on water quality, and marine resource within the estuarine system. The study of Begg (1978) study seems to be the only one that is descriptive on estuaries. Following this study, few efforts have been made to fully characterize the province's estuaries. However, development pressure has caused unabated and negative effects of human intervention in these sensitive systems (Cooper, 1994). According to Cooper (1994) human interventions as well as natural forces have created numerous environmental problems in these life-supporting systems, inter alia:

- Over-exploitation of resources
- Urban, industrial and agricultural pollution
- Sewage contamination

- Problems associated with sand-winning
- Sedimentation problems
- Damage to estuarine ecosystems
- Agricultural and recreational use of floodplains
- Diminished freshwater inputs
- Effects on estuarine riparian vegetation

1.2 Aim of the study

The aim of the study was to determine the influence of anthropogenic and natural impacts upon the health status of eight estuaries of Kwazulu-Natal.

1.3 Specific research objectives

The following were specific objectives of the research:

(a) To analyse selected estuaries of KZN in terms of their general natural characteristics.
(b) To study the morphological features, riparian vegetation and land use of the estuaries
(c) To determine the influence of anthropogenic and natural impacts in the estuaries.
(d) To assess the health status and water quality of the estuaries in the study area.
(e) To propose management strategies where appropriate.

1.4 Relevence of the study

The choice of the study was triggered by various natural and anthropogenic factors that have adverse impacts on estuaries which are regarded by geographers and ecologists as very important as life supporting systems specifically in the aquatic ecosystems. The estuarine environment constitutes a complex ecosystem that is impacted upon by both marine and freshwater inputs and is consequently very sensitive and easily stressed (Cooper, 1994). The estuarine environment is also recognized as one of the most productive ecosystems on earth (Begg, 1984).

When examining impacts and consequences of natural estuarine stresses, it is also imperative to check the role of antropogenic activity and land use in the catchment areas in order to determine its consequences on social, ecological, hydrological, and geomorphologic trends. It is also important to examine whether these conflicts have both local and global implications that are relevant for biodiversity management.

Since the management of the estuaries is of vital importance, the study has to reveal the extent on which potential solutions are formulated by exploring important policy developments and its success rate. While the study is examining estuarine stresses and strains, shortcomings and vacuums on policy, formulations will also be checked as the basis for estuarine conservation. It is also the aim of this research to provide information that might assist with future coastal management and planning projects, particularly with regard to estuarine ecosystems.

It is of paramount importance in terms of the maintenance of biodiversity; fisheries development; recreation and tourism; and proper coastal zone conservation and management that a study of this nature be conducted. Further, the study is intended to serve as a foundation for future research, to provide the database to which new findings may be added and to act as a catalyst for similar work elsewhere around the country.

The study is also relevant in the sense that research is recurring and never static, this explicity implies that up to date scientific information is very vital from generation to generation. Many researchers have undertaken studies on estuaries but focussing on a single estuary whilst some have studied two or three estuaries simultaneously. The only comprehensive prior work is that of Begg (1978) who, under contract to the then Natal Town and Regional Planning Commission Provincial, surveyed all the estuaries of the province of KwaZulu-Natal. Begg's work is now nearly three decades old. The coastal environment is well recognized as one of the most dynamic in the world and consequently much of Begg's research is now outdated. This research is significant in that it is the most current research in the coastal environment and it examines the impact of the immense changes in development since 30 years ago.

This environmental research does not compare the estuaries within the study but it examines their health status and the extent in which catchment areas impact in the contamination of estuaries.

Changes in the estuarine environment have exerted pressure and strains in almost all physical geographers in the entire world and this has perpetuated and compeled them to revist scientific theories and models in order to have an informed scientific solutions in tackling the effects of climatic changes as they lead to environmental catastrophies. Apart from a comprehensive theoretical component to the literature survey, important information has been presented on management of estuarine environment in the literature survey chapter as well as in inferences and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Estuaries are unique water systems which are the interface between fresh river water and saline coastal water (Cooper and Mason 1987). They have a high biological productivity, and are generally situated in densely populated areas, where often many pollution problems often exist (Wim van Leussen, 1988). To preserve water resources in these systems, where complex interaction of physical, chemical and biological factors occurs, sound and informed decisions have to be made in the midst of many conflicting interests (Allanson and Baird, 1999). There is a strong and a dire need to consider water quality management.

Estuaries are found worldwide in all types of climates and tidal conditions (Olauson and Cato, 1980). They are best developed on mid-latitude coastal plains, with wide continental shelves that are undergoing marine submergence (Allanson and Baird, 1999). Estuaries also occur on coasts with over-deepened valleys resulting from glaciation or tectonic activity (Boyd *et al*, 2000). The underlying reason for the existence of estuaries is the Holocene rise of sea level. This began about 15,000 years before present (B.P.), when the sea level was about 120m below its present level (Olausson and Cato, 1980). During early Holocene when there was a rapid rise of sea level, river valleys were inundated so quickly that infilling could not keep pace with the rise of the sea level (Pillay, 1996). From about 3,000 years B.P. to the present, sea level has been rising relatively slowly, and the rate of infilling of estuaries over that time period has been rapid (Pritchard, 1967). Thus the formation and lifespan of an estuary depends on the balance between relative sea level rise and volume of sediment input (Nichols and Biggs, 1985). Estuaries deposits provide evidence of transgressive events with respect to the ancient record, and form part of the transgressive system tract. form part of the transgressive systems tract. Pillay (1996) confirmed that estuaries are ubiquitous coastal geomorphic features of the earth's surface that are dynamically evolving landforms.

In-fact every estuary is a life supporting system. There are, however, some general trends that make it possible to give outlines of the estuarine environments such as the circulation and various processes and interactions going on in estuaries (Boyd *et al.*, 2000). The growing up of large cities nearby estuaries has in many cases caused environmental disturbances, particularly due to discharge of domestic and industrial wastes (Cooper, 1994). The estuarine areas are therefore of great interest, for their economic importance and from social and anthropogenic aspects.

2.2 Geological evolution

On a geologic timescale it is generally accepted that estuaries are ephemeral features as they form, evolve and infill within a short time-span measured in thousands rather than millions of years (Pillay, 1996).

Sea level dropped by more than 100m during the late Pleistocene Ice Age and, in areas not covered by ice, rivers incised their valleys in response to the new base level (Lubke and de Moor, 1998). In the ensuing Flandrian Transgression many of the world's current estuaries formed when these incised valleys were inundated (Pillay, 1996). The variation in form and developmental stage of individual estuaries is governed by a host of formative processes: climate, wave energy, tidal range, sediment supply, sea level fluctuations, local geology, river catchment characteristics, fluvial input and other factors (Cooper, 1994). Eventually they fill up with sediment and, as actual geomorphic-hydrologic features, change their geomorphic character to that of marshes, deltas or alluvial plains or, may become extinct or 'fossils' (Fairbridge, 1980). Following the approach of Curray (1964), Boyd *et al.,* (2000) pointed out that estuary evolution is largely a function of sediment supply and relative sea level changes. The relationship between these two parameters determines transgressive and regressive scenarios. Cooper (1994) expressed this relationship as:

$$E = K\,(R_S / R_{RSL})$$

Where E is an estuary evolution index, R_s is the rate of sediment supply, R_{RSL} is the rate of relative sea level change and K is an empirical constant determined by geometry of the estuary. For values of $E > 1$ (the regressive or prograding condition), estuaries infill and $E < 1$ (the transgressive condition), estuaries expand (Cooper, 1994).

2.2.1 *Definition and Classification*

There is presently much debate as to what constitutes an estuary (Lamberth and Turpie 2001). Most geologists consider an estuary as a drowned river valley, whereas hydrologists consider bodies of water to be estuarine if the salinity is less than that of seawater (Pillay, 1996). Oceanographers regard estuaries as bodies of water in which river water mixes with and dilutes seawater (Lamberth and Turpie, 2001). The most widely used, and best general definition states that, an estuary is a semi-enclosed coastal body of water which has free access to the ocean and within which seawater is measurably diluted by freshwater from land drainage (Pritchard, 1967).

Barnett (1983) defines estuaries as the mouths of rivers, widening as they enter the sea. There is a considerable overlap between the concept of an estuary and the various kinds of rias and fiords. Some rias and fiords are valleys that have been almost completely drowned by marine submergence, receiving so little drainage from the land that they are essentially arms of the sea, but most are fed by rivers, the mouths of which can be described as estuarine (Begg, 1984).

Alternatively, an estuary may be defined in terms of tidal conditions, as the lower reaches of a river subject to tidal fluctuation, or in terms of salinity, as the area where fresh river water meets and mixes with salt water from the sea (Davies and Day, 1998). According to Olausson and Cato (1979) the term estuary comes from the Latin substantive *aestus*, heat, boiling, tide; and specifically the adjective *aestuarium* means tidal. Thus the Oxford Dictionary defines it as 'the tidal mouth of a great river, where the tide meets the current'. Physical geographers define an estuary as a drowned river mouth, caused by the sinking of land near the sea (Pillay, 1996). Geomorphologists and physical geographers stick to the original definition, the upper limit of the estuary being the upper limit of tidal action, whereas the chemists prefer to define its upper limit as the innermost boundary of water mixing (Morant, 1993).

Fairbridge and Bourgeois (1978) note that in non-tidal seas like the Mediterranean there are few estuaries, despite the presence of many rivers. Estuaries in semi-arid regions may not receive any freshwater for long periods; sometimes, as in Southern California, Western Australia, and several parts of Africa, the estuary may become blocked by longshore sand drift, so that it is ephemerally isolated from the sea

(Morant, 1993). In other regions the tidal limit, sometimes with a tidal bore, may reach 100 km or more above the limits of salt- water intrusion. Dionne (1963) defines an estuary as an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into the following three sectors:

(a) A marine or lower estuary, in free connection with the open sea;
(b) A middle estuary, subject to strong salt and fresh water mixing; and
(c) An upper or fluvial estuary, characterized by fresh water but subject to daily tidal action.

The limits between these sectors are variable, and subject to constant changes in the river discharge. Closely related to estuaries hydrologically, but different in terms of physical geography, sounds lagoons, and deltas, each of which may include or pass into an estuary (*sensu stricto*) (Dionne 1963). The bulk of the world's estuaries have only been in existence for the last 6,000 years, since when they have been progressively in-filled, aided by a eustastically oscillating sea level and by sedimentation, furnished either from rivers, or by onshore and longshore drift (Olausson and Cato, 1979). Where the fill has been principally from river-borne sediment, a delta grows at the expense of the estuary (Begg, 1984). At the present day it is the rivers with the small sediment discharges that have the open estuaries. Where long-shore drift is dominant, a lagoon or sound (a larger equivalent) is created due to the growth of barrier islands. Begg (1980) notes that, deltas form best in seas of low tidal range and limited wave action (Mississippi, Fraser, Yukon, Orinoco, Nile, Po, Rhone, Danube) and here the esturies fill most rapidly. Only streams with very low discharge rates still have open estuaries in these low-tide-range areas (e.g. in Texas (Whitfield, 2000). Estuaries are best preserved in seas of high tidal range (e.g. Seine, Thames St. Lawrence, Hudson, Si-kiang), in regions of extreme glacial entrenchment (e.g. Norwegian fjords), in regions of crustal down-warp (e.g. Delaware Bay, Chesapeake Bay, Mobile Bay), and in semi-arid regions of minimum sediment supply (Whitfield, 1998).

From the above examples it is clear that an estuary must relate to a pre-existing stream valley, and that, subject to various dynamic environmental factors, its existence is ephemeral, so that it will eventually fill.

2.3 Estuarine classification

Since the turn of the century numerous attempts have been made to classify habitats throughout the world because grouping of objects on the basis of their similarities has always been part of the 'thinking process' in man (Oluasson and Cato, 1979; Goodlad, 1986; Pradervand, 1998). Despite this, classification of estuaries is a confusing and controversial subject that has vexed the scientific community for many years largely due to of the infinite variety of environmental factors that determine the characteristics of estuarine environments in general (Begg, 1980). This has not only created confusion amongst the scientific community but also amongst people in other professions such as engineers, planners and policy-makers who have no firsthand knowledge of the subject, but nevertheless are intimately involved in coastal zone management (Pradervand, 1998).

Some of the earliest attempts to classify estuaries were made by geographers on the basis that differences were discernible between estuaries in terms of their geomorphological origin and form (Begg, 1980). For a- long time salinity was used as a distinguishing factor, and still is. In addition, salinity and modifying factors such as hydrology and climate have also been used. Subsequent approaches involved salt balance equations and differentiation between the dominant physical processes associated with circulation and mixing (Glavocic, 2000). As a common denominator measuring processes of several kinds of energy flow was used to good effect as a basis for differentiating between estuaries in the United States of America by Pritchard (1967). More recently 'biotic provinces' along the coastline based on differences in sea temperatures, tidal range, wave energy, climate and coastal geology have been used (Davies and Day, 1998). In the process, an astonishing variety of definitions and terms such as 'thalassohaline' (Delo, 1988) as a specific type of brackish water, and 'hyphalmyrobients' (Cooper, 1991) as a group of organisms associated with a particular salinity range.

A problem area in estuary classification using environmental variables is because of the dynamism of estuaries consensus that has never been reached regarding environmental variables that are most relevant for the purpose of deriving at an all-estuary (open); flask-shaped, partly blocked by bar or barrier island (with lagoons or sound)... coastal plain estuary (with barrier).

4. Low relief estuary, L-shaped plan, lower course parallel to coast...bar-built estuary.
5. Low relief estuary, seasonally blocked by longshore drift and/or dunes, with/or without aeolianite bar...blind estuary.
6. Delta-front estuary, ephemeral distributary...deltaic estuary; in interlobate embayment...interdeltaic estuary.
7. Compound estuary: flask-shaped ria backed by low plain...tectonic estuary.

From the above categories, 1and 2 are referred to as disequilibrium estuaries, while 4, 5, 6, and 7 referred to as mainly equilibrium or constructional estuaries. Category 3 is transitional. As mentioned above, estuaries in categories 1and 2 (and some in 3) tend to look like artificial reservoirs created by dams

Reinson's (1980) classification recognises a spectrum of depositional morphology (lagoonal to open-ended) as response models to the effects of increasing tidal ranges (microtidal to macrotidal). This classification is highly descriptive but also reflects the continuum of interaction of fluvial and marine influences on morphological development. Reinson's (1980) classifications is further simplified below:

1. *The lagoonal estuary*, characteristic of microtidal coasts, is generally small and shallow with low freshwater input and consequently may be completely or almost completely cut off from tidal influences by subaerial spits or barrier bars. Depending on freshwater input volumes, lagoonal estuaries may be partially stratified to well mixed. Such lagoonal conditions commonly develop in southern African estuaries due to seasonal variations in freshwater input or during protracted drought periods.
2. *Open- ended estuaries* occur on high mesotidal to macrotidal coasts (Reinson, 1980; Hayes, 1975; 1979), but may develop on microtidal coasts following periods of fluvial flooding. These estuaries have intermediate to high freshwater input and are generally partially to highly stratified.

3. *The partially closed estuary* is intermediate between lagoonal and open-ended types whilst tidal estuaries have large tidal prisms and are characteristic of macrotidal areas (Dalrymple *et al.,* 1992).

Dalrymple *et al.* (1992) distinguish between wave-dominated and tide-dominated estuaries:

1. *Wave-dominated estuaries* are commonly separated from the marine environment by a spit or barrier bar; receives sediment from both riverine and marine sources; usually contain both flood and ebb tidal deltas and are geomorphologically complex systems. Marine sediment is transported into the estuary by wave, tide or aeolian processes.

2. Ebb tidal deltas are not characteristic of *tide-dominated estuaries* and progradation takes place through the deposition and growth of tidal sand bars, tidal flats and marshes. Marine sediment is transported into the estuary as bedload (tidal sand bars) and more sediment is supplied by longshore drift current. These sediment sources combine to prograde the landward margin of the estuary (Boyd *et al.,* 1992).

According to Stow (1983) estuaries are sometimes classified according to how the tidal volume compares with the rate of fresh water influx. Stow (1983) further notes that the "tidal volume" or "tidal prism" of an estuary is the volume of water between the high and low tide surface which corresponds to the volume of water entering and leaving the estuary during any one tidal cycle. The size of the tides varies during the month, so does the tidal volume. As mentioned above by Stow (1983), estuaries are sometimes classified according to how the tidal volume compares with the rate of fresh water influx. This is essentially a measure of how strongly they are influenced by tidal effects. The scheme uses idealized conditions that are seldom met in reality as discussed previously. Nonetheless, it does provide basic guidelines for understanding similarities and differences among various estuaries (Cooper, 1994).

2.4 Estuarine flow dynamics

2.4.1 Physical processes of water movement in estuaries

Wim van Leussen (1988) notes that the knowledge of water movements makes one to be able to predict the transport of dissolved and suspended matter in the estuary. Whitfield, (2000) concurs that estuaries are complex water systems, where salt and freshwater meet each other. The mixing of these water masses and factors such as tidal range, river discharge, wind, waves and coriolis force have an important effect on the estuarine circulation. Together with variations in topography, these processes make estuarine unique systems. These ciculations dynamics and mixing between salt and fresh water result in a salinity distribution that is an important characteristic of an estuary, and can be used to classify an estuary as well-mixed, partially stratified or stratified (Whitfield, 2000). Although this classical circulation of landward bottom flow and seaward surface flow is commonly observed in estuaries, meteorological influences can also significantly affect the mean circulation (Whitfield, 2000).

2.4.2 Estuarine Fronts and Plumes

According to Whitfield (2000) mixing of fresh river water and the saline sea water is a fundamental physical process in estuaries. Often fronts are formed as well-defined boundaries between the more and less saline water masses. For example the salt-wedge estuary represents a well-defined front. Generally, fronts are characterised by locally strong horizontal gradients of salinity, temperature, density, colour and turbidity (Cooper and Flores, 1991). At the water surface, fronts appear as well-defined surface convergence zones, resulting in a line of accumulated foam and floating, organic and detrital material. Interactions of tidal motion with topographic features seem to be an important factor in generating fronts inside an estuary during part of the tidal cycle. As a result of transverse circulations in estuaries, axial convergence zones are formed (Pillay, 1996). Another example of a front is a tidal river plume, which is formed when the fresh or brackish estuarine water spreads over the more saline coastal water (Whitfield, 2000). Fronts may have an important effect on the estuarine mixing processes and the circulation of water masses in an estuary (Heydorn, 1989).

2.4.3 Turbulence and Mixing in Stratified Tidal Flow

Estuarine flows are steady, non-uniform turbulent motions, in which density differences generally play an important role (Glavovic, 2000). Herein the turbulent processes are of particular importance (Pillay, 1996). They contribute significantly to the transport of momentum, heat and mass, influencing the velocity profiles and the distribution of dissolved and suspended matter.

These turbulent processes are highly variable both in space and time. Because it is practically impossible to calculate the turbulent transport processes exactly, solutions are made by empirical or semi-empirical methods (Cooper, 1994). The turbulent transports are usually expressed in terms of empirical exchange coefficients for momentum and mass. Because the physical processes are hidden in these coefficients, they have to be determined for each specific estuary for the circumstances considered (Allanson and Baird, 1999).

2.4.4 Internal waves and Interface Stability

Internal waves are characteristic phenomena in stratified and partially stratified estuaries (Cooper, 1994). These waves are typically generated by the interaction of the tidal flow with the bottom topography, but can also enter an estuary from outside, or be generated by sailing vessels or a varying surface stress from wind action. An important question is the role of internal waves in influencing the production of turbulent energy and its effect on mixing (Goodman, 2000). Internal waves may cause mixing when they break, but can also influence the production of turbulent energy when they dissipate before breaking. The Intensive Mixing Periods (IMP's) may have significant effect upon the dispersal of pollutants (Lindsay, 1996).

2.4.5 General circulation patterns

Lindsay (1996) argues that if there were no tides, we would expect a stable current pattern in estuaries to show the salt water intruding in a wedge along the bottom, with the fresh water above and then the mixture exiting at the surface. The fresh water from the stream would flow out along the surface. Denser salt water would flow in along the bottom, mix with fresh water above, and then flow out with the fresh water at the surface in a somewhat diluted form (Lindsay *et al*, 1996).

Lindsay (1996) still maintains that in most estuaries, however, this simple salt wedge picture is considerably modified by a number of factors. One of these is the rising and falling of tides twice a day, flood tides entering the estuary and ebb tides leaving cause the interface between salt and fresh waters to move rhythmically back and forth along the length of the estuary (Allanson and Baird, 1999). Actually, mixing across the interface between the two waters causes the transition between the two to be gradual rather than abrupt. This mixing is caused by a variety of factors. The two water masses moving in opposite directions create turbulence across their interface, which speeds up mixing. The mixing is greatly enhanced in estuaries with large tidal ranges, where large tidal currents induce large-scale turbulence and mixing (Cooper, 1994). In broad, shallow estuaries, such as lagoons, wind can create currents and waves that help mix the waters, and heavy surface evaporation can cause further mixing. In most estuaries, the mixture of waters existing in the estuary's mouth at the surface is nearly as salty as the ocean waters (Cooper, 1994). The large amount of salt water in this mixture indicates that the rate of flow of salt water entering the estuary in the salt wedge is considerable larger than the rate of flow of fresh water from the river or stream (Pillay, 1996). Because there is a net flow of fresh water into the estuary at the head, there must be a net flow out of the estuary at the mouth. Of course, currents flow both ways through the mouth as the tides come and go, but on the average, slightly more must flow out with the ebb tide than flows in with the flood tide (Whitfield, 2000). Thus, the two parts of the tidal cycle are not quite symmetrical. Ebb tide usually lasts slightly longer than flood tide or ebb tidal velocities need to be greater.

Because large tidal currents and wind-or weather-induced surface effects tend to create turbulence and mixing, the ideal salt-wedge model for currents in estuaries is often severely modified in reality (Pillay, 1996). The salt-wedge model is usually most accurate in deep stream-cut channels where tidal influences are overshadowed by the fresh water flow, and the great depth minimizes surface effects (Cooper, 1991). Nonetheless, the basic salt-wedge idea should underlie the analysis of patterns in most estuaries, even when large modifications must be made to accommodate tidal and surface effects.

According to Stow (1983) some estuaries have submarine sills that isolate their bottom waters from communication with the ocean. Many fjords are like this because the glacier that carved the fjords dumped its sediment load at the mouth of the valley where the glacier met the ocean. In these estuaries, the sill prevents the salt- water wedge intrusion. Dense water fills the basin behind the sill, but does not get flushed with the tidal cycle as it does in most estuaries. Of course, there is some mixing with fresh water flowing out along the surface, which slowly removes the denser deeper water (Glavovic, 2000). This is replaced by a corresponding small flow of salt water in over the sill. But usually this is a very slow process, and the turnover time for the water trapped behind the sill is quite long. For the most part it can be considered to be stagnant. It is usually anoxic, because it is too deep for plant life to replace the oxygen that has been depleted through respiration and decomposition of detritus from the surface (Allanson and Baird, 1999).

Several researchers have classified estuaries according to their circulation (Pritchard, 1967; Cameron & Pritchard, 1963; Schubel, 1971; Dyer, 1973; Pillay, 1996). Such classification includes vertical circulation, salt wedge estuaries and partially-mixed estuaries.

2.4.6 Vertical circulation

Differences in circulation within estuaries are caused principally by variations of river discharge and tidal range whilst tidal currents are considered the prime mixing agents (Murray *et al.*, 1975). Estuaries may be classed in four groups on the basis of mixing and circulation.

2.4.7 Salt wedge estuaries

Where river discharge is high, the less dense fresh-water tends to flow outwards over the sea--water which penetrates along the estuary bottom as a salt wedge (Dyer, 1979). There is little or no vertical mixing of the salinity intrusion into the overlying freshwater. This creates vertical salinity stratification with a sharply defined halocline that can reach 30 ppt in 0.5 m (Dyer, 1979).

2.4.8 Partially- mixed estuaries

Pillay (1996) notes that in estuaries where the fluvial input is low compared to the tidal prism, tidal movements into and out of the estuary are appreciable and cause considerable friction and turbulence between the surface and the bed of the estuary. This turbulence causes mixing of the salt water into fresher surface layer and a downward mixing of fresher into the salty water. Therefore salinity progressively increases from the head of the estuary to its mouth (Pillay, 1996).

2.4.9 Well- mixed estuaries

Very large tidal ranges produce sufficient turbulence to completely break down vertical salinity stratification. Here the water column becomes vertically homogenous although lateral variations in salinity and velocity may persist (Whitfield, 2000).

2.4.10 Fjords

Fjords occupy glaciated valleys and can be considered salt wedge type estuaries but with a very deep saline layer (Whitfield, 2000). In these estuaries, the freshwater layer is of the order of tens of metres deep and the salinity of the bottom layer does not vary significantly from mouth to head (Dyer, 1979).

2.4.11 Transverse circulation

This classification emphasises the vertical circulation that occurs in estuaries. Secondary flows are common in estuaries and are caused by several inter-related effects including coriolis effect which causes water to move towards the left in the southern hemisphere. Since the estuary in cross-section is not smoothly rectangular, vertical salinity exchange is unevenly distributed. The cross section of the estuary is not consistent longitudinally thus flow is deflected towards deeper parts of the channel and the outside of bends. Consequently, transverse circulation arises from a balance between topography, Coriolis Effect as well as the lateral density field (Dyer, 1997).

2.5 Structure and functioning

Estuaries form where a river meets the sea. They are that portion of a river system or a drainage system, which has, or can have interaction with the sea (Huizinga and Van Niekerk, 1997). Unlike estuaries elsewhere, most South African estuaries particularly in KZN are prone to closure by sand bars or through catchment-derived sediments that block off the mouth for varying lengths of time (Heydon, 1989). This study has learnt that the closure of the KZN estuaries is mostly claimed to anthropogenic malpractices occurring in the catchment areas. During this closed phase direct interaction with the sea ceases but as water within the estuary is derived from both the river and sea, they still fit the definition of estuaries (Huizinga and Vankerk, 1997).

Not all estuaries are the same. While some are permanently opened, others are temporarily closed (Cooper, 1994). Out of the eight estuaries researched in the present study, two of them could be classified as temporary closed.

2.5.1 Temporarily closed/ open estuaries

The estuaries falling under this catergory were St. Lucia/ Mfolozi, Mngeni, Zinkwazi, Mvoti, are under the study delimitation and are falling under this category. The fact St Lucia/ Mfolozi, Mngeni and Mvoti adequately fit the description of an estuary whilst the Zinkwazi, Mvoti, Isipingo and Mkhomazi fit a description of a lagoon. The temporarily closed estuaries as mentioned above are often closed for many months each year and sometimes for more than a year at a time. These estuaries have been found to have small catchments and limited penetration by tidal waters when they are open. Mouth opening events usually occur after periods of high rainfall. River flow and tidal exchange are not sufficient to keep the mouth open. During very high seas, marine water sometimes washes over the sand bar at the mouth and top up the estuary on the other side (Whitfield, 2000).

2.5.2 River mouths

All rivers flowing into the seas have a river mouth e.g. Mfolozi. The categorisation river mouth estuary reflects properties other than the presence of a mouth (Hughes, 1990). These estuaries are usually permanently open to the sea. The river, not the sea dominates the physical processes within these estuaries. Penetration of marine water upstream is limited by river flow and in some systems penetration may even be confined to the lower reaches for much of the year. When high river flows occur, the mixing zone between freshwater and seawater can be pushed offshore and marine water is not able to enter the estuary (Morant, 1993).

2.5.3 Estuarine lakes

Estuarine lakes under the study were found at St Lucia in KwaZulu-Natal. They occur where a coastal lake is connected to the sea by a channel of varying length and width. The mouth of an estuarine lake can be either permanently or temporarily open as it is the case with St Lucia. Salinity levels vary in both space and time and they largely reflect the balance between freshwater and seawater flow into the lake, as well as evaporation from lake surface. Because they are usually large and shallow, water temperatures in these systems are more related to solar heating on their surfaces than to the influence of the temperature of either rivers or the sea (Allanson and Baird, 1999).

2.5.4 Estuarine Bays

These Bays include Durban Bay and Richards Bay. These estuaries have wide mouths with strong tidal exchange resulting in a continuously open mouth, and the regular replacement of marine water in the lower and middle reaches (Heydon, 1989). Even under high river flow conditions, seawater salinities persist in the bottom waters of the lower reaches as the less dense fresh water flows over the more dense seawater. Water temperatures in an estuarine bay are more strongly influenced by the sea than the river. These marine dominated systems are sometimes dredged to improve their value as harbours for large ships (Glazewski, 2000).

2.5.5 Physical processes

2.5.5.1 Tidal exchange

Accoring to Whitfield (2000) incoming flood tides force seawater into estuaries raising the water level. Water levels near the mouth decrease more quickly than higher up on the outflowing (ebb) tides. The difference in water level can result in strong outflowing currents. In large estuaries (e.g. Knysna) tidal exchange assists in keeping the mouth open.

2.5.5.2 Deposition and removal of sediments

Deposition and removal of sediments are very important processes. Erosion, when sea level was lower than at present, erosion created the physical form of the estuary and cycles of deposition and removal of sediments modified this (Morant, 1993). Rivers bring in sediment from the land and during floods they scour sediment out. In addition wind and coastal currents transport marine sediment into and out of estuaries. When river flow is low the river and incoming tides may bring in more sediments than outflowing tides can remove, this causes the mouth of the estuary to shallow or close (Glavovic, 2000). Deposition sediments are stabilised by plant growth that increases resistance to erosion (Whitfield, 1998). The supply of sediments to estuaries is very variable from both the land and the sea. Amost all the estuaries under the study area received high loads from land and sea so they were greatly modified by sediment accumulation (Whitfield, 2000). Estuaries change continuously as sediments accumulate and then are scoured out to the sea, returning the estuary to an earlier condition

2.5.5.3 Mixing of fresh and seawater

Freshwater is less dense (lighter) than seawater (Pillay, *et al*, 1996). Consequently, fresh water flowing into an estuary can flow over the top of seawater in the estuary, particularly if the river water is warm relative to the seawater (Lindsay, *et al.,* 1996). The layering of different densities is most strongly developed in deep parts of the estuary where mixing processes are weak.

2.5.6 Chemical processes

The ability of an estuary to support plants and animals depends largely on the physical and chemical characteristics of the water column and sediments (Whitfield, 1998). Typically estuaries exhibit a mix of river and seawater and of material brought down by the river and transported in and out by the sea. This mix is modified by the growth, death and decay of organisms living in the estuary, and by alternating processes of sediment deposition and resuspension that trap or release nutrients and toxic materials (Lindsay *et al*, 1996). The result is a unique chemical environment, that is highly variable in time and space and that can change suddenly. There are usually marked salinity differences between the upper and lower parts of an estuary and this salinity gradient is an important determinant of biological processes (Glavovic, 2000). Rivers transporting large sediment loads can reduce the clarity of the water. This can also occur when dissolved organic matter in river water is mixed with seawater. The resulting particulate material is very important food source for estuary animals. Turbidity reduces light penetration and determines the depth at which photosynthesis can take place. By reducing visibility it also makes it easier for small animals to escape from predators (Whitfield, 2000).

2.5.7 Biological processes

The success of organisms inhabiting estuaries is linked to physical and chemical processes (Glazewski, 2000). Many organisms (e.g. prawns, crabs, and some fish) have to spend time at sea to complete their life cycles and movement in and out of estuaries promotes exchange of genetic material. The seasons and cycles of the moon commonly determine the occurrence of movements, the duration and time of mouth opening (Whitfield, 2000). The chemical composition of water flowing out to sea provides cues that orientate animals so they can enter or return to estuaries. Organisms respond to changing conditions (Glavovic, 2000). Changes in salinity, nutrient content of the water and sediment deposition favour some species over others so that sequential change of species (succession) occurs. Floods, flushing and scouring can reinstate earlier conditions favouring formerly successful species. These cycles occur over periods of days in the case of microscopic plants and animals, to many years in the case of large plants such as reeds and mangroves (Whitfield, 1998).

The productivity of estuaries relates closely to nutrient-rich material transported by rivers. Rooted plants t capture solar energy (photosynthesis), while burrowing animals enable nutrients and energy to enter the food web transferred by growth, death and decay, grazing and predation (Whitfield, 1998).

2.5.8 Variety and distribution of plants

Plants living in estuaries vary from large trees (e.g. mangroves) to tiny plants floating in the water (Whitfield, 1980). These plant species are also found in and around the estuaries of KZN. Each species has special requirements, which determine where they live, resulting in species zonation up and down the estuary, in the intertidal area and in the water column (Whitfield, 2000). Changing conditions also determine when they come and go (succession). Estuary type, sediment distribution and properties, and water temperature are important determinants of distribution and, since similar conditions may occur in estuaries, many species are widely distributed (Lindsay *et al*, 1996).

2.5.9 Types of plants

According to Whitfield (1981) there are six different plant community types that are common in estuaries within the study area.

2.5.9.1 Small algae (microalgae)

Individual microalgae are seldom visible to the naked eye (Whitfield, 2000). On mud, sand and bigger plants large populations of these organisms give surfaces a green or brown tinge. Large populations in the water column greatly restrict light penetration and water appears green, brown or red. Growth responds quickly to availability of nutrients, and microalgae in the water column (phytoplankton) are good indicators of nutrients status and pollution (Goodman, 2000). Phytoplankton produce oxygen during photosynthesis but when dense populations start to die, decay can consume so much oxygen that fish and other organisms are killed (Whitfield, 2000).

2.5.9.2 Large algae (macroalgae)

These plants are not distinguished into roots, stems and leaves although some may have root-like structures attaching them to various surfaces (Whitfield, 2000). Large algae are present in almost all estuaries and comprise two main groups, those with a thread-like (filamentous) form and those that are firmly attached and have a leafy (thalloid) form. Seaweed varieties are more common than fresh water algae and occur mainly in the lower reaches where salinities are highest (Glavovic, 2000). Some filamentous algae occur in the lower and middle reaches where dense growths can smother rooted plants (Whitfield, 1980).

2.5.9.3 Submerged large plants (macrophytes)

These rooted plants have stems and leaves that may reach the water surface (Lindsay *et al*, 1996). Some species (e.g. eelgrass) can survive desiccation during exposure at low tides and, whilst able to survive strong tidal currents, whole beds can be washed out during floods. Flowering and fertilisation occurs both above and under water. Eelgrass beds are widespread in the lower reaches of larger estuaries but they are replaced by other species in the upper reaches where salinities are lower and water currents less strong (Whitfield, 2000). Submerged macrophyte beds are important habitats for other organisms living in estuaries (e.g. fish) (Whitfield, 1981).

2.5.9.4 *Salt marshes*

These develop at high elevations (e.g. flood plains) in estuaries and are more prevalent in the lower and middle reaches (Whitfield, 2000). Salt marshes are flooded daily (at high tide) or less frequently, but the soil is always saline. Few species can tolerate these conditions and species diversity is low. One or two species dominate and may include grasses (e.g. soutbossie), some with jointed stems (e.g. glassworts). Salt marshes are important habitats. They provide protection for certain invertebrates (e.s crabs) and organic litter that sustains many species (Whitfield, 1981).

2.5.9.5 *Mangroves*

These are trees and shrubs that grow in tidal and saline coastal areas (Whitfield, 2000). They occur naturally in parts of warm estuaries from the river system to the Isipingo Estuaries. High tides submerged their aerial roots and lower stems but they can be exposed for several hours at low tide (Heydon, 1989). They are intolerable of prolonged flooding with either fresh or saline water that covers their roots because this restricts exchange of gases, especially oxygen. The stems and roots provide large surfaces areas for colonisation by small organisms, that together with leaf litter, supply energy and nutrients for other species. Mangrove wood is durable and is used for building material. Because of the limited extent of mangrove swamps in South Africa harvesting needs to be conducted in a sensitive manner (Whitfield, 2000).

2.5.9.6 *Reeds and sedges*

Whitfield (2000) noted that the presence of these species in estuaries usually indicates fresh or brak (slightly saline) water conditions. Reeds and sedges occur extensively in the middle and upper reaches, while the common reed may extend into lower reaches, especially in temporarily closed systems or where fresh water seepages occur (Whitfield, 1998). During droughts and periods of high salinity they die back, only recovering after floods have flushed away the saline water. Reed and sedge beds are particularly important sources of energy and nutrients during the fresh water phase of some estuaries, because they replace those plant species that flourish under saline conditions. They are also important in subsistence economies, providing materials for craftwork (e.g. rushes and sedges) and construction (e.g. reeds) (Whitfield, 1998).

2.5.10 Variety and distribution of animals

Large animals (hippos and crocodiles) were formerly widespread but nowerdays their presence is largely restricted to estuaries in conserved areas (Whitfield, 1998). Nowdays size varies from large fish (kob and leervis) to microscopic animals inhabiting the water column and sediments. Species tend to be widespread within two broad zones defined largely by temperature. Animals differ from plants in that they are able to move and many actively seek favourable conditions in estuaries. Salinity, type of substratum (rock, sand, mud), and presence of other species (e.g. submerges plants) influences the distribution and abundance of individual species. Generally, the diversity of marine species decline up the estuary and the fresh water species decline towards the mouth. There are few truly estuarine species and estuaries have lower species diversity, but higher abundance, than adjacent fresh water and marine systems (Whitfield, 1998).

2.5.11 Types of animals

2.5.11.1 Invertebrates

These are all those animals (e.g. crabs and worms) that do not have a backbone (Whitfield, 2000). Those are known as benthic species live (e.g. crown crab and sand shrimp) in the sediment (e.g. bloodworm and sand prawn). Others known as nektonic species swim actively in the water column (e.g. swimming prawn). The two groups are not rigidly separated as the larval stages of many benthic species spend time in water column, thus allowing them to establish in areas different from parent populations. Small nekton (zooplankton), barely visible to the naked eye, can be abundant and may move down and settle on the sediment during daylight hours (Whitfield, 1998).

Benthic species aerate and release nutrients from sediments through burrowing and water pumping. Invertebrates are very important processors of living and dead plant material, making energy and nutrients available to other species (Whitfield, 1998).

2.5.11.2 Fishes

The fishes found in KZN estuaries especially in the study areas can be divided into five main groups depending on their origin, biological adaptation to estuarine conditions and their degree of dependence on estuaries for survival (Wallace, 1984). The dominant groups are marine species that breed at sea and whose juveniles show varying degrees of dependence on estuaries as nursery areas. The second most important group comprises truly estuarine species, which breed within estuaries and spell all or most of their lives within these systems. The third group comprises freshwater species for which the degree of penetration into estuaries is determined by salinity tolerance. The fourth group comprises marine species that stray into estuaries, usually occurring in the lower reaches and are not dependent on estuaries (Wallace, 1984). The final group comprises the anguillid eels that use estuaries as a conduit between the sea and river. The larval eels swim through estuaries during their upstream migration, finally returning along the same path on their way to the marine environment where spawning occurs. Estuaries are important nursery areas for juvenile marine fish (Whitfield *et al*, 1981). Diet varies among species. Some feed directly on plant material (e.g. stumpnose) others (e.g. mullet) feed on fine living and dead particulate material and some (e.g. grunter and kop) are carnivorous feeding on other animal species. Diet can change as species mature (Whitfield, 1998).

2.5.11.3 Birds

The variety of food resources and habitats provides opportunities for a diversity ofbird species (Wallace *et al*, 1984). Waders, waterfowl, kingfishers, cormmorants, gulls, terns egrets and herons may be found in and estuaries of KZN. Birds are often the most conspicuous animals on the tidal flats, moving from one area to another as conditions (such as tide) change. Three major groups may be recognized on the basis of diet; those feeding primarily on vegetation (e.g redknobbed coot), those feeding mainly on invertebrates (e.g. green shank) and those that feed primarily on fish (e.g. fish eagle and cormorant). There are more bird species found at east coast estuaries than at the west coast coast estuaries. This is largely due to the diversity of wading birds found at east coast estuaries, most of which are sedentary, fish eating species. On the west coast bird densities tend to be higher and the dominant species are migratory, invertebrate feeders (Whitfield, 2000).

Palearctic waders (those that migrate seasonally to and from northern areas e.g. Europe) vary markedly in their preference between tidally influenced estuaries and lagoons and fresh water coastal lakes. Most Palearctic waders are restricted to tidal habitats (e.g. grey plovers) and decrease in abundance progressively around the coast from west to east (Whitfield, 1998).

2.5.11.4 Other vertebrates

Prior the advent of the rifle, the top predator in most large subtropical estuaries along KwaZulu-Natal coast was the Nile crocodile (Wallace *et al*, 1984). Today this reptile is predominantly confined to protected estuarine lakes such as St Lucia and Kosi where even humans have to be careful not to become a prey item in its varied diet. Other predatort vertebrates, that make use of South African estuaries, but are seldom seen because of their shyness, include two species of otter and the water mongoose (Whitfield, 2000). The most widespread large mammal associated with KZN estuarine systems was the hippo. However, this species was eliminated from all estuaries between the Western Cape and Lake St Lucia where several hundreds individuals survive today. The hippo is an important transporter of terrestrial plant material into adjacent water bodies in the form of dung, and one can only guess at the impact of the loss of these large herbivores on the food webs in Eastern and Western estuaries (Whitfield, 1980).

2.5.12 Estuaries food web

Whitfield (1991) noted that food webs in estuaries are structured around producers, decomposers and consumers. Plants containing green pigment (chlorophyll) dominate the producers. They are able to use light energy, nutrients and water in growth (photosynthesis). The large primary producers aquatic macrophytes) in estuaries are generally not directly consumed. Instead they supply material that decays and is broken down by micro-organisms, particularly bacteria and fungi (Whitfield, 1991). The fine particles of organic matter that result (detritus) are then consumed by a variety of species including invertebrates (e.g. prawns) and fish (e.g. mullet) that are collectively referred to as detritovores (Wallace *et al*, 1984) . Microalgae in the water may be directly consumed by components of the zooplankton (primary consumer), but a large prppotion of the microalgae population also undergoes processing to detrirus before passing on through the food web. Foodwebs in estuaries are complicated by their connections to fresh water systems, that are in turn strongly connected to land systems and to marine systems. These sources augment detrirus originating within the estuary. Much of the detritus accumulate on the surface of the mud where it is consumed by benthic organisms, which live in or on the substratum. These include above surface filter feeders (bivalves such as mussels and clams), crabs, that feed selectively on larger particles, and worms that ingest mud to extract nutritive substances. Invertebrates are dominant amongst the organisms that consume detritrus (primary consumers). They provide food for secondary consumers (e.g. predatory fish) and ultimately tertiary consumers (e.g. predatory birds and man). Detritus forms the main food base for almost all the estuarine animal life and the abundance of this resource is the primary reason for the high productivity of these systems (Whitefield, 1981).

2.5.12.1 *Sustaining food webs*

Food webs in estuaries are constructed around a diversity of plants and animals and linkages to fresh water and marine systems (Whitfild, 1981). If the productivity of estuaries is to be sustained then both the diversity of plants and animals in an estuary is determined by a variety of factors including the size of the system, and the variety of habitats present. The position of the estuary along the coast, the nature of the mouth, the salinity and the temperature also is a determining factor. (Whitefield, 1980).

2.5.13 Biogeography and biodiversity

Biogeography is perhaps the most important factor that influences plant and animal diversity in South African estuaries. There are three main biogeographic regions in the sub-continent; the subtropical zone between Kosi and Mbashe estuaries, the warm-temperate zone between the Mbashe Estuary and Cape point, and the cool-temperature zone between Cape Point and the Orange River (Whitfild, 1998).

The biodiversity of estuaries in the cool-temperature zone is considerably lower than in the warm-temperate zone, with the subtropical estuaries having the highest species diversity of plants and animals on the continent (Whitfield, 1998).

Despite the increase in biodiversity from the south western to the north-eastern part of the country, the proportion of endemic species is much higher in the south than in the north. Therefore estuaries in the temperate zones have a major role to play in terms of providing a sanctuary to plants and animals that are found on the subcontinent and nowhere else in the world. The linkages to fresh water and marine systems are strongly influenced by anthropogenic activities particularly those that alter the pattern of fresh water supply to estuaries (Whitefield *et al*, 1981).

2.5.14 Size of South African estuaries

South African estuaries are small by world standards (Huizinga, 1997). South Africa has the region of 260 functional estuaries and together they are smaller than the Chesapeake Bay system on the eastern seaboard of the United States of America (Huizinga, 1997). Southern African estuaries range in size from the huge Lake St Lucia (32 500 hectares) to the tiny Mkumbane Estuary (0.3 hectares), they have catchments as large as 852 000 square kilometres (Orange River Estuary) or as small as four- square kilometres (Ku-Boboyi Estuary). The majority of South African estuaries have surface areas smaller than 50 hectares. Water depths are also highly variable and range from less than one metre in many small temporarily open/ closed estuaries to more than 10 metres in some of the larger estuarine lakes and bays (Huizinga, 1997).

2.5.15 Age of South African estuaries

Virtually all South African estuaries are only a few thousands years old and originated when a rising sea level at the end of the last northern hemisphere ice age drowned the adjacent river valleys (Boyd *et al*, 1992). Although estuaries have existed for million of years in South Africa, those that are currently seen along the coast are temporary features that will change with future rising or falling sea levels.

2.6 Estuarine management principles

Estuaries are well known for their high productivity, high carrying capacity and ability to support a variety of migratory fish, birds and invertebrates apart from the resident species (Allanson *et al*, 1996). The maximization of this capacity depends on a variety of interacting attributes or features several of which reflect the significance of processes in the catchment and the need for a holistic approach for successful estuarine management.

Biodiversity in estuarine systems is enhanced by a number of factors such as, the size of the system, the habitat diversity, the presence of inter-tidal areas whether salt marsh, mangrove, sand or mud flats and by the presence of an axial salinity gradient, i.e a gradient from full seawater at the mouth of freshwater or significantly reduced salinities at the head of the estuary (Boyd *et al*, 2000). It is therefore clear that a combination of an open mouth, tidal action and freshwater input are generally positive factors in estuarine functioning (Allanson *et al*, 1996). This should not, be interpreted as implying that the frequent closure of many estuaries in KZN, both large and small, renders them biologically or ecologically insignificant and therefore less deserving of sympathetic development. A variety of fish species as well as invertebrates such as the sand prawn and the mangrove crab all survive quite adequately in temporarily closed systems and may in fact be favoured by the conditions that exist during such periods (Glavovic, 2000). The life cycles of many of these species are geared to the natural cycles of opening and closing and arbitrary artificial breaching can adversely influence the successful completion of these cycles.

According to Glavovic (2000), a major adverse influence in KZN estuaries is accelerated sedimentation because of anthropogenic activities in the catchment. This results in progressive and generally irreversible loss of aquatic habitat. The only way of counteracting this loss of aquatic life, is to encourage agricultural practices which reduce erosion (Glavovic, 2000). Any activity which or restricts tidal action in a normally tidal system should be discouraged as this interferes with a great variety of conditions or functions ranging from oxygen availability to larval dispersal. Modification of freshwater inputs through abstraction affects scouring, mouth closure patterns, salinity levels and gradients and nutrient inputs (Allanson *et al*, 1999). Wherever possible, this should be prevented or at least catered for through an integrated water release management plan for major dams. Artificial breaching of sandbars at arbitrary times can be disruptive to normal patterns of migration associated with seasonal rainfall. Any form of artificial mouth management should form part of a comprehensive, holistic management plan for the estuary and catchment (Boyd *et al*, 2000).

However, the estuarine habitats around the world are under threat because of anthropogenic pressures, usually in the immediate area but at times because of abusive land use patterns in catchment areas hundreds of kilometres away and this has become a challenge to many geographers, ecologists, environmentalists, and many water concerned stakeholders (Boyd *et al*, 2000). The inherent attractiveness and productivity of many estuarine areas sows the seeds of their own ultimate destruction through port and urban development, pollution or over-exploitation of their living resources. This has already occurred on a frightening scale in regions of the world richly endowed with estuarine environments (Glavovic, 2000). In the Southern African situation where estuarine habitat is such a small proportion of the total coastal environment it is even more incumbent on us to be aware of the nature and value of this very special environment.

2.6.1 The impact of land use and anthropogenic activities

The relationship between catchments and estuaries is undisputable. Estuaries are the focul point of any catchment. The impacts of all activities within a catchment that have any effect on either the quantity or quality of runoff are focussed on the estuary (Cooper, 1996). It is very imperative to highlight adverse consequences of anthropogenic influencent in the catchment areas. This is not important for ecological reasons only but for conservative purposes as well. What people are doing in the catchment areas have a direct impact in the stream flow and consequently in the estuary, for example the volume of water flowing into the estuary is reduced due to human activities taking place in the catchment areas. Barnes (1996) notes that the reduction in the volume of water flowing into estuary can be a result of increasing number of dams and other impoundments being built in the catchments and also of interbasin water transfers where water is pumped from one river system into another. It has been noticed that through anthropogenic interference, there are changes in the nature of runoff and water quality that is attributed to industrial pollution, runoff from agricultural activities, sewage effluent and the runoff from urban areas (DWAF, 2003).

There is evidence of the severity of poor catchment management practices (DEAT, 2000). This evidence is proved by the poor state of many estuaries along the

KwaZulu-Natal coast. Findings have exposed Mvoti in the north and Isipingo in the south as the estuaries that are in the most appalling and unecological state.

The above findings about these estuaries specifically are disturbing and a bad news for geographers and researchers. Subsistence farming has also been seen as a major contribution for poor state of estuaries especially in the coastal areas. It is therefore important to the future well being of these estuaries, that various tiers of catchment management authority presently put in place by the Department of Water Affairs and Forestry are successful. This does not however, minimise the responsibility of local authorities with jurisdiction over an estuary. It is very important that such authorities proactively manage land uses and anthropogenic activities on and around the estuaries in order to minimise potential impacts on the systems. These activities often have greater impacts on the estuary than the activities in the rest of the catchments.

2.7 Implications for policy management

The primary estuary management legislation of 1998 is to maintain an acceptable standard of natural ecological function, providing estuary service that involves both economic and social values. Sound estuarine management implies that the responsible role player must have a good understanding of the manner in which both the natural and biological components interact to provide the conditions supporting the biological components. It is humans that are managing estuaries and ultimately, this management is for the benefit of humans. The Water Act (36) of 1998, inter alia, requires that suffificient water of suitable quality be delivered to estuaries to ensure that they retain a minimum ecological status or class (DWAF, 1999). The management of estuaries is the legal mandate of DEAT but the provision of adequate water to sustain estuaries is the legal mandate of DWAF. Since the amount of water flowing into estuaries, together with its quality, are the two major physical and chemical factors affecting the estuary environment, much of the primary responsibility for estuary condition develops to DWAF.

The biodiversity Act of 2004 is another policy that provides for the management and conservation of South Africa's biodiversity within the framework of the National

Environmental Management Act of 1998, the protection of species and ecosystems that warrant national protection, the sustainable use of indigenous biological resources, the fair and equitable sharing of benefits arising from bioprospecting involving indigenous biological resources, the establishment and functions of a South African National Biodiversity Institute, and for matters connected therewith DWAF, 1999). This Act covers and protects estuaries as well since they play a significant role in aquatic ecosystems. The protection and sound estuarine utility is emphised and enshrined in South African constitution. It is stated that although everybody has an access in the environmental resources but caution and sensitive in overexplotion is condemned.

Institutional management and the participation of all stakeholders such as environmentalists, scientists, ecologists, hydrologists, geomorphologists, and researchers are necessary to ensure the successful use, development, conservation, and management of wetlands and water resources such as lagoons and estuaries (DEAT, 2000). This implies that the institutional framework outlined in the National Water Act (a legislation passed in 1998 informing the public that everybody has an access to water resources) must provide for the progressive decentralisastion of water resource management to the appropriate level as well as providing for participation in water resources management in South Africa (DWAF, 2003). Significant water resources such as estuaries and other wetlands can be depleted and harm almost all species that rely on them for ecological stability. Recent reports have revealed business people who side step environmental policies when they want business projects to continue even if the policy is contravened (Basson *et al*, 1997).

Glavovic (2000) maintains that without public participation, the goals of water resources management cannot be achieved. Short cut and artificial solutions such as dredging cause more harm than good in coastal management especially to KwaZulu-Natal estuaries specifically Isipingo, Zinkwazi, Amanzimtoti, and Umkhomazi as they are always closed. Lack of consultation within various stake holders will always hamper any strategic breakthrough. The study will make everybody involved in water rsource management to be aware of the importance of being transparent and consultative. It is against this background that this study is aimed at sensitizing those responsible for water resource management and the importance of timeous consultation.

2.8 Co-operative governance

Estuaries are public assets for which the elected government has ultimate responsibility. DWAF (1999) maintains that, the intention of government is to promote partnerships in management between the regulator (government at all levels) and the regulated, the people who make use of the goods and services of, in this case, estuaries. The strength of such a partnership reflects the extent to which estuary stakeholders are able to contribute constructively to envisioning and attaining the preferred state of the estuary (DWAF, 2003). The stakeholders need to be organised and recognised by government if they are to exert meaningful influence. The poor state of the estuaries and lagoons of the KwaZulu- Natal implies that the organisation of stakeholders by both national and provincial government is lacking (Harrison, *et al* 2000). Constitution of estuary management forums provides an organisational entity with which government can engage (DWAF, 1999). Estuary management forums may be formally constituted (e.g. as a sub-committee of a local authority; or as part of a coastal forum) or they can be citizens' action groups that include estuarine specialists and environmental water expects (DWAF, 1999).

Sound planning and management of the estuary and its surrounds like dunes and vegetation should be promoted. This needs monitoring and regular reporting. These cannot be achieved until the forum has linkages with other relevant parties (DEAT, 2000).

Table 1: Relevant legislation applicable for estuary sediment management (From: DWAF, 1999)

Legislation	**Sections Applicable to estuarine management**	**Relevant Authority**	**Description of an Act** This is a legislation passed in the parliament to conserve and protect all the wetlands
National Environmental Management Act 108 of 1998	Section 28 (1)	Provincial Environmental Authority	Projects to conform with an Estuarine management Act
National Water Act 23 of 1998	Chapter 8	Department of Water Affairs and Forestry	Applicable to characteristics of a water course
Environmental Impact Assessment Regulations published in terms of Environment Conservation Act 73 of 1989	Government Notices No's R 1182 & 1183 of 1997	Provincial Environmental Authority	Applicable to: (a) the construction or upgrading of structures below high water mark (b) the construction or upgrading of canals or channels including diversions of the normal flow of water in a river bed (c) the construction or upgrading of dams (d) the reclamation of land below the high water mark and in wetlands
The White Paper for Sustainable Coastal Management	Chapter 10	Department of Water Affairs and Forestry	National, Provincial and Local
Sensitive Coastal Area regulations published in terms of Environmental Conservation Act 73 of 1989	Government Notices No's 879-881 of 1996 and 1526-1531 of 1998	Local Authority	Applicable in KZN south coast sensitive coastal area (Pennington to Umtamvuna)
Sea Shore Act 21 of 1935	Section 3	Provincial Environmental Authority	Before evaluating a project in terms of this statute the status of the work area in relation to section 2 (2) of the Act must be assessed

2.9 Coastal management institutions

The White Paper for Sustainable Coastal Developmnt sets out an institutional framework for coastal management in South Africa. The institutional framework is described below (DWAF, 2000).

2.9.1 National coastal management sub-committee

At a national level the White Paper also recommends the establishment of a Coastal Management Sub-committee of the Committee for Environmental Co-ordination (DEAT, 2000). This sub-committee, chaired by the Department of Environmental Affairs and Tourism's Marine and Coastal Management Chief Directorate, is responsible for co-ordinating the implementation of the national coastal policy (DEAT, 2000).

2.9.2 Provincial coastal working groups

The Whiter Paper also recommends that provincial coastal working groups be established in each of the coastal provinces (DWAF, 1999). This implies that KwaZulu- Natal is no exception, infact this is the province that needs special priority, especially as a major commercial coastal province in South Africa. The working groups should report to the coastal management sub-committee. The purposes of coastal working groups are to advise the provincial department with responsibility for coastal management and to facilitate dialogue, co operation, co-ordination and integration between coastal role players (DEAT, 2000). Obviously all scientists should be part of working groups and even the provincial departments need coastal scientists for good facilitation and genuine environmental protection.

2.9.3 Local coastal forums

Local coastal forums again will never play a major role without the intervention and participation of environmentalists (Allanson *et al,* 1999). As in the long term the policy is aiming to establish coastal forums throughout the coast, coastal specialists must be involved when facilitation of dialogues takes place, and it must be inclusive and bring all the role players up front in order to guide local authorities amicably. All these role players must become involved in management and part of decision makers regarding coastal resources such as estuaries, but still with the guidance of coastal specialists (Allanson *et al,* 1999).

2.9.4 Estuary management forums

An estuary management interest group or forum provides a structure for people with common interest, the estuary and shared vision of what it should be like, to engage and contribute to planning and management at the local level (Boyd *et al.*, 2000). The linkages through coastal forums and working groups to the national coastal management subcommittee provide for integration so that local actions contribute to attainment of national objectives (Cooper, 1994). Such a forum or interest group would have little legitimacy and authenticity without the inclusiveness and participation of coastal scientists, so as to adequately reflect the diversity of opinions and perspectives surrounding the use of estuaries (Boyd *et al.*, 2000)

2.10 Water management institutions

The National Water Act establishes a number of water management institutions that have roles to play in the management of estuaries (DEAT, 2000).
The various institutions in place are metioned below:

2.10.1 Catchment management agencies

According to DWAF (2000) nineteen water management areas have been designated. For each of them there is a Catchment Management Agency (CMA) accountable to a Board appointed by the minister and whose membership must be broadly representative. This is indeed broadly representative of coastal expects like estuarine researchers, ecologists or any support group that deals with coastal environment (DWAF, 2003). A CMA manages water resources within its water management area. Amongst other requirements it must develop and implement a catchment management strategy for water resources like estuaries that is in harmony with the National Water Resources Strategy (Boyd *et al*, 2000). This must be done in a manner that secures and guarantees co-operation and agreement from stakeholders and interested persons like the ones mentioned above. Water resources like estuaries are scientific natural resources that can never be well managed without scientific strategies from specialise coastal scientists (Whitfield, 2000). Because of the size of water management areas, and thed complexity of achieving equitable and efficient use, statutory and non-statutory bodies assist in the process. CMAs are funded from water use charges (DEAT, 2000). A catchment management strategy and a water allocation plan would be incomplete if problems affecting estuaries are not addressed specifically.

2.10.2 Water user associations

DWAF, (1999) shows that Water User Associations (WUA) are statutory bodies that may be established for any form of water use including:

- Taking and using water for irrigation purposes on a commercial or subsistence scale and supply of water for domestic, industrial and municipal use;
- Stream flow reduction activities (e.g. afforestation);
- Treament of effluent and waste and its disposal;
- Control of the use of water for recreational and/ or environmental purposes

A WUA is a body corporate with a management committee directly accountable to its members and broadly accountable to the minister or to the CMA, if the minister has delegated responsibility (DWAF, 1999). The CMA is the key water resource management institution in a water management area. WUAs assist in the implementation of the catchment management strategy at local level. However, it is disturbing to geomorphologists and other coastal scientists to note and discover that most of the substantial accumulation of sedimentation in the estuaries is catchment derived (DWAF, 2003). One is forced to question the role that the CMA is claiming to play in as far as water resource management is concerned.

According to DWAF (2000) the broad role of a WUA is to enable people within a community to pool their resources (money, human resources and expetise) so that they will carry out water related activities effectively. The the capacity of the WUA to ensure and guarantee the availability of the water expertise within the community is very important., since there is shortage of skills in wetland bodies like estuaries and other surface retentions including the lagoons. The Water White Paper spells out clearly that members of the community should benefit from the coastal environment, but the shortcoming is that there is no clearity in as far as the harmonious usage of coastal environment (DEAT, 2000). Water ecosystems like estuaries are only balanced if water biodiversity is not disturbed. WUAs are normally funded through water use charges levied on members.

2.10.3 Catchment forums

The National Water Act places considerable emphasis on public participation and cooperative governace (DEAT, 2000). It is desirable therefore that the stakeholders who share a common interest or concern or who have interests in a particular area, should be able to develop and articulate their interests and concerns in an orderly and constructive manner (Heydon, 1989). This would enable stakeholders to participate actively in cooperative governance. Interest groups or forums of this type commonly emerge spontaneously. Some endure indefinitely whereas others arise around an issue and disappear once the issue is resolved. These organisations are the most active centres of paricipation by civil society in governance at local levels (Lamberth and Turpie, 2001). Because these forums are established by civil society to serve their own interests, they are non statutory. Their management structures are accountable to their members and they are self- funded.

2.10.4 Management process

Lamberth and Turpie (2001) believe that one lives in a world of continuity and changes and everybody strives to change the way things are and because nature is never constant. Our ability to foresee change and adapt our actions timeously determines whether we set and achieve realistic goals (Lamberth and Turpie, 2001). Management, therefore, is continuing, self-informing process in which a conscious attempt is made to prepare for change (strategic adaptive management).

Strategic adaptive management requires that we define a preferred state (condition) for the estuary (DWAF, 1999). This is a state we could reasonable expect to achieve and maintain given present circumstances, our perceptions of changes which lie ahead, and our ability and capacity to influence the direction and form change. As we implement actions to achieve our preferred state, and as the effects of other people's actions in the catchments (land, and sea) become evident, it will be necessary to reassess the realism of our preferred state (DWAF, 2003). Man therefore has no choice but to ensure that his interference with nature is always in harmony with his actions, because if it is not so he himself will suffer the consequences of his destruction and consequently he will starve and be unhappy for the rest of his life (Pradervand, 1998). This therefore forces the government to invest in the scarce coastal resources like those that are found in estuaries. Good environmental policies will protect estuaries for generations to come (DEAT, 2000).

Estuaries provide a stream of diverse goods and services for people with quite different interests in recreation and spending spare time. As individuals and groups strive to maximise their benefits, different views on the preferred state of the estuary usually arise. These different views have to be reconciled so that actions can be aligned and become mutually supportive in promoting attainment of preferred state (Allanson and Baird, 1999). Water management must always be a participatory, and a transparent, and sustainable.

2.10.5 Properties of successful management of estuaries

2.10.5.1 Integration

Whitfield (1998) maintain that estuaries are complex in their structure, form and functioning, in the way goods and services are used and in cascading effects of disturbance (natural and anthropogenic). Furthermore estuaries in most cases are state property and as such are viewed as public assets over which civil society (local, national, and even global) is able to exert influence. It is inconceivable that such interrelated systems can be divided into discrete compartments that are managed in isolation from one another (DEAT, 2000). The complexity of estuaries must be accepted and human must learn to acknowledge and manage them accordingly. Integration has more to do with how things are done unanimously without estuaries being interferred with. It requires human to focus on the bigger picture, the greater good, and to align what they do with it (DEAT, 2000). Consequently, if integration is practiced it will result in proper and sound actions and life-supporting systems like estuaries can never suffer. Integration is also not easy and it does not happen naturally, but it is possible and very essential as ingredient for success in the conservation and preservation of estuaries (Whitfield, 2000).

2.10.5.2 Access to goods and services

The South African Constitution, supported by legislation, makes provision for equitable access to the benefits and sharing of costs associated with the use of resources, including estuaries (DWAF, 2003). Since supply of estuaries is far less to meet the demand and not all uses are compatible, resources have to be allocated through a participative, consultative, transparent and equitable process (DWAF, 1999). Interactions between people lie at the heart of equitable allocations, which result in safe, efficient and sustainable use as required by law. Because estuaries require an assured supply of fresh water that derives at a distance from them, negotiations and consultation must take place with people in the catchment areas (Whitfield, 2000). In complex and uncertain circumstances such as the usage of estuaries, absolute rights to goods and services are exceptionally difficult to establish (DWAF, 1999). Conflicting parties therefore generally decide to negotiate access and use in terms of their interests, but still within the parameters of the law.

2.10.5.3 Influence and relationships

Legislation requires co-operative governance and this applies to management of water resources, rivers and estuaries (DEAT, 2000). Appropriate and correct management of estuaries in KwaZulu Natal will do more good than harm. Neither the state nor any other single body will be able to succeed in managing estuaries or catchments by command and control or by cohesion and reward (DWAF, 1999). No single body, even that of academics has jurisdiction over all the components of the system that affects the state and functioning of catchments and the estuaries that they feed (DWAF, 2003). The complexity of forces of change deriving from the land, the sea and estuary, with its diverse users, creates conditions for conflict and confusion. Estuary management consequently has as much to do with managing the interactions between people as they have to do with managing the impact of their activities (Goodman, 2000). Implications of such an approach are profound because decisions on estuary management reflect the extent of influence one has, and the strength of relationships between individuals and organisations (Goodman, 2000). Building relationships and influence are essential skills in the new approach to manage the use of resources like estuaries. The purpose of expanding influence and building relationships is to help others promote their interests and achieve their goals whilst addressing personal and own organisational interests and goals (Lindsay, 1996).

Relationships founded and built on trust are a perquisite for managing complex systems whether they are estuaries, cities or oil refineries (Cooper, 1994).

2.10.5.4 Comprehension

Experience cannot be harness and future cannot be anticipated unless knowledge is managed. Experience and knowledge are personal and compliment each other (Lindsay, 1996). They are attributed to individuals and these individuals manage complex life supporting systems like estuaries collectively and if this collectiveness breaks or is interrupted a dubious damage the systems are incurred (Cooper *et al*, 1991). So without sharing knowledge people die with this knowledge without being invested to generations to come and consequently management of the ever-changing world is retarded (Cooper, 1994). The technology for communication, particularly computers, has advanced much more rapidly than has our communication behaviour (Dallas, 2004). It is now possible to share experience and knowledge and develop new insights in a collective way. Widely separated organisations and individuals must co-operate especially when they share same environmental thinking (Lindsay, 1996). This can be achieved with a culture of knowledge sharing in which due attention is directed towards building and sustaining relationships. Obviously the government at all levels should take a lead in facilitating this knowledge sharing through inclusiveness supported by proper environmental policies (DWAF, 2003).

One understands the obligation and tasks that the government is carrying since economic stabilisation is a need in the 21^{st} century especially as South Africa has entered global markets as a new democractic country. The government is under pressure and attacked for the high rate of unemployment, and GEAR as its economic strategy. However, as long as the environmental policies, especially those that include sensitive resources such as estuaries and lagoons are overlooked and side stepped, an irreversable damage will occur in the long run and the government itself will pay a big price. This will also create animosities and conflicts among the environmental role players.

It is very imperative to remember that our decisions are made in order to influence the future and probably this is the reason why professional inteference of relevant stakeholders is of paramount importance and a necessity for an uncertainty.

2.11 Environmental management

There are many different definitions for environment. Allanson and Baird (1999) define the environment as the biosphere in which people and other organisms live. It consists of renewable and non-renewable natural resources, natural ecosystems and habitats that have been constructed or modified by people (DWAF, 1999). Estuaries therefore are also natural ecosystems and habitats that support various species for energy flow (Lubke and de Moor, 1998). This explicitly implies that if estuaries are polluted or negatively affected by anthropogenic practices from the catchment areas, food chains and food webs are also negatively affected. Therefore the sound management of the environment would imply a healthy life for estuaries as a habitat of various species (DEAT, 2000). Unfortunately, this study revealed that estuaries like Zinkwazi, Mvoti, Isipingo, mkhomazi, are hardly opened due to sedimentation attributed to their catchments.

2.11.1 The governanceof environmental management

- Environmental management is a joint responsibility of national and provincial government (Lindsay, 1996). The national policy for the management of the environment is laid out in the White Paper on Environmental Management Policy for South Africa that was published in May1998, (DEAT, 2000). The policy lays out the principles to be applied to environmental management and the goals and objectives of national environmental management. One of the key principles is that renewable and non-renewable natural resources, cultural resources and land are all part of South Africa's environmental heritage. They are public assets belonging to the nation's people. The other one is that the government acknowledges the constitutional duty to protect the environment for the benefit of current and future generations (DEAT, 2000).

The National Environmental Management Act (No 107 of 1998) gives effect to the White Paper on Environmental Coordination that comprises representatives of national government departments, relevant provincial departments and local government (Goodman, 2000). The purpose of the Committee is to promote the integration and coordination of the environmental functions of the various organs of state. The Committee has a Coastal Management Subcommittee. The Act also establishes a number of procedures to promote cooperative environmental governance (Acocks, 1975). The Act requires that national government departments whose activities may affect the environment prepare environmental implementation plans (Goodman, 2000). Similarly, all national government departments that are involved in the management of the environment are required to prepare environmental management plans.

One of the key issues of the Act is a provision that empowers members of the public to take legal action in the public interest or in the interest of protecting the environment (DEAT, 2000). This legal action can be taken when a law concerned with the protection of the environment has been broken (or there is threat that such a law may be broken). This is a very powerful provision that allows anyone to take legal action to ensure that the environmental laws of the country are upheld (DWAF, 1999).

2.11.2 Integrated environmental management

The National Environmental Management Act includes a section that gives effect to the objectives of integrated environmental management (DEAT, 2000). This section allows activities that may significantly impact on the environment to be identified by Minister of Environmental Affairs as requiring authorisation prior to implementation. No regulations have yet been passed in terms of this section (DEAT, 2000). However, Environmental Impact Assessment Regulations were promulgated on 5 September 1997 in terms of the Environmental Conservation Act (No 73 of 1989). Eventually these regulations will be superseded by regulations under the National Environmental Management Act (DWAF, 1999).

2.11.3 Environmental impact assessment regulations

The September 1997 regulations list activities that may be harmful to the environment (DEAT, 2000). Permission to implement any listed activity is required from the environmental department of the province in which the activity is planned to take place. To obtain permission an application must be made to the environmental department (DEAT, 2000). The department could then require that the applicant complete one or more environmental reports. According to Lindsay (1996) many of the activities listed could impact estuaries, for example:

- The construction or upgrading of marinas, harbours and all structures below the high-water mark of the sea;
- The construction or upgrading of public and private resorts and associated infrastructure; and
- The reclamation of land below the high-water mark of the sea and inland water including wetlands or estuaries

Civil society plays a very important role in environmental impact assessments because government looks to society for direction in decision making (DWAF, 1999). Estuarie Management Forums would be influential interested and affected parties.

2.11.4 Fresh water and estuaries

Whitfield (1998) maintain that estuaries are dependent for normal functioning on an inflow of fresh water. The management of fresh water resources can therefore play an important role in the management of an estuary.

2.11.4.1 The governance of water resources

The management of South Africa's water resources is the responsibility of national government (DWAF, 2003). This includes the management of kwaZulu-Natal estuaries. National government policy for management of water resources is laid out in the White Paper on Water Policy published in April 1997. The policy includes a number of water law principles. Two key principles are that all water, wherever it occurs in the water cycle, is resource common to all, the use of which shall be subject to national control and the water required must meet basic human needs and the needs of environment shall be identified as the reserve and shall enjoy priority of use by right. The use of water that remains after the Reserve's need has been satisfied is subject to authorisation.

The first principle confirms that water is a national asset and that it is controlled by national government. The second principle establishes the concept of Reserve for basic human needs and the environment (DWAF, 1999). The Reserve has a priority over all other water uses. All other water uses require authorisation.

The National Water Act (No 36 of 1998) gives effect to the White Paper on water policy (DEAT, 2000). The Act defines the Reserve as the quantity and quality of water required to meet basic anthropogenic needs and to protect aquatic resources. To give effect to the Reserve the Act requires that a Reserve should be determined for all significant water resources (DWAF, 1996).

The Act also sets out the framework for the management of water resources in South Africa. The framework provides for three levels of management: national, provincial and local (DWAF, 1999).

2.11.4.2 National water management

The Minister of Water Affairs and Forestry has overall responsibility for the management of water resources (DWAF, 2003). The act requires the development of a national water resource strategy. This strategy provides the framework for the protection, use, development, conservation, management and control of water resources for the country.

2.11.4.3 Catchment management

The Act provides for establishment of catchment management agencies for the water management areas that have been defined in terms of the Act (DWAF, 2003). Each water management area covers several catchments. Catchments management agencies have several functions, including the development of catchment management strategies.

The catchment management strategies that are developed by the catchment management agencies must be compatible with the national water resource strategy (Davies and Day, 1998). The Act requires that a catchment management strategy should set the strategies, objectives, plans, guidelines and procedures for the catchment management agency for the protection, use, development, conservation, management and control of water resources in its water management area (DWAF, 1999). A catchment management strategy should include social component, institutional component, biophysical management component, legislativce/ policy component, water allocation plan and economic component (DWAF, 1999).

2.11.4.4 Local

The Act provides for the establishment of water user associations (DWAF, 1999). A water user association is essential as a co-operative association of water users that jointly manage water related activities. Water user associations provide catchment management agencies with a mechanism to devolve aspects of their catchment management strategies to a local level (DWAF, 2003). Water user associations can take responsibility for the local level execution of aspects of the catchment management strategy (DEAT, 2000).

According to the Water Act of 1998, Water user association can be established for a wide range of purposes including prevention of the wastage of water resources, to protect water resources and to supervise a water resource (DEAT, 2000)

An estuary management forum could perform some of these functions on behalf of a water user association.

2.11.5 Coastal management

The National government policy for coastal management is laid out in the White Paper for Sustainable Coastal Development in South Africa (Pradervand, 1998). The White Paper includes a vision, principles, goals and plan of action for coastal management (DEAT, 2000). The key messages highlighted by the White Paper are:

- the value of the coast must be recognised;
- sustainable coastal management must be facilitated;
- coastal management must be coordinated and integrated;
- government must adopt a cooperative style of management

2.11.5.1 Management level

The white paper lays out a framework for national, provincial and local coastal management (DEAT, 2000). The Department of Environmental Affairs and Tourism is the coastal management lead agent and is be responsible for preparing State of the Coast reports and coordinating the implementation of the plan of action required in the white paper (Lindsay, 1996). A coastal management subcommittee of the Committee for Environmental Co-ordination established in terms of the National Environmental Management Act is to be constituted (DEAT, 2000). Each of the coastal provinces is required to identify a department that will be the coastal lead agent (DWAF, 2003). This lead agent will be reasponsible for monitoring the state of the coast and reviewing provincial legislation. In each province a Coastal Working Group will be established. Municipalities must be involved in many coastal management responsibilities and local coastal forums are established to promote dialogue and improve coordination between coastal roleplayers (Lindsay, 1996).

2.11.5.2 Coastal management legislation

According to Harrison *et al* (2000) the White Paper is being implemented, but this has not yet led to new coastal legislation. The primary coastal law that currently exists is the Sea-Shore Act, which dates back to 1935 (Act 21 of 1935). The act establishes the government as the owner of the sea (the territirial waters of South Africa) and the sea-shore (the area that lies between the high water mark and the low water mark of the sea), except where ownership was transferred to individuals prior to the promulgation of the Sea-Shore Act (Harrison *et al*, 2000). The Act includes estuary water surfaces in its definition of the sea-shore. Only land uses specified by the Act or a resolution of parliament can take place on the sea-shore. Otherwise, the public has the right to use the sea-shore and the sea, provided this use does not contradict other rights granted in terms of the Act.

Development on land within the visual basin of an estuary that falls outside the defined sea-shore area is controlled by local authority plans, local by-laws, provincial planning legislation and national planning and environmental legislation (Cooper *et al*, 1991).

2.11.5.3 Management principles

Estuaries are well known for their high productivity, high carrying capacity and ability to support, apart from the resident species, a variety of migratory fish, birds and ivertebrates (Goodman, 2000). The maximization of this capacity depends on a variety of interacting attributes or features several of which reflect the significance of processes in the catchment and the need for holistic approach for successful estuarine management (Cooper 1994). Biodiversity in estuarine systems is enhanced by a number of factors such as the size of the system, the habitat diversity, the presence of intertidal areas whether salt marsh, mangerove, sand or mud flats and by the presence of an axial salinity gradient, i.e. a gradient from full seawater at the mouth to freshwater or significantly reduced salinities at the head of the estuary (Goodman, 2000). It is clear from the preceding sentence that a combination of an open mouth, tidal action and freshwater input are generally positive factors in estuarine functioning. This should not be interpreted as implying that the frequent closure of many of KwaZuluNatal systems, both large and small, renders them biologically or ecologically insignificant and therefore less deserving of sympathetic development (Cooper, 1994). A variety of fish species as well as invertebrates such as the sand prawn and the mangrove crab all survive quite adequately in temporarily closed systems and may in fact be favoured by the conditions that exist during such periods (Glavovic, 2000). The life cycles of many of these species are geared to the natural cycles of opening and closing and arbitrary breaching can adversely influence the successful completion of these cycles (Cooper et al, 1991). On the basis of the above arguments it is likely to draw up a list of actions or activities that should be avoided or prevented because of their potential for immediate or long-term damage to estuarine systems.

A major adverse influence in KwaZulu Natal estuaries is accelerated sedimention because of anthropogenic activities in the catchment (Glavovic, 2000). This consequently causes progressive and generally irreversible loss of aquatic habitat. The only way of counteracting this problem is to encourage agricultural practices that reduce erosion. Any activity that reduces or restricts tidal action in a normally tidal system should be discouraged as this interferes with a great variety of conditions or functions ranging from oxygen availability to larval dispersal (Glavovic, 2000). Modification of freshwater inputs through abstraction affects scouring, mouth closure patterns, salinity levels and gradients and nutrients inputs. Wherever possible, this should be prevented or at least catered for through an integrated water release management plan for major dams (Whitfield, 1998). Artificial breaching of sandbars at arbitrary times can be disruptive to normal patterns of migration associated with seasonal rainfall (Heydon, 1989). Any form of artificial mouth management should form part of a comprehensive, holistic management plan for the estuary and catchment. Dredging can have potentially disastrous effects through erosion, remobilisation of pollutants from sediments with accompanying increases in turbidity, burial of organisms and general habitat destruction (DWAF, 1999). Any dredging project should be subjected to a proper environmental impact assessment and it would require a permit from the Department of Mineral and Energy Affairs (DWAF, 2003). Uncontrolled exploitation of living resources of estuaries through fishing or bait collection with its associated habitat disturbances in the context of the relatively small total area of KwaZulu Natal's estuaries can have serious effects (DEAT, 2000). These activities are subject to regulations set by the various provincial conservation authorities and the enforcement of these controls is very important.

Wetlands in the context of estuaries include salt marshes, mangrove swamps, intertidal sand and mud flats as well as reed and all are integral components of estuarine environments (Lindsay, 1996). Excavations, reclaiming or draining these areas contribute to a loss of estuarine functions and the damage done that is often irreversible except at great expenses. All these activities must be subjected to a proper environmental impact assessment before being permitted or undertaken (Goodman, 2000).

Goodman (2000) notes that all forms of pollution are a major problem in estuaries and should be avoided and reduced at all costs. The explanation for this is the estuary's position as the final recipient of catchment input as well as tidal inflows from the sea (Wallace *et al*, 1984). Depending on the nature of the pollutant, its concentration and degradibility, effects may vary from negligible to disastrous. Organic wastes from sewage or from sugar or paper mills lead to oxygen depletion that is reversible although lethal to many species in the short term, and the sustained input of excessive amounts will result in a permanently lifeless system (Harrison *et al*, 2000). Oil is also organic and hence will ultimately break down although this is very slow in anaerobic estuarine muds. Its sticky nature and blanketing effect adversely affects and may kill birds and any other animals or plants with which it comes in contact. Inorganic wastes from industrial activities include all manner of toxic materials including the heavy metals (Harrison *et al*, 2000). Some of these toxins may become concentrated in higher predators including man. Outflow of coolant water from power stations may have lethal effects in warm estuaries where animals or plants are already living at temperatures close to their upper lethal limits (Allanson and Baird, 1999). Unlike the above that can all be considered as "point sources" of pollution that can be identified and possibly dealt with, agricultural fertilizers and pesticides, that are also potential pollutants, enter rivers in a diffuse fusion with run-off water. The fertilizers can induce blooms of aquatic vegetation that subsequently die and rot causing oxygen depletion (Allanson and Baird, 1999). Some pesticides such as DDT, Dieldrin and other chlorinated hydrocarbons may persits for years and passed up the food chain due to their tendency to accumulate in fat deposits (DEAT, 2000).

2.11.5.4 Key issues to consider

There should be significant issues to consider as aids to the assessment of a planned structure or activity in terms of its potential impact on the estuarine environment or on normal estuarine functioning (DWAF, 2003). The severity or significance of the impact would have to be assessed in relation to the nature of the particular estuarine system in question taking into consideration aspects such as size, rarity, conservation status or presence or absence of similar areas in neighbouring estuaries or in the same geographical area. There are numerous questions to be asked as noted by DWAF (1999) and some of them are about the development or activity that destroys or modifies any part of the estuary environment including wetlands, the modification of the natural patterns of mouth opening or closure and the observation of the extent in which the position of natural breaches in any sandbar at the mouth is affected, the result of any change in natural water levels in the case of an open and therefore tidal system that affects the tidal exchange, the modification of patterns of sedimentation and erosion and a change in positions of channels, the acceptability of the aestheticity of the estuary, the accessibility of the sensitive areas such as mangroves or salt marshes, and their vulnerability to disturbance by people or domestic animals, the result of the increased anthropogenic activty in areas sensitive to disturbances, e.g. bird feeding or roosting sites, the action as a source of litter or pollution, e.g. boat fuel at a jetty, wastewater, fertilizers or seepage from septic tanks associated with housing developments or camping/ caravan parks, the effects or consequences in the mobilisation and re-distribution of sediments and the effects of an increased turbidity, the presupposition of the development and dependence on an assumption of natural stability, e.g.of a bank or sandbar that is actually dynamic, the clear understanding of the proposed development within or below a known floodlevel, a clear knowledge about the introduction of alien species of plants or animals, and the compatibility of other activities or structures in their pre-existence and planning.

It is very important to note that an estuarine manager or intended user should be aware of events beyond the actual bounds of the estuary and particularly in the catchment that could ultimately impinge on the estuary (Goodman, 2000). These handful concerns about catchment activities impinging the estuaries need to be addressed vigorously and sorted out amicably for the benefit of environmental role players and the public at large. Some of these concerns include the development or activity that influences the input of freshwater into the estuary and the manner in which the input itself can be affected including the net reduction and a change in seasonal flow patterns, the effects of the abstraction and impoundment in damping any flood peaks permanently, the availability of a sufficient control of water releases to be able to stimulate a flood if necessary as part of an integrated estuary management plan and the state of the outflowing of water from the impoundment of natural river water in terms of the suspended material, nutrient content, temperature, or oxygen content and the likelihood of changes to be expected in estuaries there after (Goodman, 2000).

Infact not only KZN estuaries that are under threat because of anthropogenic pressures (Cooper *et al*, 1991). Almost all estuarine habitats around the world are under threat due to anthropogenic inteferences. Usually in the immediate area but at times because of abusive lands use patterns in catchment areas hundreds of kilometres away. The inherent attractiveness and productivity of many estuarine areas sows the seeds of their own ultimate destruction through port and urban development, pollution or over exploitation of their living resources (Cooper, 1994). This has already occurred on a frightening scale in regions of the world richly endowed with estuarine environments. In the Southern African situation where the estuarine habitat is such a small proportion of the coastal environment it is even more incumbent on people to be aware of the nature and value of this very special and precious life-supporting ecosystem (Heydorn, 1989).

2.11.5.5 Estuary resource use

The national government policy is laid out in the Marine Fisheries Policy for South Africa that was published in 1997 (DWAF, 2003). The foundation of the policy is a belief that all natural marine living resources of South Africa, as well as the environment in which they exist are a national asset and a heritage of all people, and should be managed and developed for the benefit of present and future generations in the country (DEAT, 2000). Marine Fisheries Policy excludes estuary species; however, the policy laid the basis for the Marine Living Resources Act (No 18 of 1998).

The Marine Living Resource Act regulates marine living resource use within South African waters including estuarine areas (DWAF, 2003). The main purpose of the Act is to provide for the conservation of the marine ecosystem, the long-term sustainable utilization of marine living resources and the orderly access to exploitation, utilization and protection of certain marine living resources. According to DWAF (2003) the Act lays down a number of important objectives and principles including the necessity of achieving optimum utilization and ecologically sustainable development of marine living resources without exploiting them, the importance of conserving and conserving marine living organisms for both present and future generations, the necessity of utilizing marine living resources to achieve economic growth, human resource development, capacity building within fisheries and culture branchies, employment creation and a sound ecological balance consistent with the development objectives of the national government and this can be achieved if all the role players are involved and consulted, the importance and necessity of protecting the ecosystem as a whole including species which are not targeted for exploitation and the necessity to preserve marine biodiversity ecologically (Dwaf, 2003).

An important feature of the Act is that no fishing can be undertaken unless a right to fish (a license) has been granted by the minister of Environmental Affairs and Tourism (Harrison *et al*, 2000). The minister also determines the maximum quantity of fish (and other marine animals and plants) of individual species or groups of species that are available for harvesting annually. In addition, the Minister determines limitations regarding the number of vessels and methods of fishing for individual species or groups of species and what portion of the total harvest is allocated to which sectors. The Act also provides the Minister with a number of other mechanisms to regulate fishing such as the establishment of fisheries management areas, the declaration of priority fishing areas, the establishment of zones for subsistence fishers and the establishment of marine protected areas (Harrison *et al*, 2000).

2.11 5.6 Planning

A plan is a statement of intent at a particular time. Planning is a process whereby one continually envisions the future and prepares for it. So planning is an ongoing activity involving continual adjustment (DWAF, 20003).

Glavovic (2000) maintains that planning the development of an area is the responsibility of the municipality of that area. Various national and provincial laws lay the framework in which this municipal planning takes place. One of the key national laws is the Local Government Transition Act (209 0f 1993) that requires all municipalities to draw up Integrated Development Plans for the development and management of their areas of jurisdiction (Glavovic, 2000). Planning for many areas that are dealt with by municipalities, such as water planning, transport planning, spatial planning and environmental planning is ecompassed by an Integrated Development Plan (IDP) (DEAT, 2000). Some provinces like KwaZulu-Nataland Easter Cape have planning laws of their own. The Council for Scientific and Industrial Research (CSIR) suggested a generic planning process for an integrated development plan. They include the the Workplan phase that involves the preparation of workplan for the preparation of an integrated development plan, the vision phase thiat involves developing a vision for the area, the Development Framework phase that spells out the key issues for the area and goals of the integrated development plan which are developed, the Development Strategies phase which develops strategies for attaining the integrated development plan goals, the Operational Planning phase which monitors that the necessary finances and resources are allocated to ensure the implementation of the styrategies during this phase and the Monotoring, Evaluation and Review phase which looks at the assessment of integrated development plan whilst monitoring the outcomes of the assessment feed into the ongoing development of the integrated development plan (Glavovic, 2000).

CHAPTER THREE: THE STUDY AREA

3.1 Location of the study area

The study area comprises of eight (10%) larger estuaries of the province of KwaZulu-Natal (Begg, 1984). The province of KwaZulu Natal is situated on the east coast of South Africa and has a coastline that extends 570 km between the border of Mozambique, in the north, and the border of the eastern Cape in the south (Cooper and Flores, 1991). The province is bordered by the Indian Ocean to the east and the coast parallel to Drakensberg mountain range approximately 250 km to the northwest. Although the coastline is relatively straight, it is interrupted by 73 estuaries of varying sizes that contrast markedly with those of Mozambique and those of the Eastern Cape (Maud and Orr, 1974; King, 1974; Orme, 1974). The coastline's straightness is largely because of different geomorphological influences, a climatic regime and the characteristics of the contributing watersheds (Begg, 1978).

Due to the fact that the hinterland catchments rise so steeply (more than 3000 m over a horizontal distance of 250km), rivers generally occupy incised valleys in linear catchments (Pillay, 1996). River courses of the eastern escarpment are therefore narrow and have poorly developed floodplains offering little storage of riverine sediment (Pillay, 1996). On the southeast, the 593km long KwaZulu-Natal coastline contains 74 estuaries made up of 55 minor perennial rivers (catchment areas < 300 km^2), 10 secondary rivers (catchment areas of $300km^2$ to $1000km^2$) and 9 major perennial rivers (catchment areas of greater than $1000km^2$) (M^c Cormick *et al.*, 1992). Only the largest of these, Tugela River, maintains a fully open mouth condition. The character of all the other estuaries, including the Mfolozi River with a catchment of approximately 10 $000km^2$, fluctuates from being fully lagoonal during extended drought or low fluvial flow periods, to partially closed during summer rainfall periods, to open ended following floods (Allanson and Baird, 1999) .

KwaZulu Natal is predominantly a summer rainfall region and this is reflected in the seasonal character of stream discharge pattern (Dallas, 2004). The nature of the catchment topography and the large size of the catchment ensure that high volumes of sediments are delivered to the estuaries and nearshore environments. Poor management of catchments and their increased agricultural use has contributed on high sediment yields (Dallas, 2004). Also, extreme events such as severe floods dramatically increase sediment output.

The Tugela River forms a natural interfluve between southern and northern KZN. The coastal area north of the Tugela is dominated by the Zululand coastal plain (Maud, 1961; Orme, 1974), with sub-tropical and a tropical fauna and flora, and strongly influenced by the warm southward flowing Agulhas Current (Begg, 1978). South of the Tugela the topography becomes steeper, with a consequent increase in the number of rivers draining smaller catchment in which precipitation, sreamflow and land use patterns are different. Within this area are 62 small, poorly studied estuaries. On average their frequency of occurrence is one estuary per 3, 9 km of coast. In total (excluding Durban Bay) they occupy 650 ha, i.e. only 1, 6% of the total extent of what could be considered as estuarine waters in KwaZulu-Natal.

This eight estuaries of KZN on which the study was done are, St-Lucia, Mfolozi, Mngeni, Zinkwasi, Mvoti, Isipingo, Amanzimtoti and Mkomazi (Figure2).

Apart from size and relative importance, these particular estuaries were chosen since were within 200 km of Durban Metro, thereby reducing the costs and time spent in travel. Moreover, they varied in environmental condition from good to poor with a considerable variation in terms of size, mouth condition, salinity, bathymetry, vegetation and the extent to which man-induced or natural perturbation was evident. The contamination of an estuary determines the health and environmental conditions as well as the quantity of aquatic species available in the estuaries. For instance the more contaminated the estuary the few the species are found in the estuary. At the Isipingo for example, the estuary was very muddy and almost no animal species were found and the estuary was catergorised as a very poor estuary in terms of the environmental condition. The colour of the estuary played a major role in the catergorisation of it. .

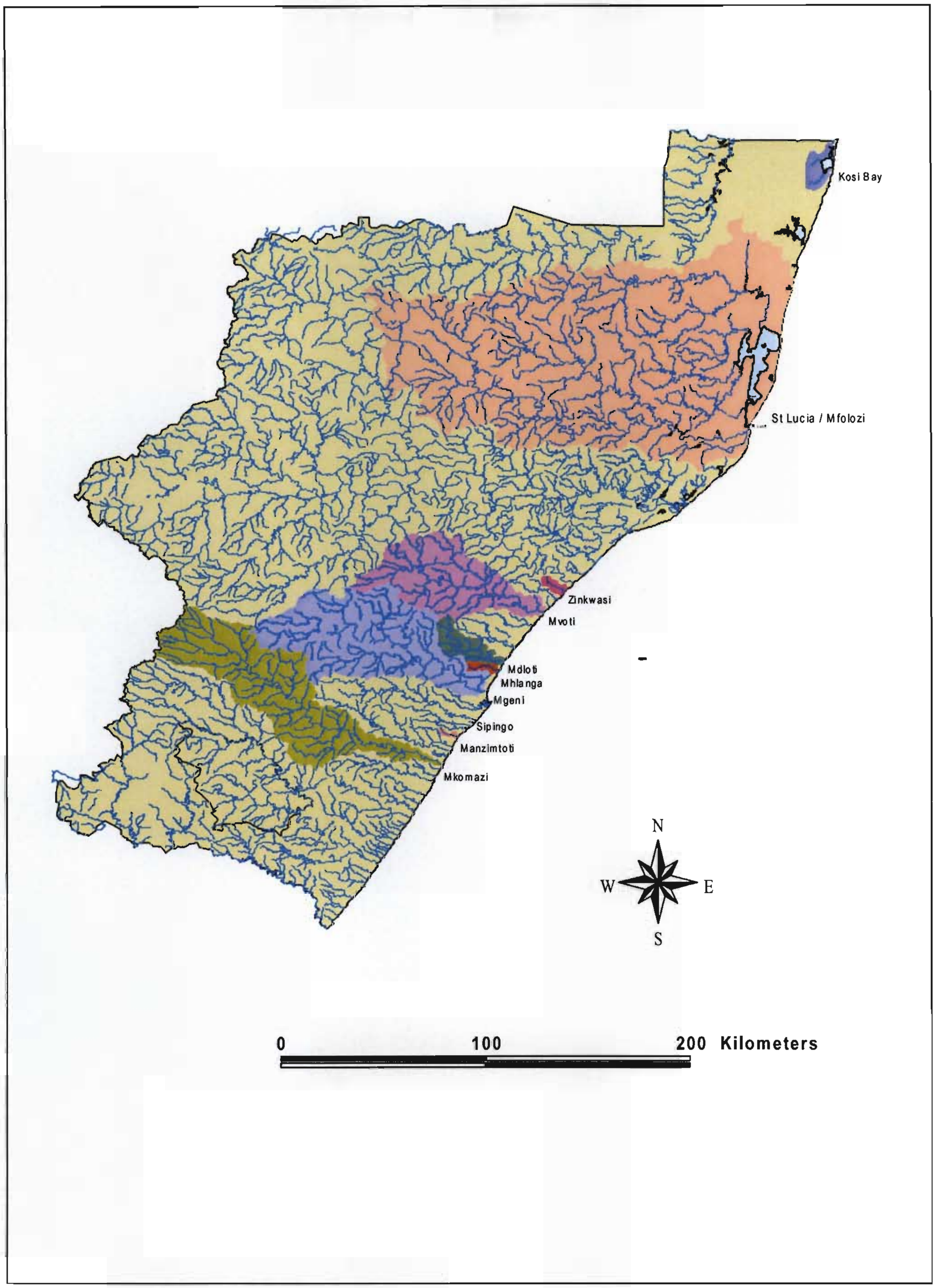


Figure 2: Map of Kwa Zulu-Natal showing the eight estuaries and river catchmemts within the study

3.2 Physiographic characteristics of kwazulu-natal

3.2.1 The Continental Shelf

The KwaZulu-Natal continental shelf displays two broad morphologies on the north of 28^0 30' S and south of 30^0 20' S. The shelf is narrow with the steep continental slope whilst the Tugela Cone, displaying a broad, gentle shelf is situated between these latitudes (Martin and Fleming, 1986; Goodland, 1986; Pillay, 1996).

The St-Lucia system mouths are located at approximately 28^0 24' S, where the continental shelf is very narrow and steep. The width of the shelf north of Tugela Cone varies between 2 to 7 km and the shelf break occurs at depth of 45 to 112 m (Martin & Fleming, 1986). Martin and Flemming, (1986) mentioned five major canyons that cut the continental slope north of 28^0 30' S but undoubtedly more exist. Ramsay (1995), for example, discovered 13 such canyons in a 59 km^2 area of the shelf between Jesser Point (27^0 32' S) and Gobey's Point (27^0 25' S). The origin of these canyons are not thought to be related to the position of modern river mouths but may probably be linked to the paleo-outlets of major fluvial systems (Orme, 1975; Wright, 1995, Ramsay, 1995, Pillay, 1996). Sydow (1988) is of the opinion that these canyons originated through mass wasting of unstable, late Pliocene progradational sequences on the steep, upper continental slope. These canyons were subsequently exploited by paleo-drainage during regressional phases.

3.2.4 Climate

KwaZulu-Natal catchments experience a wide range of rainfall conditions with crippling droughts alternating with devastating floods and this scenario results to extremely abnormal flows (Looser, 1985). Rainfall is at its highest near the coast, and decreases inland except where the elevation of the area is above 1200m. Floods occur at any time of the year but mainly in summer, but because the time of concentration is of relatively long duration, long storm durations are required for the generation of large floods (Looser, 1985). However, there is a totally new trend that has been witnessed in the coastal areas of KwaZulu Natal, where heavy and torrential rainfalls have been in persistence and this unprecenteded situation has had adverse consequences both in crop farming and the ecosystem.

Boyd, *et al,* 2000 noted that the estuaries under the study area are dominated by coastal plain, tropical to sub-tropical climate and, fauna and flora. They are strongly influenced and enhanced by the warm southward flowing Agulhas Current.

The occurrence of tropical cyclones over northern KwaZulu-Natal is not common. When they occur as with Cyclone Domoina in 1984, extensive flood damage ensues. Heavy, widespread rainfall may also be produced when "cut off lows" are isolated over the province (Brijlal, 2004).

Temperatures are generally warm to hot in the catchment. Mean annual temperatures vary from 16-18^{o} Celicius in the hinterland to 18-23^{o} Celcius in the coastal region. Hot and humid conditions therefore prevail along the coast. Cold winters with regular frosts are experienced in the catchment interior (Looser, 1985).

The Zululand coastline trends north-northeast/ south-southwest approximately 010^{0} to 020^{0}) and, although there are marked seasonal variations, coast-parallel winds dominate. Such coastal winds with longshore components are important for their role in aeolian sand transport and in the dynamics of the coastal ocean (Brijlal, 2004).

The December winds are dominantly north to north-easterly whilst both southerly and northerly winds occur with equal frequency in June (Brijlal, 2004). These winds are related to alternate dominance of cyclonic frontal systems and the Indian Ocean anticyclonic high pressure systems (Martin & Flemming, 1986; Cooper, 1991) and to lesser extent on the intensity and frequency of coastal lows advancing to the north-east along the coast.

3.2.5 Major Biomes of the Province

Broadly, the major biomes in the province include the Savanna that extend from the coastal zone to the Drakensberg Mountains; the Succulent Karoo biome that are dominant in the major river catchments and, grassland characteristic of the southern part of the province and the highland region (Allen, 1991).

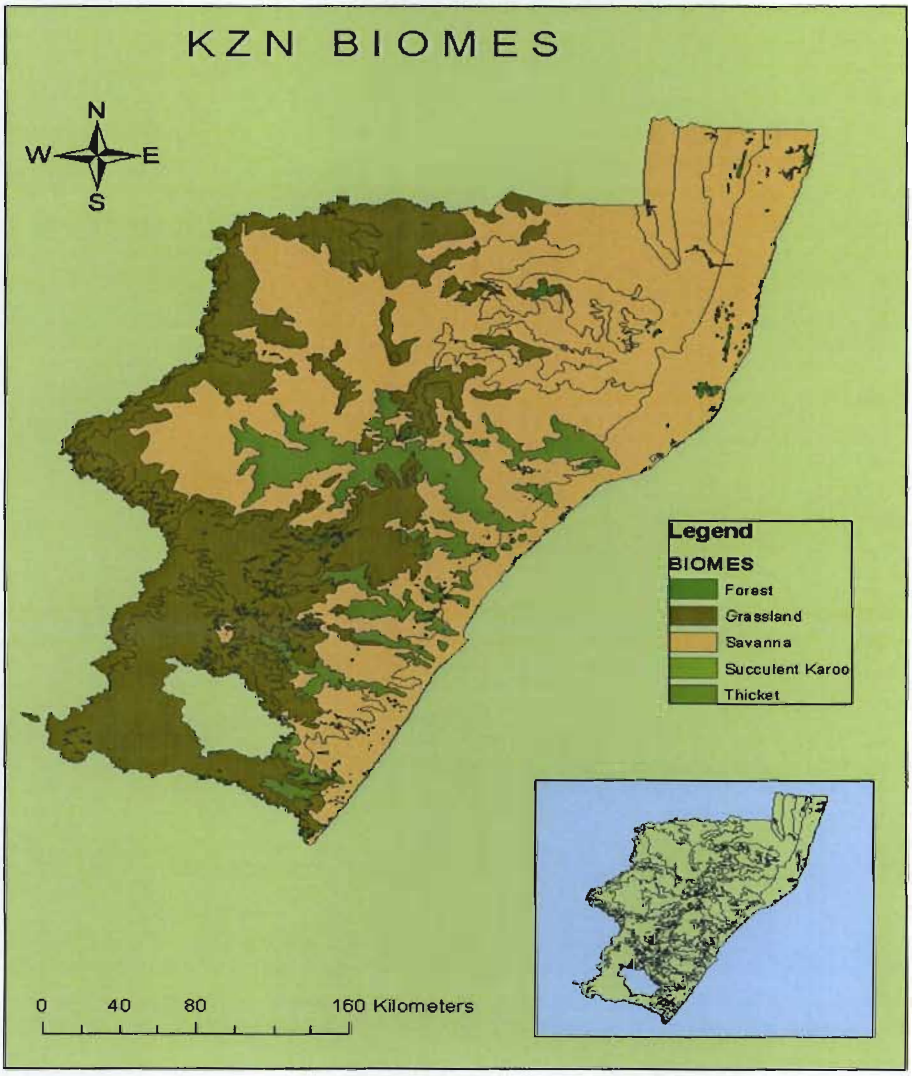


Figure 5: Major biomes of KwaZulu-Natal (from Ahmed, 2006)

3.2.6 Geology

The nature and volume of sediments delivered to any estuarine environment is controlled largely by the geology of river's catchment and its near-shore environment (Pillay, 1996).

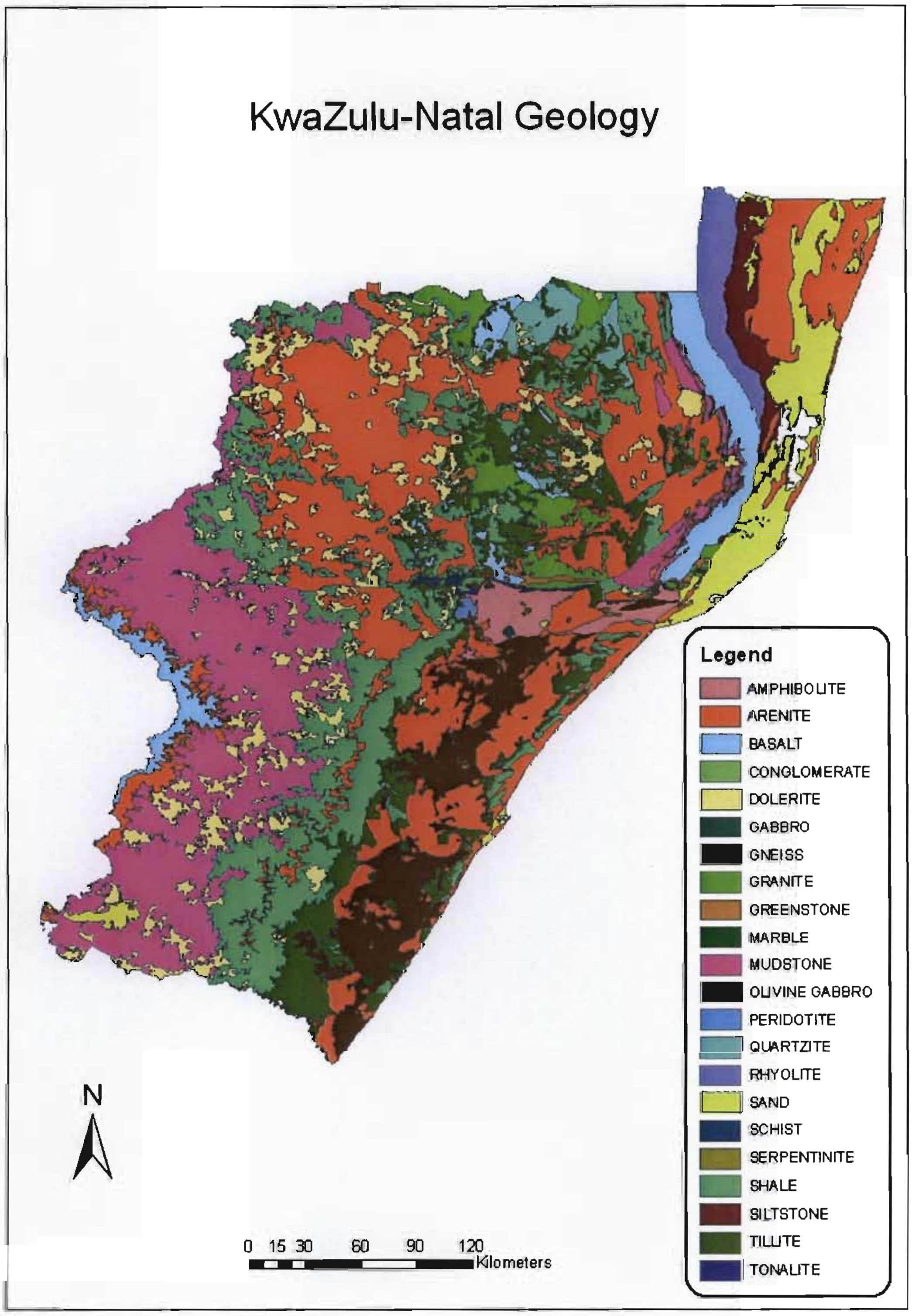


Figure 6: Simplified geological map of the province showing the distribution of the major lithologies (from N. Poona, 2008)

The catchment of the Mfolozi River comprises of rock sequences ranging from the basement granites and schists of Archaean to Quaternary unconsolidated sediments of the coastal plain and estuary (Cooper, 1994). These major units outcrop in north-south bands are up to 20 km wide and sub-parallel to the coastline

3.3 Location and general characteristics of the individual estuaries selected for the study area

Previous studies in the area have typically focussed on one or two estuaries with the exception of Begg (1978) who provided a comprehensive review of the status of the estuaries of KZN. His review is now close to three decades old and an updated review is urgently required, particularly in view of the recent rapid rate of coastal zone development in this province.

This study is one of the few that focuses on 8 estuaries (10%) of KwaZulu-Natal particularly combining the impacts in the catchment areas as well as in the estuaries themselves. The eight estuaries were selected based on relative importance in terms of size, human utilization, accessibility, and the availability of information from prior research.

3.3.1 The Mfolozi-St Lucia Setting

The combined Mfolozi-Msunduzi and St Lucia estuary complex is situated on the border of the Zululand coastal plain of KwaZulu-Natal, South Africa. Although the Mfolozi /Msunduzi and St Lucia are unique, discrete systems, their mouths often join to form a common estuary mouth (Cooper, 1994). Under such conditions the combined estuary is located at 280 24' S; 32^0 25' E, approximately 245 km north of Durban.

The Mfolozi-St Lucia system is highly dynamic. The entire system or large parts of it may change drastically in the course of catastrophic floods or above average discharge periods following extensive hinterland rainfall. Pillay (1996) notes that catastrophic flood events such as Cyclonie Domoina in 1984 and the September 1987 cut-of low floods have yielded such high discharges that large volumes of sediment in the estuary and surrounds have been scoured and flushed offshore and new mouth positions created for the Mfolozi further south of the combined mouth position. Pillay (1996) highlighted that the Mfolozi mouth position has been artificially relocated on several occasions since 1952 by anthropogenic intervention in the system. In these situations, the Mfolozi mouth may be located between one and two kilometres south of the St-Lucia mouth.

3.3.2 The St Lucia System

The St Lucia is situated on the coastal margin of the Zululand Coastal Plain, occupying a position between 27^0 52' S to 28^0 24' S and 32^0 21 E to 32 ^{0} 34' E (Begg, 1978). Lake St Lucia has a surface area fluctuating between 420 and 215 km^2, depending on lake levels (Begg, 1978). St Lucia is recognised as the largest lake-estuary and has a reputation for its fishing and bird life. The lake has a mean depth of less than 1m. Lake St Lucia comprises two north-south-trending bodies of water, False Bay and St Lucia proper, with a connecting strait known as Hell's Gate. Estimates of the St Lucia catchment area vary from 8900 km^2 to 9065 km^2 (Pillay, 1996). Lake St Lucia is connected with the Indian Ocean by a 21 kilometre long channel known as The Narrows. Tidal effects penetrate 14 km up the Narrows and thus the St Lucia Estuary is the seaward 14 km of the Narrows (Cooper, 1994).

The freshwater supplied to the lake is derived from rivers, rainfall, and from groundwater seepage along the eastern shores. The estimates of the St Lucia catchment as mentioned above contribute a mean annual discharge of 287 x $10^6 m^3$ to the lake. The most important river, the Mkuze, supplies more than 80% of the fluvial input to the lake. The Mkuze River is intercepted on its way from the north-west towards the lake by the extensive Mkuze swamp covering an area of 120km^2 (Pillay, 1996).

The other significant rivers flowing into the lake from the west are the Mzinene, Hluhluwe, Nyalazi and Mpate (Wallace, 1975; Begg, 1978; Pillay, 1996).

Figure 7: The combined Mfolozi/St Lucia Estuarine system. The St Lucia system curving to the north (with the town of St Lucia nestling in the arm of the first major bend known as Honeymoon Bend. The Mfolozi System in the south with the main river is meandering off to the west and a minor tributary (although wider due to tidal effects), the Msunduzi River flowing in from the south. (Photograph provided by A. Singh, CSIR).

3.3.3 The Mfolozi River and Estuary

The Mfolozi River is situated in northern KwaZulu Natal and flowing from the lower Drakensberg across the southern Zululand coastal plain, has the second largest catchment area in Natal after the Tugela River (Cooper, 1994). The size of the Mfolozi catchment approximates 10 000 km^2 (Pillay, 1996). The Mfolozi has a river length of 395 km and bifurcates into two large tributaries, the Black and White Mfolozi River, approximately 75 km upstream of its mouth. Both rivers rise in the northwest portion of the catchment but at different altitudes. The White Mfolozi rises on the Skurweberg Plateau at an altitude of 1 620 m above sea level (a.s.l.), 20 km northwest of Vryheid and the source of the Black Mfolozi is the slopes of Mount Mnyati (1 524 m.a.s.l.) 20km north of Gluckstadt.

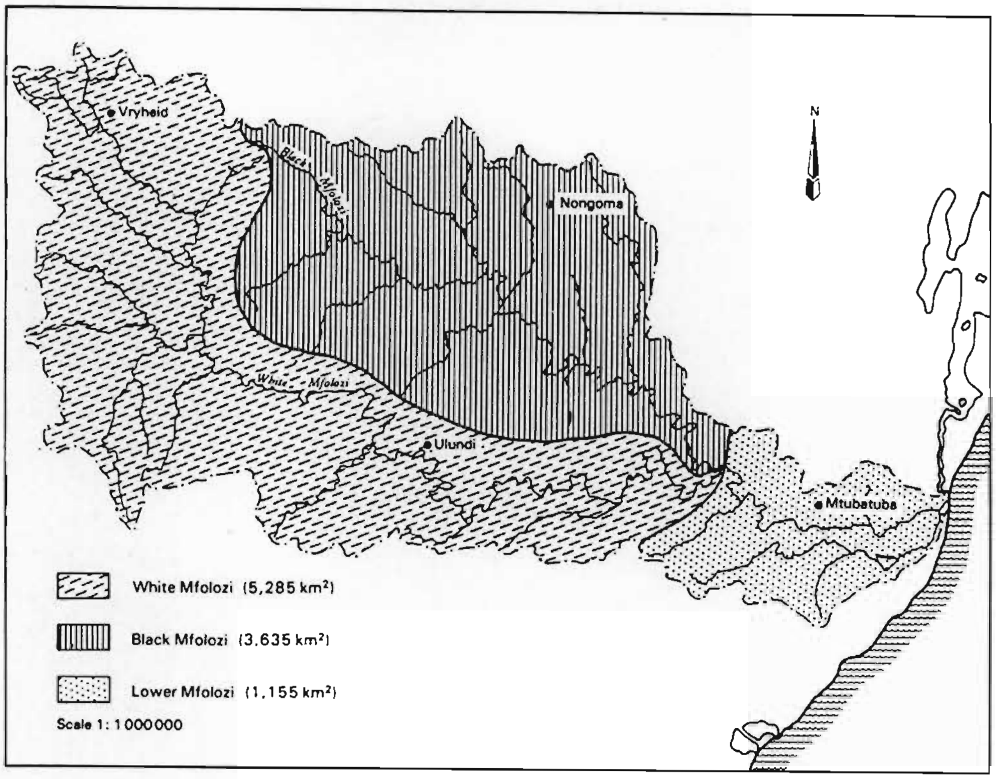


Figure 8: The Mfolozi River, its catchment area, main tributaries and, the Mfolozi Flats (after Pillay, 1996)

Stream-flow of the Mfolozi is extremely erractic with average winter flows being as little as 3 m^3 s^{-1} and average summer flows being 63 m^3s^{-1} (Begg, 1978; Orme, 1974) whilst extreme events such as Cyclone Domoina in 1984 are capable of delivering in excess of 16500 m^3 s^{-1} (Wright & Mason, 1993). Mean annual runoff estimates vary from 1060x 10 $^6m^3$ (Chew and Bowen, 1971) to 746x 10^6m^3 (Hutchinson, 1976). Discharge data collected by Pillay (1996) at six gauging stations in the Mfolozi catchment suggest a mean annual runoff of 887x 10^6m^3 although this is very highly variable (Pitman 1980; Begg, 1984). Perry (1986), for instance, calculated a monthly coefficient of variation of 218% for the Mfolozi River discharge.

Unlike rivers south of the Tugela that do not encounter a coastal plain, the Mfolozi River flows across the Zululand coastal plain between Mtubatuba and Maphelane on the coast, a distance of approximately 30 km. The floodplain of the Mfolozi in this area is known as the Mfolozi Flats (Figures 8).

The length of the Mfolozi Estuary varies from 5.5 km (when the mouth combines with the St Lucia Estuary) to 3.5 km (when the mouth is situated at Maphelane). Previously the St Lucia and Mfolozi estuaries shared a common mouth but currently, due to protracted low rainfall in the catchments, the mouths of both systems have been sealed off from the marine environment and from each other by massive sediment deposits (Figure 9).

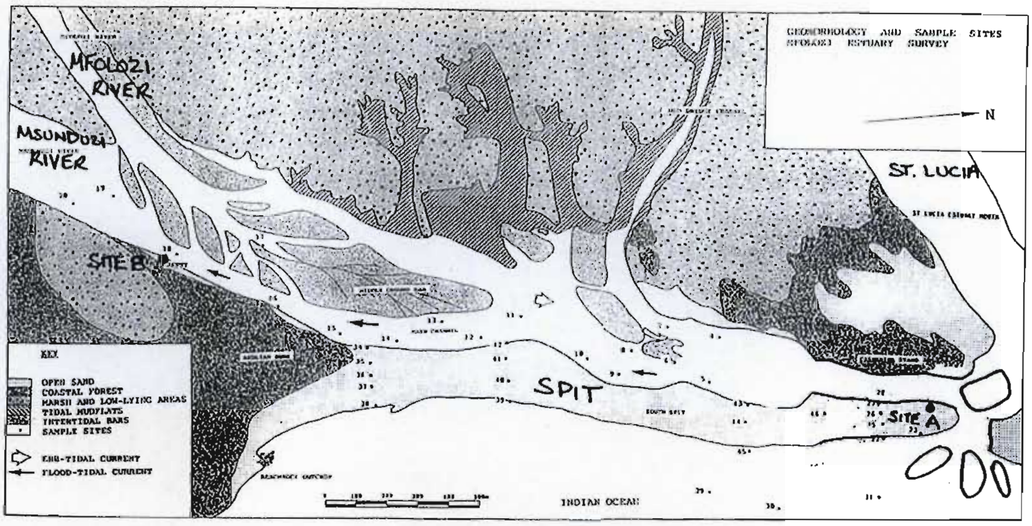


Figure 9: The Mfolozi / St Lucia estuarine complex under combined mouth conditions and showing the main morphological units (after Pillay, 1996)

3.3.4 The Mvoti System

The location of Mvoti is 29^0 24' S; 31^0 21' E. and its accessibility to the road is about 80 km north east of Durban. The catchment of Mvoti covers the area of 2700 km^2 with a river length of 215 km. The only major tributary is the Hlimbitwa River. Mean annual run-off is betwen 134 x 10^6 m^3 and 461 x 10^6 m^3 (Begg, 1978).

Figure 10: The Mvoti floodplain and the estuary under closed mouth conditions. Note the backfill and expansion of the lagoon behind the sand spit.

Figure 11: The Mvoti estuary under open mouth conditions. (Figure 10 and 11 provided by A. Singh, CSIR).

The Mvoti system assumes a character of its own and has a different plant community composition from any of the other systems (Cooper, 1991; Begg, 1978). The system has been in-filled by sediment, the bed level of the Mvoti lies above sea level and in this condition it is atidal (Begg, 1978). Since the Mvoti drains a fairly large catchment, a constant flow of fresh water during the rain season normally maintains the mouth in an open condition.

3.3.5 The Zinkwasi System

The location of Zinkwasi estuary is $29^0$16'S; $31^0$27' E and its accessibility to the road is about 90km north east of Durban. The main national road (N2) is 7.8 km away. Secondary roads lead down to the edge of the lagoon at several places on the southern bank

There is a road bridge across the upper reaches of the lagoon, 2.5 km from the mouth. Zinkwasi lagoon is one of the longest in KwaZulu-Natal, as it stretches out approximately 7.5 km inland (Begg, 1984).

Figure12: The Zinkwazi estuary and its catchment. It has one of the longest lagoons in KZN (Photograph provided by A. Singh, CSIR).

Figure 13: The Zinkwazi estuary and part of its catchment. In the figure above, it is clear that much of the catchment is used for agriculture; the figure below shows the town of Zinkwazi on the left bank of the estuary. (Photograph provided by A. Singh, CSIR).

3.3.6 Mngeni

The Mngeni River has the fourth largest catchment of the 67 rivers which discharge into the Indian Ocean along the KwaZulu-Natal coast (Orme, 1975; Begg, 1978). The Mngeni River rises in the foothills of KwaZulu-Natal Drakensberg and discharges into the Indian Ocean at Durban. Estimates of the Mngeni catchment area vary from 4385 to 5850 km^2 (Begg, 1978). The Mngeni estuary is situated 5.5 km north of Durban Harbour. It is funnel shaped and subject to tidal salinity fluctuation in its lowest 2.5 km (Cooper, 1994).

Beachwood Creek, a small tidal tributary which runs southwards parallel to the coastline for about 2 km, connects with the Mngeni system near the estuary mouth. The mangroves at Beachwood form extensive stands in the middle and upper reaches of the Creek and strips in the lower reaches.

Figure 14: The Mgeni estuary (Photograph provided by A. Singh, CSIR).

The Mngeni-Beachwood estuary developed as a barrier island complex and the present-day Beachwood Creek is the remnant of a former coastal lagoon that has progressively reduced in size since 1860 (Cooper, 1994). Reduction of the lagoonal area was due to progressive downstream spread of mangroves from the upper reaches of the Creek and the sporadic development of washover fans from the beach (Cooper, 1994).

3.3.7 Isipingo

The location of the Isipingo estuary and lagoon is 30^0 00'S; 30^0 57'E. The system lies approximately 21 km south-west from the centre of Durban and is easily accessable by road (Cooper, 1994). Various roads provide access to both banks of the lagoon, the most convenient being those leading to the southern bank. On the entrance to the southern limb of the lagoon, there is a small road bridge, providing access to the Isipingo Island Hotel (Orme, 1975; Begg, 1978). At the head of the lagoon (on the northern limb) a major road bridge crosses the system.

The Isipingo system has an area of $44km^2$ although this is variable due to size changes during flood or drought periods. River length is 27km and the mean annual runoff is $3.34x10^6$ m^3 (Goodman, 2000)

Figure 15: Isipingo estuary (Photograph provided by A. Singh, CSIR).

3.3.8 The Amanzimtoti estuary

The Amanzimtoti estuary is located within the Greater Durban Metropolitan Area but at its southern extremity. It is situated at 30^0 04'S 30^0 53'E. The Amanzimtoti River flows through and forms the southern boundary of the town of Amanzimtoti (Goodman, 2000). By road the Amanzimtoti lagoon is 31km south west of Durban. Almost any point of the lagoon is accessible due to the complex of secondary roads on both banks. Access to the northern bank is the easiest (Goodman, 2000). About 84.2% of the catchment area is human influenced and it comprises the Umlazi location and Amanzimtoti Mission reserve (DEAT, 2000).

Figure16: Amanzimtoti estuary (Photograph provided by A. Singh, CSIR).

3.3.9 Mkomazi

The Mkomazi River is one of the largest rivers of the province and it usually flows and enters the Mkhomazi estuary which has a grid reference of about about 30 degrees 12 minutes S and 30 degrees 49 minutes E (Begg, 1978). Begg (1978) gives the meaning of the word to be either "the river of the cow whales" or "the great whale river". Begg (1978) suggests that the estuary was so named because it was here that "Africans saw whale cows suckling their young". By road, the Mkomazi estuary is 49 km south west of Durban. Provision for vehicular access to the mouth has been made on the southern bank, but elsewhere (except at one sport on the northern bank) the estuary is relatively inaccessible, except by boat (Pillay, 1996). A railway line runs along the southern bank to the South African Indusrtial Cellulose Corporation (SAICCOR) factory.

Figure 17: The uMkomazi estuary (Photograph provided by A. Singh, CSIR).

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This chapter outlines the sampling methods and analyses used in the study.
This research with its focus on the KZN estuaries is an interdisciplinary study involving a combination of environmental, geomorphological, anthropogenic and policy management considerations. This necessitated the adoption of a number of information/data gathering methods which are described here.

It is important to note that several difficulties had to be overcome during the field surveys. Considerable distances had to be covered in the course of the field surveys as the total distance from St Lucia to the Mkomazi estuary is about 200 km. Each field survey thus lasted for approximately four weeks. During the first 2-weeks of the survey, the estuaries north of Durban were tackled, and in the subsequent week the estuaries south of Durban. Two seasonal surveys were conducted in all estuaries:

September 2004 (reconnaissance survey of all estuaries)
December 2005 (summer);
July 2006 (winter);
September 2006 (spring) Mfolozi/ St Lucia field survey,
January 2007 (summer)
July 2007 (winter)

In addition, other difficulties included the presence of crocodiles and hippopotami in the Mfolozi and St Lucia estuaries; the generally low water levels in some estuaries and the difficulty of accessing sampling sites due to rough terrain, thick muds or dense vegetation overgrowth. These problems forced the abandonment of the use of multiple sampling points or fixed traverse lines. Samples were therefore taken at/near the mouth, mid-estuary and the upper limit of the estuaries. Effort was put into finding the most easily accessible points during the reconnaissance survey and these were fixed by Differential Global Positioning System (GPS). Despite logistical problems, every effort was made to sample at the same sites on subsequent surveys

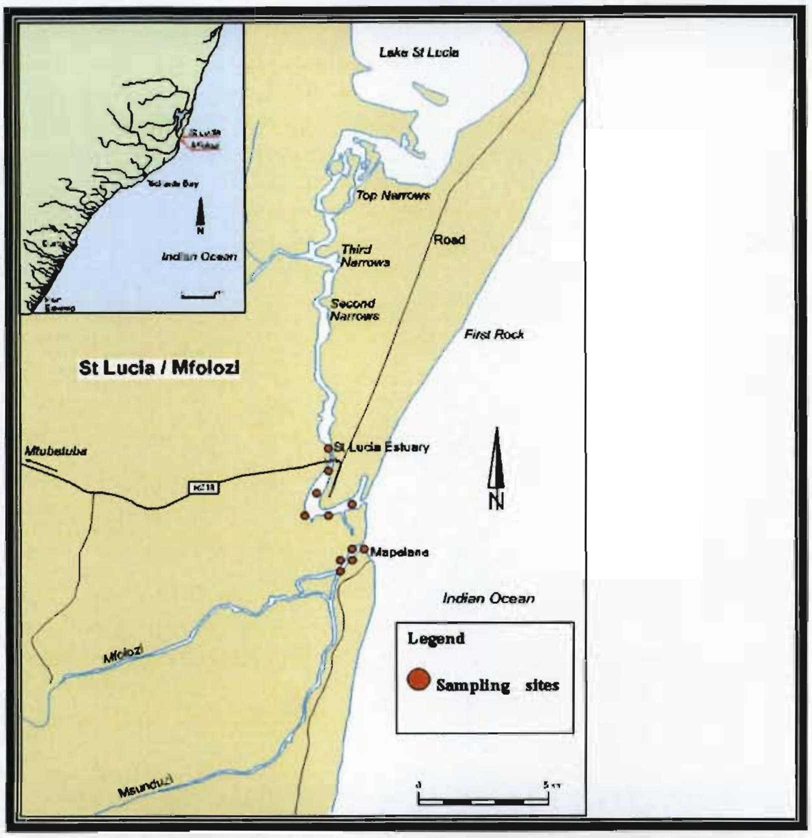


Figure 18: Map of the St Lucia and Mfolozi estuaries showing the location of the sampling points.

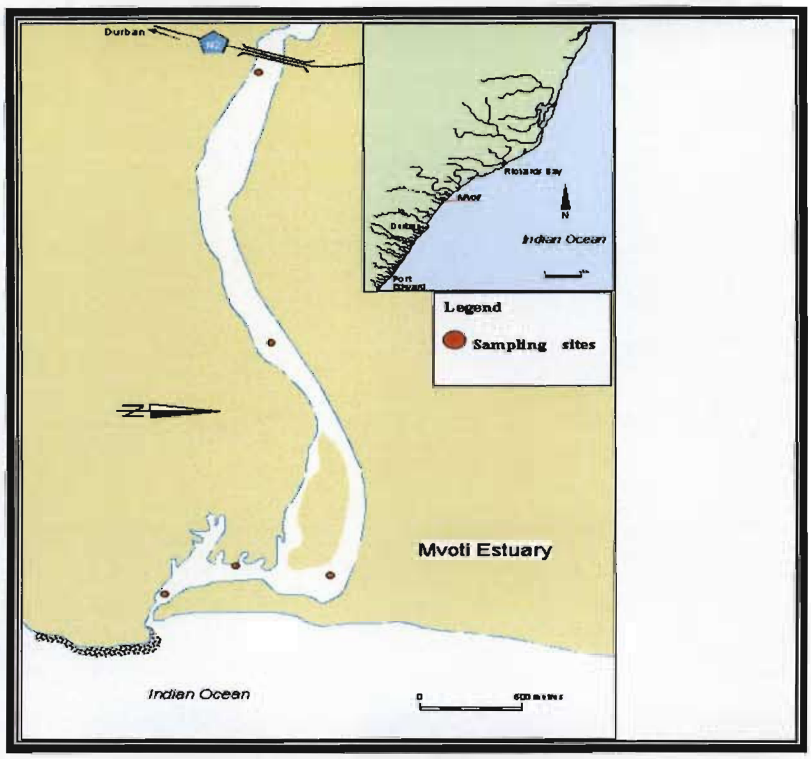


Figure 19: Map of the Zinkwazi estuary showing the location of the sampling points.

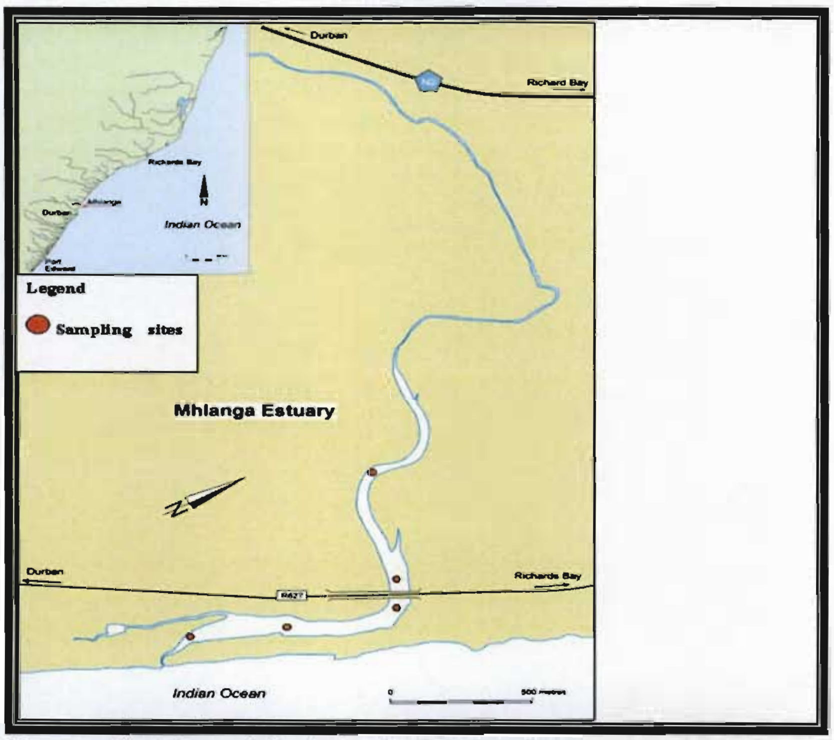


Figure 20: Map of the Mvoti estuary showing the location of the sampling points.

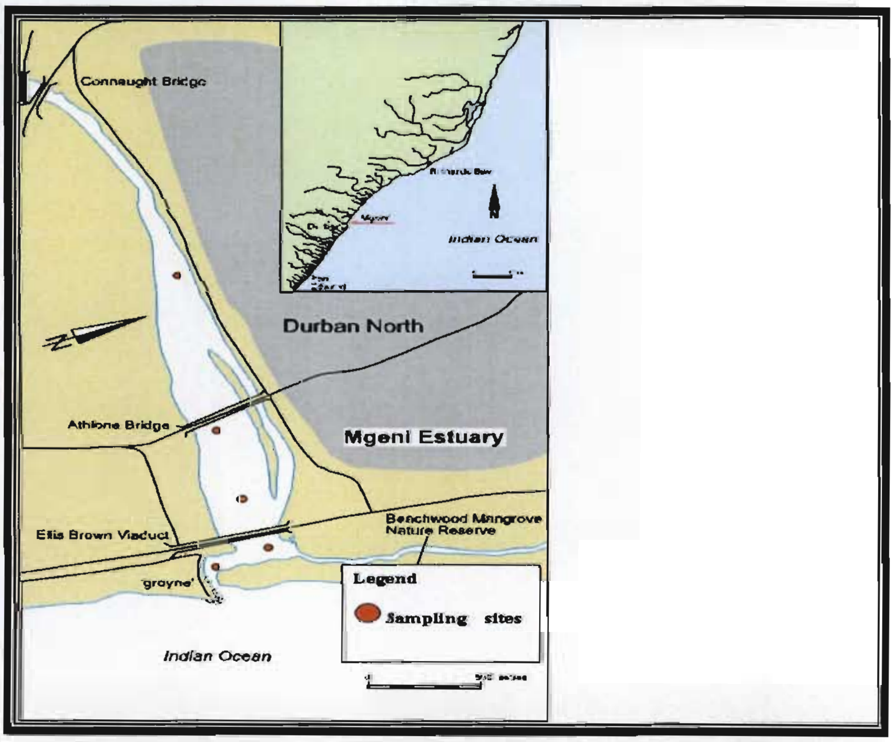


Figure 21: Map of the Mngeni estuary showing the location of the sampling points.

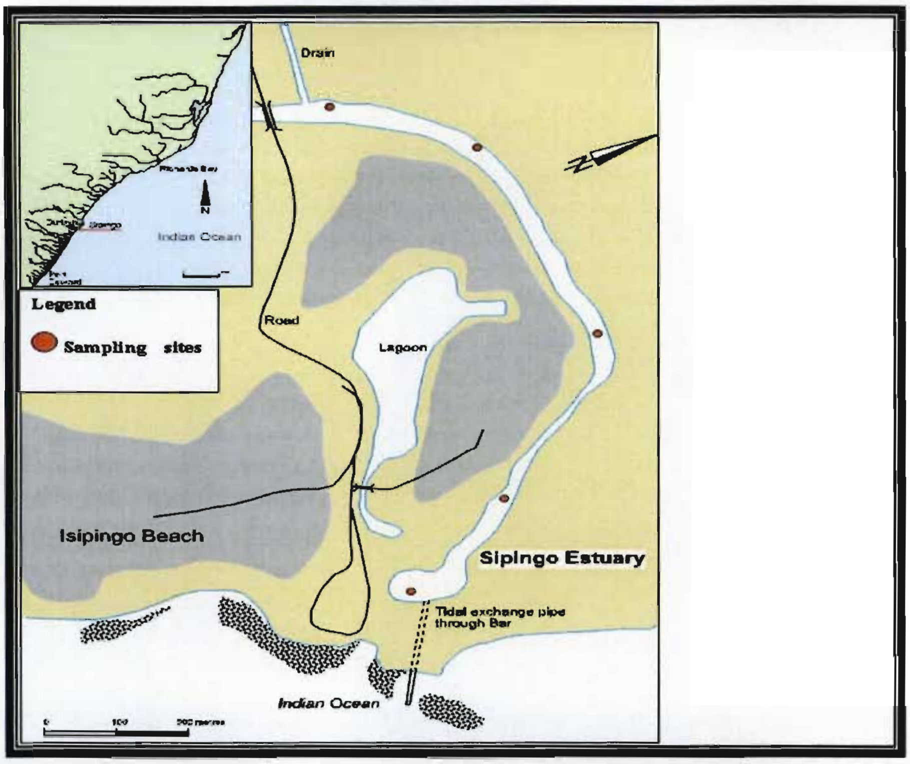


Figure 22: Map of the Isipingo estuary showing the location of the sampling points.

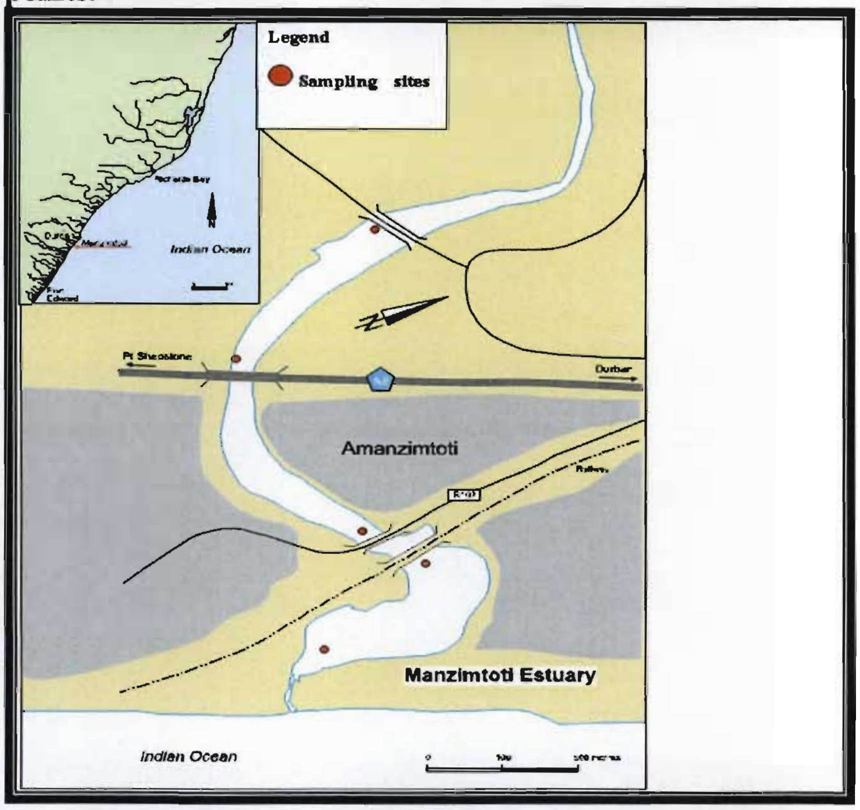


Figure 23: Map of the Amanzimtoti estuary showing the location of the sampling points.

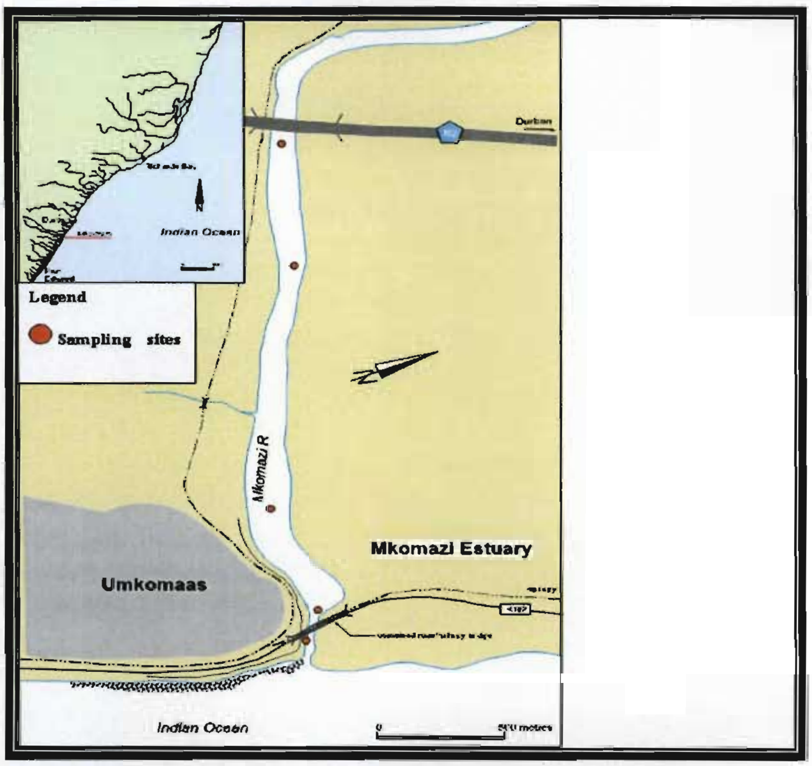


Figure 24: Map of the Mkomazi estuary showing the location of the sampling points.

4.2 Field surveys/ Data collection

The eight estuaries were surveyed seasonally between December 2005 and July 2007. An initial reconnaissance survey was conducted in September 2004, during which sampling sites for each of the estuaries were chosen, fixed by GPS (Global Positioning System) and marked on aerial photographs and topographical maps. During the subsequent seasonal sampling surveys a number of parameters were measured in the field and sampling was conducted at these sites. Since no floods occurred during this time, it was possible to pinpoint the sampling sites accurately for the successive surveys. For each estuary, five sampling sites were chosen, approximately equally distributed from the mouth to the middle to upper reaches. The sampling sites and broad physiographics of the estuaries are shown in figures 17 to 21. Note that for all estuaries, sampling sites are numbered uniformly from the mouth (Site 1) to the head of the estuary (Site 5).

During each of the seasonal surveys and at each site, the following measurements / samples were taken:

- Water sampling
- Sediment sampling
- In situ measurement of water quality parameters using the YSI 6920 water quality meter visual observation of water quality
- Mapping of morphological features
- Mapping of land uses

4.2.1 Water sampling

Sterile 500ml glass sampling bottles were used for all collections, as every sample would be subjected to microbiological examination, and thus the requirement to avoid contamination. The sample bottles were submerged into the stream to a depth of approximately 20 cm, the same at every location, the required volume (100% of volume of sample bottle) attained and the bottles sealed and stored on ice. The sample bottles were filled to volume negating oxidation or chemical reactions in the samples attributed to the presence of atmospheric oxygen.

Figure 25: Setting up for water sampling in the Mvoti estuary.

- Each sample bottle was accurately labelled to indicate the GPS position at which sample was taken, sample number, time taken and depth of sample. Each sample position was fixed using a GPS. On subsequent surveys, samples were taken as close as possible to the original GPS fixed positions. On completion of sample collection, samples were transported to the eTekweni Water laboratory for analysis. Some of the samples were analysed at the Water and Wastewater Research Laboratory at the Durban Institute of Technology (DIT) (now known as Durban University of Technology, DUT). It was of utmost importance to transport the samples immediately to the laboratory, as secondary (chemical) changes in the samples may produce erroneous results. During the latter part of 2006, an accurate, multi-parameter environmental monitoring system and water quality meter, the YSI 6920 model, was made available for this study and this reduced costs tremendously as readings could be taken *in situ* in the field. This 6-series environmental monitoring system is normally intended for use in research, assessment and regulatory appliance applications.

Figure 25 below shows the YSI meter used in this study and Figure 26 shows the researcher deploying the instrument in the Isipingo estuary.

Figure 26: The YSI 6920 multi-parameter environmental monitoring system.

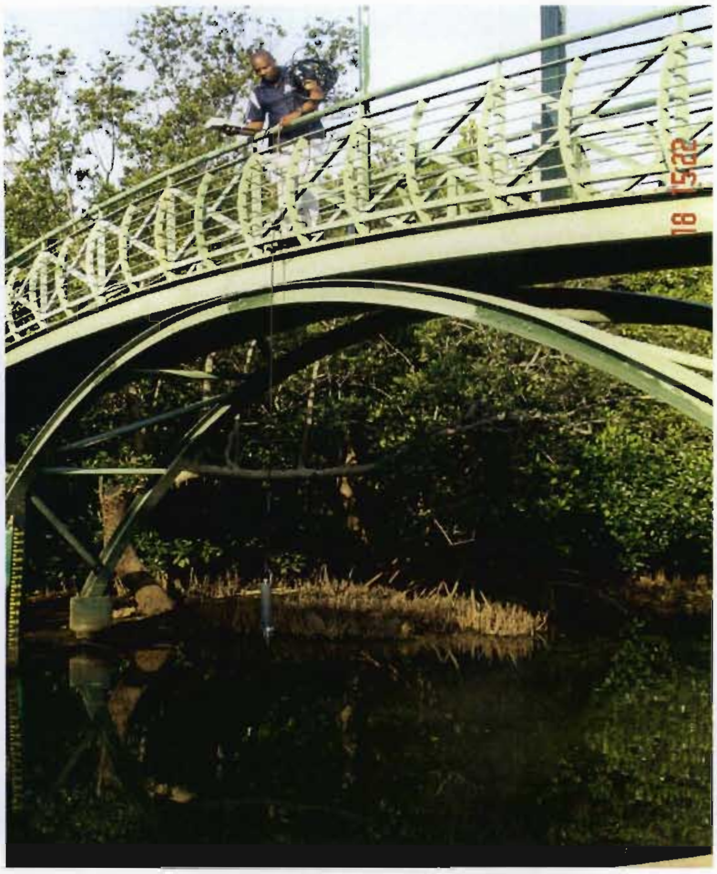


Figure 27: The researcher deploying the YSI 6920 meter in the Isipingo estuary.

4.2.2 Water Quality

Samples to determine water quality for estuaries were analysed in the eTekwini Water Laboratory as well as by Dr Gengan of Durban University of Technology (DUT). Although the scientific results of samples for water quality were not the same, they never the less reflected a multitude of physical, chemical, ecological and biological interactions. Every sample was subjected to microbiological examinationThis is demonstrated by continuous accumulation, circulation, and transformation of energy and matter through the medium, as well as aquatic biota and their activities. This dynamic balance is frequently upset by human activities resulting in pollution, which manifests itself as a fish kill or offensive odour and taste. Sedimentation also showed evidence of anthropogeninc intereference as most of the grain size of deposits especially in those estuaries which were highly contaminated and polluted was slight big and consisted of course material. Sampling of water in determining its quality was executed and achieved through many reconnaissance surveys for result validity.

According to Gray (1994), since water is a good solvent there is an almost endless list of materials which could be present in a particular sample. The relevance of choice of various water quality parameters depends upon the nature of the water or wastewater and its actual or potential use. There are three basic types of characteristics which are of importance. These include:

4.2.2.1 Physical Characteristics

These are properties which are often apparent to the observer and include such parameters as colour, taste, odour, temperature and suspended solids, etc. (Gray, 1994).

4.2.2.2 Chemical Characteristics

Alkalinity, hardness, organic content, nutrients, dissolved oxygen, inhibitory and toxic compounds comprise the category of chemical characteristics (Gray, 1994). The ten parameters measured for the estuaries of the study were Ammonia, Chloride, Conductivity, Diffused Oxygen, Nitrates, pH, Salinity, Total Dissolved Solids (TDS), Temperature and Turbidity.

4.2.2.3 Biological Characteristics

Tchobanoglous and Schroeder (1985) noted that natural waters normally form a balanced ecosystem containing micro-organisms such as bacteria, protozoa and algae which in turn provide food for fish and other higher life forms. They further contend that wastewaters can contain large numbers of micro-organisms, particularly bacteria and are potentially hazardous because of their connection with water-related diseases and hence the disposal of partially treated or untreated wastewaters into natural systems poses particular hazards for the natural biota. As a general rule, it is common for blanket determinations of biological populations to be determined from samples although on occasion individual species may be identified (Tchobanoglous and Schroeder, 1985). Microbiological contamination of water is measured utilizing either membrane filtration or multitude fermentation tests that provide an indication of the number of fecal coliforms organisms present in a measured volume of sample, typically 100ml (Revelle & McGarity, 1997). The latter technique was used in this study to determine the extent E. Coli and faecal contamination in selected estuaries.

Figure 28: Sampling in the St Lucia estuary. Note the herd of hippopotamus in the top right corner of the photograph.

The bottom of the pipe was then positioned in a suitable container (20L bucket) and the rubber bung slowly removed to allow the trapped sample to be gradually released into the bucket. In this way it was possible to retrieve fairly undisturbed cores of up to 50 cm depth of the estuarine bed. A section of the top 20 cm of the core was then spooned into pre-prepared sampling bottles, which were then properly labelled and stored on ice for transport to the laboratory. This method of sediment sampling was used at all estuarine mouths. Where possible, sediment samples were also taken at various locations of the subaerially exposed parts of the channels, mudflats, bars, flood-tidal and ebb-tidal deltas.

4.4 Aerial photos

All estuaries studied using available aerial and oblique photographs. Where possible, time series analysis of changes to the estuarine environment was conducted from past photographs. In most cases it was difficult to trace and obtain historical photographs and information regarding estuarine changes was gleaned from recent photographs and from published data.

These photographs were obtained from a variety of sources *inter alia* the Durban Metro, the C.S.I.R., Air Survey Co. and from published sources, duly acknowledged.

A complete set of aerial photographs covering each individual estuary studied was obtained via Mr. A. Singh (previously with CSIR, Durban); a second set was obtained via the internet at Google Earth.

These enabled the determination and mapping of broad land use zones adjacent to the estuaries and the changes that have occurred in these land uses over recent time. Oblique angle photographs taken by the researcher and similar previously obtained photographs allowed for the study and mapping of morphological features of the estuaries and, the riparian vegetation. In addition, in the course of site visits, the researcher photographed and made a visual survey of the mangrove swamps prevalent at some of the estuaries (St Lucia, Mfolozi, Mvoti, Umgeni, Isipingo) to assess their physical condition.

4.5 Data analysis

4.5.1 Laboratory Analysis of water samples

Examination of water in the laboratory (Raju, 1995) provides information regarding the presence and concentrations of the varying impurities in water. Water analysis is essential as it provides an indication of the quality of the water; a measure of the waters' self-purifying capacity and, the extent to which it can withstand pollution. Generally though, water is analysed to determine the content of various chemical substances, the concentrations of which may be compared to critical limits as established by recognised authorities (e.g. the Water Research Commission in SA or some international standard). Should the concentration of a given chemical substance exceed the given critical limit, then this substance may be considered a pollutant.

For purposes of this investigation, the samples collected were analysed for the following:

- pH
- Nitrates
- Ammonia
- Chloride

- Total Dissolved Solids
- Conductivity
- Temperature
- Salinity
- Diffused Oxygen
- Turbidity

4.5.2 Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)

At the laboratory the water samples were chemically analyzed with the use of the Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). According to Walsh (1997) and Skoog *et al.* (2004), the ICP-AES is presently acknowledged as a common method and technique for the analysis of elements. ICP-AES is one of the most commonly used methods in geochemical analysis, and Skoog *et al.* (2004) explains its feasibility whilst Walsh (1997) states that it is unproblematic and easy to utilize. The atomic spectra of the elements being determined was measured by the ICP-AES (Walsh, 1997, p.41). With regards to atomic spectra, different atoms emit and absorb different electromagnetic waves, at their specific and distinctive wavelengths. This enables the analyst to examine specific elements, without chemically separating them (Walsh, 1997). The ICP-AES was utilized, instead of other methods, based on the following reasons. Firstly, the ICP-AES allows the "sequential or simultaneous multi-element capability over large calibration ranges" such as "from parts per billion to parts per million". Additionally, Robinson (1990) in Stoeppler (1992), states that the ICP-AES is a multi-element method, due to the fact that large orders of magnitude can be noted. Secondly, it contains minimal flame interferences. Thirdly, it produces reproducible data or results. Finally, the ICP-AES has a high sensivity (Walsh, 1997: Stoeppler, 1992). Walsh (1997) asserts that the ICP-AES is the chosen method for the analysis of major and minor trace metals in geochemistry. It tests the samples in a solution form and is able to detect several elements at the same time, and is easy to set-up. ICP-AES can be used for water, rock, soil and mineral analysis (Walsh, 1997). The radiation within the ICP-AES is caused by flames, plasmas or sparks, and there are several transitions that occur (Stoeppler, 1992).

According to Skoog *et al.* (2004), the instrumentation and sectors of the ICP-AES is inclusive of the nebulizer, radio frequency supply, plasma, wavelength isolation device, transducers, signal processing and the computer system.

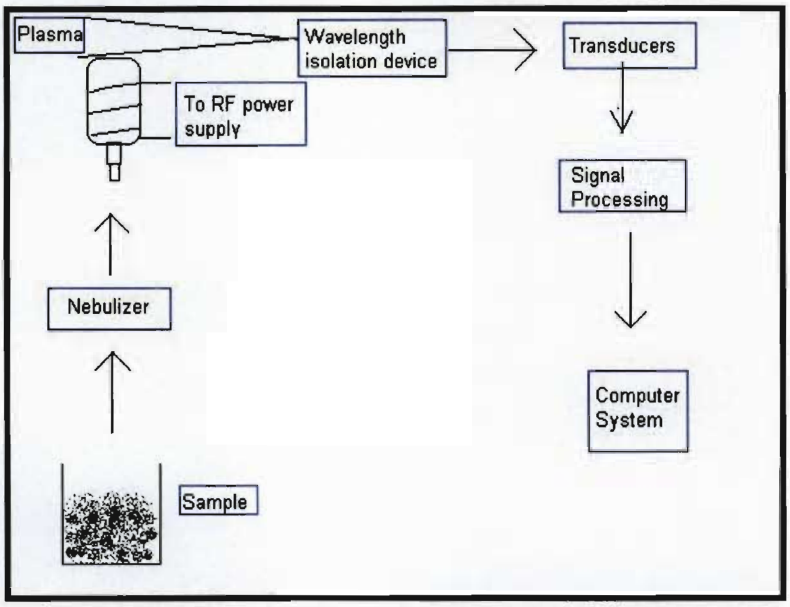


Figure 29: Instrumentation and process of the ICP-AES (Redrawn from Skoog *et al.* (2004) by Ahmed, 2006)

According to Walsh (1997); the three main components of the ICP-AES instrument are as follows:

- Source unit or the ICP torch,
- Spectrometer and
- Computer.

These components each have different functions. The source unit is responsible for the provision of the energy in order to produce the emission spectral lines. The spectrometer separates and resolves the emission spectral lines, as well as measures their strength. The computer, allows the analyst to convert the signal into a numerical value or measurement, of the concentrations of the specific elements being analyzed (Walsh, 1997). According to Stoeppler (1992), the spectral lines, especially those generated from heavy elements, are regarded as highly complex, and several lines are dependent on the excitation temperature. Skoog *et al.* (2004), explain that the initial and most important step, in any atomic spectroscopic methods includes the process of atomization. Atomization is a procedure in which the sample is volatilized, and is therefore modified into gas phase atoms or elemental ions (Skoog *et al.*, 2004). Furthermore the temperature of atomization within the ICP-AES method ranges from 6000°C to 8000 °C (Skoog *et al.*, 2004).

Therefore, there are several steps and procedures involved in the ICP-AES, ranging from the sample preparation to the actual process within the instrument (Walsh, 1997). Once the analysis of the sediment is completed, the concentrations of several elements, in this case, heavy metals would be generated. The ICP requires that the elements are to be analyzed in solution. An aqueous solution is preferred over an organic solution, as organic solution requires special manipulation or transformation prior to it being placed into the ICP. Solid samples also discouraged as clogging of the instrumentation can occur (Skoog *et al.*, 2004).

The light emitted by the atom of an element in the ICP, this must then converted to an electrical signal that can be measured in a quantitive form (Walsh, 1997). This method is accomplished by resolving the light into its component radiation and then measuring the light intensity with a photomutipler tube at the specific wavelength for each element line (Stoeppler, 1992). The light emitted by the atoms or ions in the ICP is converted to electrical signal by the photomultipler in the spectrometer instrument. Thereafter the intensity of the electron signal is compared to previous measured intensities of known concentration and a concentration is input into the computer database. Each element used in this procedure will have many wavelengths in the spectrum, which could be used for analysis (Skoog *et al.*, 2004).

4.5.3 Sediment analysis

From each sediment sample, sub-samples of approximately 1 kg were taken and thoroughly mixed. This sub-sample was then split into 2 equal parts for textural and organic matter content analysis. Both parts (A and B) were oven dried overnight at 110 ^{0}C in order to remove moisture. Sub-sample A was weighed, then placed in a 1000 mL beaker and treated with hydrogen peroxide before being allowed to react overnight. The sub-sample was then dried again and the reweighed to determine the percent organic matter content.

Sub-sample B was wet sieved through a 63 μm screen to remove the mud (clay) fraction which was then determined as a dry weight percent. The remaining mineral matter was again dried and sieved through a set of screens (2mm; 1mm and 0.2mm which allowed for the determination of the percent gravel, coarse sand, mediun sand, fine sand and silt.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Introduction:

This chapter focuses on a discussion of the results of the field surveys and laboratory analysis conducted; and also includes broad discussion of the findings of the study. Since several estuaries make up the study, the researcher has found it convenient to organize the presentation systematically per group of characteristics per estuary studied. The chapter commences with descriptions of the general sediment characteristics of the eight estuaries as these were similar to all estuaries studied. Each estuary is discussed thereafter in terms of its morphology and dynamics followed by physical and chemical characteristics and, anthropogenic impacts.

5.2 Sediment characteristics of the estuaries studied

Consistent with most marine coastal environments, sediments in all the estuaries reseached are sourced from aeolian, fluvial and marine action and also through chemical and biological action. The wide range of morphological features existing at at any given time in these estuaries is dependent on the volume, characteristics and movement of sediment. Sediment movement in water is accompanied by the organisation of grains into a range of bed-forms. Experimental results from flow channels have shown that a number of existing bed-forms are stable only between certain values of flow strength. Bed-form states occupy distinct fields on plots of flow strength against grain size. For example, various bed states develop in a fine sand bed as flow strength is gradually increased. Therefore, an influencial factor in the control of process and response in the complex estuarine environment is the volume, type of movement and distribution of sediment.

Since most of the sediment characteristics are generally similar as shown above for the most estuaries of the study area, they are described in general here and, where appropriate, particular bedforms encountered at individual estuaries are mentioned in more detail.

5.2.1 Coarse gained sediment

5.2.1.1 Gravel

The coarsest sediment occurring at all the estuaries is gravel (>2mm diameter). The overall percentage composition of the gravel fraction is minimal (< 1%), comprising rounded to well-rounded quartz and rounded shell fragments (as viewed under the stereoscopic microscope). The gravel is found as a lag deposit on the old flood-tidal delta (Mfolozi/St Lucia; Umgeni; Mvoti), and is generally made up of sediment that has been reworked into the estuary from the offshore environment. It is evident that very little to no gravel emanates from the landward side except during flood events. The remaining gravel in the estuaries is found as deflation lags on the spits that occur across all mouths. These deposits are clearly visible especially where the finer sand has been winnowed out by the wind.

5.2.1.2 Sand

Only small amounts (<1%) of coarse sand (diameter > 0.50mm) were countered in the estuaries studied. Medium sand (diameter of 0.25 to 0.50 mm) makes up the bulk of marine sand. The catchment-derived sand is dominantly fine and very fine (diameter <0.25mm), apart from a lobe of medium sand associated with bar deposits found in the upper part of the Mfolozi estuary and on the deltaic deposits within the Umgeni estuary. Sand is transported throughout the estuaries by water and wind and includes reworked fluvial, aeolian, lagoonal-estuarine and marine sand. The sand fraction therefore forms 4 different populations:

- catchment-derived sand;
- aeolian sand deposited on the spit and in the estuary by north/ south prevailing winds blowing;
- marine sand deposited on the sand barriers/spits by the flood tide;
- bank erosion of the dune cordon and surrounding estuarine deposits

TABLE 3: Percent textural composition of sediments from the eight estuaries

			GRAIN SIZE (mm)			TOTAL
SITE	GRAVEL (>2)	COARSE SAND (1 –2)	MED SAND (0.5-1)	FINE SAND (0.2–0.5)	FINES (<0.2)	
St Lucia	0.2	4.3	38	30.3	7.2	100
Mfolozi	0.5	3.3	43	31.2	22.0	100
Mvoti	0.37	9.28	59.88	25.23	4.14	100
Zinkwazi	0.2	5.7	54	33.5	6.6	100
Mngeni	0.6	11.7	40.7	37.1	9.9	100
Isiphingo	0.9	5.7	45.6	35.2	12.6	100
Amanzimtoti	0.7	3.7	47.3	38.7	9.6	100
Mkhomazi	0.9	4.1	52.6	35.6	6.8	100

In the St Lucia/Mfolozi mouth area, historical data from previous researchers Lindsay et al, (1996) Pillay et al, (2003) indicate that during open mouth conditions, medium-grained marine sand would enter the estuary on the flood-tide and build emergent flood-tidal deltas which were typically dominated by flat-topped straight-crested dunes. Prior evidence from these workers also shows that medium-grained sand was carried further up into the Mfolozi and St Lucia estuaries on the flood tide. During the course of this study, the mouths of both esturies were well sealed off from the sea by a massive sand barrier. Consequently, the researcher was not in a position to corroborate the findings of the latter mentioned workers.The central portions of both estuaries is dominated by fine sand whilst the mudflats on the western banks of Mfolozi and the head of the St Lucia estuary contain mainly very fine sand.

The sediment of the central portions of the Mfolozi, Mvoti, Umgeni, and Umkomaas estuaries contained high proportions of medium and fine grained sand with some sections exhibiting a dominance of fine sand. This coarsening may have resulted from increased aeolian input or, in some instances, a recent change in the character of fluvially derived sediment. Observations by Wright (1990) in the St Lucia estuary indicate that most sand is transported upstream as quick pulses when spring high tides coincide with storm swells. This has occurred across the province during June 2007 when stormy climatic conditions coupled by storm swells caused massive erosion and sediment transport into estuaries.

5.2.1.3 Mud

Fine sediment (silts and clays) can modify the flow of water through density and sedimentation effects and can transport pollutants through adsorption (Pillay, 1996). Acoording to Harrison *et al*, (2000) the entire area of all the estuaries studied, except for the barrier environment and a small area of the flood tidal deltas was found to be dominated by mud. Rivers transport muds from the catchment and upon reaching saline water, suspended clays flocculate out of suspension and are deposited. Sedimentation accumalation also occurs through trees, logs, reeds and other matter brought down the catchment during floods (Gray, 1994). It is important to note that significant mud deposits occur in estuaries which have high erosion losses. Typically this occurs in catchments degraded by poor management such as the Mfolozi.

5.2.2 Influence of wind on sediment transport

Highest SPM was recorded in the Mfolozi ($3.7gL^{-1}$), September 2006, when very strong northeasterly winds caused much turbulence in the estuarine waters. On the other hand, December 2005 sampling period, which was fairly calm, showed uniformly low SPM levels in all estuaries.

It was clear from all sampling periods that wind induced surface wave turbulence was a major factor in re-suspending bed muds and grossly increasing the turbidity of the estuarine waters. Accordingly, whilst this needs to be taken into account for comprehensive management policy considerations, the norm appeared to be that calm conditions prevailed for most of the year. However, given long term wind data for the coastal zone of KwaZulu-Natal, it is important that this should be factored into any long-term model of impacts on estuarine waters.

5.3 Morphometry and specific characteristics of the estuaries studied

5.3.1 St Lucia / Mfolozi system

5.3.1.1 Morphometry of the St Lucia System

The St Lucia system displays great seasonal variation. The mean depth of both the lakes and the estuarine systems is less than 1m (Begg, 1978). The Narrows are 0.5m to just over 2m deep and average depths in the estuary recorded during this study was 0.74m. Rainfall in the catchment fluctuates between 650mm and 1200mm although extreme events may result in extreme flooding (Begg, 1978). Over the past decade, the St Lucia estuary has been closed by considerable volumes of marine and aeolian sand and all attempts at re-opening the mouth has failed (Harrison *et al*, 2000). At its widest point the barrier environment is over 425m wide. The sand deposits at the mouth have developed dunes of variable sizes from a few metres up to 4m amplitude (Lindsay *et al,* 1996). Some dunes have characteristic barchan shapes but all have been observed to be extremely mobile (Lindsay *et al*, 1996). They form and dissociate under strong north-easterly and south-westerly winds. The system is therefore highly dynamic and displays monthly, seasonal and annual variations. The Natal Conservation Service and St Lucia Wetlands Authority have tried, unsuccessfully, to breach a mouth for the St Lucia on several occasions (DWAF, 2000). It would perhaps be better to wait for natural events to take its course and, should there be a catastrophic event such as a cyclone or sufficiently stormy seas coupled with heavy and prolonged rainfall in the catchment, the mouth would be breached naturally with no cost implications (DWAF, 2000).

Tidal flats within the estuary have become stabalized by vegetation and bed sediments comprise of thick accumulations of fluid mud. The old flood tidal delta within the estuary has also become vegetated and as the water has receeded, it has become one continuous feature with the north bank (Lindsay *et al*, 1996).

Figure 30(a): above showing a well formed barchan dune on the barrier environment of the St Lucia mouth and the vegetated flood tidal delta within the St Lucia estuary below Figure 30(b)

5.3.2 The Mfolozi Flats

In its pristine condition the Mfolozi Flats constituted a major wetland capable of absorbing vast amounts of flood derived sediments (Cooper, 1991). Begg (1984) noted that agriculturalization of the Flats began in 1927 with the construction of a network of narrow canals with artificial levees to aid drainage and prevent over bank flooding. However this also caused a lowering of base level and the local water table and, increased subsidence (Van Heerden and Swart, 1986). Agriculturalization of the Flats reduced its buffering and filtering capacity and its function as a sink for fluvial sediments (Cooper *et al*, 1991). Warner's Drain, constructed in 1937, straightened and shortened the river course and linked it directly to a large meander on the Msunduzi River (a minor tributary of the Mfolozi) approximately 2 km from the present mouth (Cooper, 1991). This resulted in the direct advection of large volumes of sediment to the combined Mfolozi/St Lucia estuaries, exacerbating the problems of excessive siltation, prolonged mouth closure, estuarine degradation and severe ecological stress within the estuaries and the St Lucia system.

Intensive sugarcane farming on the Flats in the period 1940 to 1950 led to a massive influx of sediments to the estuary causing rapid shallowing and closure of the combined estuary in April, 1951 (Heydorn, 1973). This untenable situation forced the artificial diversion of the Mfolozi mouth 2.3 km to the south at Maphelane in 1952.

Nevertheless, this diversion still impacted negatively on the St Lucia system by cutting off the supply of fresh water to the St Lucia Estuary (Boyd *et al*, 2000). Also, prior to human intervention in the Mfolozi Catchment and estuaries, the relatively clean waters of the Mfolozi scoured much of the accumulated sediment from the St Lucia Estuary and helped maintain the open mouth status of the combined estuaries. Closure of the St Lucia mouth thus became increasingly persistent and forced the institution of an expensive dredging programme to maintain an artificial connection to the sea (Boyd *et al*, 2000).

5.3.3 The Mfolozi Estuary

The Mfolozi estuary lies immediately to the south of the St Lucia estuary and its length varies between 3.5 km (when its mouth is located at Maphelane (Figure 9) to

5.5km when its mouth is located adjacent to or linked with the St Lucia system (Fig10) (Cooper, 1994).

Allanson *et al*, (1999) note that the Mfolozi estuary is separated from the sea by a well formed marine barrier that may reach a length of 2.3km. The barrier witdth varies from approximately 50m to over 175m (field measurements). The average depth of the estuary is approximately 0.72 meters although other researchers have reported greater depths during higher flow conditions (Allanson *et al*, 1999). Extensive mudflats are found on the north bank of the estuary and several subaerial mud deposits (middle ground bars) are found in the upper part of the estuary just before it bifurcates into the Mfolozi River proper and its minor tributary, the Msunduzi River (Cooper, 1991).

5.3.4 The Mfolozi /St Lucia Estuary

Under pristine conditions prior to 1927, the combined Mfolozi-St Lucia estuary remained open for the greater part of the year from December to July (Kriel *et al.,* 1966). Closure generally occurred during August to November. The earliest maps published in 1879 and 1884 (Kriel *et al.,* 1966) reveal that the Mfolozi flowed in a northerly direction and discharged its waters at Honeymoon Bend. Croft's survey (1905) showed that this confluence subsequently split into two forks, both of which migrated seaward and over time, the western fork was abandoned (Figure 3).

Van Heerden and Swart (1986) confirmed that all early surveys and maps indicate a central location for the combined estuary with a shallow arm extending north behind the north spit. These authors postulate northward mouth migration during periods of flooding. After the flood-derived nearshore sediment supply diminished, the mouth would re-establish in a more normal, central position, forced by wave overwash erosion processes and tidal scour. Mouth closure during such low flow periods would have encouraged deposition of fine grained sediment in the estuary and forced freshwater up the estuary into Lake St Lucia (Barnes, 1996). This freshwater input diluted the lake waters and delayed or prevented the onset of hyper-salinity conditions. Floods in the Mfolozi and St Lucia catchments subsequently scoured out the estuary giving rise to a cycle of flooding, opening of the estuary by flood and tidal scour, followed by sediment deposition and mouth sealing (Allen, 1991).

Allen (1991) noted that anthropogenic intervention in the system has caused dramatic changes in the combined system's sedimentation patterns. Sediments advected directly across the Flats in artificially constructed channels have caused heavy siltation, prolonged mouth closure, estuarine degradation and severe ecological stress (Barnes, 1996).

5.3.5 Mfolozi Mouth Mobility

During floods, a new mouth position for the Mfolozi is usually established naturally when the flow is sufficiently strong to breach the spit at a point close to Maphelane (Barnes, 1996). Under natural conditions, the northward longshore drift current causes a gradual build-up of the south spit and a northward migration of the Mfolozi mouth until it eventually joins the St Lucia Estuary (Cooper, 1991). A net northbound longshore drift transport rate of 1 x $10^6 m^3$ has been calculated for this area by Van Heerden & Swart (1986). Consequently, the migration rate of the Mfolozi Estuary mouth may be fairly rapid (rates of 300 m yr^{-1} were measured from aerial photographs) depending on the intensity of the drift current and the available sediment supply.

5.3.6 Water Quality

The water quality of the St Lucia and Mfolozi estuaries was measured in September 2004; December 2005 and June 2006. At this time the morphology and sediments of the systems were also assessed. The water quality of the other estuaries was studied in 2005/6 and 2007. The time difference and number of variables measured resulted from funding and logistical difficulties encountered by the researcher. For this reason, the water quality of the St Lucia and Mfolozi systems are discussed first and the more comprehensive data for the other estuaries follows. It is important to note that the water quality of the Mfolozi and St Lucia estuaries is assumed to be little affected from direct anthropogenic effects. Pollutants accumulating in the systems may come from farmlands in the case of the Mfolozi and from the town of St Lucia in the case of the St Lucia estuary. In both cases, more important negative effects are clearly due to excessive sedimentation. For this reason, only a few relevant water quality parameters were measured. These include salinity, pH, DO, temperature and nutrient enrichment.

5.3.6.1 *Salinity distribution*

Salinities in the St Lucia estuary during the study period ranged from 22 to 29%. These values are lower than those measured by previous workers (e.g. Pillay, 1996) when the St Lucia mouth maintained an open connection with the sea. In addition there has been no addition to salinity via overwash processes as the barrier environment closing off the mouth was too wide to allow for overwash to occur. Accordingly, salinity levels would not be responsible for making living conditions for estuarine biota stressful. More important may be the lack of the cycling of salinity for particular organisms and the rather low water levels.

The Mfolozi estuary on the other hand does reflect some cycling of salinity as the mouth had often been breached periodically. Salinities thus varied from freshwater to measured maximum of 30% close to the mouth. Upstream at the Maphelane jetty, salinities of 2% were encountered.

5.3.6.2 *pH*

The Mfolozi estuary demonstrated slightly higher pH levels of 7.3 to 7.7 as compared to the St Lucia system which reflected pH of 6.9 to 7.4. This may be due to the influence of nutrient enrichment of the Mfolozi system following leaching of farmlands on the floodplain.

5.3.6.3 *Temperature stratification*

Water temperatures in both systems averaged 22-23^{0}C in summer with little stratification between surface and bottom. In winter temperatures of 17-20^{0}C were measured. Although some seasonal variation was observed, it was not significant as the winters of the sampling period were fairly warm and dry.

5.3.6.4 *Diffused Oxygen*

Diffused Oxygen levels measured for this system varied between 7.1mg/L and 10.5mg/L. Thus dissolved oxygen levels in the system are generally within an acceptable range when compared to the acceptable limits for uptake by aquatic organisms (6-12mg/l; Target Water Quality Guidelines for Aquatic Ecosystem Health, DWAF, 1996). However, these guidelines are primarily appropriate for use in the freshwater environment and there is some debate regarding their appropriateness in estuaries. Dissolved oxygen levels were similar in the surface and bottom waters, confirming the well-mixed nature of the system and is related to the fact that water levels were very low during this low rainfall period when sampling occurred. The fact that there is no significant decrease in the dissolved oxygen levels in bottom waters suggests that the estuarine sediments are oxygenated and are not presently being adversely affected in any significant way, by inputs of agricultural nutrients particularly from the Mfolozi Flats area.

5.3.6.5 Turbidity

No measurement of turbidity was taken during the field visits to the Mfolozi and St Lucia sites. Also, considering the different methods used to measure the turbidity of the estuary water, no direct comparison of Begg's historical data with recent data was found. CSIR (1992) data have indicated that water in the estuary was clear, especially in the mid to lower reaches. Higher turbidity values in the upper reaches were considered normal given the river inflow bearing catchment-derived sediments. Apart from increased fluvial discharge creating high turbidities, frequent wind induced turbidity is probably responsible for much of the turbidity during normal or low flow periods. For the Mfolozi system, it has been well documented that poor catchment management and agriculturalization of the Mfolozi Flats has led to massive accumulations of mud in the Mfolozi Estuary. The accumulations here will probably only be removed offshore by an extreme cyclonic event such as Cyclone Domoina of 1986.

5.3.6.6 Nutrient Enrichment

It is to be expected that since much of the Mfolozi Flats is under sugarcane agriculture, some enrichment of the estuarine waters is to be expected. Data from this study showed that nitrate levels averaged 1.2 mg/L. In terms of eutrophication of the estuary and the consequences for aquatic biota, it would appear that there is some enrichment due to agriculture but this requires much more study. The St Lucia estuary showed low values for nitrates (0.03mg/L)

5.3.6.7 E. Coli

The Mfolozi and St Lucia estuarine environments are generally considered to be fairly pristine, natural environments with minimal human impacts. Greater anthropogenic impacts are experienced in the Mfolozi catchment but the researcher assumes that much of the pathogenic effects are filtered out as the river courses through the Mfolozi Flats wetland area. In the St Lucia estary, it is assumed that pathological effects as a consequence of the location of the town of St Lucia are also minimal as the population of the town is still small and the discharge of effluents offshore.

5.3.6.8 Summary of water quality

The results of the water quality analyses revealed that salinities, temperatures, and dissolved oxygen levels were all within acceptable limits

Table 4: Summary of the Water quality for the eight estuaries

ESTUARIES								
WATER PARAMETERS	SL	M	MV	Z	UG	I	AM	MK
Salinity distribution (%)	22-29	22-29	21-24	1.77-9.5	23.4-33.56	0.77-7.75	2.8-13.33	4.7-15.51
pH	7.3-7.7	7-3-7.7	8.26-8.64	8.26-8.45	7.2-7.8	7.2-8.56	7.3-7.91	7.9-8.1
Temp (° C)	22-23°C	22-23°C	24.89-25.18°C	15.88-17.59	21.97-23.8	21.94-22.09	23.87-29.98	18.97-25.01
Diffused Oxygen (mm/ L)	7.1-10.5	7.1-10.5	6.5-9.08	6.89-7.54	5.06-5.87	3.78-7.74	5.67-6.01	6.3-7.72
Turbidity (units)	-	-	7.25-13.6	10.89-54.29	6.99-7.25	7.24-9.65	9.38-23.34	21.16-47.29
Nutrient enrichment (mg/ L)	1.2	1.2	0.61-0.72	0.71-0.75	0.61-0.63	1.32-4.54	0.041-0.53	0.02-0.94

St Lucia = SL; Mfolozi = M; Mvoti = MV; Zinkwazi = Z; Umngeni = UG; Isipingo = I; Amanzimtoti = AM and, Mkhomazi = MK.

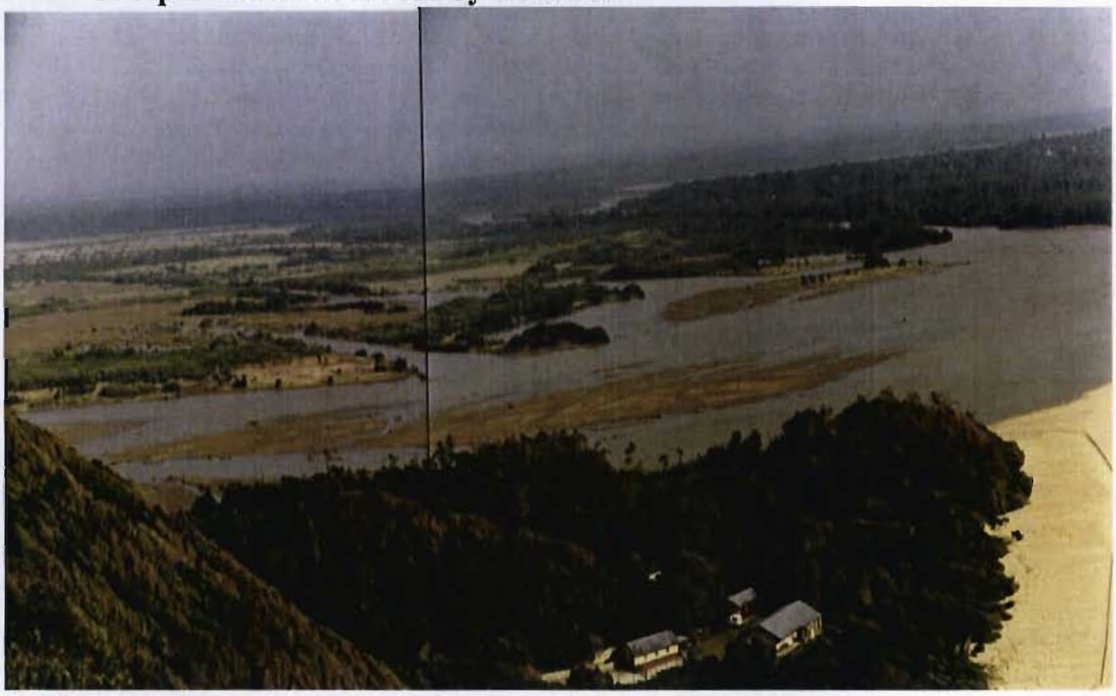
Issues of concern were the observed high turbidity and the raised nutrient levels possible due to runoff from adjacent sugar cane fields for the Mfolozi system

High turbidity in the two systems is reflective of excessive muds input from the Mfolozi catchment due to poor management and, due to the re-suspension of bed muds by wind generated, wave induced tuebulence as well as high fluvial discharges in the catchment following good rainfall.

5.3.7 Current Status of the Mfolozi St Lucia System

Over the last decade, low rainfall over the catchments of this region has led to a rapid drop in lake water levels and the mouth of the St Lucia estuary has been completely closed by marine and aeolian sand deposits. Numerous attempts have been made to re-open the mouth but without success. The Mfolozi and St Lucia estuaries have consequently been separated by thick sediment deposits and, both are cut off from the sea by massive marine barrier deposits. Recently, attempts have been made to try to link the lagoonal waters of the St Lucia estuary with those of the Mfolozi estuary and to breach a new mouth for the artificially combined systems at a point close to Maphelane where the barrier separating the Mfolozi from the sea was narrowest. The success of this endeavour was short lived as the two systems became isolated by sediment between them as levels of the water in the St Lucia dropped. It is clear that a protracted period of rainfall in the catchment areas of both systems and a catastrophic rainfall event such as a hurricane is required to move the massive accumulations of sediment at the mouths of the systems and to allow for a more continuous interaction with the marine waters. This came to pass in May 2007 when the systems breached the barriers for the first time in almost a decade.

Figure 31(a): Photograph of the St Lucia/Mfolozi system (a) St Lucia estuary above (photo by R. Taylor, 1991) and (b) the Mfolozi estuary is in the below. Both are separated from the sea by a barrier.



It is important to note that approximately six weeks prior to the winter sampling, heavy rainfall was experienced over all the catchments studied. This has led to leaching and flushing of nutrients from natural, undisturbed environments but has led to particularly heavy chemical loading of certain nutrients into the estuarine waters from farmlands and rural settlements.

5.4 The Zinkwazi Estuary

5.4.1 Morphology of the Zinkwazi Estuary

The Zinkwazi is generally regarded as a fairly pristine estuary with a nearshore sandy beach that is backed by a dune cordon which is well vegetated (Achtzehn, 1991). The estuarine embayment is normally fairly wide and shallow and a relatively short marine-built sand barrier separates it from the marine environment (Boyd *et al*, 2000).

At the time of the study, the Zinkwazi estuary was calculated to cover an area of 18.75 ha. This of course, would change as the tide changes during open mouth conditions. The estuary has a length of approximately 5 km and a shoreline length of 8.7 km (calculations from aerial photograph).

There is little natural riprarian vegetation as development on the south bank extends to the water's edge and, on the northern bank, sugarcane agriculture uses all available land. At the first bend of the estuary, a small patch of natural vegetation survives and a thin line of dune forest extends northward and separates the beach from the sugar plantations behind (Whitfield, 2000).

Figure 32: The Zinkwazi estuary. The town of Zinkwazi is located on the south bank, the elongate barrier environment; the open mouth condition of the estuary; the estuarine embayment and the agriculturalization of the catchment. (Photograph by Singh, CSIR)

The lower reaches of the estuary is an "apparent stable" system although the extent of the water body of the estuary is gradually narrowing probably due to gradually diminishing fluvial input (CSIR, 1981; Achtzehn, 1991).

Aside from the loss of the channel around the northern side of the original island and a decrease in width, the main channel has remained relatively stable (CSIR, 1981). During the course of this study the researcher recorded that the main estuarine width remained constant but that the mouth of the estuary fluctuated in size from approximately 2 metres to about 4 meters width depending on discharge. However, Achtzehn (1991) indicates that the decrease in mid-estuary channel width is still occurring and was attributed to a combination of encroachment of the fringing reed beds into the water body of the estuary and sediment deposition. The latter is evidenced from the fact that in addition to becoming narrower, the estuary is also becoming shallower.

The main channel of the estuary immediately west of what was previously an island, had decreased from being approximately 6m deep in the 1930's to less than 1m deep in 1981 (CSIR, 1981) and approximately 0.8m from field surveys of this study.

Depths recorded in the lower course of the estuary in 2006 ranged from 0.10 to 2,3m. Scouring to depth may occur on strong ebb flows, particularly following mouth breaching.

5.4.2 Water quality

A composite of the water quality parameters measured is presented in Table 4 and Figure 32 below:

Table 5: Water quality of the Zinkwazi Estuary for the 5 sites sampled:

	sample 1	sample 2	sample 3	sample 4	sample 5
Ammonia (S) (µg/L)	0.92	0.89	1.21	1.08	0.77
AMMONIA (W) (µg/L)	2.46	2.48	2.77	2.69	3.02
CHLORIDE (S) (mg/L)	0.12	0.13	0.12	0.03	0.03
CHLORIDE (W) (mg/L)	0.05	0.02	0.09	0.10	0.14
CONDUCTIVITY (S) (mS/m)	6.92	6.77	6.34	6.78	6.24
CONDUCTIVITY (W) (mS/m)	6.83	8.41	8.59	9.95	11.75
DO (S) (mg/L)	6.19	5.87	5.91	6.06	5.44
DO (W) (mg/L)	7.43	7.31	7.33	7.24	7.54
NITRATE (S) (mg/L)	0.47	0.44	0.56	0.83	0.92
NITRATE (W) (mg/L)	0.51	0.50	0.49	0.41	0.41
Ph (S)	8.26	8.33	8.38	8.39	8.43
Ph (W)	8.46	8.44	8.54	8.59	8.64
SALINITY (S) (ppt)	9.52	6.82	3.53	2.19	1.77
SALINITY (W) (ppt)	7.87	7.43	3.36	3.09	2.91
TDS (S) (mg/L)	66.10	67.00	55.40	38.90	34.50
TDS (W) (mg/L)	84.30	72.70	67.80	51.50	49.40
TEMP (S) (°C)	24.1	24	23.5	22.4	22
TEMP (W) (°C)	17.59	17.17	16.89	16.43	15.88
TURBIDITY (S) (NTU)	54.29	61.01	58.32	48.11	10.89
TURBIDITY (W) (NTU)	18.3	19.52	20.41	15.97	14.63

5.4.2.1 Ammonia:

Ammonia in the Zinkwazi estuary was found to be below the TWQR of = 7µg/L for all sites and both seasons. There is, however, a noted increase in winter but this is probably related to the heavy rains that occurred several weeks prior to sampling which caused excessive leaching of the catchment farmlands. The fact that concentrations increase upstream also point to a catchment source.

5.4.2.2 Chloride

Acceptable concentrations of chloride were recorded during both seasons. Concentrations were much lower than the DWAF TWQR of =0.2 µg/L. The Zinkwazi is a relatively well utilized estuary, particularly for recreational purposes and it is important that concentrations chloride not exceed target limits.

5.4.2.3 Conductivity (mS/m) and TDS

This parameter measures the relative ability of the water to conduct an electrical current and is a function of the concentration of ions present in solution in the water. Conductivity levels in the Zinkwazi are, in all likelihood, influenced also by the presence of nutrients (e.g. sulphates and phosphates) but which were not measured in the field in this study. It is expected that seasonal variations in conductivity will occur as recreational usage of the estuary increases and, during heavy rains when greater concentrations of nutrients is flushed into the system.

5.4.2.4 Dissolved Oxygen availability

Lowest DO levels measured for this system was 5.44 mg/L and a high value of 7.54 mg/L was measured in the winter of 2007. Thus dissolved oxygen levels in the system are generally within an acceptable range when compared to the acceptable limits for uptake by aquatic organisms (6-12mg/l; Target Water Quality Guidelines for Aquatic Ecosystem Health, DWAF (1996) Dissolved oxygen levels were similar in the surface and bottom waters, confirming the well-mixed nature of the system. This is particularly important in the Zinkwazi system considering the potential for high nutrient accumulation.

5.4.2.5 Nitrates:

The Zinkwazi catchment is relatively small and for the most part utilized for sugarcane agriculture hence enrichment of the estuarine waters is to be expected. However, the levels recorded fall within the mesotrophic category as indicated by DWAF (0.5 – 2.5 mg/L). Evidently, pollutants from the adjacent sugarcane fields in the catchment may rapidly increase nitrate concentrations following rainfall and have the potential to create eutrophic conditions in this perhed estuary.

The CSIR recorded some enrichment during early 1992 with slightly elevated phosphorus and nitrate levels. The ranges of nitrates were 0.010-0.091mg/l; soluble orthophosphate was 0.050-0.090 mg/l. It would thus appear that over a period of 15 years there has been some enrichment due to agriculture and from anthropogenic sources in the town of Zinkwazi as well as increasing tourist usage of the estuary and this requires monitoring by managers of the system.

5.4.2.6 pH

The pH of the estuary water is mildly alkaline with values ranging from 8.26 to 8.64. This situation is reflective of the high nutrient content and TDS of the system. It is important that regular flushing of the system occurs to reduce the potential for long term damage to the biota of the system.

5.4.2.7 Salinity distribution

Due to the elevation of the bed of the estuary being above sea level there is a resultant strong outflow of fresh water when breaching occurs leading to the entire system becoming essentially fresh water. However, past records and conversation with residents indicates that this rarely occurs. Injections of saline water occurs due to wave overwash which result in the incorporation of some sea water into the system thus increasing salinity levels slightly.

There was a slight increase in salinity from the lower to the upper reaches of the estuary (9.52 ppt to 1.77 ppt) with no significant differences between the bottom and surface layers. It was noted during the field sampling that some saline water become trapped in deeper pools further upstream within the estuary embayment yielding high salinity measurements.

5.4.2.8 TDS

The DWAF general limit for TDS is 200 mg/L (DWAF, 1996). TDS is a measure of the organic and inorganic matter that is dissolved in the water. Obviously, increased pollutants in the water will yield higher values of TDS as is the case for the Zinkwazi. The TDS readings ranged from just above 34 mg/L to above 84 mg/L and are well within the DWAF limits.

5.4.2.9 Temperature

The Zinkwazi system is a fairly shallow system and no thermal stratification was detected at the time of sampling. Average temperatures of 23.2°C measured in summer and 16.79 °C in winter confirming that water temperatures are strongly seasonal.

5.4.2.10 *Turbidity*

Waters of the Zinkwazi estuary were fairly clear with Turbidity values ranging from 61.01 NTU to 14.63 NTU. During the sampling period, aeolian effects were minimal but this may not be the case during strong wind conditions as the generated turbulence would easily re-suspend bed muds in this shallow estuary and thus increase the turbidity which may have detrimental effects for biota.

5.4.2.11 *E. Coli*

E.Coli was not recorded in this study but it is worth mentioning that prior researchers have determined that the main water quality problem associated with the Zinkwazi estuary is the high levels of *E. Coli* that have consistently been recorded both in the upper and lower reaches of the system (e.g. Begg, 1978, Cooper,1991). The CSIR recorded far lower counts in the upper reaches (< 19 per 100 ml) in 1992, which were within the target water quality range of recreational use (100 per 100ml; (DWAF, 1996). These studies indicate that contamination of the estuary is a serious health hazard particularly to the increasing numbers of people who bathe in its waters. Although there was no much questioning that occurred during sampling but many young swimmers from the vicinity were looming around and looking ignorant about the consequences of swimming in contaminated streams.

Water quality results for Zinkwazi indicate that although generally the estuary is in a physically appealing condition visually, its waters contain fairly high levels of nutrient pollutants and that levels of E.Coli may also be a serious problem and efforts need to be made to limit or decrease the potential for eutrophication.

It has been observed also that the Zinkwazi estuary is very popular with tourists and is becoming increasingly heavily used particularly during vacation periods. However, site visits conducted during *off peak* times confirmed that even during these times, a considerable number of people visit the area.

The heavy utilization of the estuary by tourists and locals from the town of Zinkwazi which is situated directly on the south bank of the estuary places much pressure on the water quality of the estuary. The very high *E.Coli* counts create a serious health risk to tourists.

The last field visit confirmed that the mouth was closed by a sand barrier and no attempt has been made by the town authorities to breach it. This is because there is little need to as boats may be easily launched directly into the surf.

5.5 The Mvoti estuary

5.5.1 Morphology of the Mvoti Estuarine System

Brijlal (2004) notes that the Mvoti estuary is a typical bar-built estuary that has a southward extending spit (Plate 13) that may completely seal off the estuary from the marine environment during low fluvial flow periods. The barrier or spit is just over a kilometer in length and is a marine feature built by longshore drift accretion.

Figure 33: (a) A low oblique aerial view of the Mvoti estuarine system looking inland from the sea.

Figure 33 (b): A high oblique aerial view over the Mvoti estuary. (Photographs by Singh, CSIR)

From aerial photographs it is calculated that the estuarine area covers approximately 18.04 ha and has a length of 2.4 km. The shoreline length is approximately 3.0 km (Cooper, et al, 1991). The estuarine catchment is dominated by sugarcane agriculture although thick reed beds comprise most of the riprarian vegetation particularly on the west bank of the estuary making access very difficult (Cooper and Mason, 1991). Natural riprarian vegetation extends along both banks for approximately 2.3 km upstream of the estuary and appears in fairly good health (Begg, 1984). This vegetation provides a natural habitat for a wide variety of fauna including a variety of bird species. Beyond the riprarian vegetation extends sugarcane plantations. The south bank of the estuary mouth comprises an outcrop of dolerite rocks which, due to its resistance to erosion, has formed a minor headland around which approaching waves refract (see Plate 13 above). This has resulted in the soft sediment north bank to be indented and the sand barrier to the north is curved inward due to the resultant refracted wave approach enabling the spit to grow southwards across the mouth during times of low fluvial flow (Boyd and Dalrymple, 1992).

The maximum depth of the estuary during field surveys was 1.5 m and this depth was encountered at the scour point on the main bend of the system just upstream of the mouth where the main flow of the Mvoti undercuts the bank. The average depth of the system during the course of this study's survey was 0.8m. The Mvoti floodplain in the vicinity of the estuary has a very low declivity and is prone to flooding. Access and sampling was made very difficult by the thick reed beds that occur in this vicinity.

According to Morant (1993), during winter a northward spit may form closing off a section of the estuary and resulting in a lagoon forming. Occasionally the north spit is bulldozed due to risk of cane being flooded. This is of particular importance, as mouth closure will result in an even lower outflow rate and a rapid concentration of pollutants within the estuary. The estuary is already in a state of degradation and the impact of the low volumes of outflow will adversely affect the system. During low outflow conditions the effluent released into the river remains unmixed and undiluted for majority of the downstream movement. This results in high biological oxygen demands due to the extensive deoxygenation of the instream habitat (Morant 1993).

5.5.2 Water quality

Much of the pollutants present in the Mvoti estuary can be traced back to anthropogenic sources located in the upstream floodplain and further in the densely populated hinterland of the catchment. On the floodplane are located major industries – sugar milling and paper-pulp manufacturing from wood.

Table 6: Water quality of the Mvoti Estuary for the 5 sites sampled:

	sample 1	sample 2	sample 3	sample 4	Sample 5
Ammonia (S)	1.08	2.09	2.13	3.12	3.49
AMMONIA (W)	2.45	3.41	3.28	4.59	6.86
CHLORIDE (S)	359	412	348	365	355
CHLORIDE (W)	1628	987	515	503	432
CONDUCTIVITY (S)	78.7	63.9	97.1	51.3	34.7
CONDUCTIVITY (W)	45.5	56.5	39.8	22.0	16.5
DO (S)	5.58	4.8	4.2	4.54	5.2
DO (W)	4.86	4.56	4.41	4.2	4.16
NITRATE (S)	6.2	5.4	4.6	3.7	2.8
NITRATE (W)	11.0	9.5	8.0	8.0	9.4
Ph (S)	7.7	8.3	8.19	8.26	8.44
Ph (W)	8.02	8.02	8.06	8.31	8.38
SALINITY (S)	1.1	0.9	0.88	0.7	0.3
SALINITY (W)	2.34	2.41	1.65	0.93	0.45
TDS (S)	535.31	408.28	630.07	381.65	276.11
TDS (W)	308.8	376.76	267.11	148.48	91.76
TEMP (S)	23.51	23.2	24.51	24.46	24.89
TEMP (W)	17	17.66	17.81	18.087	19.86
TURBIDITY (S)	20	20.5	19.5	19.3	20.1
TURBIDITY (W)	32.9	34.01	34.43	41.09	48.53

5.5.2.1 Ammonia:

Levels of ammonia in the Mvoti have deteriorated since the summer sampling from acceptable to levels that are close to the limit of the TWQR of = 7µg/L. It is important that ammonia levels be closely monitored in this notoriously polluted estuary. Apart from contributions from industry, it is likely that upstream sugarcane farms draining into the Mvoti contribute significant amounts of ammonia following fertilizer applications.

5.5.2.2 Chloride:

The levels of chloride was extremely high and far exceed the DWAF TWQR of =0.2 µg/L. Summer values for chloride range from close to 350 µg/L to over 400 µg/L whilst winter values range from +400 to +1600 µg/L. All of the sites measured yielded concentrations considerably higher than the Acute Effect Value of 5 µg/L. One of the major industries located on the Mvoti floodplain is SAPPI, the pulp and paper manufacturer. It is well known that this type of industry utilizes considerably high volumes of chloride used for bleaching and slimicide purposes (DWAF, 1996). Also, this particular company has recently changed part of its chemical treatment process (advertised by the company in the local newspaper) to reduce odour emissions and it would be useful to test whether this has had any adverse effect on chloride concentrations in the estuary. From the winter survey of this study (conducted after implementation of the new plant) it would appear to have resulted in increased chloride contribution to the aquatic environment. A Conversation between the researcher and some fishermen confirmed that it is useless to fish at or near the estuary because it is devoid of any fish.

5.5.2.3 Conductivity:

Conductivity is much higher for this estuary as compared to the Zinkwazi. The waters of the Mvoti estuary has always known to have high concentrations of nutrients, particularly chloride and nitrates, hence conductivity levels are high and is further enhanced by the presence of other nutrients (e.g. sulphates and phosphates) which were not measured in the field in this study. Unlike the Zinkwazi, the Mvoti estuary is generally not utilized for recreation hence variations in conductivity levels is more likely to reflect changing nutrient output from anthropogenic activity in the catchment.

5.5.2.4 Dissolved Oxygen availability

The Mvoti system is known to be highly polluted with effluents from industries located on its floodplain causing major degradation. It is not surprising that, very low levels of diffused oxygen were encountered in the system. During both summer and winter, all sites recorded levels of below the acceptable range when compared to the acceptable limits for uptake by aquatic organisms (6-12mg/l; Target Water Quality Guidelines for Aquatic Ecosystem Health, DWAF (1996). From DO levels alone, it is clear that the Mvoti Estuary is in need of attention and proper future management.

5.5.2.5 Nitrates:

The Mvoti catchment is heavily utilized. Areas of influence include large formal and informal settlements, commercial enterprises, the urban centre of Stanger, light and heavy industralization (notably SAPPI and the Gledhow Sugar Mill) and extensive sugarcane agriculture. It is therefore to be expected that since much of the catchment is being utilized that enrichment of the estuarine waters is to be expected.

Nitrate levels were higher in the winter reaching 11.0 mg/L. This concentration makes the system hypertrophic (according to DWAF, 1996). In this estuary Nitrate concentrations were several times greater than the TWQR of 0.5 mg/L. In terms of eutrophication of the estuary and the consequences for aquatic biota, it is a matter of serious concern that such increases in these nutrients have occurred and it is crucial that attention be given to alleviating the pollution of this system. The system is therefore characterised by very low levels of species diversity and fishermen in the area have confirmed a death of fish in the estuary.

5.5.2.6 pH

The pH of the estuary water is mildly alkaline with values ranging from 8.26 to 8.64. This situation is reflective of the high nutrient content and TDS of the system. If one considers that the Mvoti system has had a history of high pollutant levels from anthropogenic sources, it is important that regular flushing of the system occurs to reduce the potential for long term damage to the biota of the system.

5.5.2.7 Salinity distribution

Sedimentation in the estuary has elevated the bed of the estuary above sea level giving it perched characteristics. During low flow periods, the barrier across the estuary is easily maintained by longshore drift. However, flooding in the catchment results breaching of a new mouth which may occur at any point along the spit causing a strong outflow of fresh water due the the enhanced gradient. During this time salinity levels become very low. Some saline water trapped in backwaters may feed into the main embayment and, coupled with saline water derived from wave overwash increases salinity levels slightly (notice the low levels recorded for summer in the table above. In the winter survey there was an increase in salinity due to overwash following storm conditions. The average salinity recorded by Begg from the period September 1979 to July 1981 was 21%. With the mouth open and under normal flow conditions, it would be expected that the system would be saline in the lower reaches, and become progressively fresh towards the upper reaches of the estuary.

5.5.2.8 TDS

TDS levels were higher in summer when the mouth was closed for protracted periods. Concentrations were generally above the DWAF general limit for TDS of 200 mg/L (DWAF, 1996). In winter, much of the dissolved solids had been flushed out following stormy conditions and breaching of the barrier environment. The Mvoti estuary needs close monitoring since the potential for pollutant loading is great considering the heavy anthropogenic use of the catchment.

5.5.2.9 Temperature stratification

The water temperatures for summer indicated that the waters were fairly warm (temperatures reaching 24.89°C) whilst winter temperatures were fairly regular throughout the estuary at 17.00 to 19.86°C. No stratification with depth was encountered probably due to the shallowness of the system.

5.5.2.10 Turbidity

Highest values of turbidity were measured in the winter survey when the waters of the Mvoti appeared to be particularly muddy with a high value of 58.53 NTU recorded at the upstream station. The summer survey was conducted in calm conditions and this is reflected in lower turbidities as the water body was in a more tranquil state. Trapping and buffering of finer material by riprarian vegetation during tranquil conditions also aids in keeping re-suspension of material to a minimum. However, large inputs of material from adjacent farmlands may dramatically increase suspended material concentrations and sedimentation in the estuary.

5.5.2.11 Summary of water quality

The results of the water quality analyses revealed that while salinities and temperature were within acceptable limits, the estuary showed considerable nutrient enrichment and corresponding low levels of diffused oxygen. This has serious health implications for estuarine biota and it is something that needs urgent monitoring. It is clear that this situation has persisted for a considerable period of time and it is uncertain whether the local municipality has actually given up rehabilitation efforts altogether. Sometimes from time to time the estuary may be dredged as sulphide reduction creates nasty odours.

The Mvoti is a seriously impacted estuary. Even the local municipality and a major contributor to the pollutant levels of the estuary attest to this by virtue of the warning signs they have placed at the estuary (Plate 14):

Figure 34: The acknowledgement of the polluted state of the Mvoti estuary. Sign posted at the estuary by the local municipality and SAPPI (photograph by T. Hardev)

Visits to the estuary have confirmed that whilst visually the estuary may appear to look aesthetically pleasing, there are signs of pollution abound on closer examination. There appears to be some eutrophication of the system in that there is significant algal growth and, there are numerous sites, particularly along the riparian vegetation, of flocculated and foaming chemicals.

The barrier environment is well developed although at the time of the winter sampling, the mouth of the estuary was open. Following recent stormy weather, some erosion of the berm has occurred but marine sediment has been gradually redeposited onto the beach face.

5.6 The Mngeni estuary

5.6.1 Morphology of the mngeni estuary

The Umngeni River flows into the Indian Ocean approximately 5 km north of the CBD of Durban. The mouth of the estuary is narrow (approximately 7 m wide) but may fluctuate between 6m and 20 m depending on discharge and marine dynamics.

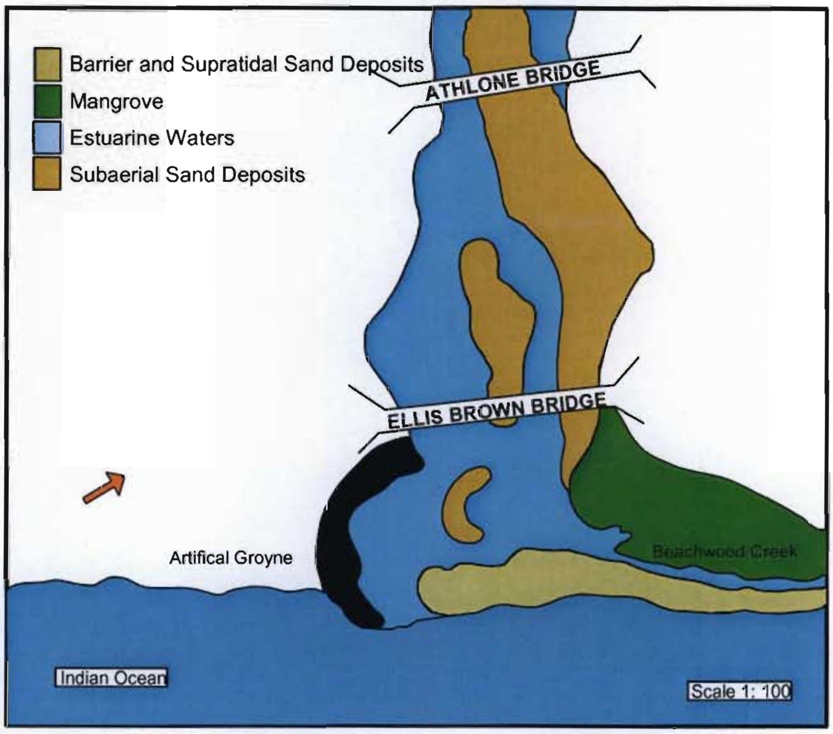


Figure 35: General morphology of the mngeni estuary (after Brijlal, 2004)

Figure 36: Low obligue photo of the Umngeni estuary (Photograph by Singh, CSIR)

The south bank is anthropogenically fixed in place by rock deposits and the impermeable road surface whilst the north bank comprises a marine built barrier environment that extends for over 700m (Brijlal, 2004). Behind this barrier environment, a large, shallow embayment is present wherein marine sand deposits predominate. Further upstream, braided sand deposits are common but ephemeral so that their shapes constantly change as flow and sediment load characteristics change. The barrier environment separates the marine and estuarine environments but overtopping of the barrier occurs during high tides and saline water may directly enter the eatuary (Pillay *et al,* 2003). This process also creates fan shaped deposits on the estuarine side of the barrier. The northern bank of the estuary is populated by a dense stand of mangroves which extend along a minor coast parallel stream known as Beachwood Creek. Prior to this study several morphological changes occurred in the estuarine environment and these played a role in the overall dynamics of the system. Due to prolonged low rainfall from February 2003, water levels in the estuary gradually declined, allowing for increased shoaling of the inlet (mouth) due to the flood dominance of the tide and through wave overwash processes (Brijlal, 2004).

Brijlal (2004) notes that as the mouth inlet began to close, venturi effects became more pronounced and allowed for the accumulation of considerable volumes of marine sand in the estuary embayment and the building up of a significantly large flood tidal delta (Figure 6.4). The mouth inlet gradually became more restricted and eventually closed completely on 20 July 2003, creating lagoonal conditions within the estuary. Catchment derived water began to dam up in the estuary embayment and most sedimentary morphological features (flood tidal deltas, subaerial deposits/ islands, back-barrier environments and beach deposits) were submerged (Figure 6.5). The National Conservation Service (NCS) decided to artificially breach open the mouth as water was backing up into Beachwood Creek and flooding the mangroves. Shortly thereafter, rainfall within the Mngeni catchment allowed for stronger fluvial flows and the re-opened mouth stabilized. This open connection to the sea has been maintained throughout winter and spring of 2004. Throughout this study period, the mouth has maintained an open condition.

5.6.2 Water Quality of the Mngeni Estuary

The table below summarizes the water quality parameters measured for the five sampling sites of the Umgeni estuary and is also presented in the graph below:

Table 7: Water quality of the Mgeni Estuary for the 5 sites sampled:

	sample 1	sample 2	sample 3	sample 4	sample 5
AMMONIA (S)	0.55	0.43	0.4	0.77	0.85
AMMONIA (W)	0.91	1.01	0.97	1.61	1.66
CHLORIDE (S)	0.08	0.09	0.08	0.08	0.07
CHLORIDE (W)	0.10	0.10	0.10	0.08	0.08
CONDUCTIVITY (S)	16.62	19.19	17.44	16.62	15.31
CONDUCTIVITY (W)	22.15	21.12	20.22	19.91	18.14
DO (S)	5.87	5.61	5.64	5.9	5.06
DO (W)	5.51	5.89	5.94	5.97	5.89
NITRATE (S)	0.63	0.74	0.68	0.57	0.61
NITRATE (W)	0.72	0.68	0.59	0.56	0.93
Ph (S)	7.8	7.8	7.1	7.2	7.2
Ph (W)	8.48	8.61	8.59	8.01	8.02
SALINITY (S)	33.55	33.34	28.93	26.11	23.4
SALINITY (W)	33.46	32.31	29.64	27.44	25.98
TDS (S)	107.6	138.7	117	106.6	103.9
TDS (W)	166.2	161.9	154.4	153.1	126.7
TEMP (S)	23.89	24.09	25.58	25.4	24.91
TEMP (W)	22.16	22.14	22	22.09	21.97
TURBIDITY (S)	6.99	23.38	18.77	18.51	42.5
TURBIDITY (W)	5.34	41.03	17.45	9.9	10.21

5.6.2.1 Ammonia

Ammonia in the Mgeni estuary is well below the DWAF limits and is good for the biota of the estuary. Previous studies (Brijlal, 1984 and others) have also found low ammonia concentrations in this estuary.

5.6.2.2 Chloride

Chloride also, was found to be in concentrations that are quite acceptable. The winter sampling was conducted in flood conditions and this may have had an influence on the slightly higher than expected values similar to those measured in summer.

5.6.2.3 Conductivity

Summer concentrations were slightly lower than those measured in winter. The water of this estuary is evidently affected by the heavy concentration of industries located on its floodplain and the heavy utilization of the hinterland catchment. The winter sampling was also influenced by the influx of sea water into the estuary at the time of sampling.

5.6.2.4 Diffused Oxygen

The lower estuary is well oxygenated as there is continual tidal flushing of the system. The narrow mouth leading to a wide embayment causes venture effects that lead to increased turbulence of the waters at the mouth and this account for high values of DO recorded at the mouth and further upstream. Winter values were only slightly higher probably due to a slight lowering of biotic metabolism in a cooler environment.

5.6.2.5 Nitrates

The Umgeni system is one of the most heavily utilized catchments in the province and may be expected to show high levels of nutrient enrichment. The estuary displays low mesotrophic levels of nitrates (0.5 – 2.5 mg/L) which has the potential to limit species diversity. The estuary is heavily utilized and faecal pollution from vagrants occasionally inhabiting the river banks causes contamination of the waters. Further upstream is the Sea Cow Lake sewerage works and although this plant is noted for its efficiency, occasional enrichment is possible. Other sources of contamination include the many recreational users of the estuary, the concentrated industrialization on the floodplain and informal settlements.

5.6.2.6 pH

Summer pH was only marginally above 7 whilst winter sampling revealed values of above pH 8 when more nutrient contamination was experienced. Whilst the water quality status of the Mgeni is only partially described in this study due to logistical and financial constraints, a more comprehensive survey covering the entire spectrum of pollutants will explain fully the indicator values recorded in this study.

5.6.2.7 Salinity distribution

In common with the other systems, salinity levels are strongly linked to the status of the mouth – whether closed or open. During open mouth conditions, a longitudingal gradient of decreasing salinity from close to sea water concentrations at the mouth to freshwater conditions at the head of the estuary prevails. Salinities of between 12 to 24 ppt are common in the embayment during lagoonal conditions. In this study, sea water incursions into the estuary ensured high salinities near the mouth wher values approximating sea water concentrations were recorded. No vertical stratification of salinities was evident during sampling surveys and this is to be expected as the water of the embament was very low.

5.6.2.8 TDS

Total dissolved inorganic and organic solids in the Mgeni are in the acceptable range as all sites recorded levels lower than the DWAF TWQR of 200 mg/L. Umgeni Water is the authority monitoring and managing the Mgeni system and it is clear from this survey that they have managed to keep the water quality of the estuary within the desired standards required despite the heavy utilization of the catchment.

5.6.2.9 Temperature stratification

Thermal stratification is absent in this system due to its shallowness hence water temperature in the system is influenced predominantly by ambient air temperature. Temperatures of just over 23°C to close to 25°C were measured in summer and winter temperatures hovering at about 22°C confirming that water temperatures are strongly seasonal in this estuary.

5.6.2.10 Turbidity

Estuarine waters of the Umgeni system are generally clean with low turbidity values. Marine waters entering the system on the flood tide suffer venturic deformation and a rapid reduction in velocity causing a sudden loss of capacity and competence hence material is deposited. Aeolian induced wave turbulence may initiate re-suspension but this is infrequent.

5.6.2.11 Summary of water quality

The results of the water quality analyses revealed that salinities, temperatures, and dissolved oxygen levels were all within acceptable limits. Issues of concern were the TDS concentrations and conductivity. Since the parameters measured for in this study fall within the DWAF limits, it is apparent that others that were not measured may be in relatively high concentrations and may pose problems as pollutants. However, for the measured parameters, it is pleasing to note that these are kept below problem levels and the Ungeni Water Board is to be commended for this noting that the catchment and estuary is heavily utilized for agriculture, industry, residential (both formal and informal) and, recreational uses. The high levels of water abstraction from the system mainly by the large storage dams (Midmar, Nagel and Inanda) are added.

The estuary is currently heavily utilized for recreation as Durban is a favoured holiday destination for a large number of tourists, particularly during vacation periods.
The mouth has been kept continuously in an open condition during the study period to facilitate recreational activities and a number of fishermen frequent both the estuary and beach environment.
The barrier environment has grown considerably during the period of study as longshore drift has welded thich accumulations of sediment onto the beach face and wave washover has extended fan development into the lagoonal embayment. Within the embayment of the estuary are several large sediment lobes that have been deposited on the flood tide. These are largely built by flood tidal flows and comprise largely marine sand underlain by lagoonal muds of fluvial origin.

Thousands of people frequent the park facilities on the south bank of the estuary each week but they are very busy over weekends and the beach environment is similarly popular.

5.7 The isipingo estuary

5.7.1 Morphology of the Isipingo estuary

The Isipingo lagoon and estuary is situated to the south of the Ethekwini Metropolitan area, on the east coast of South Africa. The Isipingo River has a catchment area of approximately 6.6km^2 (Ward, 1980; Brand, 1967), and is 27km long with a mean annual runoff of 3.34x10^{6}m^3 (Shand *et al.*, 1971). The Isipingo arises near Inwabi approximately 16km in a north westerly direction from its mouth. Its tributaries, which are now mostly canalized, drain the greater portion of the Isipingo Flats (Kalicharran, 1990). The highest flood level that was ever recorded was 2.5m above the sea level (Orme, 1974) and the latest severe flood occurred in 1935, but since the diversion/canalization of the Umlazi River in 1952 and also the diversion of the Isipingo River into the Mbokodweni in 1969, the flood dangers have been significantly reduced (Begg, 1978).

Figure 37: The Isipingo estuary and lagoon system. The area is densely populated and industrialized. (Photograph by Singh, CSIR)

The Isipingo estuarine system consists of both a lagoon and estuary. This is a unique morphological combination since, although the two systems are linked by a short canal, they may be treated as distinctly different systems. For instance, the systems may be linked and, under conditions where the mouth of the estuary is open to the sea, tidal interchange may occur in between. On other occasions when the mouth is cut off from the sea by a sand barrier, the link between the estuary and the lagoon may still be maintained under conditions of high fluvial input from landward drainage. When dry conditions ensue, or when under conditions of prolonged mouth closure, the link between the estuary and the lagoon becomes silted up.

The estuary and lagoon forms a valuable recreational and ecological asset but due to its geographical position in a rapidly expanding urban industrial area, it has been subjected to the negative impacts of urban development (Kalicharran, 1990).

The estuary is 1.4 km long and approximately 50 m at its widest point but constricted at a point close to the lagoon where the free flowing water has been impeded by weeds, building rubble and general domestic waste which have been deposited on the banks and in the water as the lower reaches of the Isipingo flows through the residential area (Kalicharran, 1990).

Begg (1984a) described the lagoon as being more ecologically viable as it is isolated and receives only residential storm water runoff.

Figure 38a: A low oblique aerial photograph of the Isipingo Estuary and Lagoon system viewed from the north. Note the extensive residential development all around the system with the exception of the mangrove fringe and the extensive mangrove area in the foreground. Island Hotel is situated on the island between the lagoon and the estuary/river; industries in the bottom left corner and, other industries and shops to the right of the open ground adjacent to the lagoon. Figure 38b: below is a view from the seaward side showing clearly the Prospecton Industrial Area. (Photograph provided by Singh, CSIR)

5.7.2 Water Quality of the Isipingo estuary

The table below summarizes the water quality parameters measured for the five sampling sites of the Isipingo estuary and is also presented in the graph below:

Table 8 Water quality of the Isipingo Estuary for the 5 sites sampled:

	sample 1	sample 2	sample 3	sample 4	sample 5
Ammonia (S)	1.3	1.6	18	79	29
AMMONIA (W)	2.43	0.97	2.21	2.46	3.78
CHLORIDE (S)	0.17	0.10	0.14	0.10	0.3
CHLORIDE (W)	0.08	0.04	0.24	0.25	0.24
CONDUCTIVITY (S)	34.7	28.61	31.83	28.87	28.12
CONDUCTIVITY (W)	29.22	29.43	29.3	27.51	27.32
DO (S)	7.47	6.71	5.32	4.83	3.78
DO (W)	10.14	12.08	6.54	4.54	1.35
NITRATE (S)	1.32	3.23	3.87	4.14	4.54
NITRATE (W)	1.13	1.29	1.45	3.29	3.28
Ph (S)	7.3	7.6	7.6	7.4	7.2
Ph (W)	8.37	8.56	8.38	8.12	7.81
SALINITY (S)	7.75	7.87	6.32	3.12	0.77
SALINITY (W)	12.43	12.54	5.61	0.97	0.39
TDS (S)	242.2	195.3	241.5	185.87	184
TDS (W)	213.1	215.7	213.87	187	188
TEMP (S)	25.02	24.41	24.98	25.44	25.65
TEMP (W)	22.09	21.86	21.3	21.43	21.94
TURBIDITY (S)	9.65	9.47	6.8	6.99	7.24
TURBIDITY (W)	17.74	18.07	13.42	13.55	14.37

5.7.2.1 Ammonia

During the summer sampling it was found that levels of ammonia in the Isipingo estuary are very low at sites one and two but increased drastically to several times that of the TWQR of DWAF. A particularly high concentration of 79 µg/L was measured at site four and a high of 29µg/L at site five. These concentrations fall between the chronic and acute effect values of 15 µg/L and 100 µg/L as specified by DWAF. Chronic effects reduce hatching success, growth rates and morphological development as well as pathological changes in gill, liver and kidney tissues (DWAF, 1996). Acute effects are more life threatening and include loss of equilibrium, hyperexcitability, increased cardiac output, convulsions and death (DWAF, 1996). This estuary has had a history of public outcry over high pollution and has often recorded fish mortality, the most recent occurring in 2005. It is good to note that concentrations of ammonia have dropped to acceptable levels since the summer sampling.

5.7.2.2 Chloride

The TWQR for chloride is = 0.2µg/L. Whilst summer concentrations were acceptable, it was found that there were some sampling sites which demonstrated concentrations slightly above this value yet not quite in the Chronic Effect Value range of 0.35 µg/L. Thus minor increases in the levels of chloride output from industries located on the Isipingo catchment may prove dangerous for this estuary. Continuous monitoring and adherence to limitations for chloride is crucial for the maintainence of good health of this estuary.

5.7.2.3 Conductivity

Conductivity in the Isipingo estuary is fairly high and this is understandable given that this estuary regularly receives industrial effluent from industries located immediately upstream of the estuary. Nutrient enrichment has been an ongoing problem for the estuary and regular monitoring is required to ensure that a healthy biotic environment is maintained.

5.7.2.4 Dissolved Oxygen

During both the seasons, DO levels were higher near the mouth and gradually decreased upstream. Site 5, located upstream, yielded an extremely low DO concentration. On the other hand, during the winter, Sites 1 and 2 yielded extremely high DO concentrations of 10.14 and 12.08 mg/L respectively (this translated to 130% and 154% saturation respectively. Further upstream, DO concentrations dropped markedly to 1.35 mg/L! It should be pointed out that the optimum condition is one of saturation in aquatic systems. Concentrations less than saturation causes increasngly stressful conditions whilst spersaturation may cause gas bubble disease in fish (DWAF, 1996).

5.7.2.5 Nitrates

Extremely high nitrate concentrations characterize the Isipingo estuary. These concentrations are indicative of eutrophic conditions (2.5 – 10 mg/L) in the upper estuary which is also heavily industralized. As mentioned above, the Isipingo estuary is known as a heavily polluted system. Clearly, high nitrates are a consequence of industrial outfall and these effluents become trapped in deep pools that occur in the upper estuary. Algal blooms and excessive growth of aquatic plants characterize the upper estuary as a consequence.

5.7.2.6 pH

Summer pH levels were marginally above 7 whilst winter pH was generally above 8 indicating some concentration of nutrients during winter in lower flow conditions.

5.7.2.7 Salinity

Salinity levels were generally low throughout. Slightly higher salinities were measured for Sites 1 and 2 in winter suggesting some incursion of sea water. Note also that these were the sites that yielded DO concentrations of >100% saturation.

5.7.2.8 TDS

The Isipingo estuary contains fairly high levels of dissolved solids and all sites sampled yielded concentrations close to or exceeding the DWAF TWQR of 200 mg/L. This high loading was anticipated in this estuary which has a history of pollution. It is interesting to note though that TDS concentrations decrease landward. This is probably due to the effect of ebb flow and the draining of contaminated water seaward.

5.7.2.9 Temperature

Whilst winter temperatures were found to be over 20 °C, seasonal cycling of temperature is noted as summer temperatures were between 24.41 and 25.65 °C. No variability of temperature with depth was recorded as the system is for the most part well mixed. However, there are some deeper pools of water in the upper estuary that may well demonstrate temperature stratification.

5.7.2.10 Turbidity

Turbidity levels are generally low through the estuary although it should be noted that winter turbidities were higher than those measured in summer. This may be reflective of lower fluvial flows in winter hence leading to concentrating of pollutants.

5.7.2.11 Summary of water quality

The results of the water quality analyses revealed that this estuary has the potential to become seriously polluted as it is situated in an area of heavy industrialization. Added to this is its close proximity to residential landuses and the Durban airport. High levels of ammonia, nitrates, dissolved solids and temperature characterize the estuarine environment. In the past, several fish kills have occurred in the estuary prompting action from the authorities. The results of this survey point to more potential problems in the future.

The estuary is currently utilized for recreation and contains a large stand of mangroves, the largest south of Durban. It has been a matter of concern that this natural environment has had to suffer so much degradation at the hands of the surrounding industries and a committee of concerned residents of the area have taken it upon themselves to maintain the health of the estuary. Industries in the catchment continue to pose a potential threat as they indiscriminately spout pollution from some residents. The beach environment is a popular retreat for recreational seekers and fishermen as is the lake area. The recent storms and high tides have helped seal off the mouth completely and it will require a major effort to re-establish this link with the sea. However, the pipe linkage with the sea still persists and tidal exchange with the sea continues.

5.8 Amanzimtoti

5.8.1 Morphology of the Amanzimtoti Estuary

The amanzimtoti system is small but very aesthetic with a pronounced lagoon that caters for much of the tourists that visit the town of Amanzimtoti during vacation periods. It is also a very popular destination for locals especially during the festive seasons and this exert more pressure and strain in the system since popllution at some stages cannot be avoided. The estuary makes an "S"shape and is crossed over by five bridges in a well developed town. The catchment of the Amanzimtoti River is well developed and densely populated but, since industrial development is minimal, much of the impacts on the estuary derive from commercial, residential and tourist related activities. Therefore, the Amanzimtoti estuary is a highly modified system where much of the original flood plain has been infilled and utilised for urban development such as shopping centres and municipal offices. Municipal refuse was used as fill material on the south bank inland of the freeway (Begg, 1984).

The mouth of the estuary has also been modified in that a small weir has been built across it (Cooper, *et al*, 1991). It would appear that this weir has also been modified since the 1980's (Begg, 1984). It is now a fairly substantial structure that spans the entire mouth channel. The purpose of this weir is to ensure that the estuary does not drain completely when the mouth is breached as this would expose the anoxic sediments.

The depths measured in the estuary in the basin below the railway bridge (at the time of sampling the mouth was open) - the water level was thus at the minimum level as controlled by the weir and depths were between 0.7 and 0.8m. Although Amanzimtoti estuary is naturally considered as a closed estuary, the mouth of the system is frequently and artificially opened by the Local Council for pollution control.

The barrier environment comprises beach environments (up to on 20m wide) on either side of the mouth. Wave overwash contributes some salinity and marine sand into the estuarine embayment and most fine grained sediment is fluvially derived.

Figure 39: A low oblique view of the mouth of the Amanzimtoti estuary (Photography by Singh, CSIR)

The Amanzimtoti estuary covers an area that is approximately 3.5km long by 3 km wide. The catchment of the estuary has been extensively developed. Dunes occur on either side of the estuary mouth and are covered with natural vegetation. The dunes are smaller on the north side and much larger on the south side. Further in land the main valley narrows and before widening again into a broader valley. Whilst at the estuary head, urban structures abound, they are followed by dense residential settlements and further off, sugan cane fields.

5.8.2 Water Quality

The table and graph presented below measured water quality for this estuary.

5.8.2.1 Ammonia

Concentrations of ammonia at all sampling points and for all seasons were well below the TWQR of DWAF. The highest concentrations measured ranged from approximately 2μg/L to 3.68 μg/L and these are safely below the target of =7 μg/L.

5.8.2.2 Chloride

For both seasons, all sites measures yielded extremely low chloride levels which were below the TWQR of 0.2µg/L. This estuary therefore is unpolluted with reference to chloride concentrations.

Table 9: Water quality of the Amanzimtoti Estuary for the 5 sites sampled:

	sample 1	sample 2	sample 3	sample 4	sample 5
Ammonia (S)	0.6	0.8	0.8	1.1	1.1
AMMONIA (W)	0.95	1.27	1.97	2.2	3.68
CHLORIDE (S)	0.08	0.06	0.09	0.07	0.03
CHLORIDE (W)	0.05	0.05	0.05	0.02	0.02
Cod					
CONDUCTIVITY (S)	17.71	13.71	12.11	5.08	5.32
CONDUCTIVITY (W)	8.40	6.27	6.48	5.64	1.8
DO (S)	6.01	6.06	5.88	5.93	5.67
DO (W)	6.21	7.07	6.84	6.34	6.21
NITRATE (S)	0.041	0.34	0.36	0.45	0.45
NITRATE (W)	0.29	0.26	0.40	0.44	0.53
Ph (S)	7.3	7.4	7.7	7.79	7.8
Ph (W)	7.91	8.07	8.17	8.08	8.26
SALINITY (S)	13.33	10.23	10.72	3.43	2.8
SALINITY (W)	5.47	4.09	4.05	2.21	1.06
TDS (S)	124.3	96.6	82.3	31.2	27.6
TDS (W)	62.9	47.0	47.6	39.1	13.4
TEMP (S)	24.34	24.77	24.12	23.87	24.98
TEMP (W)	18.09	18.04	18.94	18.81	19.34
TURBIDITY (S)	23.34	18.12	15.54	9.61	9.38
TURBIDITY (W)	9.2	14.04	9.34	9.88	10.65

5.8.2.3 Conductivity

Conductivity in the Amanzimtoti estuary was found to be consistently low throughout the estuary with winter levels being lower than those measured in summer.Waters of the estuary consequently are in a reasonably good condition but local authorities claim that much of the suspended matter settles out in the lagoon in fairly sheltered, tranquil conditions.

5.8.2.4 *Nitrates*

The Amanzimtoti is an oligotrphic system with nitrate concentrates generally less than 0.5 mg/L. An exception is the winter site 5 reading where some contamination due to feacal pollution may have increased concentrations to slightly above 0.5 mg/L. The oligotrophic nature of this system implies moderate levels of species diversity but with fairly rapid nutrient cycling and no nuisance growth of aquatic plants (DWAF, 1996). Indeed, this estuary, with a large embayment, visually demonstrates little algal growth and is recreationally intensively used in summer months.

5.8.2.5 *pH*

pH in this system ranges from slightly over 7 to values marginally above pH 8. The system does not contain high concentrations of nutrients and pH shows only slight fluctuations through the year.

5.8.2.6 *Salinity*

The Amnzimtoti estuary is a perched system which is further restricted from access to the sea by an anthropogenically constructed weir. Hence salinities in the lagoon is very low throughout the year and is only influenced by wave washover during high tides.

5.8.2.7 *Temperature*

There is a distinct seasonal variation of temperature with seasons with summer temperatures above 24 °C an winter temperatures at around 18 °C. There is an approximate drop of 0.4 °C/m with depth in the lagoon during winter whilst in summer only a 0.2 °C/m on the western side of the lagoon was detected.

5.8.2.8 *TDS*

The Amanzimtoti system yielded low TDS values indication very low levels of solutes in the water. This is also the reason for the low conductivity recorded for the system. Whilst it is possible for pollutants to accumulate in the protected embayment of the lagoon, it is likely that much of the previously accumulated pollutants had been flushed out of the system in the storms that preceeded the winter sampling by approximately two months.

5.8.2.9 Turbidity

During summer, turbidity in the lagoon and estuary increases. Increased turbulence caused by increased recreational use and possibly also higher sediment loding from increased rainfall in the catchment leads to this increase in turbidity. In winter, the system is more calm and tranquil giving rise to clearer conditions and lower turbidity.

5.8.2.10 Sumary of the water quality

Parameters measured yielded low values throughout. Some enrichment of nitrates was evident. The estauary was recently opened and some flushing of accumulated pollutants may have occurred. This estuary drains a fairly small catchment which is populated and has the potential for enrichment. Monitoring is important as the estuary is heavily favoured by tourists. During the surveys conducted, water quality was good and the estuary was in an apparently healthy state. The sand barrier across the mouth was well developed and dunes to the north and south in fairly good condition. On the last field trip, the mouth was closed and water was accumulating in the estuarine embayment.

5.9 The mkhomazi estuary

5.9.1 Morphplogy of the Mkomazi estuary

The Mkhomazi estuary has a slight curve and is consistently wide throughout its length up to the N2 Freeway Bridge. Almost the entire length of the estuary is aerially visible from the mouth. The Mkomazi estuary is wide and shallow (average depths of 1.1m) with a mouth that very seldom closes as a consequence of the discharge from one of the larger rivers of the province. There are two existing bridges across the estuary. These are the combined road and rail bridge across the mouth and the new N2 freeway bridge further upstream. In the 1920's the estuary was reportedly not less than 6m deep at any point (Begg, 1978). In 2004 much of the estuary appeared to be approximately 1m deep and the estuary is now a shallow system with banks that are exposed over low tides.

Figure 40: The Mkomazi estuary. Town of Mkomazi to the left; catchment sugarcane agriculture is clearly evident. The mouth is in an open state and the estuarine embayment has been flooded – none of the large sand lobes are evident in this photograph. (Photograph by Singh, CSIR)

The Mkomazi is one of the larger river systems presently being reviewed. It is a broad river that has a significant flow throughout the year and has carved a large valley through the landscape. The indigenous people in the area refer to it as a river that is fed by wind meaning in Isizulu that "uMkomazi ogcwala ngomoya". This is precisely because the Mkomazi River is an exotic river that is also fed from the upper reaches and the local people do not understand this geomorphological phenomenon. The lower section of the visual catchment is extensively settled. The area has also tourism potential since it is a particularly popular local diving destination.

Dune vegetation is highly disturbed at the river mouth. Rehabilitation of this area might reduce urban influence of the settlement that could be beneficial for recreational and tourism uses and this can be a good news for the economy of the area. The Mkomazi estuary is from a regional perspective considered as one of the important estuaries along the KwaZulu-Natal coast. It is one of the largest and few estuaries fed by a river without any major dams.

The rate of sedimentation deposition in the estuary appears to have accelerated since the turn of the century. This has eventually led to a substantial loss in the volume of water of the estuary and this obviously has an adverse effect on the biological functioning of the system.

5.9.2 Water Quality

5.9.2.1 Ammonia

As with the Amanzimtoti estuary, the Mkomaas estuary contains low concentrations of ammonia which are well below the TWQR of DWAF. This is in spite of the large industrial complex of SAPPI SAICCOR located just upstream of the estuary and agriculture in parts of the catchment.

5.9.2.2 Chloride

Concentrations of Chloride in the Mvoti estuary are well within the target levels set by DWAF (2003). It is well known that the effluents from the SAPPI SAICCOR plant located further upstream is piped out to sea hence there is little direct contamination in the estuarine waters of the Mkomaas.

Table 10: Water quality of the Mkomaas Estuary for the 5 sites sampled:

	sample 1	sample 2	sample 3	sample 4	sample 5
AMMONIA (S)	2.03	1.11	2.46	1.23	1.07
AMMONIA (W)	2.55	4.26	4.26	2.21	1.38
CHLORIDE (S)	0.2	0.15	0.14	0.03	0.08
CHLORIDE (W)	0.07	0.07	0.06	0.06	0.08
CONDUCTIVITY (S)	24.1	18.60	16.5	9.5	11.3
CONDUCTIVITY (W)	21.45	11.36	12.02	13.88	14.36
DO (S)	7.72	7.56	6.54	6.91	7.21
DO (W)	6.3	7.18	7.44	7.3	7
NITRATE (S)	0.11	0.95	0.80	0.80	0.94
NITRATE (W)	0.02	0.03	0.30	0.21	0.21
Ph (S)	7.9	8	7.9	8.1	8
Ph (W)	8.48	8.61	8.59	8.43	8.01
SALINITY (S)	15.51	7.36	5.44	4.87	4.7
SALINITY (W)	14.81	7.52	7.94	8.32	9.02
TDS (S)	171.2	128.8	115.9	72.2	77.3
TDS (W)	147.1	84.5	88.9	97.6	100.3
TEMP (S)	25.1	24.8	23.9	24.1	24.3
TEMP (W)	18.97	18.41	18.62	21	21.38
TURBIDITY (S)	33	42	48	65	51
TURBIDITY (W)	21.37	21.16	21.38	47.29	54

5.9.2.3 Conductivity

Conductivity levels are fairly high in this estuary and are derived from a number of sources in the catchment. These include industry, informal settlements and agricultural sources.

5.9.2.4 Nitrates

The Mkomaas fluctuates from oligotrophic to mesotrophic conditions with nitrate concentrations ranging from 0.11 mg/L to over 0.9 mg/L. Oligotrophic conditions appear to prevail during winter and nitrate contentrations increase to mesotrophic conditions in summer. The system should therefore be characterized by moderate to high levels of species diversity and with little nuisance growth of aquatic plants and this is indeed the case as determined from visual observations. Effluents from upstream industry and informal settlements and, runoff from agriculture need to be controlled to ensure that nitrate levels do not increase. Rather, attempts to reduce concentrations need be made.

5.9.2.5 pH

pH values for summer centred around 8 (slightly alkaline) to 8.5 in the winter when water levels were lower, and nutrient levels higher. However, overall the pH of the estuarine water is within pH targets for aquatic systems.

5.9.2.6 Salinity

Low salinity was recorded throughout the sampling periods and for all stations as the system was ebbing at the time of sampling, unlike the Mgeni system mentioned above which was in flood at the time of sampling.

5.9.2.7 TDS

The Mkomaas estuary contains intermediate amounts (with reference to the DWAF target limit of 200 mg/L) of dissolved substances in its waters. TDS concentrations range from a low of 72.2 mg/L to 171.2 mg/L, the highest concentration measured during summer and close to the mouth of the estuary. Concentrations are consistent throughout except for the sampling sites close to the mouth which have slightly elevated TDS probably due to the influence of saline water incursion into the estuary on the flood tide.

5.9.2.8 Turbidity

Fairly high turbidity was encountered in the Mkhomazi estuary and this is a consequence of natural process (wind induced) and the fact that parts of the estuary bed has a layer of fine muds that are easily suspended. Values of above 33 NTU were recorded in summer and above 20 NTU in winter.

Figure 41: Highly turbid waters and muddy banks of the Mkomaas.

5.9.2.9 Summary of water quality

Intermediate total dissolved solides and nitrates were found in this system. Moderate conductivity also characterise the estuary. Total dissolved solids are high and may indicate pollution by constituents not specifically measured for in this study. Given that a major industry is located just upstream of the mouth and that the river drains a fairly large catchment, it is significant that pollutants measured are so low. Parts of the estuary exhibit high turbidity which may be caused by the windy conditions. Constant monitoring is essential to ensure that the health status of the estuary is maintained.

Some significant erosion of the coastline has occurred recently due to the high tides and stormy weather. This has allowed for significant volumes of sediment to be deposited in the estuary. The waters of the Mkomaas appear to be fairly turbid but this is a natural phenomen. The barrier environment on the north side is well developed with a wide berm and beach face. Some reconstruction of the south side is required to facilitate recreation and other beach users (Plate 21):

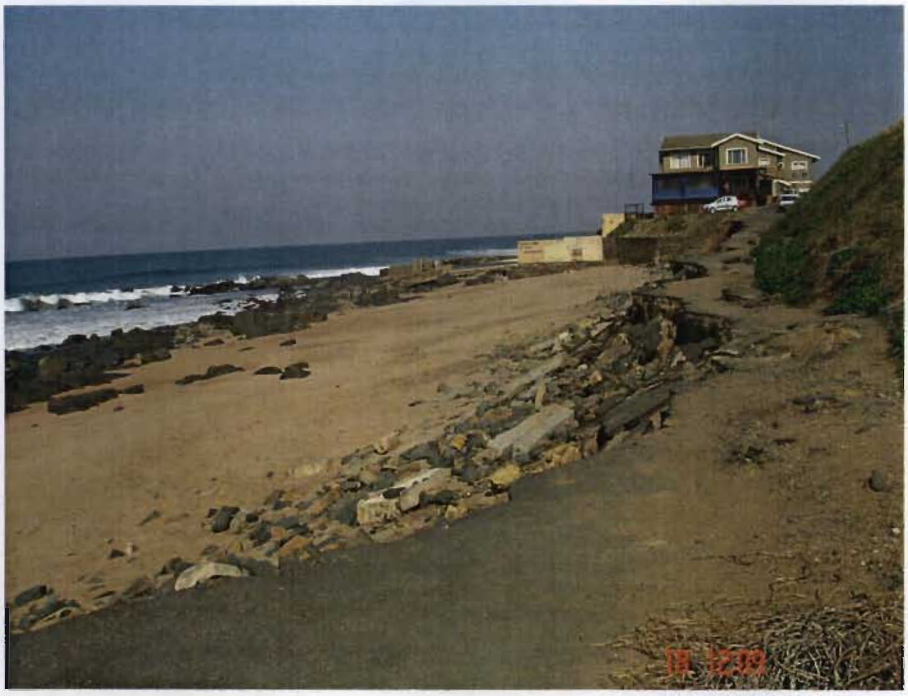


Figure 42: Extensive erosion to the south of the Mkomaas mouth following stormy weather in winter.

5.9.3 *General comparison of water quality parameters of all estuaries*

5.9.3.1 Ammonia

The concentrations of ammonia were generally low for all estuaries but showed marked increases in summer in the isipingo estuary. Both the Isipingo and Mvoti estuaries indicate the potential for serious ammonia pollution and need to be closely monitored. Clearly, this arises from the location of industries adjacent to these estuaries and, further upstream, on the river floodplain. In the case of the Isipingo estuary, toxic levels were found to be present during summer and increasing toxicity in the upstream direction. This estuary has a history of serious pollution with fish kills recorded as recently as 2005. The subsequent measures to reduce pollution have seen a marked decrease in ammonia levels (winter readings). Part of the problem may be related to the concentrations of pollutants accumulating in deep pools at the head of the estuary. Whilst on field surveys, it was noted by the skipper of the boat that several deep pools existed in the upper estuary. Depths of three of these were identified and measured 4.7m; 3.9m and 4.1m. Consequently, monitoring of the high levels of ammonia in the Isipingo estuary is essential and, in addition, polluters located in the catchment need to be identified, monitored and if necessary, punitive measures instituted.

Another estuary of concern is the Mvoti where values approaching the TWQR were recorded in summer. Again, the Mvoti is noted for high levels of pollutants as a consequence of effluent discharge into the river by industries located there.

For the other estuaries, the highest ammonia concentrations measured were below the TWQR. Thus it is clear that ammonia is generally not a problem in these estuaries even where human activities in the estuary and river catchment was pronounced.

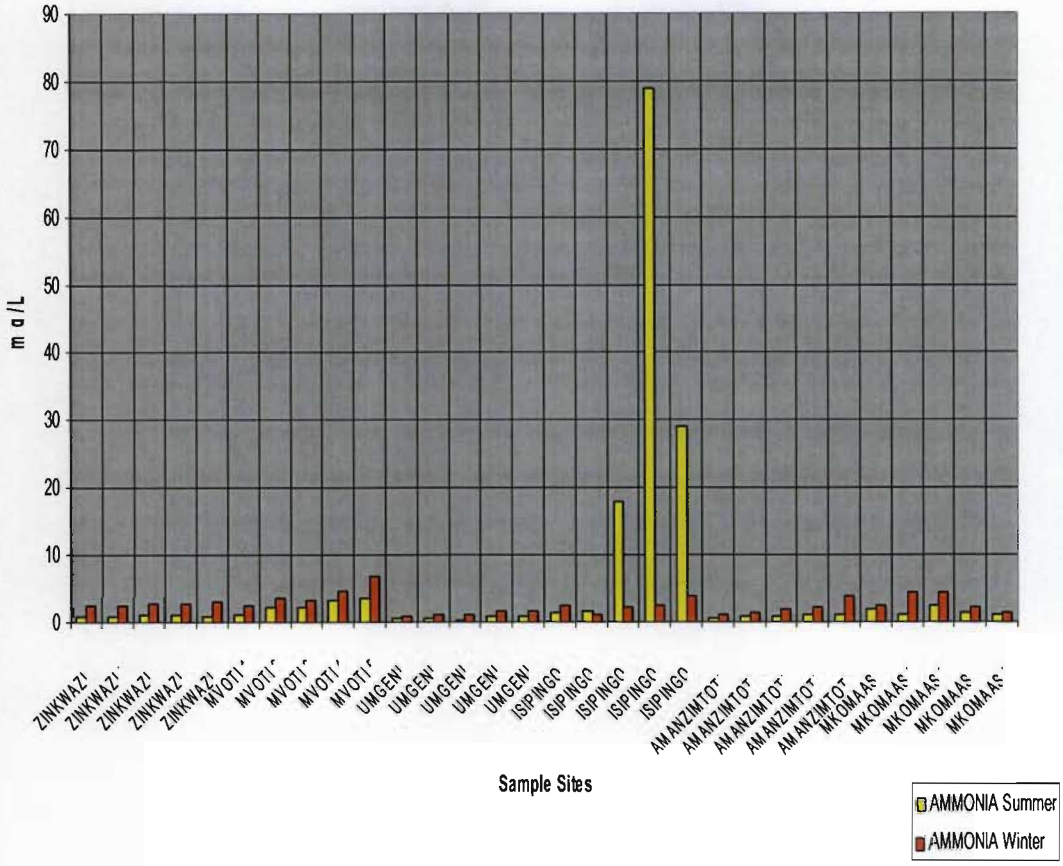


Figure illustrating AMMONIA content within the study area

Figure 43: General comparison of water quality parameters of all estuaries studied

5.9.3.2 Chloride

It is clear from the above comparative graph that pollution due to chloride is of a major concern for the Mvoti estuary. The paper and pulp manufacturers located on the floodplain of this estuary utilize significant quantities of chlorine in the bleaching process and this may well be a source of the high levels of chloride measured in the estuary. Other pollutant sources deriving from industry and agriculture in the catchment obviously enhance pollutant potential of chloride for this estuary.

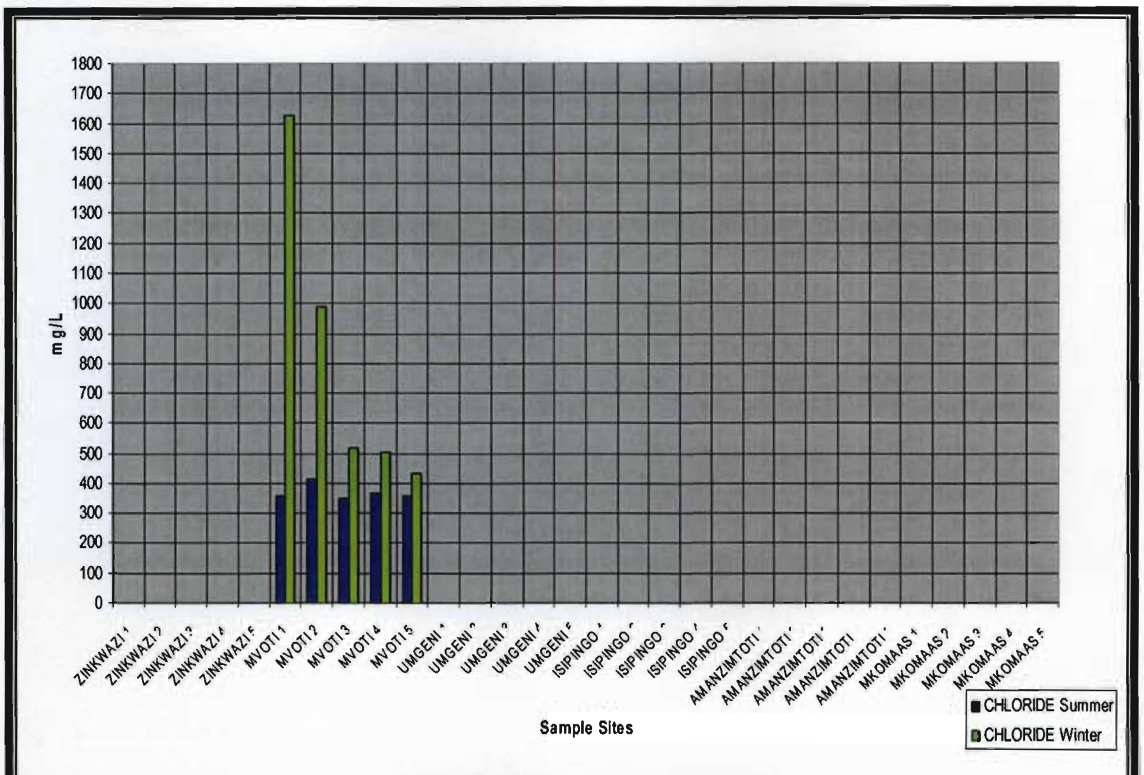


Figure illustrating CHLORIDE levels within the study area

Figure 44: Chloride of certain estuaries within the study area

5.9.3.3 Conductivity

Conductivity levels were high for the Mvoti and the Isipingo estuaries whilst the Mgeni and Mkomaas estuaries demonstrated moderate levels of conductivity. Whislt concern must be expressed for the former two estuaries the latter two need close observation to ensure that levels do not increase seriously. For the most part, conductivity appears to be slightly higher in summer than winter and this is especially the case for the Mvoti estuary.

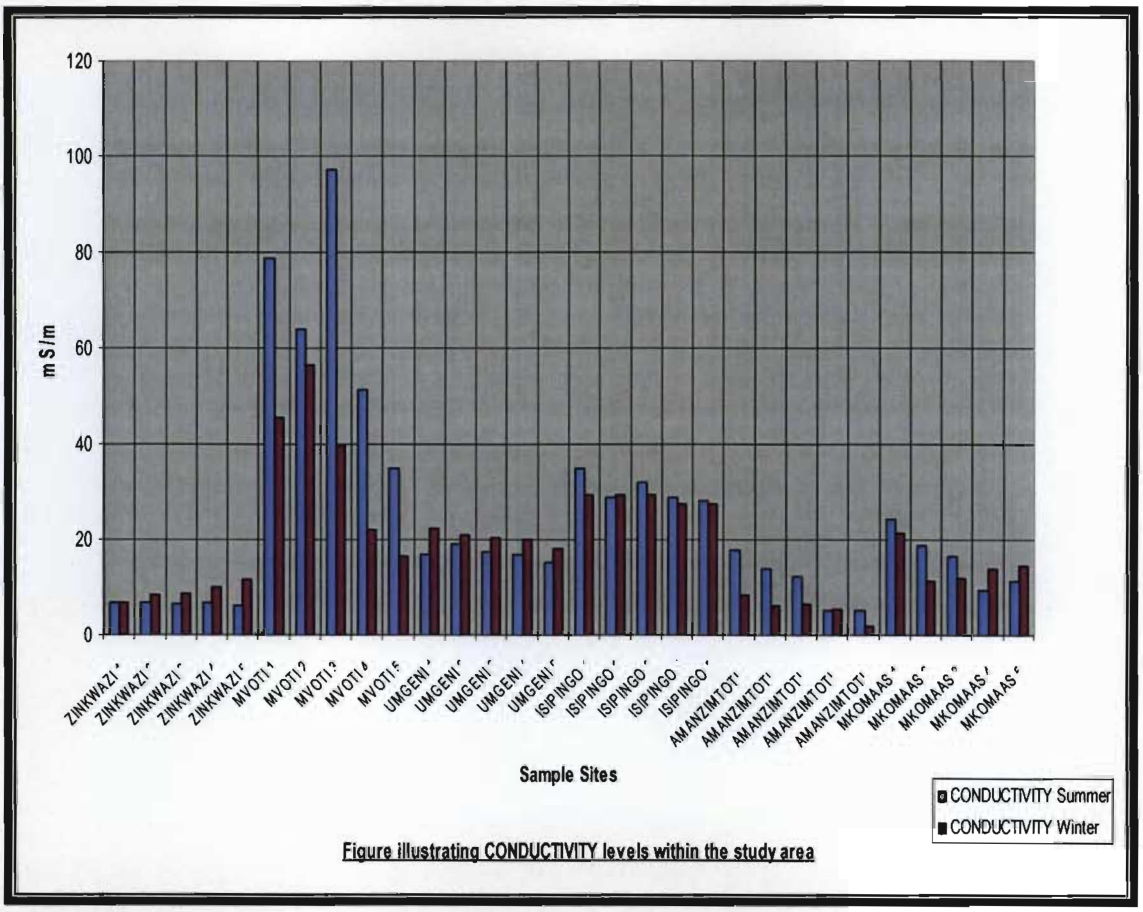


Figure 45: Summer and winter conductivity within the study area

5.9.3.4 Dissolved oxygen

For all aquatic organisms, the levels of DO in the water are crucial for survival. Whilst all estuaries recorded reasonable levels of DO, alarming dips in concentration were recorded in the Mvoti and in the upper Isipingo estuaries. Analomous high DO levels were recorded near the mouth of the Isipingo at an offshoot arm of the estuary which appeared to be teeming with fish. Overall, DO concentrations of 6 mg/L were the norm for the estuaries measured.

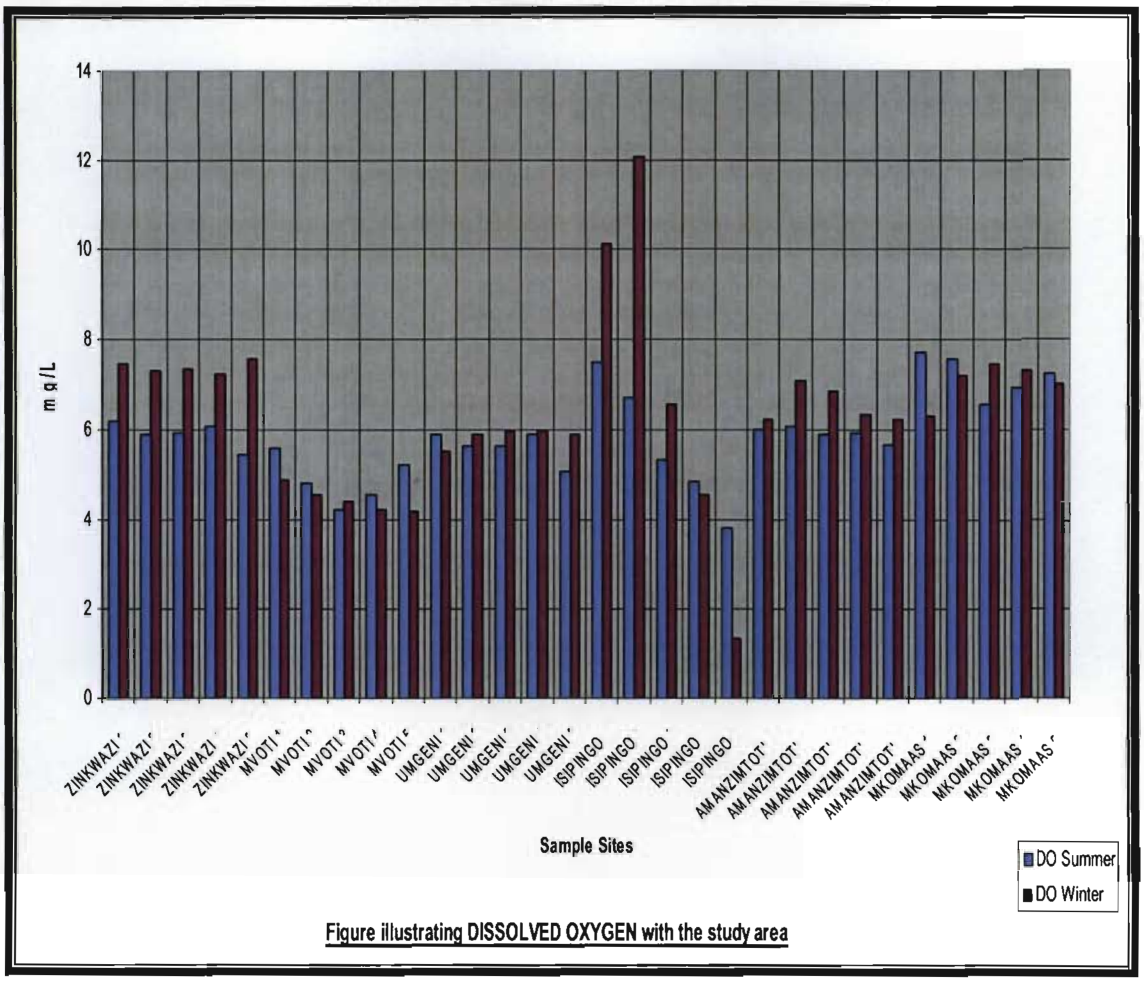


Figure 46: Dissolved Oxygen within the study area

5.9.3.5 Nitrates

Virtually all estuaries demonstrate oligotrophic characteristics due to minor nitrate enrichment. However, the Mvoti and Isipingo estuaries demonstrate hypertrophic and eutrophic concentrations due to the high levels of industrialization in their catchment.

Whilst highest concentrations for the Mvoti were measured in winter, summer concentrations were higher in the Isipingo estuary.

Amanzimtoti recorded the lowest levels but this may not always be the case as the prolonged closure of the mouth may lead to concentration of nitrates during part of the year, emphasising the need for continuous monitoring. All other estuaries show low concentrations with slightly higher summer than winter concentrations.

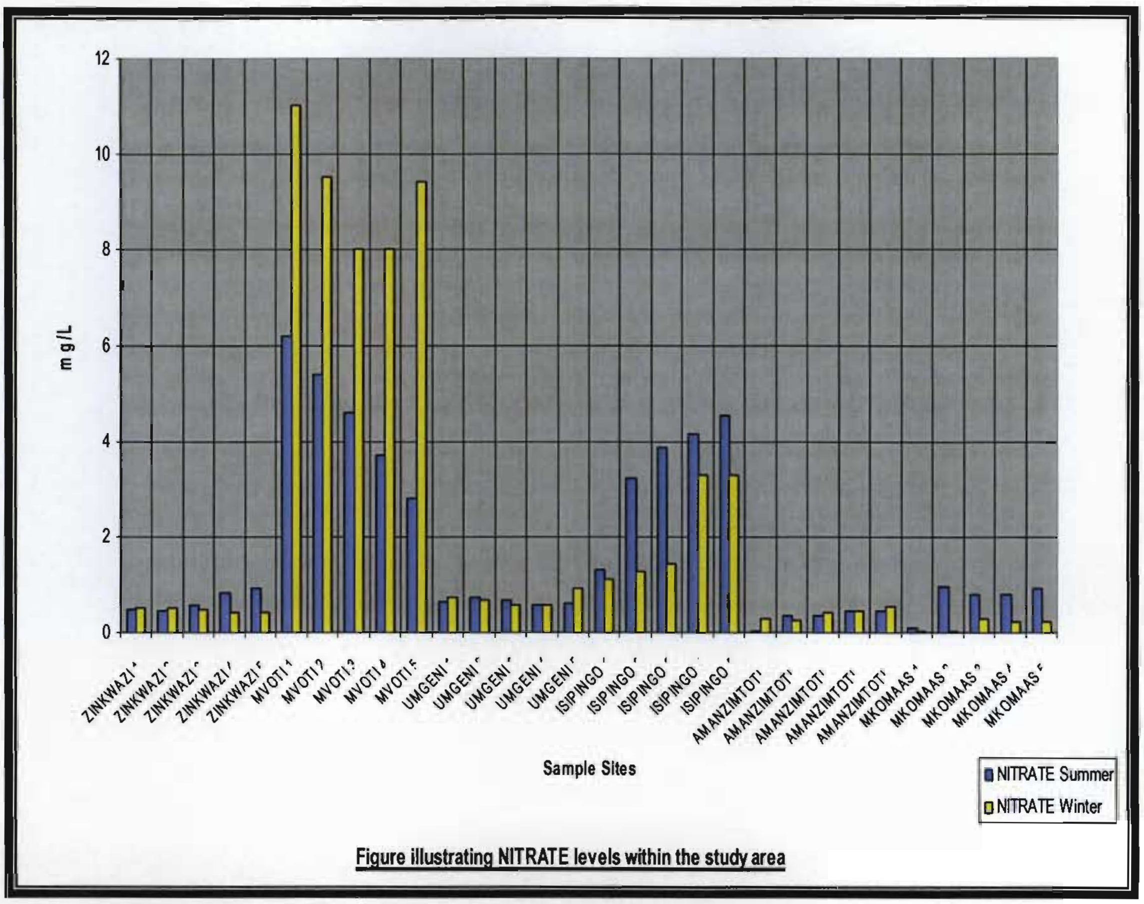


Figure 47: Nitrate concentrations within the study area

5.9.3.6 Total dissolved solids

The trend of high pollution levels associated with the Mvoti and Isipingo estuaries is also mirrored in the TDS concentrations measured. The summer concentrations for both estuaries are higher in the winter. Moderate levels of >100 mg/L were measured in the Mgeni and Mkomaas estuaries. It is clear from this appraisal that whilst it is clear that the Mvoti and Isipingo demonstrate high levels of pollution, there is a need to closely and continuously monitor the Mgeni and Mkomaas estuaries in order to prevent environmental disasters occurring

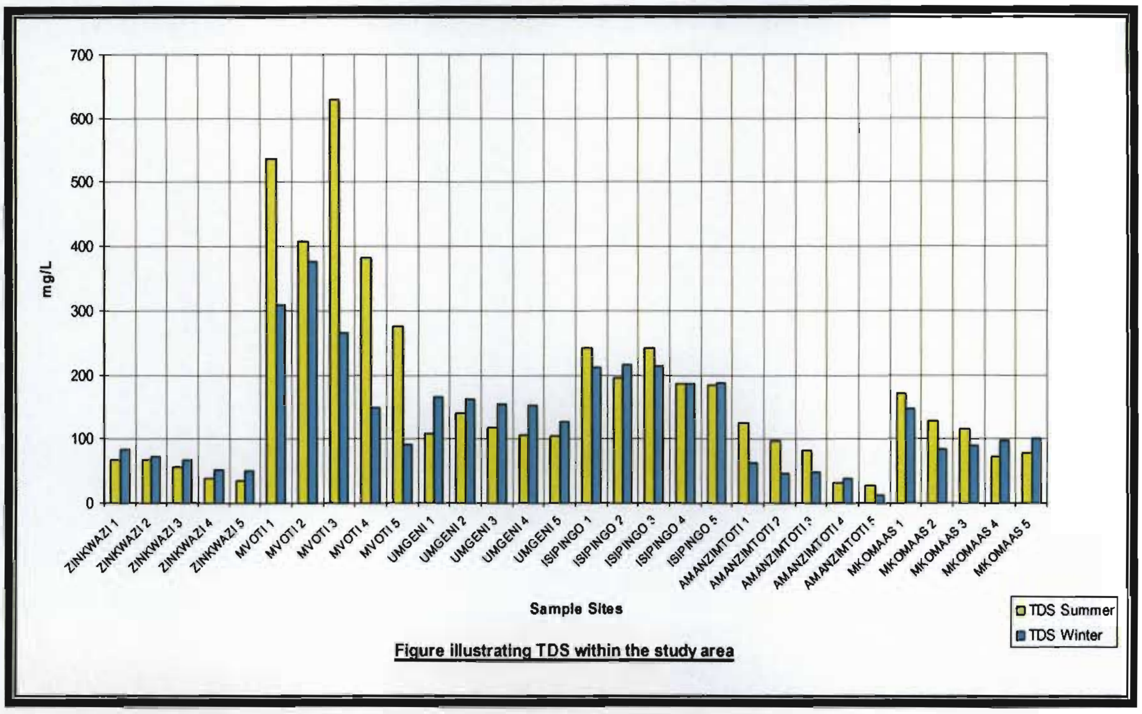


Figure 48: Total dissolved solids within the study area

5.9.3.7 Turbidity

All estuaries demonstrated high turbidity levels except those that are sheltered. The Isipingo has extensive mangroves that provide an ideal shield against the wind and the Amansimtoti is well sheltered from southerly and south-westerly winds by a high vegetated south dune. All the other estuaries are open to the Aeolian effects which induce turbulence on the water surface and resuspends bed muds thus leading to increased turbidity. For the Mvoti, Isipingo, Mgeni and Mkomaas estuaries, high sediment and dissolved solids also contribute to the observed turbidities.

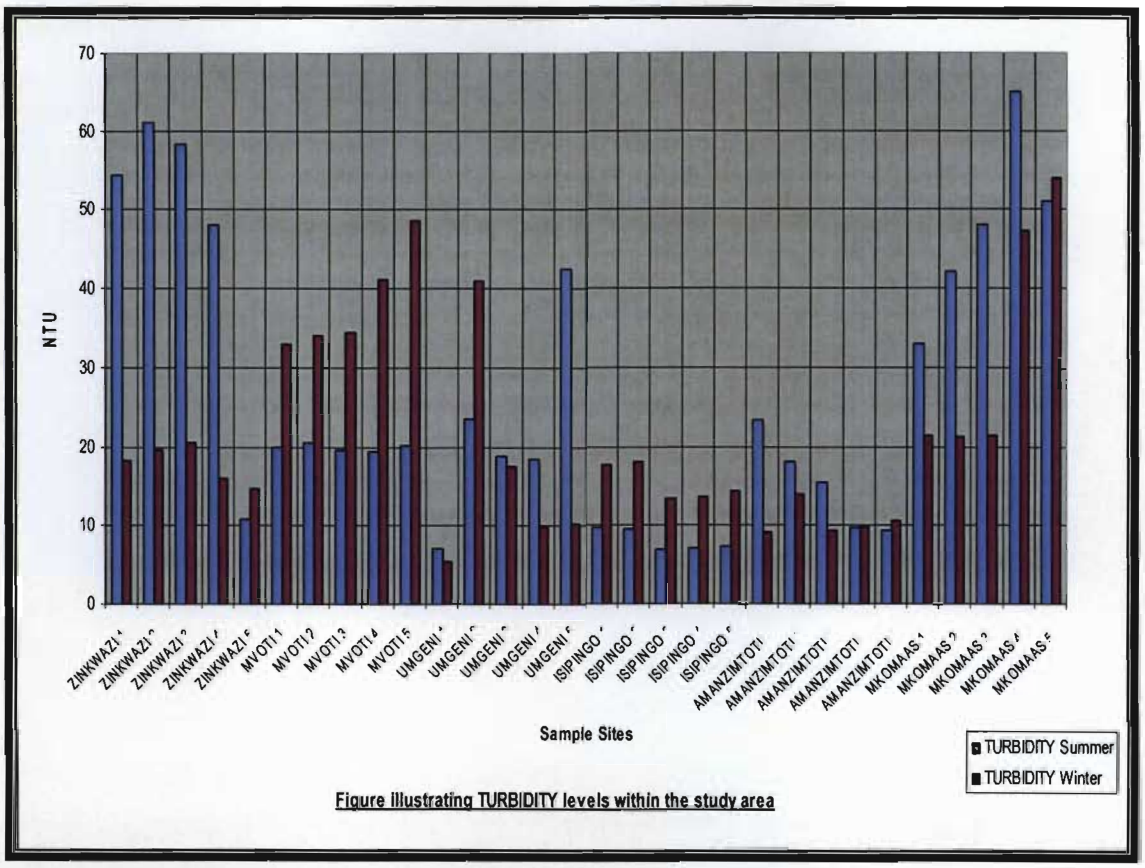


Figure 49: Turbidity within the study area

5.10 Sythesis of results

Goodman (2000) has noted that South Africa has a total of some 250 listed estuaries spread along a coastline of over 3000 km, as well as a number of minor river outlets. These fall into markedly different climatic and oceanographic regimes, from subtropical in the east to warm temperate in the south and cool temperate in the west. In addition, the different geomorphological characteristics of the catchments and coastlines mean that there will be correspondingly large variations in estuarine types. As in most parts of the world, estuaries form some of the most desirable real estate available. The pristine beauty of estuaries, the rich biotic diversity, and the availability of fresh water attract people all over the world. In many cases estuaries have also proved favourable for the location of protective harbours and the siting of commercial and industrial enterprises (Goodman, 2000)

All over the world, including South Africa, more people have migrated to these areas of beauty, and consequently, developments have spoilt and detracted from these assets. Developments have also impinged on the natural functioning of the estuaries, ranging from dams in the catchments of the parent rivers limiting freshwater input, to roads, bridges, buildings and other structures restricting natural flow regimes. Both ecological and biological resources of South African estuaries have been exploited, and this has led to the destruction of habitats and ecosystems and the reduction or even elimination of some species of biota (Goodman, 2000).

Despite the fact that South African estuaries are small by world standards, in part because of the limited fresh water runoff from rivers in a generally semi-arid interior (Schumann, 2003), they nonetheless still continue to provide facilities for recreation and commercial enterprises. Many of these activities are centred- around fishing or other exploitation of natural resources that are very imperative for balanced ecosystems.

The patterns of land use change along the estuaries of KZN researched are typical of many estuaries in South Africa especially along the Indian Ocean. Generally, land use change show increasing urbanization. Nine towns bordering northern and southern coastal estuaries chosen in this study, Empangeni, Tongaat, Stanger, La Lucia, Mhlanga, Durban, Isipingo, Amanzimtoti, and Umkhomazi have some of the fastest growing populations. Wright & Mason (1992) provide useful information concerning the problems of land use change in the Kwa Zulu-Natal estuaries. According to them the four land use types identified are urban, agriculture, tourism and recreation, wetland and forest. Aerial photographs obtained from Durban metro Municipal offices reveal that there is a decrease in vegetation cover and sugarcane plantation especially in Durban north region. This trend has been confirmed by Ahmed (2006) and, of the 8,556 decrease in acreage of sugarcane, most became urbanized. Decrease in sugarcane land has increased dramatically since 2000 as development escalates. This is also noted by the Department of Agriculture (DA) which reported that the northern coast of KZN has witnessed a drastic change in agriculture, where sugar cane plantation has been substituted by urban expansion of upmarket housing that developed around Durban coastal areas. A report on the National Estuaries workshop by Boyd *et al.*, (2000) revealed that the north coast which contain soils most favourable for agriculture have been lost to urban expansion, land speculators, and transportation routes.

It is not surprising therefore that catchments of KZN estuaries have been dammed, dredged, drained, channelized, filled, received wastes discharged from municipal and industrial sources, received pesticides from agricultural run off and suffered from environmental impacts associated with building homes, recreation and tourism. The natural processes and functioning of estuaries have consequently been modified and in many cases suffered varying degrees of degradation. Scientific research documenting the impacts of anthropogenic activities on these individual hydrological processes have been performed by many geomorphologists; for example, Pillay (1996); Cyrus (1988) and others.

In this study of eight of the estuaries of KZN, it is apparent that human activities in the catchments have severely impacted on some of the estuaries and less so on others. Two of the most impacted estuaries were the Mvoti on the north coast and the Isipingo on the south coast. Although further studies will be done on these estuaries to accurately quantify the extent of the damage done, it is apparent from this study that the Mvoti estuary is in a severely degraded state to the extent that it is biotically unproductive. This has indeed been acknowledged by the authorities (the KwaDukuza Municipality) in that they have posted a restriction warning on all swimming, fishing or drinking at the estuary. Elder residents of Stanger (the town upstream of the Mvoti estuary) have through personal communication noted that fishing in the estuary was very good more than two decades ago but since the establishment of industries on the floodplain the estuary is no longer used for fishing.

It should be clear that this environment is in dire need of proper management and that serious measures need to be taken to address affluent disposal in the estuary. The researcher has noted that attempts have been made by the most serious polluters to have the estuary dredged during times when the toxicity levels become unbearable and the entire estuarine environment emits a foul odour. It is recommended that alternate waste disposal modes be sought by industry and that the system be allowed time and the natural impacts of extreme floods events to cleanse themselves and re-establish the health status.

The Isipingo estuary is the other heavily impacted estuary requiring attention. Fortunately, its status has been the focus of much research and concern and attempts are being made to return it to its pristine condition. However, the estuary is surrounded by a host of industrial types and is, every now and then, devastingly affected by industrial pollutants. It has proved difficult to track the polluters but all industries located in the catchment have indicated commitment to adhering to pollution controls. High levels of ammonia, nitrates, dissolved solids and temperature characterize the estuarine environment. In the past, several fish kills have occurred in the estuary prompting action from the authorities. The results of this survey point to more potential problems in the future.

The Isipingo estuary is currently utilized for recreation and contains a large stand of mangroves, the largest south of Durban. It has been a matter of concern that this natural environment has had to suffer so much degradation at the hands of the surrounding industries and a committee of concerned residents of the area have taken it upon themselves to maintain the health of the estuary. However, industries in the catchment continue to pose a potential threat.

The Isipingo estuary beach environment is a popular retreat for recreational seekers and fishermen as is the lake area. The recent storms and high tides have helped seal off the mouth completely and it will require a major effort to re-establish this link with the sea. However, the pipe linkage with the sea still persists and tidal exchange with the sea continues.

On the other extreme, the St Lucia and Mfolozi estuaries are less affected by industrialization but more so by tourism (former) and agriculture (latter). However, these impacts are minamized by the fact that tourism is not yet of a high magnitude at St Lucia and the fact that the wetlands of the Mfolozi Swamps act as natural filters for agricultural runoff. Hence, the water quality of the Mfolozi and St Lucia estuaries are little affected from direct anthropogenic effects. Pollutants accumulating in the systems may come from farmlands in the case of the Mfolozi and from the town of St Lucia in the case of the St Lucia estuary. In both cases, more important negative effects are clearly due to excessive sedimentation. The latter problem has been investigated by a number of researchers and all point to the poor catchment management in the Mfolozi system as being the major problem (e.g. Ramagopa, 1996). Thus, high turbidity in the two systems is reflective of excessive muds input from the Mfolozi catchment due to poor management and, due to the re-suspension of bed muds by wind generated wave induced tuebulence as well as high fluvial discharges in the catchment following good rainfall.

In assessing the current status of the Mfolozi and St Lucia Systems, it is noted that over the last decade, low rainfall over the catchments of this region has led to a rapid drop in lake water levels and the mouth of the St Lucia estuary has been completely closed by marine and aeolian sand deposits. Numerous attempts have been made to re-open the mouth but without success. The Mfolozi and St Lucia estuaries have consequently been separated by thick sediment deposits and, both are cut off from the sea by massive marine barrier deposits. Recently, attempts have been made to link the lagoonal waters of the St Lucia estuary with those of the Mfolozi estuary and to breach a new mouth for the artificially combined systems at a point close to Maphelane where the barrier separating the Mfolozi from the sea was narrowest. The success of this endeavour was short lived as the two systems became isolated by sediment between them as levels of the water in the St Lucia dropped. It is clear that a protracted period of rainfall in the catchment areas of both systems, and a catastrophic rainfall event such as a hurricane is required to move the massive accumulations of sediment at the mouths of the systems and to allow for a more continuous interaction with the marine waters. This came to pass in May 2007 when the systems breached the barriers for the first time in almost a decade.

Water quality results for Zinkwazi indicate that although generally the estuary is in a visually appealing condition , its waters contain fairly high levels of nutrient pollutants and that levels of E.Coli may also be a serious problem and efforts need to be made to limit or decrease the potential for eutrophication.

The Zinkwazi estuary is very popular with tourists throughout the year and this heavy utilization of the estuary by tourists and locals from the town of Zinkwazi which is situated directly on the south bank of the estuary places much pressure on the water quality of the estuary. The very high *E.Coli* counts create a serious health risk to tourists.

The last field visit confirmed that the mouth was closed by a sand barrier built by extensive marine sand deposits following stormy weather in March and June of 2007 and no attempt has been made by the town authorities to breach it. This is because there is little need to as boats may be easily launched directly into the surf.

The Mngeni estuary is currently heavily utilized for recreation as Durban is a favoured holiday destination for a large number of tourists, particularly during vacation periods. The mouth has been kept continuously in an open condition during the study period to facilitate recreational activities and a number of fishermen frequent both the estuary and beach environment. The barrier environment has grown considerably during the period of study as longshore drift has welded thick accumulations of sediment onto the beach face and wave washover has extended fan development into the lagoonal embayment. Within the embayment of the estuary are several large sediment lobes that have been deposited on the flood tide. These are largely built by flood tidal flows and comprise largely marine sand underlain by lagoonal muds of fluvial origin.

Chemical analysis of the water quality revealed that for the most part the waters of the Umgeni estuary were within DWAF target water quality limits. This is remarkable as the Umgeni is undoubtedly the most heavily utilized catchment in the province. It was evident from TDS readings that the estuary may contain high levels of pollutants not tested for in this study and this can only be confirmed by a more comprehensive survey. However, Umgeni Water, the authority responsible for the river and catchment evidently is doing a very good job of maintaining the health status of this very important water system

The Amanzimtoti estuary yielded low values throughout for the water quality parameters measured. Although some enrichment of nitrates was evident the results obtained were somewhat surprising as this estuary was often thought of as being very polluted as contaminants may easily accumulate in the estuarine embayment. The estauary was recently opened during stormy weather conditions and some flushing of accumulated pollutants may have occurred. This estuary drains a fairly small catchment which is densely populated and has the potential for enrichment. Monitoring is important as the estuary is heavily favoured by tourists.

The sand barrier across the mouth was well developed and dunes to the north and south in fairly good condition. On the last field trip, the mouth was closed and water was accumulating in the estuarine embayment.

In the Mkhomazi system, intermediate nitrates and conductivity were detected. Total dissolved solids are high and may indicate pollution by constituents not specifically measured for in this study. Parts of the estuary exhibit high turbidity which may be caused by the windy conditions. Constant monitoring is essential to ensure that the health status of the estuary is maintained.

Some significant erosion of the Mkomaas coastline has occurred recently due to the high tides and stormy weather. Some reconstruction of the south side is required to facilitate recreation and other beach users. The stormy conditions has allowed for significant volumes of sediment to be deposited in the estuary. The waters of the Mkomaas appear to be fairly turbid but this may be related to the resuspended muds following windy conditions. The barrier environment on the north side is well developed with a wide berm and beach face and is very popular with tourists and fishermen.

From the above it is clear that the estuaries of the province reflect fairly accurately in terms of its condition the level to which catchments have been utilized. High levels of agriculturalization and industrialization have severely impacted on some of the estuaries (Mvoti and Isipingo) whilst others are better managed (Umngeni and Mkomaas).

Each estuary consists of a number of different habitats including the water column, salt marshes, intertidal banks, mangroves and reedbeds. Each habitat is a product of the physical features and the biological features. The combination of these features generates the potential of each estuary to supply goods and services. This study demonstrates the importance of the need for continuous monitoring of this valuable resource in order that the supply of estuarine goods and services and habitats is maintained. Further, whilst sound management policies are available, it is imperative that the relevant authorities and municipalities take the lead in implementing them to ensure that the status of the estuaries is not deteriorating.

Not only are estuaries particularly important to the lives of many marine organisms, but they also seem to be specifically attractive to human populations as well due to their natural beauty (Glavovic, 2000). Their popularity has resulted in a high value of housing development around them, infact, it has been discovered during the research that housing prices along the estuaries within the study area are abnormally exuberant. Most of the world's metropolitan areas are centred on the estuarine systems, for reasons that are easily understood. Consequently estuarine development is costly and has the highest value. South Africa therefore is not an exception as their estuaries are highly occupied and very expensive. At St Lucia, Zinkwazi, Mvoti, Mngeni, Isipingo and Mkomazi for instance, land value for housing development is very expensive. The northern estuaries tend to be highly populated and consequently have more value than southern estuaries (DEAT, 2000). The fame and popularity of the estuarine habitation tend to be a world wide trend. However, there is a conflict of interest between naturalists and anthropogenists and this has been worsened by acute human population intensity.

One of the main concerns over the influence of humans on estuarine system involves the addition of "pollutants. It takes a significant amount of time to develop a stable intricate biological community, with various organisms filling various important ecological niches. Altering any component upsets the entire community. Often our pollution is not constant in time, so that stable communities of organisms cannot develop (Stow, 1983). Fortunately, there are some natural processes that help cleanse estuaries of our pollutants. Some settle out in the sediments, and some are carried out to sea. Many of our pollutants are surface-active, meaning they tend to adhere to surfaces. The fine sediments suspended in turbid coastal waters provide a large amount of surface area altogether onto which these pollutants can be absorbed. As these sediments settle out of suspension, then, these pollutants tend to settle without them. The concentration of pollutants in the bottom sediments is a concern, of course. Although removed from the water, these pollutants are still there in hibernation, waiting for future turbulence, waves, or currents to stir them up again. Only extreme events such as major floods are expected to adequately flush out polluted bottom sediments but this has the effect of destroying whatever ecosystems that may be in place at the time. However, it is well documented that estuarine ecosystems are very resilient and re-establish fairly rapidly.

Although estuary condition reflects both natural and anthropogenic behaviour, this study has discovered that catchment influence is a dominant factor in determining estuarine health. The relationship between catchments and estuaries is undisputable. Estuaries are the focal point of any catchment and various anthropogenic activities within a catchment have positive and negative effects on either the quantity or quality of water that enteres the estuary (DWAF, 2003).

There is evidence of the severity of poor catchment management practices. This evidence is proved by the poor state of some of the estuaries along the KwaZulu-Natal coast. This has also been found within the study area especially where agriculture is a dominant practice as is the case for the Mfolozi and Zinkwazi estuaries. It is therefore important to the future well being of these estuaries, that various tiers of catchment management authority presently put in place by the Department of Water Affairs and Forestry are successful. This does not however, minimise the responsibility of local authorities with jurisdiction over an estuary. It is very important that such authorities proactively manage land uses and anthropogenic activities on and around the estuaries in order to minimise potential impacts on the systems (DWAF, 2003).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The evidence of the study confirms that most of the estuaries surveyed are under pressure through natural and anthropogenic phenomenon. However, there are a handful of them which are in healthy conditions. They are all suffering and gradually getting contaminated and depleted but in an unequal rate through anthropogenic activities taking place uncontrolled and randomly in their catchmenmt areas. It is very important that the metropolitan authorities, on behalf of the government, private sector and the local communities work hand in hand in protecting the endangered wetlands including the estuaries. It is also revealed from the study that lack of knowledge from the indigenous communities contributes as well in an unintended destruction of the natural resources. This therefore triggers many questions concerning the success of capacity building and training which should be led and monitored by government.

Humans are the main culprits for estuarine contamination and degradation. It has been revealed and realised through this research that about 84.2% of the catchment areas within the study area are human occupied and have the prevalence and domination of both primary and secondary activities. The suffering of estuaries through anthropogenic inteference differs as it depends on the extent in which catchment areas are utilized. Where anthropogenic activities take place alarmingly, estuaries also suffer a great deal. This poses a challenge to ecologists, hydrologist and environmentalists generally, and to physical geographers specifically since they regard estuaries as very important for their nursery functions and ecological balances.

The results of the study indicate that those estuaries that are heavily utilized consequently show the greatest impacts. The Isipingo and Mvoti estuaries are severely impacted and their appauling state is perpetuated by industrial and agricultural sources. The uMngeni, on the other hand, was found to be in a fairly healthy state despite having the most heavily utilized catchment hinterland. uMkhomazi as an estuary unexpectedly yielded low degradation values and this was very strange since this estuary drains a large catchment. Clearly, where sound management is capacitated by a continuous monitoring, estuaries appear to be in a state of relatively sound environmrental health.

The study has revealed that the Mfolozi mouth position has been artificially relocated on several occasions since 1952 by human intervention in the system. In these situations, the Mfolozi mouth may be located between one and two kilometres south of the St-Lucia mouth.

Catastrophic flood events such as Cyclone Domoina in 1984 and the September 1987 floods from cut-off lows have yielded such high discharges that large volumes of sediment in the estuary and the surrounding have been scoured and flushed offshore and new mouth positions was created for the Mfolozi further south of the combined mouth position. There is evidence of extremely poor catchment management practices. This evidence is proved by the poor state of many estuaries along the KwaZulu-Natal coast. Extremely poor catchment management practices have also affected Zinkwazi, Mngeni, Amanzimtoti and uMkhomazi estuaries. The study has therefore recommended that for the important future well being of these estuaries, various tiers of catchment management authority must be presently and successfully be put in place by the Department of Water Affairs and Forestry (DWAF) and the Department of Environmental Affairs and Tourism (DEAT) .

6.2 Recommendations

A national government must ensure effective pariticipation of the relevant stakeholders in water resource decisions that affect them. Probably understanding water law could be one of the steps towards effective participation. The National Water Act must assist and provide the understanding and describe in user-friendly language the purposes and principles of the National Water Act, as well as the strategies and institutions proposed to achieve its goals. The Act must outline the measures contained in it that are designed to protect life- supporting ecosystems like estuaries, lagoons, dunes and mangroves etc. The National Water Act must be accessible to both water users and to all the stakeholders working in water resource management. Before the government imposes heavy fines to those who degrade estuaries either ignorantly or purposely, there should be proof that training of the people on the ground and capacity building has been done and monitored. All the majors and mechanisms should be put in place to protect the environmental resources like water, soil and flora and fauna.

Training of the indigenous or local communities is one of the main principles outlined in the White Paper for Environment and Tourism. It is stated catergorically that capacity building is achieved through proper training and job creation.

There should be significant issues to consider as aids to the assessment of a planned structure or activity in terms of its potential impact on the estuarine environment or on normal estuarine functioning. The severity or significance of the impact must be assessed in relation to the nature of the particular estuarine system in question taking into consideration aspects such as size, rarity, conservation status or presence or absence of similar areas in neighbouring estuaries or in the same geographical area.

There is evidence of extremely poor catchment management practices. This evidence is proved by the poor state of many estuaries along the KwaZulu-Natal coast. The study has therefore recommended that for the important future well being of these estuaries, various tiers of catchment management authority must be presently and successfully be put in place by the Department of Water Affairs and Forestry.

The Department of Environment and Tourism is also expected to play an important role and should encourage and monitor the responsibility of local authorities with jurisdiction over an estuary. It is very important that such authorities proactively manage land uses and anthropogenic activities on and around the estuaries in order to minimise potential impacts on the systems. These activities often have greater impacts on the estuary than the activities in the remainder of the catchments. Besides that, estuaries play a vital role as life supporting systems as food chains and food webs, they are also a source of aquatic species such as prawns and fish that contain a lot of proteins.

The population of South Afirca exceeds food resources and ignorantly destroy arable land and as result this has an adverse impacts in estuaries specifically and the environment generally. It is therefore very significant that environmental policies are implemented and monitored for the betterment of the natural resources and the population of South African. It is also necessary that the government is taking a drastic step in ensuring that the poorest of the poor is empowered and benefiting from the environment without destroying it.

There is an urgent and a dire need to integrate planning issues and environmental considerations, especially with respect to forward panning principles and procedures. Estuaries are sensitive, productive and very attractive for tourists and the local communities so their protection is imperative, and their conservation and preservation must be reciprocal in the sense that, people's access to estuaries is always monitored.

Environmental legislations and policies must bite to anyone who destroys the environment. It is therefore compulsory that administrative procedures for processing applications and legislative provisions for regulating potentially damaging activities need to be installed. Activities in the catchment of an estuary, in the estuary itself, or in the local coastal environment affect the state of that estuary and often causing degradation. Symptoms of degradation in estuaries may be manifest in terms of changes in water flow, changes in sedimentation, changes in water quality or aesthetic changes. In order to restore a degraded estuary, the symptoms of degradation must be identified, the probably cause of degradation must be determined, a desired restored state must be decided upon, nd alternative strategies for restoration must be assessed.

CHAPTER SEVEN: REFERENCES

Achtzehn, H.G.O., 1991: Zinkwazi Beach & surrounding area, Natal North Coast: History, personalities, developments. Achtzehn Family, Zinkwazi Beach.

Acocks, J.P.H., 1975: Veld: types of South Africa Botanical Research Institute, No. 40, Pretoria.

Ahmed, F.A., 2006: The Impacts of Tourist & Residential Development on the Kwazulu - Natal North Coast:- Umhlanga Rocks to Salt Rock. Unpub. Masters thesis, UDW.

Ahmed, R., 2006: A study of the heavy metal content of the sediments in the Northern KwaZulu-Natal coastal zone, South Africa. Unpub. Honours thesis, UKZN.

Allanson, B.R., and Baird, D, 1999: Estuaries of South Africa. Cambridge University Press, Cambridge, 320pp

Allen, J.R.L., 1991: Physical Processes of Sedimentation, 40 (120 -190. George Allen & Unwin. London.

Barnes, N., 1996: Environmental Policy in an International Context: Environmental Problems as Conflicts of Interest, 19: 72-80.

Barnett, T.P., 1983. Recent changes in sea-level and their possible causes. Climatic change, 5: 16-47.

Begg, G.W., 1978: The estuaries of Natal. Natal Town and Regional Report Vol. 41 Pietermaritzburg.

Begg, G.W., 1978: The Estuaries of Natal. Natal Town and Regional Planning Report, 41: 657pp.

Begg, G.W., 1980: The Wetlands of Natal (Part 2): The distribution, extent and status of wetlands in the Mfolozi Catchment. Natal Town and Regional Planning report. Volume 71: 657pp.

Begg, G.W., 1984. The estuaries of Natal part II Natal Town and Regional Planning Report Vol. 55 Pietermaritzburg.

Belderson, R.H., 1961. The size distribution characteristics of the recent shallow marine sediments off Durban, South Africa. Unpubl. MSc Thesis. University of Natal, Durban: 96pp.

Boyd, A. J.,Barwell, L., Taaljard, S., 2000. Report on Natural Estuaries Workshop. 3-5 May 2000, Port Elizabeth, South Africa.Report No 2, Marine and Coastal Management Implementation Workshop. Department of Environmental Affairs and Tourism, Cape Town.

Boyd, R. & Dalrymple, B.A. 1992. Classification of classic Coastal depositional environments. Sedimentary Geology, 80: 139-150.

Brand, P.; Kemp, P.H.; Pretorius, S.J. and Schoonbee, H.J., : 1967 Water quality and abatement of pollution in Natal rivers, 1: Objectives of river surveys, descriptions of methods used and discussion of water quality criteria. Natal Town and Regional Planning Report 13: 1-101.

Brijlal, N. (2004). The environmental and health status of the Mngeni Estuary in KwaZulu-Natal, *South Africa,* unpublished MSc Thesis, University of KwaZulu-Natal, Durban.

Cameron, W.M. & Pritchard, D.W., 1963. Estuaries. In: Hill, M.N. (ed.), The Sea, Vol. 2 John Wiley &Sons, New York

Chew & Bowen, 1971. The water resources of the coastal areas of Northern Natal and Zululand. Natal Town and Regional Planning Commission Report 17: 1-18.

Cooper, J. A. G. & Mason, T.R., 1986. Subaerial Washover fans in the Beachwood Mangrove area, Durban.S.E.A.L. Report No.1. Dept of Geology and Applied Geology, University of Natal, Durban, 2: 94pp.

Cooper, J.A.G. & Flores, R.M., 1991. Shoreline deposits and diagnesis resulting from two Late Pleistocene highstands near + 5 and + 6 metres, Durban, South Africa. Marine Geology, 97: 325-343.

Cooper, J.A.G., 1991. Sedimentary models and geomorphological classification ofriver mouths on a subtropical, wave-dominated coast, Natal, South Africa.Unpub. PhD thesis, University of Natal. Durban, 401pp.

Cooper, J.A.G., 1994. Shoreline changes on the Natal Coast. Natal town & Regional Planning Commision Report, Vol 79.

Cooper, J.A.G.,& Mason, T.R., 1987. Sedimentation in the Mgeni Estuary. S.E.A.L. Report, Department of Geology and Applied Geology, University of Natal, Durban.2: 97pp.

CSIR 1981: Hydrological/hydraulic studies of Natal estuaries: Forty second Steering Committee meeting Marine disposal of effluents and estuarine investigation committee. Report No. 5. NRIO Memoradum 8115.

Curray, J.R., 1964. Transgression and Regressions. In: Miller, R. L. (ed), papers in Marine Geology, Sheperd Memorial Volume. Macmillan, New York, 175-203.

Curray, J.R., 1965. Late Quaternary history, Continental Shelves of the United States. In: Wright, H.E. & Frey, D.G. (eds), The Quaternary of the United States (INQUA Volume). Princeton University Press, Princeton, New Jersey, 723-735.

Cyrus, D.P., 1988. Turbidity and other physical factors in Natal estuarine systems, Part 1: Selected Estuaries. J.Limnol. Soc. Sth Afri., 14(2) 50-60.

Cyrus, D.P., 1988[b]. Episodic events and estuaries. Effects of cyclonic flushing on the benthic fauna and diet of Solea bleekeri (Teleostei) in Lake St lucia on the South-eastern coast of Africa. J. Fish Biol. 33 (Supplemented A), 1-7.

Dallas, H.F. and Day, J.A., 2004. The Effect of Water Quality Variables on Aquatic Ecosystems: A Review. Water Research Commission (WRC), Freshwater Research Unit. Report No. TT 224/04. University of Cape Town, Rondebosch.

Dalrymple, R.W. Zaitlin, B.A. & Boyd, R., 1992. Estuarine facies models: Conceptual basis and stratigraphical implications implications. J. Sed. Petrol.

Davies, B. and Day, J., 1998. Vanishing Waters. University of Cape Town Press, Cape Town, 337pp. See coastal lakes and estuaries p 153- 57

Davies, J.L., 1980. Geographical Variation in coastal development. Longman, London.

Day, J.H., 1951. The ecology of South African estuaries, 7: The biology of Durban Bay. Ann. Natal Museum, 13: 240-246.

Delo, E.A., 1988. Estuarine Mud Manual. Hydraulic Research Report SR164, Wallingford, U.K.

Department of Environmental Affairs and Tourism (DEAT) 2000. Key elements of the White Paper for Sustainable Coastal Management, Cape Town.

Department of Water Affairs & Forestry 1999. Resource Directed Measures for protection of Water Resources, Volume 2: Integrated Mannual, Version 1.0. Pretoria, South Africa.

Department of Water Affairs & Forestry, 2003. Assessment of the financial feasibility related to the establishment of a catchment management agency for the Usuthu to Mhlatuze water management area.

Dingle, R.V.& Rodgers, J. 1972. Pleistocene paleogeography of the Agulhas bank. Trans. Roy Soc. S. Afr., 40 : 135-175

Dionne, J.C., 1963. Towards a more adequate definition of the St. Lawrence estuary. Zeitschr. F. Geomorph., 7 (1) : 36-44

DWAF, 1996: South African Water Quality Guiglines. Vol 7 Aquatic Ecosystem

Dyer, K.R., 1973. Estuaries: a physical introduction. John Wiley, London.

Dyer, K.R., 1979. Estuarine hydrography and sedimentation. Cambridge Univ. Press., Cambridge

Dyer, K.R., 1997. Estuaries: a physical introduction, John Wiley & Sons. Chichester.

Edwards, R. & Moll, E.J., 1972. The Beachwood mangroves and their present status and a plan for their conservation. Project Report, Wildlife Society of South Africa, Natal Fieldwork Section: 21: 15pp.

Fairbridge, R.W.& Bourgeois, J.S.V., 1978. The Encyclopaedia of Sedimentology. Dowden, Hutchinson and Ross, Stroudburg: 901-930.

Fairbridge, R.W., 1980. The estuary: Its definition and geodynamic cycle. In: Olausson, E.& Cato, I. (eds) Chemistry and biogeochemistry of estuaries. John Wiley & Sons, New York: 1-35.

Glavovic, B. C., 2000. Our coast for life. From policy to local action. Department of environmental Affairs and Tourism, Pretoria,23pp.

Glazewski, J., 2000. Environmental Law in South Africa. Butterworths, Durban, 830pp.

Goodland, S.W., 1986. A tectonic and sedimentary history of the Mid-Natal Valley (S W Indian Ocean). Joint Geological Survey/ University of Cape Town Marine Geology Programme Bulletin, 15: 415 pp.

Goodman, P.S., 2000. Determining the conservation value of land in KwaZulu- Natal. KZN NCS Biodiversity Division Draft.

Gray, N.F., 1994. Drinking Water Quality: Problems and Solutions. John Wiley & Sons, Chichester.

Harrison, T. D., Cooper, J.A.G., and Ramm, A.E., L., 2000. State of South African estuaries:geomorphology, icthyofauna, water quality and aesthetics. State of the Environmental Series, Research Report 2, 117pp. Department of Environmental Affairs and Tourism, Pretoria.

Hayes, M.O., 1975. Morphology of sand accumulations in estuaries. In: Cronin, L.E. (ed), Estuarine Research Volume 2. Academic Press, N.Y.: 3-22.

Hayes, M.O., 1979. Barrier island morphology as a function of tidal and wave regime, In: Leatherman, S.P. (ed.), Barrier Islands, Acadfemic Press, N.Y.: 1-28)

Heydorn, A.E., F., 1989. The conservation status of Southern African estuaries. In Huntley, B.J. (ed.) Biotic Diversity in Southern Africa, Oxford University Press, Cape Town, 280pp.

Hughes, P. 1990. Global sea-level rise, fact or fantacy. Conserva, 5: 14-15.

Huizinga, P. & Van Niekerk, L., 1997. The dynamics of the Tugela Estuary. In: Thukela Estuarine freshwater requirements: An initial assessment. Prepared by N Quinn on behalf of the Consortium for Estuarine Research and Management, for the Department of Water Affairs and Forestry. February 1997.

Hutchnson, I.P.G., 1976. Lake St Lucia: Mathematical modelling and evaluation of ameliorative measures.

Hydrological Research unit, Report 6/75. University of the Witwatersrand, Johannesburg.

Imbrie, J. & Imbrie, K.P., 1979. Ice ages Solving the mystery. Harvard University Press, Cambridge, Massachusetts: 224 pp.
Jersey, 782 pp.

Kalicharran, D., 1993: Proposal for the Rehabilitation and Management of the Isipingo Lagoon and Estuary. Department of Environmeental and Geographical Science, University of Natal, Durban.

Kelbe, B.E., 1992. Hydrology. In: Environment Impact Assessment, Eastern Shores of Lake St Lucia, Kingsa/ Tojan Lense area. 1 (1). CSIR environmental Services, Pretoria.

Lamberth, S. and Turpie, J., 2001. The role of estuaries in South African fisheries : economic importance and management implications. Unpublished.

Lindsay, P., 1996. Influence of Tidal Range and River Discharge on Suspended Particulate Matter Fluxes in the Forth Estuary (Scotland), Estuarine Coastal and Shelf Science, 41- 47.

Lindsay, P., Mason, TR., Pillay, S., Wright, C I., 996. Suspended particulate matter and dynamics of the Mfolozi estuary, KwaZulu Natal: Implications for environmental management.

Looser, U., 1985. Some problems in the Mfolozi Catchment: Assessment of research requirements. Department of Water Affairs, Pretoria, 120pp.

Lubke, R. and de Moor, J., 1998. Field Guide to the Eastern and Southern Cape Coasts. University of Cape Town Press, Cape Town, 445pp.

Martin, A.K. & Flemming, B.W., 1986. The Holocene Shelf Sediment wedge off the South and east coast of South Africa. In: Knight, R.J. & Mclean, J.R. (eds.). Shelf Sands and sandstones. Canadian Soc.Petrol. Geol. Mem., 11: 20-46.

Martin, A.K., 1986. The Holocene Shelf Sediment Wedge off the South and east coast of South Africa. In: Knight, R.J.& Mc Lean, J.R. (eds.) Shelf sands and sandstones. Canadian Soc. Petrol. Geol. Mem., 11: 27-44.

Maud, R.R., & Orr, W.N., 1974. Aspects of the Post-Karoo geology in the Richards Bay area. Trans. Geol. Soc. S. Afr., 78: 101- 109.

M^c Cormick, S.M., Cooper, J.A.G.& Mason, T.R.,1992. Fluvial Sediment Yield to the Natal Coast: A Review. Sth. Afr. J. Aquat. Sci. 18 (1/2) 74-78.

Morant, P. D., 1993. Estuaries of the Cape: Part II: Synopses of available information on individual systems. CSIR Research Reports, Stellenbosch.

Murray, S. Conlon, D. Siripong, A. & Satoro, J., 1975. Circulation and Salinity distribution in the Rio Guayas Estuary, Ecuador. In: Cronin, L.E. (ed.), Estuarine Research, Vol. II: Geology and Engineering. Academic Press, New York.

Nichols, M.M. & Biggs, R.B., 1985. Estuaries In: Davis, R.A. (Ed.) Coastal Sedimentary Environments. Springer Verlag, New York, 77-186.

Olausson, E. & Cato, I., 1979. Marine Geological Laboratory Univcersity of Goteborg, Sweden.

Olausson, E. & Cato, I., 1980. Chemistry and biogeochemistry of estuaries. John Wiley & Sons, New York: 10-42

Orme, A.R., 1974. Estuarine Sedimentation along the Natal Coast, South Africa. Technical reports, office of Naval Reseach, USA: 53pp.

Orme, A.R., 1975. Late Pleistocene channels & Flandrian Sediments beneath Natal estuaries: a synthesis. Ann. S. Afr. Mus., 70: 76-80.

Pearce, A.F., Schumann, E.H., 1977. A review of present concepts on Natal Coast circulation. Progress Report, CSIR/ NIWR, 34th Steering Committee meeting, 33: 4-20.

Perry, J.E., 1986. Basic Physical Geography/ Hydro data for Natal Estuaries. NRIO Data Report D 8607, CSIR, Stellenbosch, 6pp.

Pillay, S., Lutchmiah, J, Gengan, R.M., Lindsay, P. 2003. Morphology and Sediment Dynamics of the Ephemeral Mfolozi Estuary, kwaZulu Natal, South Africa.

Pillay, S.P., 1996. Sedimentology and Dynamics of the Mfolozi and St Lucia Estuaries, KwaZulu-Natal, South Africa.

Pitman, W. V., 1980. Hydrology of the coastal lakes of Maputaland with special reference to St Lucia and Sibaya. In: Bruton, M.N. and Cooper, K.H. (eds.). Studies on the ecology of Maputaland.

Pradervand, P. 1998. An assessment of recreational angling in Eastern Cape Estuaries. Msc thesis, University of Port Elizabeth.

Pritchard, D. W., 1967. What is an estuary: physical standpoint! In: Lauff, G. H. (ed), Estuaries. Washington D.C., American Association for Advancement of Science, Publication 83, 3-6.

Ramsay, P.J., Cooper, J.A.G., Wright, C.I. & Mason, T.R., 1989. The occurrence and formation of Indderback ripples in subtidal, Shallow Marine Sand, Zululand, South Africa. Mar. Geol., 89, 229-235.

Ramsay, P.T., 1995. 9000 years of sea level change along the Southern African Coastline. Quaternary International, 25: 4-8.

Reddering, J.S.V., 1987. Historical development of the Keurbooms Estuary in the context of Fomosa Bay, 6th Nat. Oceanographics Symposium Handbk., Stellenbosch, paper B-98.

Reinson, G.E., 1980: Barrier Islands and associated strand plan systems. In: Walker, R.G. (ed) Facies Models. Geoscience Canada, Reprint Series 1. third Printing, Geological Association of Canada: 57-74.

Revelle, C. and Mcgarity, A.E., Eds. *Design and operation of Civil and Environmental Engineering Systems.* John Wiley and Sons Inc., 1997, New York.

Rossouw, J., 1984. Review of existing wave data, wave climate and design waves for South African & South West African (Namibian) Coastal Waters: CSIR Report T/ SEA, Stellenbosch, 8401: 66pp.

Schubel, J.R., 1971. Estuarine circulation and sedimentation. In: Schbel, J. R. (ed.), The estuarine environment. Am. Geol. Inst. Washington, D.C.: Vl, 1-17

Schumann, E. H. & Orren, M. J., 1980. The Physico-chemical characteristics of the South west Indian Ocean in relation to Maputaland. In: Bruton, M.N. & Cooper, K.H. (eds.) Studies on the Ecology of Maputaland.

Shand, Ninham and Parteners, Natal, 1971: Water Resources of Natal South Coast. Natal Town and Regional Planning Commission Report, 18, 1-30.

Skoog, D. A., West, D. M., Holler, F. J. & Crouch, S. R. (2004). *Fundamentals of Analytical Chemistry*, Eighth Edition, Thomson, Brooks Cole, United States.

Stoeppler, M. (1992). Analytical methods and instrumentation – a summarizing overview. In Stoeppler, M. (Eds), *Hazardous metals in the environment*, Techniques and instrumentation in analytical chemistry, Volume 12, Elsevier Science Publishers, Amsterdam, 97-132.

Stow, K., 1983. Ocean Science. (second edition),Califonia Polytechnic State University, John Wiley & Sons, Inc, New York.

Swart, D.H. & Serdyn, J.V., 1981. Statistical analysis of visually observed wave data from voluntary observing ships for the South African east coast. Unpubl. Rep., CSIR, Stellenbosch.

Swart, D.H.& Serdyn, J.V., 1981. Statistical analysis of visually observed wave data from voluntary observing ships for the South African east coast. Unpubl. Rep., CSIR, Stellenbosch.

Swart, D.H., 1980. Effect of Richards Bay Harbour development on the adjacent coastline. CSIR Rep. T/SEA, 8015, CSIR, Stellenbosch: 40pp.

Swart, D.H., 1986. Erosion of manmade dune, Beachwood mangrove area. N.R.I.O. ad hoc Report: 49pp.

Taylor, R., 1991. The Greater St Lucia Wetland Park. Young & Rubicam, Cape Town.

Tchobanoglous, G. and Schroeder, E.D., 1985. Water Quality. Addisson-Wesley: Publishing Company, Massachusetts.

Tucker, M.E., 1973. The sedimentary environments of tropical African Estuaries. Freetown Peninsula, Sierra Leone. Geol. Mijn., 42 122-130
Unpublished MSc Thesis, Department of Geology & Applied Geology, University Of Natal, Durban.

Van Andel, T.H., 1989. Late Pleistocene Sea-levels and human exploitation of the Shore and Shelf of Southern Africa. J. Field Archaelogy, 16: 123-149.

van Heerden, I.L.& Swart, D. H., 1986. Fluvial Processes in the Mfolozi Flats and the consequences for St Lucia.Estuary. Proc. Of the 2nd S. African National Hydrology Symposium, 202-218.

Wallace, J.H., 1975. The estuarine fishes of the east coast of South Africa, 1: Species composition and and length distribution of the estuarine and marine environments, 2: Seasonal abundance and migrations. Investigational Report Oceanographic Research institute, 40: 1-72.

Wallace, J.H., Kok, H. M., Beckley, L.E., Bennet,B., Blaber, S.J. M., and Whitfield, A.K., 1984. South African estuaries and their importance to fishes. South African Journal of Science 710, 220-226.

Walsh, J. N. (1997). Inductively coupled plasma-atomic emission spectrometry (ICP-AES). In Gill, R. (Eds), *Modern analytical geochemistry, an introduction to quantitative chemical analysis for earth, environmental and materials scientists.* Pearson Education Limited, England, 41-66.

Ward, J.V., 1980. *Thermal characteristics of running waters.* Hydrobiol. 125: 31-46.

Whitfield, A.K., 1980. Distribution of fishes in the Mhlanga Estuary in relation to food resources. S.Afr. J. Zool. 15, 159-165.

Whitfield, A.K., 1998. Biology and ecology of fishes in Southern African estuaries. JCB Smith Institute of Ichthyology, Grahamstown.

Whitfield, A.K., 2000. Available Scientific information on individual South African estuarine systems. Water Research Commission Report WRC 577/ 3/ 00, Pretoria.

Whitfield, A.K., Blaber, S.J. M. & Cyrus, D.P., 1981. Salinity ranges of some Southern African fish species occurring in estuaries. S. Afr. J. Zool., 16, 150-160.

Wim van Lenseen, J.D., 1988, Physical Processes in Estuaries. Delft Hydrolics, Estuaries & Seas Division, P. O. Box 177 2600 M H Delft, The Netherlands 207- 302.

Wright, C. I. & Mason, T.R., 1993. Management and Sediment Dynamics of the St Lucia Estuary Mouth, Zululand, South Africa. Journal of Environmental Geology, 22 (3): 227-241.

Wright, C. I., 1990. The Sediment Dynamics of the St Lucia Estuary Mouth, Zululand, South Africa.

Wright, C. I., 1995. The sediment dynamics of the St Lucia and Mfolozi estuary mouths, Zululand, South Africa. Bull. of the Geol. Survey of South Africa, no. 109.

Rossouw, J., 1984. Review of existing wave data, wave climate and design waves for South African & South West African (Namibian) Coastal Waters: CSIR Report T/ SEA, Stellenbosch, 8401: 66pp.

Schubel, J.R., 1971. Estuarine circulation and sedimentation. In: Schbel, J. R. (ed.), The estuarine environment. Am. Geol. Inst. Washington, D.C.: Vl, 1-17

Schumann, E. H. & Orren, M. J., 1980. The Physico-chemical characteristics of the South west Indian Ocean in relation to Maputaland. In: Bruton, M.N. & Cooper, K.H. (eds.) Studies on the Ecology of Maputaland.

Shand, Ninham and Parteners, Natal, 1971: Water Resources of Natal South Coast. Natal Town and Regional Planning Commission Report, 18, 1-30.

Skoog, D. A., West, D. M., Holler, F. J. & Crouch, S. R. (2004). *Fundamentals of Analytical Chemistry*, Eighth Edition, Thomson, Brooks Cole, United States.

Stoeppler, M. (1992). Analytical methods and instrumentation – a summarizing overview. In Stoeppler, M. (Eds), *Hazardous metals in the environment*, Techniques and instrumentation in analytical chemistry, Volume 12, Elsevier Science Publishers, Amsterdam, 97-132.

Stow, K., 1983. Ocean Science. (second edition),Califonia Polytechnic State University, John Wiley & Sons, Inc, New York.

Swart, D.H. & Serdyn, J.V., 1981. Statistical analysis of visually observed wave data from voluntary observing ships for the South African east coast. Unpubl. Rep., CSIR, Stellenbosch.

Swart, D.H.& Serdyn, J.V., 1981. Statistical analysis of visually observed wave data from voluntary observing ships for the South African east coast. Unpubl. Rep., CSIR, Stellenbosch.

Swart, D.H., 1980. Effect of Richards Bay Harbour development on the adjacent coastline. CSIR Rep. T/SEA, 8015, CSIR, Stellenbosch: 40pp.

Swart, D.H., 1986. Erosion of manmade dune, Beachwood mangrove area. N.R.I.O. ad hoc Report: 49pp.

Taylor, R., 1991. The Greater St Lucia Wetland Park. Young & Rubicam, Cape Town.

Tchobanoglous, G. and Schroeder, E.D., 1985. Water Quality. Addisson-Wesley: Publishing Company, Massachusetts.

Tucker, M.E., 1973. The sedimentary environments of tropical African Estuaries. Freetown Peninsula, Sierra Leone. Geol. Mijn., 42 122-130
Unpublished MSc Thesis, Department of Geology & Applied Geology, University Of Natal, Durban.

Van Andel, T.H., 1989. Late Pleistocene Sea-levels and human exploitation of the Shore and Shelf of Southern Africa. J. Field Archaelogy, 16: 123-149.

van Heerden, I.L.& Swart, D. H., 1986. Fluvial Processes in the Mfolozi Flats and the consequences for St Lucia.Estuary. Proc. Of the 2nd S. African National Hydrology Symposium, 202-218.

Wallace, J.H., 1975. The estuarine fishes of the east coast of South Africa, 1: Species composition and and length distribution of the estuarine and marine environments, 2: Seasonal abundance and migrations. Investigational Report Oceanographic Research institute, 40: 1-72.

Wallace, J.H., Kok, H. M., Beckley, L.E., Bennet,B., Blaber, S.J. M., and Whitfield, A.K., 1984. South African estuaries and their importance to fishes. South African Journal of Science 710, 220-226.

Walsh, J. N. (1997). Inductively coupled plasma-atomic emission spectrometry (ICP-AES). In Gill, R. (Eds), *Modern analytical geochemistry, an introduction to quantitative chemical analysis for earth, environmental and materials scientists.* Pearson Education Limited, England, 41-66.

Ward, J.V., 1980. *Thermal characteristics of running waters.* Hydrobiol. 125: 31-46.

Whitfield, A.K., 1980. Distribution of fishes in the Mhlanga Estuary in relation to food resources. S.Afr. J. Zool. 15, 159-165.

Whitfield, A.K., 1998. Biology and ecology of fishes in Southern African estuaries. JCB Smith Institute of Ichthyology, Grahamstown.

Whitfield, A.K., 2000. Available Scientific information on individual South African estuarine systems. Water Research Commission Report WRC 577/ 3/ 00, Pretoria.

Whitfield, A.K., Blaber, S.J. M. & Cyrus, D.P., 1981. Salinity ranges of some Southern African fish species occurring in estuaries. S. Afr. J. Zool., 16, 150-160.

Wim van Lenseen, J.D., 1988, Physical Processes in Estuaries. Delft Hydrolics, Estuaries & Seas Division, P. O. Box 177 2600 M H Delft, The Netherlands 207- 302.

Wright, C. I. & Mason, T.R., 1993. Management and Sediment Dynamics of the St Lucia Estuary Mouth, Zululand, South Africa. Journal of Environmental Geology, 22 (3): 227-241.

Wright, C. I., 1990. The Sediment Dynamics of the St Lucia Estuary Mouth, Zululand, South Africa.

Wright, C. I., 1995. The sediment dynamics of the St Lucia and Mfolozi estuary mouths, Zululand, South Africa. Bull. of the Geol. Survey of South Africa, no. 109.