THE IMPACT OF HARBOUR AND ASSOCIATED ACTIVITIES ON THE WATER QUALITY OF THE DURBAN BAY AND THEIR EFFECTS ON INDWELLING ECOSYSTEMS

BY

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DECLARATION

I hereby declare that the following documented study reflects an original work of research by the researcher. The research was done in my capacity as a registered Masters student in the School of Environmental Sciences at the University of KwaZulu Natal, Durban. All data were collected and analyzed by the researcher and where other resources are cited in this document, due credit have been given to authors through referencing to their credit.

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(Abena M.D. Obeng)

Date………………

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(Dr. S. Pillay – Supervisor)

Date: ………………….

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DEDICATION

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ABSTRACT

Coastal systems like lagoons and estuaries are faced with severe human developmental endeavours. In South Africa, more than 30% of the population lives along the 3000 kilometer coastline. The Durban bay is no exception especially with the existing Durban harbour taking up the natural expanse of the bay. The bay is burdened with a diversity of anthropogenic endeavours, from port operations to industrial activities, to storm water drainage outlets, through to various recreational ventures. These activities have over the years caused a reduction of the bay's mangrove forest, reduced the population of some biota and caused extinction of some indigenous species.

Five areas were selected based on the specific activities and infrastructure that occurred there. Samples of water from these pre-selected sites were collected routinely and analysed for their water quality status. The overall water quality within the bay compared with the DWAF water quality guidelines for South Africa was identified as below stipulated standards. The dissolved oxygen contents as well as nutrients in the form of nitrogen content in its assorted forms are some of the most affected water quality indicators. The majority of the sub standard water quality levels, indicators which are critical to the proper functioning, growth and reproduction of biota within the ecosystems of the bay obtained could be linked directly or indirectly to the activities within the area of sampling.

The resultant chemical and physical conditions in water quality created as a result of the ongoing activities within the bay are not suitable for proper feeding, growth and reproduction of ecosystems. This has caused many species within the bay to migrate or adapt to the adverse conditions and such situations are likely to worsen if stringent measures are not taken in the near future. It appears that the some species are exhibiting some degree of resilience and are at the moment surviving the relatively harsh conditions within the bay. The long term effect of the ever expanding anthropogenic disturbances on the ecosystems are unpredictable and it is therefore imperative that more stringent environmental management plans, programs and policies, legally binding, are formulated to serve as a check on all who benefit from the bay's resources.

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BOD	Biochemical Oxygen Demand
CMS	Catchment Management Strategy
COD	Chemical Oxygen Demand
CODc	Carbonaceous Oxygen Demand
CSDP	Central Spatial Development Plan
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environment and Tourism
DO	Dissolved Oxygen
DPSIR	Driver Pressure State Impact Response
DWAF	Department of Water Affairs and Forestry
EPA	Environmental Protection Agency
ICM	Integrated Coastal Management
ICMA	Integrated Coastal Management Act
KZN	KwaZulu-Natal
MLRA	Marine Living Resources Act
MPCA	Minnesota Pollution Control Agency
NPA	National Ports Authority
NWA	National Water Act
NWRS	National Water Resources Strategy
RSA	Republic of South Africa

SAWQG South African Water Quality Guidelines

TDS Total Dissolved Salts

TSS Total Suspended Solids

UNEP United Nations Environmental Programme

WHO World Health Organization

WTP Willingness to Pay

YSI Yellow Springs Instrument

CHAPTER ONE

1.0 INTRODUCTION

Population growth and its accompanying growth in socioeconomic activities have led to an increase in demand for marine and coastal resources. Humans are therefore in a process of annihilating coastal ecosystems (Strom and Klaveness, 2003), deliberately and unintentionally. In addition to governments and economic organizations striving to meet the increasing demand for food, due to population growth, they are also being faced with the challenge of managing the social and economic pressures on marine and coastal areas which are causing detrimental impacts. Although human intrusion on coastal systems is not a new thing, such invasions over the past couple of decades have been almost uncontrollable on a global scale. Examples of coastal systems are estuaries, coastal wetlands, river deltas, and coastal shelves (Wilson *et al*., 2002). Estuaries are one of the favourite coastal ecosystems for socioeconomic developments (Kjerfve, 1994, McComb, 1995). It is evident that economic forces have shaped most, if not all coastal bodies scattered worldwide (Damassa, 2006) and therefore, their degradation has become one of the major issues of global environmental degradation concerns. The main outcomes of social and economic activities are pollution, excessive nutrient loading, altered sedimentation patterns, habitat loss and climate change (Damassa, 2006). In fact, habitat destruction is currently one of the items of much concern for coastal and estuarine ecosystems. Many world renowned estuarine bays and estuaries have lost and continue to lose their integrity as ecosystems through pollution and habitat loss; examples are the Chesapeake Bay (Willard and Cronin, 2007) and the San Francisco Bay (Meyer *et al*., 2009).

Anthropogenic activities can greatly affect the proper functioning of estuarine ecosystems. Whitefield and Elliot (2005) reveal that the fish assemblages within estuarine habitats are affected through humans impacting on the food source availability, distribution, diversity, breeding, abundance, growth, survival and behavior. In fact, it appears that food security has become a challenge not only for humans but also for aquatic life forms (Johnson, 2004). The impact of human activities on estuaries could get so high that their own sources of livelihoods, which are the estuaries, may be terminated (Courrat *et al*., 2009;

Vasconcelos *et al*., 2007) The prominent roles that estuaries play within aquatic ecosystems in biodiversity sustainability must be reason enough for them to be an integral consideration in management and mitigation measures. South Africa's coastline has an abundance of estuarine ecosystems rich in biodiversity. A relatively high proportion of urban land-cover is associated with those estuaries located near coastal cities such as the Buffalo system near East London, the Swartkops estuary near Port Elizabeth, and the Diep estuary near Cape Town (Turpie, 2004a).

Durban Bay is one of such estuaries that are experiencing high levels of human use. History has it that in the mid 1800, the bay was described as a sandy lagoon (Hutson, 2007a). The city of Durban has over the years taken advantage of the strategic location of the Durban bay and built an integrated community of socioeconomic activities in and around the bay. The most prominent of all the activities is the twenty-four-hour operations of the Durban harbour which covers the natural expanse of the bay. The harbour is to date rated as South Africans busiest multi-service port (Patel and Holtzausen, 2009) as well as Africa's busiest port (Hill and Maharaj, 2003). The bay has also served as a venue for the discharge of industrial and domestic effluent for many years, as well as an outlet for many storm water drainage pipes which drain the city during rainfalls and storms (Ports and Ships Maritime News, 2007). Urbanization and relating activities along the bay have caused biodiversity transformation like depletion of mangroves, sand dunes, and rocks (McQwynne and McKenzie, 2006). In addition, ecological processes have been altered and key species removed (Turpie, 2004b). Hutson, (2007a) reports on the gradual but impacting changes that the Durban bay has undergone over the past 160 years of its establishment as a working harbour.

1.2 RATIONALE FOR STUDY

Coastal ecosystems and estuaries have a high value of goods and services to offer (Robinson, 2001) and they have served as raw material for several socioeconomic developments of humans. In South Africa, over 30% of the population live along the 3000km-long coast (Rossouw and Theron, 2009) and benefit immensely from their goods and services. A lot of aquatic ecosystems also depend heavily on the proper running of estuaries. The Durban bay, the only estuary of its kind as an estuarine bay out of the 16 estuaries along the 98km stretch of the eThekwini coastline, is made of many ecologically sensitive areas (eThekwini Municipality, 2009). In terms of biodiversity, it serves as a breeding ground for quite a number of fish species and a habitat for some coastal dwelling birds (Forbes and Demetriades, 2008). Despite the unstable conditions created within and around the bay, it still counts as a bay with high species richness; in fact, it is seen richer in species diversity than other highly rated bays in KwaZulu Natal like Richards Bay, St. Lucia Bay and Kosi Bay (Turpie *et al*., 2002).

Despite this status, the quantity and quality of species diversity have been altered due to port operations, socio-economic activities and pressure from recreational activities (Forbes and Demetriades, 2008).

Forbes and Demetriades (2008) assert that, a highly degraded estuary is one which has had major impacts on core estuarine habitats through infilling, canalization and pollution, with estuarine support habitats and processes greatly reduced. Based on the above definition, the Durban bay can be categorized as a highly degraded estuary. A combination of first and third world threats are affecting the Durban bay as a result of diverse socio-economic activities. It is believed to be one of the highly degraded aquatic environments within the eThekwini municipality (eThekwini Municipality, 2009). The bay has undergone severe physical and geomorphologic changes over the decades due to the quest to maintain its suitability for port operations. To date, over 426 hectares of mangrove and 1078 hectares of intertidal habitats have been displaced within the bay, with habitats of bird species being among the most disturbed (eThekwini Municipality, 2008). Although Durban bay is counted among the four most important estuaries for water bird species habitation, abundance of water bird species within the bay has reduced by over 70% and five species have been declared extinct (eThekwini Municipality, 2008). Over-development and excessive exploitation of keystone species by illegal recreational and subsistence usage among many others occur daily as well (Durban Government, 2007). Harbour operations and accidental spillage into bay waters have resulted in deleterious conditions for indwelling species. In December, 2007, the health of fish species within the bay was threatened when massive numbers of fishes were seen dead within the bay (Savides, 2007). Scientific reports were that, the fish kills were due to massive discharge of raw sewage from dysfunctional sewage pipes of some sewage treatment plants along the Mhlatuzana River, which is the freshwater feature of the estuary (The Mercury, 2008).

Apart from the above developments, further development in and around the Durban bay's catchment is ongoing and several projects are yet to be commissioned in and around the bay (Trade and Investment KZN, 2008). Currently the mangrove headland which overlooks the harbour (commonly called the Bluff) has been earmarked for a multipurpose development site comprising a core business district, residential district, hotel and retail district, recreation and heritage centre districts and either a suspended bridge or a tunnel underneath the harbor entrance to connect the main Durban city centre to the proposed development site (Trade and Investment KZN, 2008). The bay is made up of many recreational and social centers because of its conducive scenery.

An aspect of a good estuarine management scheme is routine monitoring and evaluation of the diverse activities that occur in and around the bay and their impacts on the water quality (Mardon and Stretch, 2002). As the eleventh most important estuary in South Africa out of 256 recognized ones in terms of the economy and biodiversity, (eThekwini Municipality, 2009) and with operations on the Durban bay contributing 20% of Durban's GDP and approximately 2% of the entire nation's GDP (National Ports Authority, (NPA), 2009), there is the urgent need to ensure that the bay's ecological and biophysical attributes are preserved not just in the interest of the municipality, but for the country as a whole. Proper management schemes need to be set up to guide and co-ordinate the prevailing activities. One of the most effective means of achieving such an aim is by analyzing the water quality of the bay to ascertain the impacts that point and even non-point sources of activities in around the bay are causing. Monitoring measures such as these are imperative because for most of the socio-economic functional units within the bay to continuously be viable, management of the water body needs to be approached in a comprehensive manner. It is therefore necessary to progressively analyze the sustainability of the port's operations by monitoring the habitat of the port which is the bay water.

1.3 AIM AND OBJECTIVES

The aim of this research is:

To assess the impact of harbour and industrial activities on the water quality of the Durban bay.

This aim will be achieved via the following objectives;

- To identify ongoing anthropogenic activities within the perimeter of the bay.
- To sample the water of the Durban bay at preselected sites and to analyze these for selected chemical parameters.
- To compare the acquired water quality data with readily available previous data on water quality in the Durban bay as well as existing DWAF water quality guidelines.
- To relate the water quality derived from the analysis to the particular sampling sites.
- To assess the likely impacts of water quality status of the bay on its indwelling ecosystems.

Hypothesis: Socioeconomic activities do have an impact on water quality standards appropriate for estuarine ecosystems.

Null Hypothesis: Socioeconomic activities do not have any impact on water quality standards appropriate for estuarine ecosystems.

1.4 CHAPTER SEQUENCE

Chapter one is a general overview of the research and outlines the aims and objectives of the research. Chapter two is a detailed discussion of literature reviews relevant to the research and chapter three gives an account of the methodologies and procedure used to collect and analyse the water quality data. A presentation of results in tables and graphs are presented in chapter four and they are thoroughly discussed in chapter five. Chapter six gives the conclusions to the findings for the entire research and recommendations to be considered for further research.

CHAPTER TWO: LITERATURE SURVEY

This literature review provides a generalized assessment of definitions, classifications and components of estuaries. The objectives of this chapter are as follows: establish the current and potential goods, services and functions of estuaries and how they are economically evaluated. The chapter also highlights current and potential anthropogenic influences through social and economic activities, their threats to the health and integrity of estuaries and their influence on carrying capacity of estuarine ecosystems.

2.0 INTRODUCTION

There is a lot of over-generalization among researchers when it comes to coastal systems. Technical differences are mostly ignored and bays, lagoons, fjords, estuaries, tidal rivers and straits are used based on the inclination of the researcher. Because the complexities of the functions amongst these water bodies are intricately similar, these errors do not raise many problems. For the purposes of this review and the numerous data available, estuaries, are discussed subsequently as a true representation of most coastal systems. The strategic vision for estuaries in South Africa is that " The biodiversity and functionality of South African estuaries are conserved, protected and optimally managed such that sustainability in terms of ecological integrity, social equity, and economic growth is promoted in a regional, national and global context" (Van Niekerk and Taljard, 2003: 14). To achieve a vision of such magnitude, there needs to be a collaborative effort from all stakeholders in estuarine usage and management. However, estuarine ecosystems on a global scale are experiencing vast transformations from anthropogenic influences. These transformations include habitat alteration or habitat loss, change in mouth dynamics, overexploitation, sedimentation, loss of system variability, recreational disturbances, changes in salinity levels, increased turbidity, changed nutrient status and pollution (Courrat *et al*., 2009, Kennish, 2001; Vasconselos *et al*., 2007). According to Johnson (2004) one of the factors that underpin these problems is the exponential growth of the human population. Since the new concept of the commons includes estuaries, in addition to other components like air, freshwater and the sea, it can be generalized that, estuarine ecosystems are experiencing the unwelcoming “Tragedy of the Commons”. The capacity of these systems to cope have decreased over the years and led to rapid decline in estuarine water quality and quantity (Paulay *et al*., 2002). Nonetheless these undesirable outcomes could be associated with natural processes. Algal blooms for example are natural phenomena that all estuaries experience from time to time (Adams and Matsumoto, 2007). As a means of promoting sustainable development and management of estuaries, there is therefore the need to develop detailed ecological models which take into account biophysical dynamics and anthropogenic pressures.

Practically, the description of estuaries is complex and transitional, and so, is the process of collecting and assessing data for water quality ranking purposes. In addition, most hydrodynamic models applied in such assessments are complex and usually out of reach of most coastal scientists (Fox and Bourne, 2008). Due to the complexity of estuarine processes (natural and anthropogenic), expert opinions need to be outsourced from disciplines like the academia, manufacturing industry, land use planning and governmental agencies are required in order to give a comprehensive and formidable account of activities that affect water quality and quantity and formulate programs and actions towards mitigation.

2.1 DEFINITIONS, CLASSIFICATIONS AND ECOSYSTEM FUNCTIONS

2.1.1 Definition

Each estuary possesses unique intrinsic characteristics; therefore, the task of defining and classifying estuaries is a difficult one. However from a coastal management point of view, there is the need to clear as much ambiguity as possible by developing definitions which are mutually exclusive in order to facilitate decision making. The reasons for variations in definitions are many. Perillo (1989) reveals two of such reasons as being the background of the researcher and the location of the estuary upon which the definition is based. This could be the main reason why estuary definitions and classifications vary amongst various disciplines; geologists, oceanographers, physical geographers, geomorphologists, chemists and biologists. Geologists define estuaries based on their geographical expertise and biologists are prone to dwell on the ecological features.

The most fundamental definition of estuaries is; the region of mixing between ocean and river waters (Constanza *et al*. 1997, cited in Chilli, 2008). Pritchard (1952) defined an estuary as a semi-enclosed coastal body of water having a free connection with the open sea and containing a measurable amount of sea water. About a decade later, Cameroon and Pritchard (1963) expanded the definition by saying; an estuary is a semi-enclosed coastal body of water having a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage. Another definition from Day (1980) states that an estuary is a coastal body of water in intermittent (permanently or periodically) contact with the open sea and within which seawater is measurably diluted with fresh water from land drainage. This definition is an add-on to that of Cameron and Pritchard's (1963) definition. It makes provision for the non-permanent estuaries which are common features on the South African coastline (Harrison *et al*., 2000), otherwise not mentioned in Cameroon and Pritchard's definition. Perillo (1995) however critiques these two definitions based on etymology (study of root of words) by asserting that, estuary comes from the Latin root word "*aestus*' which means 'of tide' or tidal. In his opinion, the word 'tide' and the concept of tidal exchanges are relevant and cannot be done away with in defining estuaries. He consolidates his argument by stressing on the fact that, it is tidal actions that bring about the mixing of freshwater and sea water that Cameron and Pritchard dwell on. In fact, even the physical characteristics like circulation and sediment composition are greatly influenced by tidal actions. Perillo (1995) raises another point that the word 'measurable' in the definitions are quite ambiguous and could be replaced more appropriately with a word like 'significant'. He explains that, 'measurable' confines the definitions to the availability of technology, sensitive and accurate enough to detect and measure the dilution degrees. This could raise doubts in places where such technological devices are lacking. After considering all the above, Perillo (1995:40-41) gives the following definition:

> An estuary is a semi-enclosed coastal body of water that extends to the effective limit of tidal influence within which sea water entering from one or more free connections with the open sea or any other saline coastal body of water, is significantly diluted with fresh water derived from land drainage and can sustain euryhaline biological species from either part or the whole of their life cycle.

Day *et al*., (1989) go further to define estuarine systems as coastal indentations that have a restricted connection to the ocean and remain open at least intermittently. They identify three regions of an estuarine system namely; tidal river zone, mixing zone and near shore turbid zone (Figure 2.1). The mixing zone is the estuary proper and it is this region that experiences the changing gradient of chemical, physical and biological quantities the most (Johnson, 2004).

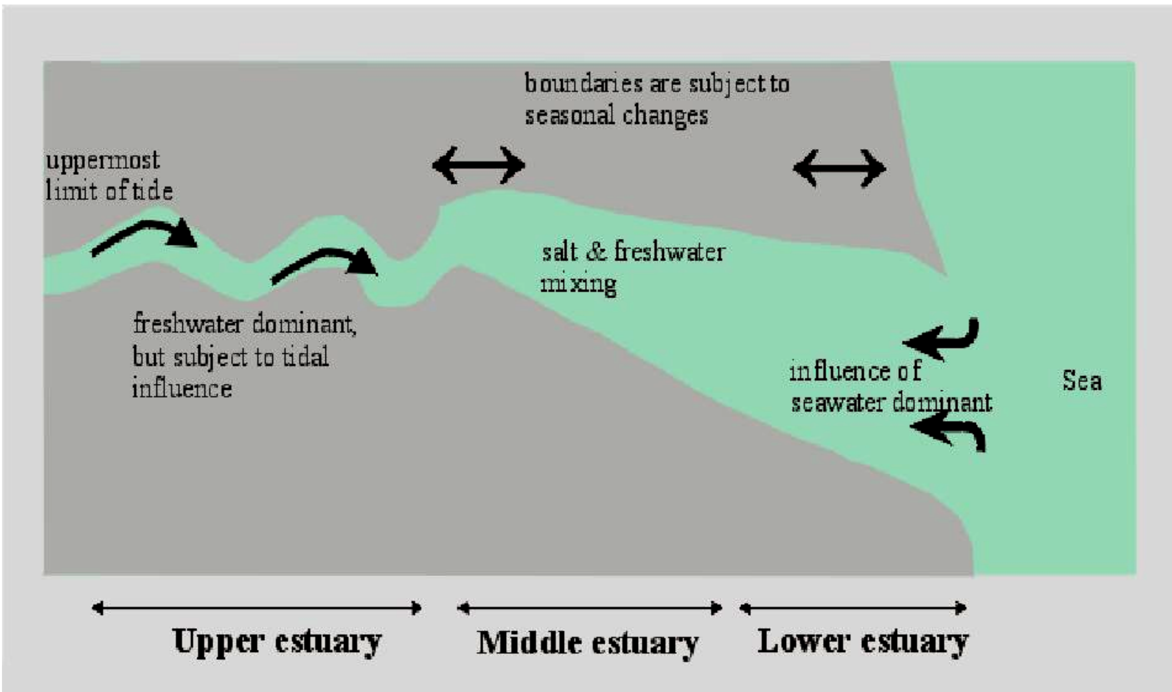


Figure 2.1: A schematic map of a typical estuary showing the divisions into lower, middle and upper estuary. The boundaries are transition zones that shift according to the seasons, the weather and the tides.

2.1.2 Classification

The primary objective of classification is to obtain a formidable basis to generalize and treat members of a category as possessing certain properties (Jones, 1970). Classifications allow researchers to assume similar outcomes for estuaries of different geographic bearings. On account of some estuaries having more research appeal and empirical data than others, classification of estuaries becomes relevant and necessary, especially in instances where management decisions need to be made on under researched estuaries.

Experts have diverse approaches to classifying estuaries. Most classification schemes are based on geomorphology (Hume and Herdendorf cited in Hume *et al*., 2007), hydrology, topography, stratification structure and salinity (Cooper, 1991; Kjerve, 1994; Perillo 1995). Others are established on a combination of the above, and some others include characteristics like, water quality, habit, ecology, and catchment (Cooper *et al*., 1994, Edgar *et al*., 1999). Although process-based ecological classifications are more useful for management, the process of collecting large and complete data sets is costly and time consuming (Hume *et al*., 2007). Some authorities of coastal and estuarine researchers have attempted to classify a range of South African estuaries on a broad spatial scale. These researchers categorized estuaries based on size, type, biogeograhical zone, forms of habitat and biota (Turpie *et al*, 2002). Intensive research by Whitefield (1992) led to five categories of classification, namely:

1. Estuarine Bay
2. Permanently Open
3. River Mouth
4. Estuarine Lake, and
5. Temporarily open (Whitefield, 1992, cited in Turpie, 2004b).

Although other classifications have come up, Whitefield's (1992) classifications is still adapted by many current researchers. Harrison *et al*., (2000) have also classified estuaries in terms of their physical characteristics with their focus on geomorphology and parameters such as mouth conditions, size and the presence of a bar. Based on these criteria, they placed estuaries into six classes:

1. Normally closed small estuaries (surface area < 2 ha)
2. Normally closed medium estuaries (surface area 2-150 ha)
3. Normally closed large estuaries (surface area > 150 ha)
4. Normally open non-barred estuaries
5. Normally open, small barred estuaries
6. Normally open, medium-large barred estuaries.

All the existing classifications still have some degrees of ambiguity attached to them. That is why Turpie (2004b) recommends that new robust classification systems still need to be developed to avoid the inherent flaws and ambiguity of existing ones.

2.1.3 Descriptions - Features and Components (Physical and Biological)

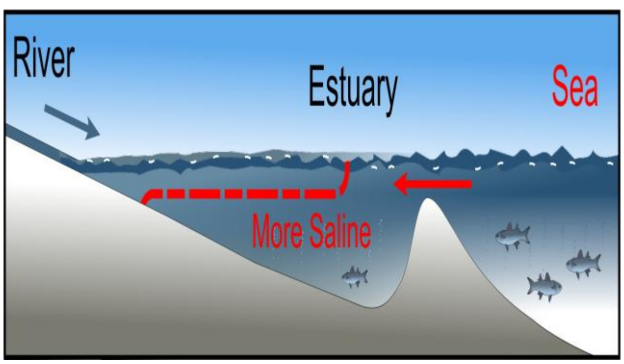
2.1.3.1 Estuarine Ecosystems

No matter how small an ecosystem is; the interspecific and intraspecific relationships that exists among the species, habitats, energy sources and the processes it involves always results in a maze of ecological processes (Elliot and McLusky, 2002). These authors assert that aquatic ecosystems are by far the most complex of all ecosystems. The transient characteristics and water dynamics of estuaries make the ecosystem composition of estuaries even more complex. For the purposes of freshwater quality analysis, DWAF (1996a) defines aquatic ecosystems as: "the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones, reservoirs lakes and wetlands and their fringing vegetation" (DWAF, 1996a pg 8). The definition also includes terrestrial biota, other than humans dependent on aquatic ecosystems for survival, for example, birds. Biotic factors are the most difficult to categorize and enumerate. They include all kingdoms of living organisms that dwell within or around the water body. There are many criteria for classifying biota however trophic status as by far the most popular criteria when dealing with water quality analysis. This criteria divides the biotic components into three main categories namely; primary producers, primary consumers and secondary consumers.

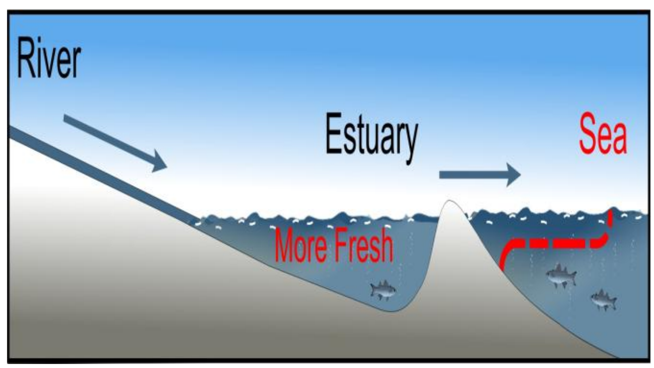
- Primary producers: They are the photosynthesizers and they use carbon dioxide and light to produce their own food. They include seaweeds and phytoplankton (Anderson, 2003).
- Primary consumers: They are heterotrophic organisms which feed directly on the primary producers and
- Secondary consumers: Are the organisms which feed on the primary consumers.

These three trophic levels establish complex feeding relationships made of basic units of food chains and complex food webs (Davies-Coleman and Cook, 2000). In estuaries, the bulk of food production which is the combination of carbon dioxide, nutrients and sunlight energy originates from phytoplankton. Estuaries are referred to as 'food factories' because of their unprecedented yields of primary and secondary productivity (Olsen *et al.*, 2006), a virtue that humans have capitalized on for years.

Abiotic factors include the chemical and physical features, for example; temperature, pH, salinity, nutrients and surfaces which serve as habitats. This component of estuaries are characterized by features such as high food availability, high salinity variations, low depths, muddy grounds, high turbidity, warm waters and diverse rich habitats (Courrat *et al*., 2009). The diverse rich habitats include marshes, meadows, mangrove forests, coral reefs and oyster reefs (Constanza *et al*., 1997). Physical component also include water and its movement patterns (hydrodynamics), water processes, and sediment dynamics. Interactions between river inflows and the sea also add to the dynamism. The river inflows may be due to floods and seasonal base flows while tidal conditions influence the sea movements. These reactions are to a large extent responsible for salinity levels within an estuary. Figures 2.2 and 2.3 illustrate the interactions between riverine and marine flows and their resultant estuarine water and salinity levels. According to Allanson (1999), the chemical properties of South African estuaries are to a large extent determined by geomorphology, fluvial and tidal patterns. Predictions are that, the country's freshwater might have been exploited to the maximum by the year 2020 (DEAT, 2005), this implies that the future of existing estuaries in South Africa is not an automatic certainty. The influence of man on freshwater flow into estuaries and on other aspects will be discussed subsequently.



(Figure 2.2)



(Figure 2.3)

The differences in water levels and salinity penetration between low tide and high tide (Van Niekerk, 2007).

The biological component of an estuary forms the bulk of the biodiversity of an estuary. They can also be referred to as the response component (Van Niekerk *et al*., 2006) because they respond to all the pressures from both physical component and human forces. The biological component is divided into flora and fauna. Flora includes vegetations such as micro-algae, submerged macrophytes, mangroves, reeds, sedges and salt marshes. Flora constitutes the bulk of primary level elements of the food chain in the estuary system and also serves as hiding place for prey from predators. Fauna constitutes benthic invertebrates (crabs, mud prawns, sand prawns, mussel species and surface feeders), fish species and bird species (Baird, 2005). Juvenile and sometimes mature benthic invertebrates serve as prey for the fish and birds. The bird species also use the estuarine environment as feeding, roosting and breeding grounds. These interactions contribute to the complexity of the feeding relationships within these ecosystems. Figure 2.4 shows some members of the biological component.

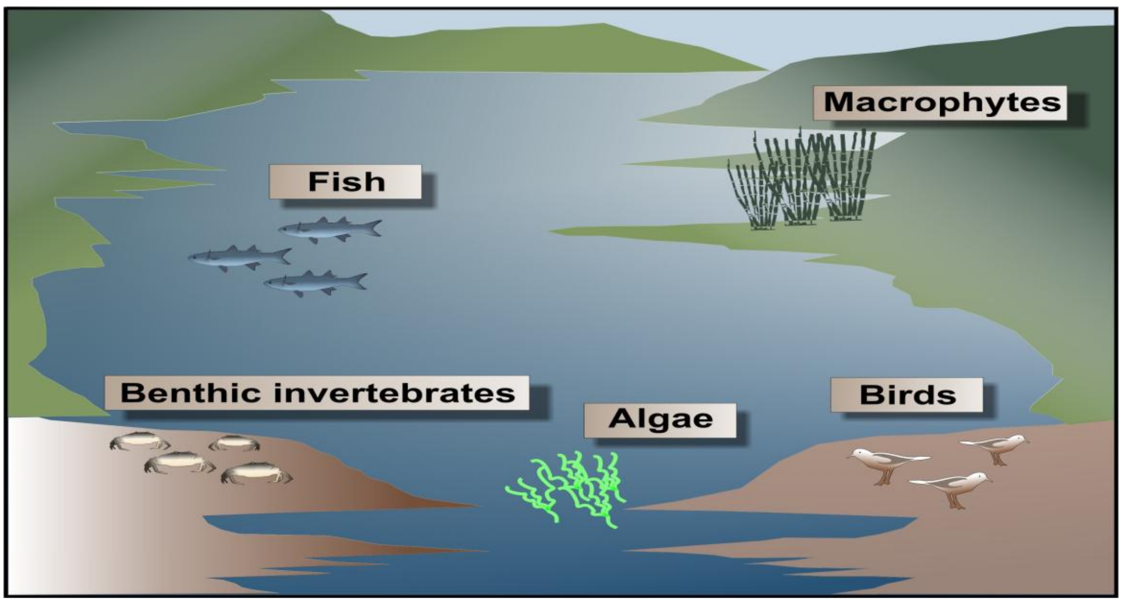


Fig 2.4 Various Estuarine Biological components (Van Niekerk, 2007)

The variations between, as well as within estuaries can present significant challenges for conservation, and management procedures (Elliot and McLusky, 2002). It is important that the Inter-specific and intra-specific relationships between members of the biodiversity is maintained not just for the sake of ecological integrity but also for survival of the many human beings who build their livelihood on the estuaries. Indeed, biodiversity is the least thought about in the collection of components known as the “commons” whenever discussions of the components experiencing the tragedy of the commons are on board (Johnson, 2004; Petrosillo *et al*., 2009).

A unique characteristic of estuaries is that the sources of the stress they experience are both natural and man induced (De Wolf *et al*., 2000). Odum (1985) defines stress as any influence that has a disorganising effect on organisms or reduces their fitness for survival. Grime (1989) also defines stress as any external condition that reduces an organism's rate of acquiring resources, growth and reproduction. Grime's definition implies that no matter how small-scaled a stressor is; it does exert a negative impact on organisms. Van Niekerk (2007) gives an alternative name to physical components as 'stressors', because they are the driving forces directly or indirectly behind the changes that the biological components go through in addition to their impact on other beneficial uses of estuaries (Van Niekerk *et al*., 2006). These components do not only impact on biological components but also affect the mensuration values on one another. Water movement patterns, for example influence sediment dynamics, water processes and even water quality and quantity levels (Meire *et al*., 2005). Other examples of natural stressors are bed sediment dynamics, physico-chemical elements and fluctuations in salinity levels of the water column (Elliot and Quintino, 2007). Chemical pollutants are the major forms by which human induced stress are exhibited (De Wolfe *et al*., 2000). Most typically estuarine species nevertheless develop physiological responses, a mechanism called environmental homeostasis, to withstand these stressors. Their tolerance levels have limitations though.

2.1.3.2 Functions (Goods, Services and Attributes)

Estuaries play multiple roles from ecological, social and economic perspectives. The features described so far contribute to the diversity in functionality of estuaries. These functions can be categorized in different ways but this discussion adopts the goods, services and attributes function groupings from Turpie, (2007). The function of providing goods could be on a subsistence or commercial scale. Goods could be in the form of food items (Wilson *et al*., 2002), like fish and crustacean species extracted on both subsistence and commercial levels. Other goods include bait for subsistence fishing and raw materials, like grass for thatching, sedges, reeds and timber (Turpie 2007).

Service provision function includes flood attenuation, regulation of flows and erosion control functions, all of which are more characteristic of tropical estuaries (Turpie, 2007). Estuaries also play the unique role of providing habitats for a number of fish species; a service that cannot be overemphasized (Elliot and Quintino, 2007). Some of these fish species depend solely on the estuarine environment for survival and others use it only during the breeding period of their life cycle. Whitefield (1998) gives the following statistics after a survey of fish species in South Africa: approximately 155 species are associated with estuaries, 27% of which permanently reside in estuaries during their entire life cycle, 40% are marine species which depend on the estuary for breeding purposes, 25% are marine species which may occur in estuarine habitats not for any specific purpose and 8% are freshwater species which use estuaries as transition routes between the two adjacent habitats. Able (2005) adds that estuaries give support economically valuable off shore fish stocks in the form of providing a place of refuge and nutrients. Windle and Rolfe (2004) assert that estuaries serve as buffer zones between lands based activities and the marine environment and this unique function helps to reduce environmental and human health risks. Turpie (2007) also adds that estuaries contribute to productivity in marine environment by transporting nutrients and sediments. Urbanized estuaries have recently become the places of convenience in waste and storm water disposal.

Estuaries serve as recreational, residential and economic hotspots. These are human endeavours naturally attributed to estuaries. The use of estuaries for recreational activities may range from mundane activities like walking, bird watching and sunbathing to highly extractive and disturbing ones like large scale fishing, power boating and canoeing (Morris, 2004). Over the years, estuaries have evolved as trade centers and convenient receptacles for disposal of wastes and storm water drainage outlets especially in urban regions. On the whole, estuaries are lucrative centers of development. Table 2.1 is an edited version of Constanza *et al*., (1997) compilation on ecosystem goods, services and attributes of aquatic water-dependent ecosystems (Estuaries) showing their levels of relevance. This compilation was based on estuaries in the temperate regions of South Africa but the findings can be said to hold for estuaries in the sub-tropical regions since they also have similar goods, services and attributes (Hosking et al., 2004) listed in the table. It is estimated that South African estuaries in general are worth 3,500 rands per hectare in food production, 2,550 rands per hectare in recreation and 141,000 rands per hectare in nutrient cycling (Lamberth and Turpie, 2003).

Table 2.1 Ecosystem goods, services and attributes of aquatic and water-dependent ecosystems, and their importance in South African (Temperate) estuaries (from Constanza *et al*., 1997).

Ecosystem Goods, Services and Attributes	Description	Level of Importance in Estuaries
GOODS		
• Food	Production of fish and plants	High
• Medicine	Production of medicinal plants	High
• Raw material	Production of craftwork and construction materials and fodder	Medium
• Gas regulation	Carbon sequestration, Oxygen and ozone production	Low
• Climate regulation	Urban heat amelioration, wind generation	Low
• Erosion control and sediment retention	Prevention of soil loss by vegetation cover, and capture of soil in wetlands, added agricultural (crop and grazing) output in floodplains /wetlands	Low

Table 2.1 Continued

Ecosystem Goods, services and Attributes	Description	Level of importance
SERVICES		
Ecosystem Goods, Services and Attributes	**Description**	**Level of Importance in Estuaries**
• Waste treatment	Breaking down of waste, detoxifying pollution, i.e. dilution and transport of pollutants.	Medium
• Refugia	Critical habitat for migratory fish, important habitats for species	High
• Nursery areas	Critical breeding habitat Nurseries for marine fish	High
• Export of materials and nutrients	Export of nutrients to marine ecosystems	High
• Genetic resources	Medicine, products for material science, genes for resistance to plant pathogens and crop pests, ornamental species	Low
ATTRIBUTES		
• Structure and composition of biological communities	Species diversity and habitat providing opportunities for recreational, spiritual and cultural activities	High

The table above gives a reflection to the functions of estuaries in tropical regions as well. There is a fine line between the attribute, service and goods functions of estuaries.

Therefore, the placing of examples under these three categorized functions is a subjective undertaking (Constanza *et al*., 1997).

2.1.3.3 Estuary Valuation

Biophysical components of estuaries and their ecosystems at large provide varied ranges of valued resources that cannot be overemphasized. To understand the reasons for the massive intrusion by humans on estuarine resources, it is appropriate to assess the monitory value (emphasis on monitory) of the environmental services derived from such ecosystems. Ecologists define value as "that which is desirable or worthy of esteem for its own sake; that is to imply, "quality having intrinsic worth" and economists define valuation as "a fair or proper equivalent in money, commodities, etc" (Webster dictionary cited in Freeman, 2003). This means that, ecologists dwell on the intrinsic value of the environment while economists dwell on the instrumental value of the environment (Boyle, 2003). Methods for valuation are many and are dependent on a diversity of parameters. Kramer (2005) reveals that, the sum of four main components is used to determine the total economic value of ecosystems. These are the use value, indirect use value, option value and non-use value. He explains these components as follows:

1. **Use value:** benefit derived from direct use of the environment, for consumption and non-consumptive purposes like swimming;
2. **Indirect use value:** The services users get indirectly; usually some distance away e.g., pollution filtering functions;
3. **Option value:** The willingness of users to pay (WTP) for preserving the resource for future use and,
4. **Nonuse value:** The willingness of users to pay to protect the resource from usage even in the future.

This implies that;

Total Economic Value = Use value + Indirect use value + Option value + Nonuse value (Kramer, 2005).

Wilson *et al*., (2002) give a comprehensive integrated economic evaluation framework (Figure 6).Their framework considers ecological processes, land use decisions (governance), human welfare (activities and influences) and the interaction between them. Although developed from an economist's perspective the framework appears to present both economist and ecologist ideologies. The bridging of the two ideologies is important because Champ *et al.,* (2003) reveal that ecologists use the term valuation slightly differently from economists. Although value analysis have been done for many environmental resources, valuation data for estuaries are very limited (Windle and Rolfe, 2004). Not many South African estuaries have been subjected to intensive economic valuation. There are numerous frameworks for assessing and evaluating estuarine ecosystems. A popular one for coastal zones was developed by Wilson *et al*., (2002), (Figure 2.5). This approach integrates biophysical drivers and the management policies in the overall assessments of the ecosystems. All methods of valuating ecosystems have their strengths and limitations. The problem of under-valuation can lead to poor management initiatives that can contribute to degradation (Lotze *et al*., 2006).

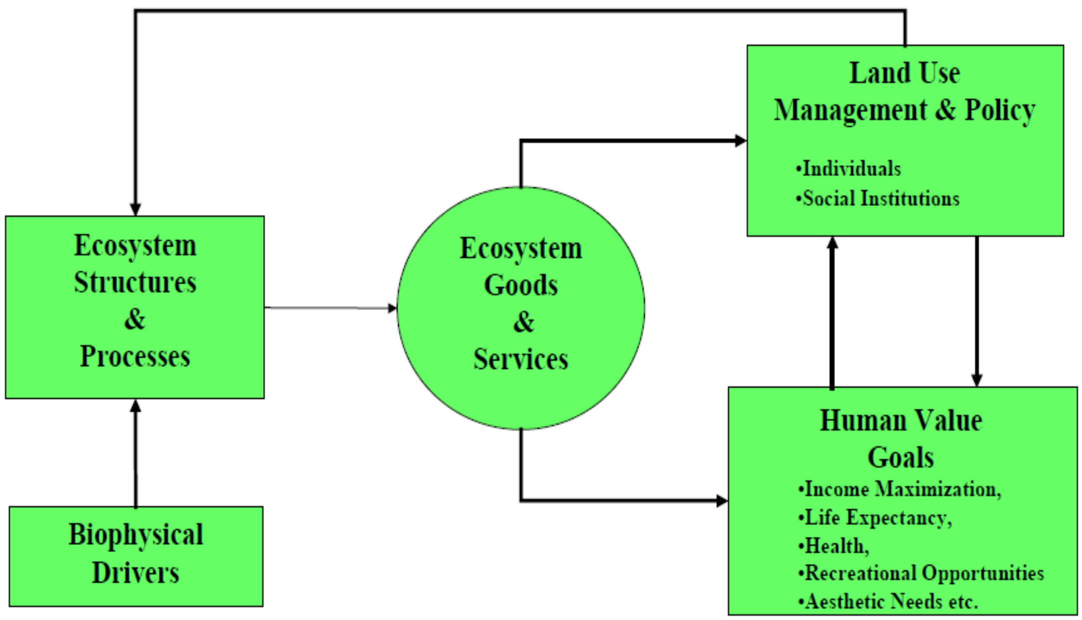


Figure 2.5 Frameworks for Integrated Assessment and Valuation of Ecosystem Functions, Goods and Services in the Coastal Zone (Wilson 2002:6)

2.2 SOCIOECONOMIC ACTIVITIES AND THEIR IMPACTS

In the year 2000, approximately 39% of the South African population lived within 100km of the 3751 km long coastal line (Earth Trends, 2003). This figure increases on an annual basis. The conceptualizing of socioeconomic development must include variables like the historical background, cultural values, economic activities, infrastructure and facilities

(Morris, 2004). Although there are no clear indications of the measurements of the rate (Nomqupu, 2005) it is clearly evident that human developments have led to degradation of major South Africa's waters. The pressure on water bodies have been so enormous that almost all important rivers have undergone one form of human induced transformation or the other (Nomqupu, 2005). Many large commercial ports and harbours around the world are built in the sheltered waters of bays and estuaries (Beckley *et al*., 2008). Ports and harbour operations exert unlimited effects on the estuaries within which they are housed. For example, the Durban bay and the Richards bay estuaries continuously undergo dredging in order to accommodate the operations of the port. Noise emanates from dredgers and ships have a great impact on the biota (Newman *et al*., 2007). Weilgart (undated) asserts that noise interferes with fish communication and schooling. The author adds invertebrates like crabs and shrimps also show impacts of noise. It is believed that noise affect physiological functions and increase the general stress levels exerted within a water body (Evans and English, 2002)

Urbanization in coastal areas has become an indicator of socioeconomic growth in tropical regions (Ginsburg, 1993, cited by Van der Meij 2009; LeMarie *et al*., 2006). Users of estuaries for whatsoever purposes need to consider carrying capacity of the estuary, which McKenzie (2005) loosely defines as "the optimum utilization of an estuary, taking into account seasonal and random changes, without degradation of the estuarine environment and without compromising the capability of future utilization of the estuary" (McKenzie 2005). Although there is currently more publicity on these issues than there ever have been, it is physically evident that not much thought is given to carrying capacity by socioeconomic developers. Although some estuaries have the capacity to accommodate exponential growth in stressful conditions from anthropogenic activities (Bishop *et al*., 2006), others give in to stress from even natural conditions (Cooper *et al*., 2004). Urbanization can partially or completely alter the processes that underpin sustainability of the related functions and services provided by the water bodies (Simenstad *et al*., 2005). After assessing human impacts on twelve once productive and diverse estuaries Lotze *et al*., (2006) presented the following results; over 90% of formerly important species were depleted, more than 65% of sea grass and wetland habitats were depleted, species invasion had accelerated and water quality was degraded and water quantity had diminished.

Sometimes the degrading activities do not necessarily occur in close proximity of the water body being impacted. Upstream and on-land practices like dam erections, river canalization, industrial effluent discharge, deforestation, bad tillage practices and chemical farm inputs can indirectly impact on estuaries downstream (Hale *et al*., 2004; Rees *et al*., 1999). These inland based activities lead to changed sedimentation patterns, chemical contamination, heavy metal accumulation within aquatic species and nutrient loading which leads to eutrophication and erosion (Newton, 2008).

From the examples above, it is apparent that indiscriminate use and low interest in conservation and sustainability impacts on the functions upon which the socioeconomic activities are built, sometimes, beyond regeneration (Beck *et al*., 2003). Degeneration below a certain level makes halting of these activities imperative.

2.2.1 Methods of Identifying Socioeconomic Influences.

There are various methods of determining anthropogenic influence on estuaries. The easiest, fastest method to distinguish anthropogenic stress from natural stress is by physical observations, with pollution being the main indicator. Pollution is a good and fast indicator because in instance of stress which is not inherent, estuaries respond to the stress in a very easily identifiable manner (Wilkinson *et al*., 2007). It is common to see opportunistic green algae forming macroalgal mats on the surface of an estuary which is influenced by organic discharges, sewage run-off and industrial effluent (De Jonge and Elliot, 2002).

Many conceptual models have been formulated as means of detecting and measuring anthropogenic impacts. Elliot and Quintino (2007), cite the Pearson- Rosenberg model as a model that has for a long time formed the basis of numerous approaches used in detecting and explaining these external stressors. These authors further explain the utility of this model in that it makes it possible for the classification and quantification of anthropogenically stressed benthic infaunal communities, most especially that for various means of organic enrichment. The use of the Pearson-Rosenberg model has led to a tangible list of likely features of a water body, most especially with hydronomically low energy areas, responding to the stress of organic matter and/or fine sediment inputs.

Another paradigm of anthropogenic stress is the Scope-for-Growth model. It is used to detect estuarine stress physiologically at the biological organization level (Widdows *et al*., 2002). A critique of both models is that they not help to distinguish natural stresses from anthropogenic stressors and therefore, cannot be solely reliable when trying to measure anthropogenic stress only. The Drivers-Pressure-State-Impact-Responses model is also a popular pattern emerging for ecological assessments. It is used to outline and connect the main precursors of socioeconomic activities (Drivers), their influence on ecosystems (Pressure), the outcomes (State) and the indentations created as a result. The outcomes then give a good platform to formulate appropriate responses (Bowen and Riley, 2003).

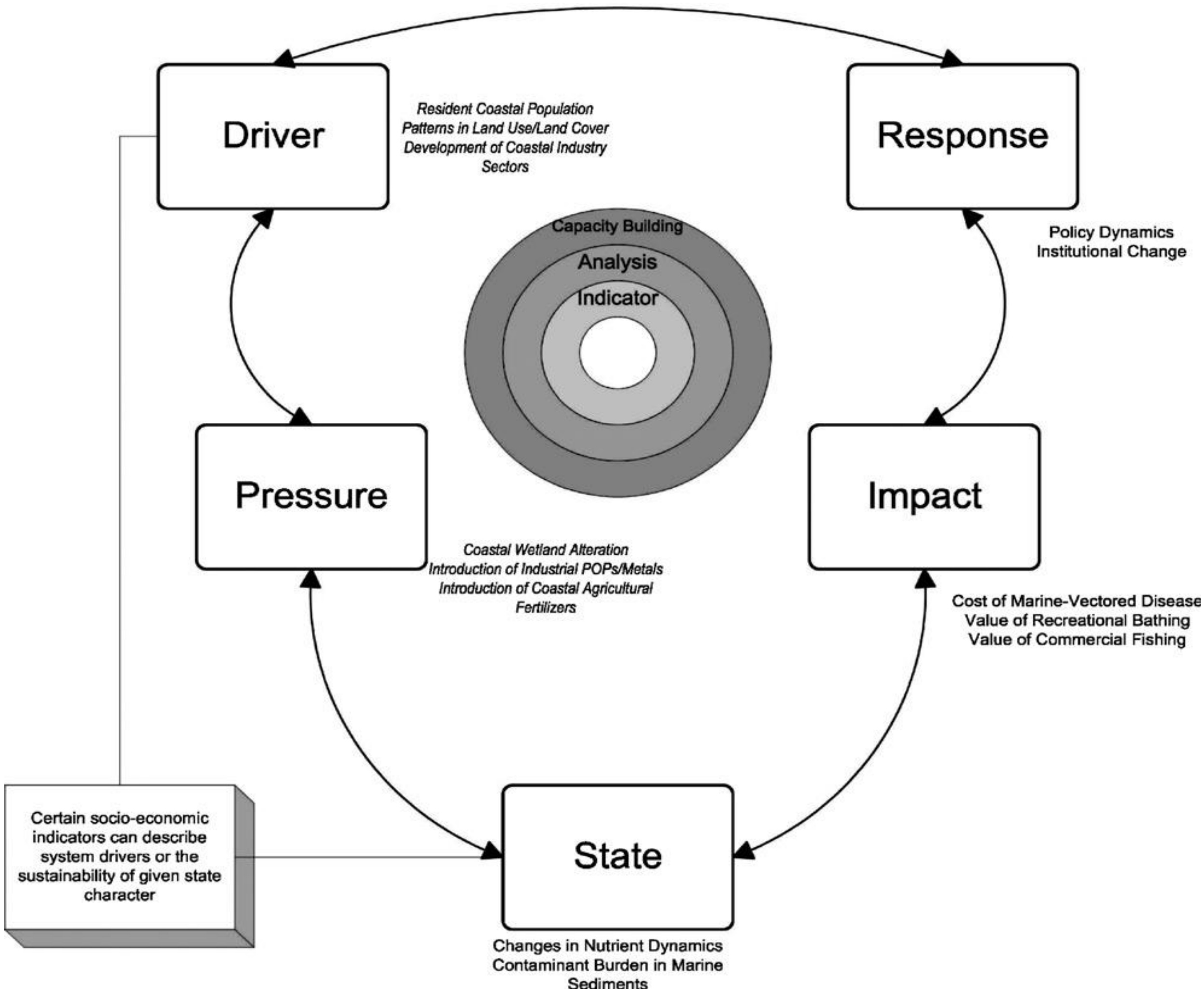


Figure 2.6 Relationships between the variables of the DPSIR model, adapted from (Bowen and Riley, 2003).

The diagram also indicates the primary drivers of management decisions. Societal responses meant to halt, ameliorate, mitigate or reverse unacceptable conditions are also shown by the open arrows, the dashed inset shows the impact assessment components and the open arrows indicate the adaptive monitoring feedback loops (Bowen and Riley, 2003).

2.3 WATER QUALITY ASSESSMENT

Water quality denotes the status of chemical, physical and biological characteristics of a water body. The processes involved in acquiring data and analyzing them involves many steps and can be approached in many forms depending on what the researcher wants. Collecting, handling and interpretation of data need to be carefully planned from the onset in order to avoid wasting time on details that are not important and neglecting salient ones. Subramanian (2002) gives a simplified flow chart on the processes of acquiring and handling data regarding water quality (Figure 2.7).

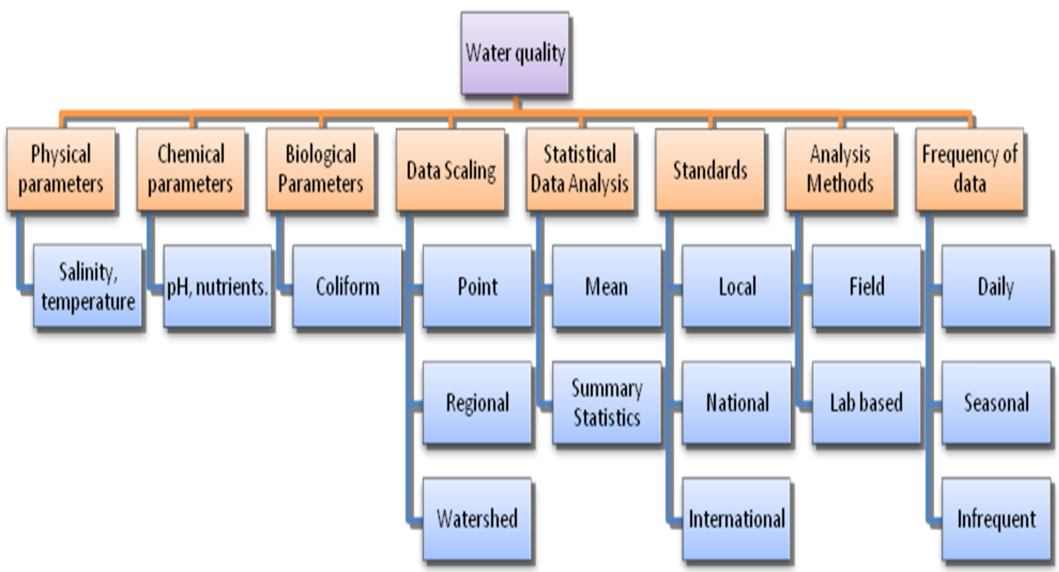


Figure 2.7 Data requirements for analysing water quality (Subramanian, 2002).

Since water bodies serve varying purposes, no water body has fixed desirable water quality measures. A consensus on the best appropriate methodology for measuring water quality and assessing trends in estuaries has thus far not been attained (Bartone, 2005).This is to say that assessment of water for recreational purposes is different from that for domestic purposes especially in terms of the desired parameters and stipulated acceptable limits. Because assessments cannot be made on the entire components of a water body, overall assessments are achieved by the use of indicators, serving as pointers to certain incidences. Aubry and Elliot (2006) define environmental indicators as parameters (qualitative or quantitative) that indicate the current state of an aspect of the environment in focus. Good estuarine indicators afford a researcher the ability to detect and measure changes within an environmental system which are beyond the accepted limits. Some water quality analysts propose that estuarine indicators must be selected at least from characteristics like oxygen status, eutrophication status, health characteristics, physical characteristics and dissolved substances (Harrison *et al*., 2000). As a consequence of the high intra-variable nature of estuaries, choosing indicators can be an intimidating task (Mouillot *et al*., 2006). Indicators are commonly confined to biophysical factors although there seems to a broadening in scope of indicators to include socioeconomic and managerial signals (Adams and McQwynne, 2004). The biophysical parameters are grouped into chemical, physical and biological. Examples under each are as follows;

Chemical: nutrient content, phosphorous, dissolved oxygen, chloride, and pH/alkalinity;

Physical: inlets, streams, wetland areas, dams, beach areas, retaining walls, boat dock, temperature and water colour;

Biological: chlorophyll a, fecal coliforms, zebra mussel invasion, turbidity, and lake depth. Harding *et al*., (2005) assert that few researchers doubt the credibility of water quality assessment based on biological factors. The problem is that such researches are time consuming, costly and requires technical expertise.

In their research to assess water quality of South African estuaries, Harrison and his team (Harrison *et al*., 2000) chose six indicators namely dissolved oxygen; oxygen absorbed un-ionized ammonia, fecal coliforms, nitrate nitrogen and orthophosphate. They grouped the indicators according to suitability for aquatic life, suitability for human contact and trophic status. Findings of their research formed the backdrop for the estuarine water quality Index (eWQI) of South African estuaries. Water quality indices are used to facilitate quantification, simplification and communication of large volumes of complex water quality data. Interpretation and use of water quality indices are nevertheless subject to the discretion of policy and decision makers.

2.3.1 Water Quality in the Context of Ecosystem Survival

Setting water quality target ranges for aquatic ecosystems is an arduous task for some of the following challenges: i) the categories of trophic levels within an ecosystem require different levels of the various water quality parameters, ii) the impact of water quality changes may not affect a particular species, although it may affect a population of species which the unaffected species depends on for its survival, iii) organisms ability to respond to stressors can sometimes give untrue reflections of pollution levels and iv) it is almost impossible to take a full inventory of all species within a water body and identify their tolerance levels for the various water quality parameters. Maltby (1999) sums it up rightly by stating that, there is not an ideal level at which to study stress. It is therefore appropriate and convenient to use an integrative approach to choose certain individuals and study their responsive behavior to water quality changes and use the results obtained to predict subsequent ecological consequences. Such an integrative approach cannot be hundred percent accurate but is somewhat comprehensive due to the interactive nature of organisms within an ecosystem. Another huge challenge is the high natural variability characteristic of estuaries which makes it difficult to directly associate human influences to ecological responses.

2.4 COMMON PHYSICAL AND CHEMICAL INDICATORS.

2.4.1 Chemical Parameters

2.4.1.1 Oxygen

Oxygen concentrations in a water body indicate its aeration status. Life forms depend on oxygen to survive, hence rapid decline or absence of oxygen within a water body is a good indicator for assessing the well being of the living organisms. Oxygen is also a requisite for the beneficial process of decomposition which is carried out by microorganisms. In the presence of a good amount of oxygen and nutrient overload, decomposing microorganisms feed lavishly and reproduce in a faster, unsustainable manner. This is why there is a strong link between oxygen and nutrients within the estuary (Orhel and Register, 2006). The optimum value of oxygen for most plant and animal species is 5mg/l and above and consequences of low oxygen in aquatic bodies progress with time (Newman *et al*., 2007). Oxygen is assessed through diverse forms. Examples are Dissolved Oxygen (DO) either in concentration or percentage, Biological/Biochemical Oxygen Demand (BOD), Carbonaceous Oxygen Demand and Chemical Oxygen Demand (COD) (Dictionary of Environmental Science and Engineering (DESE), 2008: 26, 29). BOD and COD are popular indicators for assessing oxygen status. According to the DESE, BOD is " the amount of dissolved oxygen per unit volume (mg/L) necessary to satisfy the metabolic requirements of microorganisms which utilize waste as food…..a measure of the strength of liquid waste" (DESE, 2008: 19). This implies that measuring BOD in an estuary is in fact a measure of the load placed on the existing oxygen resources of the estuary and not a measure of the actual levels of dissolved oxygen within the water body. The higher the BOD, the greater the degree of uploaded pollution. The empirical determination of BOD takes a period of five days and beyond (Custodio, 2009). Carbonaceous Oxygen demand is defined as the first phase in a BOD process. Chemical Oxygen Demand measures the requirements of a waste for oxygen other than the microbial requirements. It is a measure of the oxygen demand of all compounds both organic and inorganic. It is a preferred measurement in determining organic pollution levels (Li *et al*., 2006).

2.4.1.2 Dissolved Oxygen

Based on the explanation given above, dissolved oxygen rather than BOD will be measured in this research to ascertain the availability of oxygen for direct use by living organisms. Dissolved oxygen is a measure of the quantity of gaseous oxygen in a water body. It is measured in either mg/L or as a percentage (%) of the saturation concentration (DWAF, 1996a). Low levels of dissolved oxygen is detrimental for obvious reasons, however excessive levels, 110% and above can likewise be harmful to fish species (National Aeronautics and Space Administration (NASA), 2010). This is because; such high levels indicate algal bloom or eutrophication. Dissolved oxygen levels are dependent on physical, chemical and biological factors. The physical factors include the time of the day, season, and temperature. The solubility of atmospheric oxygen to dissolve and remain in water is largely dependent on the ambient temperature. There are strong relationships among dissolved oxygen, TDS and temperature. Predictions are that when TDS values are consistently below 3000mg/L, saturation concentrations are likely to be 12.77 mg/L at 5^0C temperature, 10.08 mg/L at 15^0C temperature, and 9.09mg/L at 20^oC temperature. Internal biological activities like photosynthesis, respiration and oxidation also regulate dissolved oxygen levels. That is why there is a cyclical daily variation in dissolved oxygen (DWAF, 1996a). Salinity is a key chemical factor that influences oxygen levels. This is explained by the fact that in general, all factors being equal, dissolved oxygen concentrations are lower in saline sea waters than in freshwaters (Newton, 2007). The kinds of species present also determine oxygen levels. The more species there are with photosynthesis abilities, the more oxygen there will be for a period of time (Figure 2.7). Dredging activities and floods can influence dissolved oxygen values of surface waters negatively by stirring up and causing the resuspension of anoxic sediments (Ohimain *et al*., 2008).

Low levels of DO result in two conditions; hypoxia and anoxia. Hypoxia is the condition created when there are low levels of oxygen (below 2-3mg/l) within the water body and anoxia is a complete lack of oxygen (Ecological Society of America, 2006). Hypoxia leads to reduced growth rate, altered distribution and behaviour of fish, changes in the importance of organisms, loss of carbon flow pathway integrity within the food web and mortality (Brietburg, 2002). Wannamaker and Rice, (2000) claim that expansion of human activities along coastal areas is a key player in the common occurrence of hypoxia in estuaries. They further add that on a global scale, hypoxic conditions are among the most widespread and accelerating deleterious impacts on the marine environments.

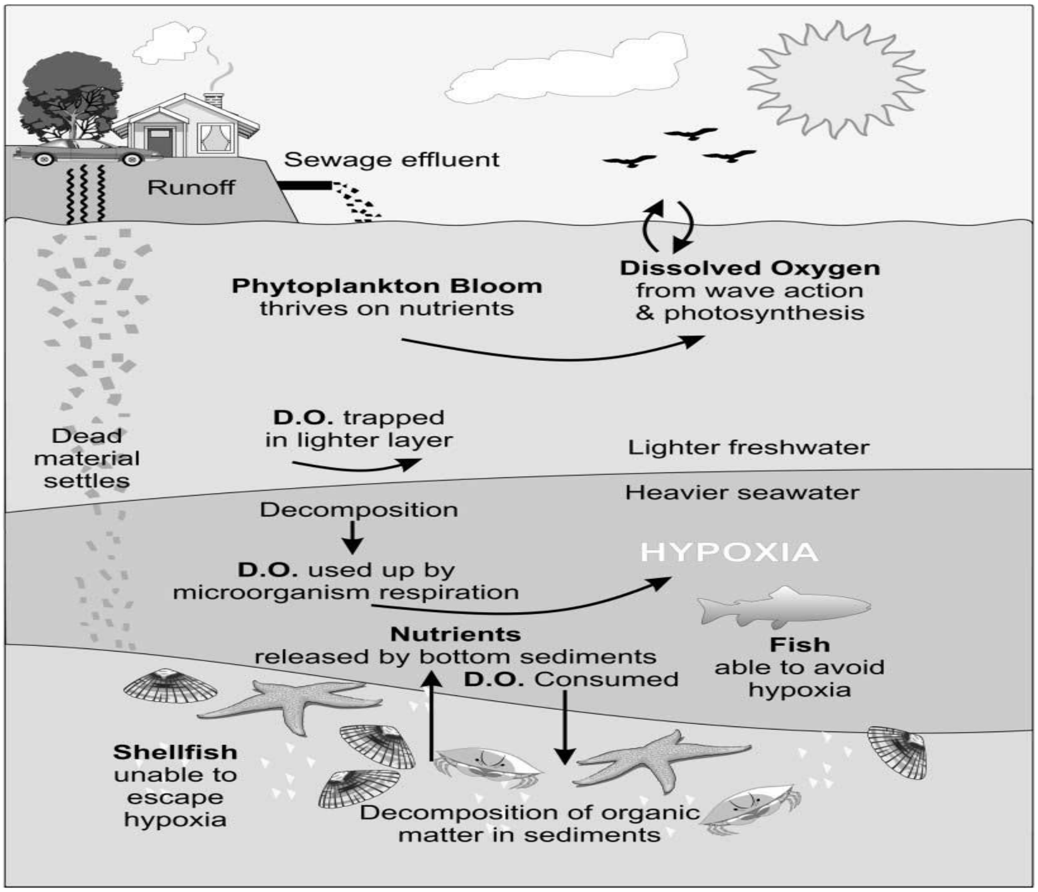


Figure 2.8: A conceptual model showing the ecological relevance of dissolved oxygen concentration in estuarine water (Kurtz et al, 2001).

2.4.1.3 Nutrients (Nitrogen and Phosphorous)

Nutrients are chemical sources for the maintenance, growth and well being for all living things including the aquatic. Examples are carbon, nitrogen, phosphorous, potassium, oxygen, silica, calcium, copper, zinc. Depending on the concentrations, nutrient levels can have either positive or negative impacts on the overall health of aquatic ecosystems (Caffrey *et al*., cited in Adams and Matsumoto, 2007). Nitrogen and phosphorous are the most needed nutrients for aquatic plants and animals. The rate of their supply is important for regulating primary production. Nitrogen for example is primarily used for protein and Dinucleotide Acid (DNA) synthesis. Phosphorous on the other hand is vital in converting sunlight into useful energy (Minnesota Pollution Control Agency (MPCA), 2008). Although the necessity for nutrient availability cannot be overemphasized, an overdose in water systems, especially estuaries, leads to a chain of depletion events (Figure 2.8), including water quality degradation, habitat loss and persistent eutrophication (Orhel and Register, 2006). In solution, nitrogen displays in forms like nitrates, ammonia, ammonium and nitrites. The behaviour of ammonium and nitrate forms will be analyzed and discussed at length over and above the other nitrogen forms and even over the other nutrients. Ammonia manifests as two chemical species in equilibrium: ionized ammonium and unionized ammonia (Newman *et al*., 2007). The equation is represented below:

$NH_4^+ + H_2O \leftrightarrow NH_3 + H_2O^*$

Ammonium ions serve as nutrients for primary producers and unionized ammonia is soluble in lipids; it is therefore easily absorbed through the membrane of fish species, causing toxic accumulations (DWAF, 1996b). Ammonia-N content is investigated when one wants to access the toxic content in a water body while ammonium-N is assessed for the amount of nutrients available. The proportions of the forms of nitrogen present in a water body are primarily based on the availability of oxygen, specific microbes and pH levels. In aerobic conditions, nitrites are oxidized to nitrates by nitrifying bacteria and under anaerobic conditions; denitrifying bacteria reduce nitrates into nitrites (Pinckney *et al*., 2001). Nitrates are the most stable species of inorganic nitrogen, and the availability, absence of or percentage abundance of these species is strongly dependent on oxygen, with other factors being temperature and salinity. Recurrent cases of nutrient overload, creates a problematic and unsightly condition known as eutrophication (Orhel and Register, 2006, Pinckney *et al*., 2001). It is basically as a result of nitrogen and phosphorous overload. Eutrophication is defined as the enrichment of water by nutrients, especially nitrogen and/or phosphorous, causing an accelerated growth of algae and their forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned (European Commission (UWWT) on Nitrates Directive cited by Andersen *et al*., 2006. This definition lays a strong emphasis on the source of the nutrient overload to be agricultural run-offs. Although due to natural conditions, eutrophication is inevitable within estuaries, it is accelerated immensely by human influence, through introduction of reactive nitrogen and phosphorous into the atmosphere (Chris *et al*., 2001). Eutrophication is also closely associated with oxygen depletion and changes in species composition (Adams and Matsumoto, 2007). In addition, Kennish *et al*., (2007) link nutrient enrichment in estuaries to succession of environmental problems like high turbidity, harmful algal blooms, bacterial pathogens and loss of essential habitats.

Chris *et al*., (2001) classify symptoms of eutrophication into primary and secondary symptoms. The primary symptoms include; high levels of chlorophyll a, epiphytes and macroalgae and the secondary symptoms include low dissolved oxygen concentration, loss of submerged aquatic vegetation and nuisance and toxic algal blooms (Chris *et al*., 2001). Common routes of nitrogen and phosphorous entry into estuaries include animal waste, industrial effluent and municipal waste water. Other sources are flow from freshwater passing over phosphate and nitrate rich geologic formations, wildlife waste, decomposing organic and nitrogen fixation from the atmosphere by some aquatic bacteria (Chris *et al*., 2001). This is why Orhel and Register (2006) suggest that, choosing nitrogen forms, as indicators help researchers predict the impact of various anthropogenic activities, assess how effective wastewater treatment plants are and also enable informed sustainable management actions to be taken.

2.4.1.4 Conductivity and Specific Conductance

Conductivity, also called electrical conductance is a measure of the electrical phenomenon occurring between opposite faces of $1cm^3$ of the substance being measured. It is commonly defined simply as a measure of the electric current conducting ability of a substance measured in micro Siemens per centimeter (µS/cm) or milli Siemens per centimeter (mS/cm). Conductivity is another means of measuring dissolved elements like sodium, magnesium, nitrates, sulphates and phosphates (Murphy, 2007). Compounds of the above elements easily dissociate in solution and consequently conduct electricity. Higher temperatures induce rapid movement of ions in solution and cause high conductivity (Orhel and Register, 2006). Specific conductivity is a more explicit measure of electric current because, it is measured at a standard temperature of 25^0C (Hounslow, 1995). Specific conductivity gives a fair background for the comparison of conductivities recorded at different places or on different occasions due to the standardized temperature. Conductivity, total dissolved salts and salinity levels most at times are similar in value particularly in seawater because high salinity means more chloride ions are present to conduct electricity and the more ions in solution, the more total dissolved salts there are. Naturally, the conductivity of seawater is high, approximately 50,000 mS/m (Murphy, 2007). High conductivity in freshwater bodies could be as a result of increased stream flow however; high conductance level recorded in streams and rivers can imply high geological influences through weathering and erosion or anthropogenic influences (DWAF, 1996a).

2.4.1.5 PH and Alkalinity

PH is a measure of the hydrogen ion concentration in a solution expressed on a logarithm scale. That is; for every 1.0 increase in pH, there is an acidic or alkaline increase by a factor of ten (Newman, 2007). It forms a part of almost all water quality monitoring programs (Orhel and Register, 2006) because of its influence on other parameters and how easy it is to measure. Data from monitoring pH over a period of time help researchers to make informed conclusion on the chemical makeup of the water body. Factors like water turbulence, bacterial activities, nutrients, runoff constituents, and sewage overflows, influence pH values. Naturally, variations in salinity and temperature can also affect levels of pH (Hoffman *et al*., 2009). The amount of dissolved carbon dioxide in water also affects the pH value and vice versa (Hansen, 2002). This means that activities of chlorophylous organisms influence the pH content within the water and the level of pH and oxygen present also influence these organisms. The pH of sea water naturally ranges between 7.3 and 8.2 (Newman *et al*., 2007; DWAF, 1996) and that of natural freshwater ranges between 6.5 and 8.0 (Newman *et al*., 2007). These are interpreted as ranging between high acidic conditions, through neutral to low basic conditions. It is important that pH values are kept within acceptable range because, pH values outside the above conducive range can become an extreme stress for even the very ductile organisms. Extreme pH conditions can denature cellular membranes of living organisms and lead to death (Murphy, 2007). In addition, small shifts in pH can affect the solubility of metals and toxins thus making them readily available to impact directly on organisms. Also, high pH values affect the maturation cycle of eggs; which is a primary estuarine function. It is believed that because pH is likely to vary in estuaries due to unstable conditions, measuring pH is not so significant in its entirety. PH value however may be used as an indicator of ionic equilibrium.

2.4.2 Physical Parameters

2.4.2.1 Temperature

Temperature measures the degree of hotness or coldness of a body in degrees Celsius (^{0}C). Because hot air rises, temperature is an important determinant of the dissolved oxygen levels that can be maintained within a water body. Many other chemical and biological processes in water as well, depend on temperature (NASA, 2010). For example, the rate of primary production, the sensitivity of organisms to toxicity, and general metabolism of aquatic organisms are all directly influenced by temperature levels (Orhel and Register, 2006).

2.4.2.2 Salinity

Salinity is a measure in parts per thousand (ppt) or parts per million (ppm) of the dissolved salts in a solution (Joyce and Viola, 2007; DWAF, 1996b). According to the International system of units in oceanography, the units of salinity are best represented in terms of a unitless "Practical Salinity Scale", this analysis is based on the fact that salinity is determined by taking the ratio between two electrical conductivities (Newman *et al*., 2007). Salinity is vital to a lot of chemical processes within an estuary. For example, the amount of oxygen that water can hold is inversely proportional to salinity levels (Murphy, 2007; Rosas *et al*., 1999). Salinity levels range from oligohaline (0.5-5.0 ppt) to polyhaline (18.0 - 30.0 ppt) to mesohaline (5.0 - 18.0 ppt) and to euhaline, (above 30 ppt or seawater salinity) (Orhel and Register, 2006). Figure 2.9 shows the division of salinity values along the length of an estuary. Estuarine salinity slowly increases as water moves away from freshwater sources toward the ocean. Typically estuarine species tolerate varying levels of salinity. Salinity and temperature differences cause water column layering within the estuary. The relatively cold, salty and denser sea water settles under the less dense warm freshwater. This is why salinity is affected by water column depth. Tides, winds and storms also have the ability to mix up the layers and cause changes in salinity levels (Watson, 2008).

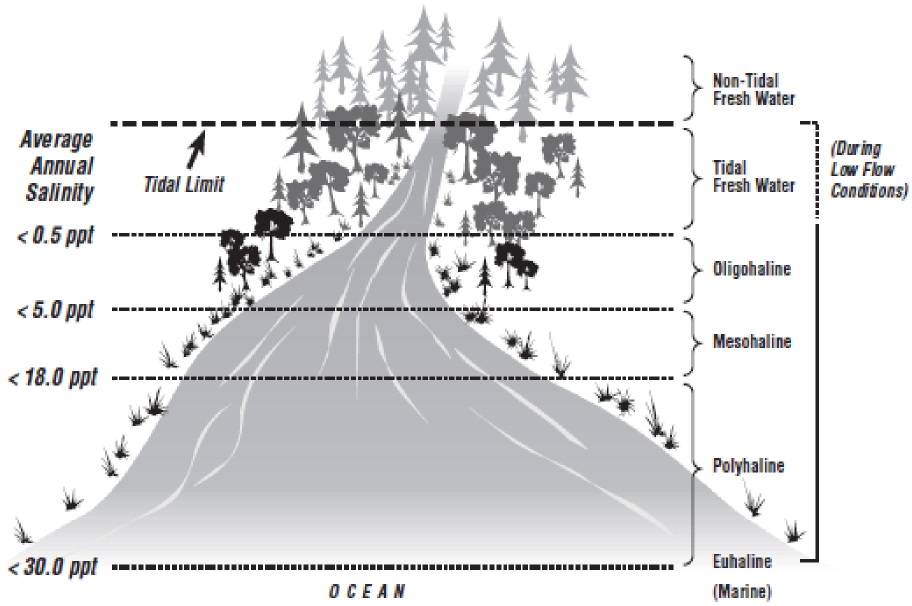


Figure 2.9 Salinity level divisions along the length of an estuary (Orhel and Register, 2006).

Analyzing salinity may give a researcher basis to predict the spatial distribution of fish species based on their affinity for salt.

2.4.2.3 Turbidity

Turbidity is a measure of the degree of transparency of water or the degree of scattering of light in water. The scattering is brought about as a result of light being blocked from its straight path of travel by suspended matter which include silt, clay, phytoplankton, organic matter and all particles within the sizes of 0,001 μm and 0,1 μm (DWAF, 1996a). Turbidity levels can be influenced by urban runoff, waste discharge, soil erosion, and algal growth. Feeding activities of bottom dwellers, as well as dredging activities, stir up settled sediments and increase turbidity (Ohimain *et al*., 2008)). Salinity also affects turbidity levels, especially within seawater. Other sources of high turbidity are decaying plants and animals, algal blooms and flooding. The suspended particles that create turbid conditions absorb heat from the sun and create warmer conditions. Turbidity in itself is not a major health concern; it is when high levels interfere with the disinfection ability of the water body that problems arise in the form of algal blooms. There is a very strong correlation between turbidity and total suspended solids (TSS) because both parameters are used to measure the amount of solids suspended in solution. TDS however does not measure the degree of scattering caused by the solids but rather measures the actual quantity of solids per unit volume of water sampled (Michaud, 1991).

2.4.2.4 Total Dissolved Solids/Salts

A total dissolved solid (TDS) is a measure of the particulate substances dissolved in the water body (Williams, 1966). The substances that dissolve in water are compounds of salts which carry charges. Cation constituents usually found in solution are calcium, magnesium, sodium, and potassium and the anions include carbonate, hydrogen carbonate, chloride, sulfate, and nitrate (WHO, 2003). Because ions can conduct electricity and they make up the bulk of total dissolved solids, their measured values are sometimes taken as a measure of conductivity (Simon *et al*., 1994)). Measuring TDS along the flow regime of estuaries help determine the degree of seawater mixing in estuarine boundaries. This is based on the assumption that dissolved salts within estuaries are primarily from seawater intrusion.

2.5 ESTUARINE MANAGEMENT, INSTITUTIONS AND POLICIES

To achieve high water quality standard within an estuary, a combination of institutional management procedures and stakeholder engagement is required (DEAT 2000). Mitchel (2008) adds that climate change and sea level rise must necessarily be integrated into coastal management although these issues bear a lot of uncertainties in the world of science. Under normal circumstances, how coastal zones and estuaries are conceptualized, form the basis for the selection of the management tools. According to Chilli (2008), the properties of successful management of estuaries are integration, access to goods and services, influence and relationships and comprehension. Van Niekerk (2007) adds that the South African legislatures which are more precise towards regulating activities in estuaries are centered on three management areas. These are: i) land use and infrastructure development, ii) water quality and quantity and iii) exploitation of marine living resources. Management schemes are forever changing, therefore, actualization of a perfect management template is arguable. In the opinion of Breetzke *et al*., (2008) coastal management is shifting from conservationist ideologies towards more human centered, stakeholder participatory and consultative strategies (Breetzke *et al*., 2009). In an article that reviews eras of coastal management, Glavovic (2006) claims that management has progressed through four eras: 1) *Ad hoc* Sector-Based Management (1970s); 2) Regulations, ecology and experts (1980s); 3) Participatory policy formulations (1990s), and 4) People centered, pro poor ICM (2000). The first two eras were not able to effect much impact in estuarine management due to their predominantly conservationists nature. Policies, legislature and Acts are supportive measures for management at a level. Policies are statements of intent which indicate how compliance to principles will be ensured (Breetzke *et al*., 2009). They are in themselves not mandatory and as such, not legally binding. Legislations provide details for implementing and enforcing policies.

Management policies and acts related to water quality and quantity are numerous in South Africa. Most are tailored towards freshwater and marine bodies with only a few particularly tailored for the different types of estuaries and lagoons. Van Niekerk *et al.*, (2006) outline the Key Acts related to water quantity and quality as follows:

- National Water Act 36 of 1998;
- Water Services Act 108 of 1997;
- Prevention and Combating Pollution of the Sea by Oil Act 6 of 1981; and
- National Environmental Management: Coastal Zone Bill.

Others are the White Paper on Marine Fisheries Policy for South Africa, White Paper on Water Policy in South Africa, White Paper on Minerals and Mining Policy for South Africa and White Paper on Spatial Planning and Land use Management in South Africa (Van Niekerk, 2007).

The most direct policy that addresses issues of the water quality and quantity of estuaries is the National Water Act (NWA) 36 of 1998. The Act ensures that estuaries are protected, used, developed, conserved, managed and controlled (RSA, 2008). These objectives are carried out nationally by the National Water Resource Strategy (NWRS) and locally by a Catchment Management Strategy (CMS). Both strategies (NWRS and CMS) operate on concepts of equity, and sustainable socioeconomic development and the need to provide basic human needs. The Marine Living Resource Act (MLRA) 18 of 1998 gives legal backing to manage extractive activities that affect living organisms through the set limits for the exploitation of marine living resources.

The estuary management legislation of 1998 is the major policy specifically on estuaries. It ensures maintenance of acceptable standards in ecological functions to guarantee economic and social activity sustenance (MLRA 1998 of RSA). The Act contains detailed guidelines for obtaining water quality, water quantity, habitat integrity and biotic integrity for rivers, wetlands, estuaries and groundwater. Another relevant policy is The White Paper for Sustainable Coastal Development. The principles of this legislation are borne on integrated coastal management (ICM). The tenth chapter of the document is more specific towards estuarine management (DEAT, 2000) through a human centered approach. The human centered approach has better prospects of achieving coastal security as compared with the conservationists' means, (Kapp cited in Glavovic 2006). Highlights of the ICM policy lead to the evolution of the Integrated Coastal Management Act (ICMA), (Breetzke *et al*., 2009). Enacted in February of 2009, it is the latest legal document on coastal zone management and still is in the testing and reviewing phase (Breetzke *et al*., 2009).

In spite of these interventions, coastal management programmes are still politically challenged due to protracted delays of converting most of these policies into bills and laws which are more mandatory and legally binding (Glavovic, 2006). The rapid changeover of government officials especially at provincial and local levels as well as the cost involved in monitoring and evaluation continue to be challenged that hinder estuarine management programs (IEC, 2009; Van Niekerk, 2007). In addition, promotion of people centered and pro-poor coastal management requires capacity building, commitment, and capital investment (Baird, 2005) which are all currently below the levels required to ensure success. Another setback is the fragmentation and overlap of responsibilities amongst the governing institutions (Van Niekerk, 2007). DWAF has the legal mandate to manage estuaries, and DEAT has the responsibility of overseeing land use activities which include the quality and quantity of water flowing into estuarine basins (Van Niekerk, 2007). It is difficult to define where the managing responsibility of DWAF ends and where that of the DEAT begins.

The success of management programs under coastal zone management is greatly dependent on the schemes of governance and the measures put in place to aid in monitoring and evaluations. Any good and sustainable management scheme must have strategic and compliance monitoring systems and evaluation schemes, to ascertain growth and progress (Tanner-Tramaine, 2007).

2.5.1 Sustainable Development

When developing schemes, policies, laws and management plans, the concept of sustainable development cannot be neglected. The Brundtland Commission (1987) defines sustainable development to be development that meets the needs of the present without compromising the ability of future generations to meet their needs. This implies that the ecological soundness of the resources must not be compromised. There is no doubt, based on the discussions made in previous sections of this review that humans in the bid to develop socially and economically, have the potential of causing more harm than good to environmental ecosystems; the very invaluable sources on which developments are based. The quest for socioeconomic development is justifiable, most especially in developing countries; however, the integrity and resilience of the key resources for such ventures must not be compromised. In fact, there are evidence all around of threats not only to the environment, but also to the society and the economy on both local and global scales (Bansal, 2002), because of irresponsible socio-economic development. Although the problem above is one of the prime reasons for making of environmental management policies and laws, it appears this caution has not as yet caught up with most social and economic developers. A regional assessment, report by the UNEP rightly puts it as follows:

> Short-term commercial interests are often prioritized over long-term sustainable development. This is due to the false assumption that environmental protection and sustainability can only be achieved at the expense of economic development and social well-being. On the contrary, by investing in environmental improvements significant economic returns can be achieved through, for example, increased ecosystem and resource productivity, improvements in public health and poverty alleviation. Sustainable development is only possible by enhancing environmental management (UNEP, 2006, 5)

The conceptual framework of sustainable developments seeks to bridge the gaps between social development, economic development and environmental integrity (Parish, 2006). A review by O'Connor (2006) however, rightly includes political organizations (Figure

2.1.1), that is, the role of governance or management, by means of implanting regulatory tools, as another important component of sustainable development framework.

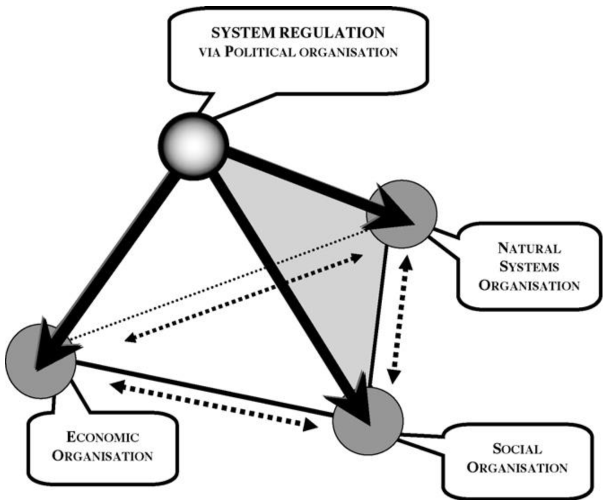


Figure 2.10 The four-sphere framework for sustainable development (O'Connor, 2006).

It is the role of the management at all levels of governance, which is national, provincial, local and community to see to it that all policies formulated meet the justifiable needs of all the other three pillars. In fact, this is the most appropriate approach for even environmental policies to yield positive results.

2.6 CONCLUSION

The criteria for classifying coastal systems are diverse, ranging from basis on water balance, ecological characteristics, circulation mixing, marine-fluvial processes and geomorphology (Kjerve, 1994). The intrinsic potential within these systems however, leaves no doubt on the importance of these systems to human survival, socioeconomic developments and proper functioning of adjacent inland ecosystems. Human pressures have so far succeeded in exerting irreversible footprints on the ecosystems of the majority of coastal systems bothering the entire globe (Garden and Garland, 2005). In recent years, additional pressures and uncertain ones yet to be impacted are also being exerted from the climate change and global warming phenomenon (Roessig *et al*., 2005, Smith *et al*., 2010). To avert this accelerating downward trend, all stakeholders, interested and affected parties need to come on board, and deliberate on these systems holistically. Their individual and collective influences on the coastal systems must be ascertained and ecosystem-based mitigation and prevention measures must be conceptualized after which steps should be developed for practical implementation. It is important that the technological aspects to achieving these aims are simplified so that individuals, communities and other social groups can actively get involved since they are the people who are most affected in the long run.

CHAPTER THREE: STUDY AREA AND METHOLODOLGY

3.1 STUDY AREA

Durban Bay is located at longitude 31º 02'E and Latitude 29º 52'S (Ports and Ships, 2003) along the coastal city of Durban in KwaZulu Natal (Figure 3.1). It is 910 hectares in size (eThekwini, 2009) and drains a catchment area of approximately 264 square kilometers with 70% of the land urbanized, and 6% farmland comprising sugar cane and commercial forest farms (DEAT,2001), appendix one shows a representation of land use within the Durban bay catchment.

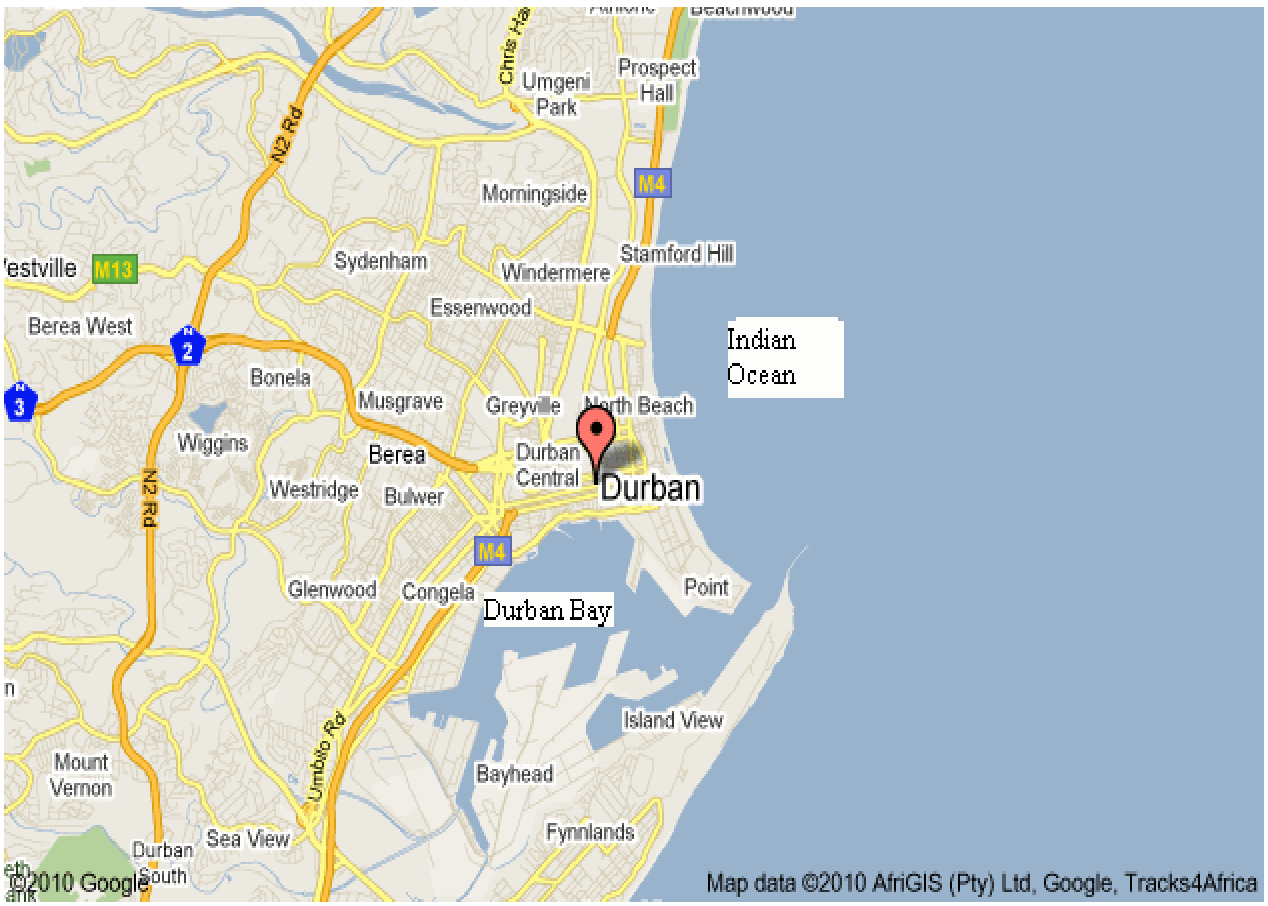


Figure 3.1 Position of the Durban bay along the KwaZulu Natal Coastline (Google earth, 2010)

It experiences water influx mainly from marine influence and minute freshwater influx from the uMhlatuzana and uMbilo rivers which have been canalized into the uMhlatuzana canal (Pradevand *et al*., 2003).

The water area of the bay, almost entirely surrounded by docks and quays is 896 hectares at high tide and 679 hectares at low tide (Forbes *et al*., 1996). The bay is popularly referred to as an estuary (eThekwini municipality, 2009, Forbes *et al*., 1996, Harrison *et al*., 2000, and Pradervand *et al*., 2003,). Harris and Cyrus (2000), assert that the bay used to exist as a permanently open estuary with a depth below 3m until the beginning of port operations in the 1800. According to Kjerfve (1994) a coastal lagoon is "an inland water body usually oriented parallel to the coast, separated from the ocean by a barrier, connected to the ocean by one or more restricted inlets, and having depths which seldom exceed a couple of meters" (Kjerfve, 1994, pg 2). This definition can be applied to the Durban bay, however, based on the literature reviewed in previous chapters, the Durban bay is classified in this research as an estuarine bay, kept opened by the artificially created breakwater piers (Figure 3.2).

Figure 3.2: Aerial view of the Durban bay showing the physical natural and artificially extended barriers of the water body to the ocean.

3.2 Topography and Land Form

The estuarine coastal bay is relatively flat with a high coastal dune system on its eastward side. The southern side of the bay entrance consists of raised geological formation approximately 80m, with steep slopes commonly called the Bluff, which is actually a part of the bay's dune system and it is the only such natural dune feature along the entire Natal coast (Gibb, 2004). The northern side of the bay entrance has a vast stretch of beaches. Both sides of the entrance have breakwaters leading out into the sea to break high tide currents and to reduce the impact of long shore drift current thus helping to maintain the mouth status of the harbour (Shorelinesa.co.za, 2009).

3.2.1 General Geology

The bay contains Quaternary age estuarine and marine deposits formed about 18,000 years ago. Its basal cover is made up of cretaceous-age St. Lucia formations (Gibb, 2004). The formations consist of weakly cemented siltstones and mudstones with the consistency of very stiff clay (Hindmarch *et al*., 2008). The fluvial sediment deposits are of 30m thickness and consist of sands, silts and clay.

A recent geotechnical survey reported of the presence of a small colony of reef located in the mouth of the bay. Experts reveal the high possibility of loss of ecosystems during the bay mouth widening and deepening project aimed at expanding the harbor's capacity (Gibb, 2004).

3.3 Climate

The weather is usually hot and humid with all year round rainfall. The average annual temperature is 21^{o}C and daytime highs can go as far as 28^{o}C, and an average of 1009 mm of precipitation is recorded annually (SAWS, 2010). The prevailing winds blow in north-north easterly and south westerly directions (Mardon and Stretch, 2002).

3.4 Marine Water

Tide occurrences within the bay are semi-diurnal and range between 0.5m at neap tides to 1.75m at spring tides (Mardon and Stretch, 2002) Due to the permanently open nature of the bay mouth, sea water flushes into the bay at least twice a day from incoming tide. Regular flushing of sea water and the relatively wide mouth of the bay gives the bay a near-marine saline condition. The inshore marine water temperatures range from 18^0C to 23^0C and mean salinity values of 35ppt are reported (Berry, 1971).

3.5 Freshwater and Water Quality of Past Studies

Two canalized rivers discharge freshwater into the system at the south-western portion of the bay. These are the uMbilo and Mhlatuzana rivers. A third river, the Amanzinyama, also flows into the bay, more towards the south eastern side. The Mhlatuzana canal which drains the Mhlatuzana and Umbilo Rivers is the freshwater feature of the Durban estuary. These rivers are two of the four major metropolitan river systems within the central portion of eThekwini (eThekwini Municipality, 2009). Although their discharges are relatively small, they greatly contribute to the stable estuarine conditions of the bay. There is evidence that the numerous industrial and residential activities along the river release wastewater that exit into the Durban bay through the silt canal. In 2007, a cleanup drive of the Durban bay yielded approximately 8 to ten tones of rubbish, much of which were from the Mhlatuzana canal (Ports and Ships, 2007). Before the First Fuel Services (FFS) Refiners Pty Ltd embarked on an environmental friendly operation drive, it was observed that a substantive amount of spillage every now and then was channeled into the canal (FFS News, 2000). There have also been several scientific reports of sewage spills into the Mhlatuzana and Umbilo rivers from sewage treatment plants located along these rivers.

Previous data on water quality analysis at specific sites within the bay are not as many as data on water quality along the coastline of the bay. Routine monitoring has been focused more on the coastline since the Durban Metropolitan council started operating two deep sea submarine sewage outfalls just off the bluff coast in 1969 (Bailey, 2000). The Specialists Studies for Transnet capital Expansion Programme on the Durban Bay conducted in 2007 outlines a monitoring programme similar to what the aims of this research are. The indicators used in the study included dissolved oxygen, turbidity, total suspended solids, nutrients, temperature. The report asserts that the bay experiences a relatively stable but high salinity level due to its overwhelming marine dominance. It also reveals that nutrient levels in the form of nitrogen are significantly high especially in areas close to the riverine inflows. The high nutrient levels initiate a chain of biological processes which eventually results in low dissolved oxygen contents. The report asserts that benthic invertebrates are almost completely eradicated in some areas around the upper riverine portions.

3.6 Ecology

Four basic ecological habitats are dominant within the bay. These are the sands, hard substrata, mud and mangroves (Forbes *et al*., 1996). Figure 3.3 shows the major habitats within the bay. The figures displayed within the diagram are the depths of water. The hard substrata includes stone, concrete, embankments, quay walls, piers and buoys which serve as habitats for organisms like sea anemones and barnacles. The sands and mud are breeding grounds for diverse species of abundance and richness amongst them being sand prawn, *Callianassa Kraussi*, (Newman *et al*., 2007). A patch of mangrove forest of about 15 hectares extent is located at the bayhead (Durban Municipality, 2009). The forest has white (*Avicennia*), red (*Rhizophora,*), and black (*Bruguiera*) mangrove tree species (Rajkaran and Adams, 2006). These tree species are clearly seen during low tide when the sand and mud are exposed. A survey by Forbes *et al*., (1996) revealed that individual species abundance was two to seven times higher in the undredged intertidal habitats than in the shipping channel which is dredged episodically.

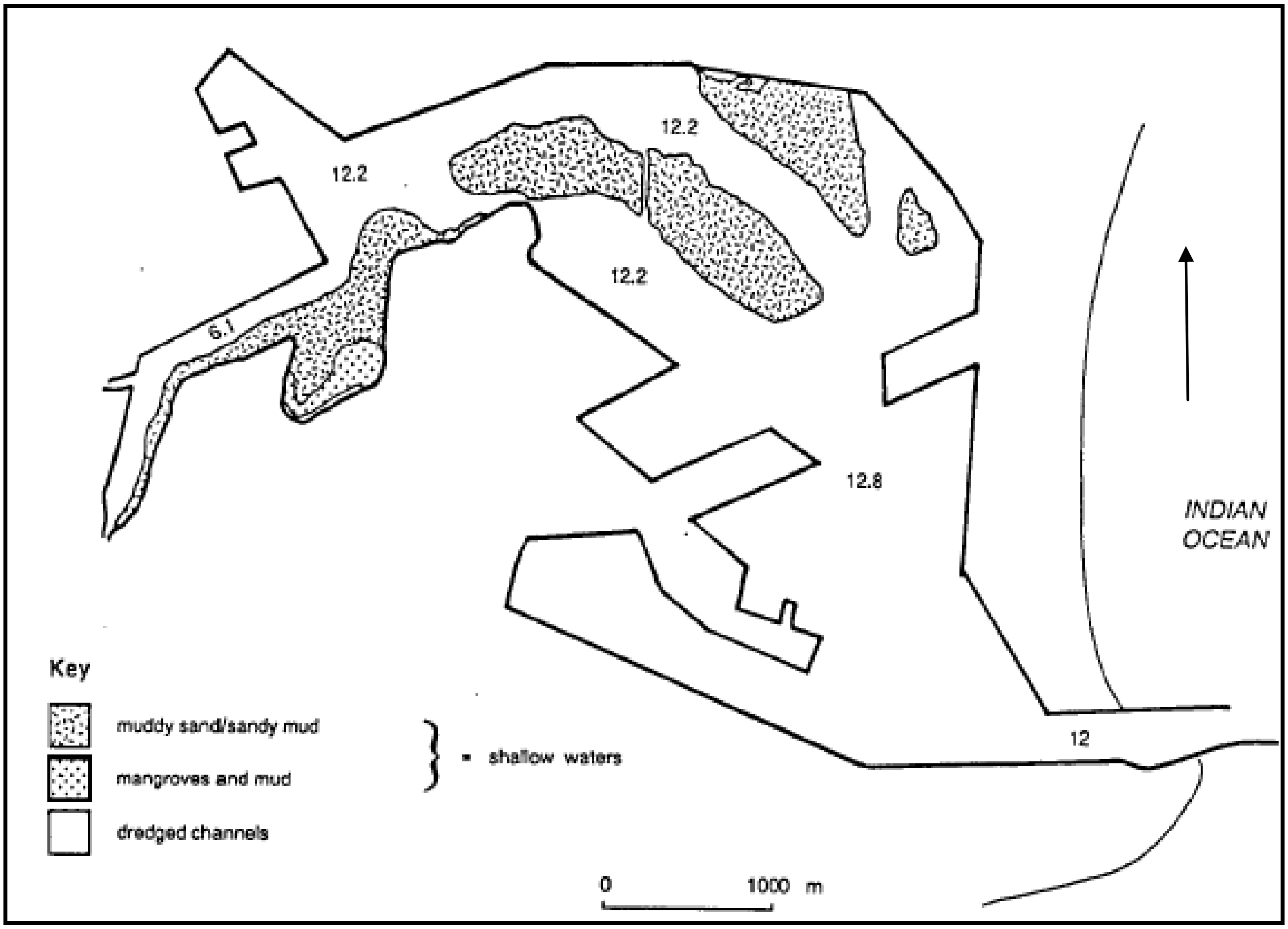


Figure 3.3: Major habitats within the Durban bay with solid lines showing the harbor developments (Forbes *et al*., 1996).

Although the permanently open nature of the bay mouth has led to it having predominantly marine characteristics, the bay still functions as a nursery ground for many estuarine fish species. The interspecific and intraspecific relationships of the freshwater and marine water systems create a complex and unique biodiversity (Foster *et al*., 2005).

3.6 Recreational and Leisure Industry

A variety of recreational activities are scattered along the perimeter of the bay. They range from Yatch clubs, boat chattering groups, restaurants, and diverse recreational fishing methods. The Durban Charter Boat Association for example operates within the bay with 19 registered boats, thirteen (13) of them are designated for reef and game fishing and the remaining 6 for cruising services (Gibb, 2004). The boats are also available on hire for parties, weddings and meetings. Pompano Angling Club is also an organized fishing clubs within the bay. KZN Wildlife monitors and regulates fishing activities by issuing fishing permits for recreational and subsistence fishing. The commonly caught fishes are; Stumpnose, spotted grunter (*Pomadasys commersonnii)* and kingfish (Gibb, 2004).

Within the bay are also popular tourist destinations like the Wilson's Wharf, Royal Natal Yatch Club, and the Durban marina, collectively known as the esplanade (Common Ground, 2004). Wilson's Wharf is a trendy waterfront precinct with craft shops, restaurants and a 165-seater internal theatre.

3.8 Harbour Operations

The Durban harbour is the busiest port in Africa with twenty four hour harbour operation (NPA, 2009). The harbour handles the greatest volume of sea–going traffic of any port in southern Africa with regards to the value of cargo handled per annum and second largest in terms of tons of cargo handled per annum (Van Coller *et al*., 2007). The harbour provides services to the Durban's industrial and commercial points, majority of Gauteng province, a great number of neighboring countries, and some parts of the world.

In the 2008/2009 financial year, 4,554 sea-going ships with gross tonnage of 114,723,266 had visited the harbour (NPA, 2009). This is approximately 38% of the total percentage of ships that called in at all South African ports. The bayhead area within the harbor is the centre for most of the containerized cargo that is brought in and taken out of the harbor (Van Coller *et al*., 2007). Longshore currents induce the constant accumulation of sand bars and sand dunes within the bay; as a result, dredging is conducted on an on-going basis. There is currently an ongoing harbor mouth widening and channel deepening project. The harbour also has a ship repair sector which is in clusters close to the silt canal (Van Coller *et al*., 2007).

3.9 MATERIALS AND METHODS

3.9.1 Location of Sampling Sites

Five sites within the bay were selected for the study.

Plate 3.4 is Durban Bay showing sample sites.

S 1 implies sample site 1. It is located at the coal terminal portion of the harbour. Coal is stock piled and loaded on ships for export at this terminal. All the coal leaving the premises of the bay are loaded at the coal terminal. There are some railway lines within the vicinity as well as sewage pipes which pass through the area and lead to the sewage treatment plant situated approximately 200m away. It is assumed that stock piling of coal can affect the chemical composition of the soil which will in turn seep into the nearby waters in the bay. Accidental spillage of coal may also contribute to changing the water quality of the bay.

Plate 3.4 Aerial view of study site showing the preselected sampling sites (Google Earth, 2010).

S 2 indicates sample site 2 which is within the Mhlatuzana canal. The canal is the major one of the two freshwater influents into the bay. It drains the light to heavy industrial areas of the Westmead in Pinetown (The Star, 2008). Such drainages are also expected to influence the water quality within the bay.

S 3 indicates sample site 3 which is an area in the Maydon wharf terminal where repairs and cleaning of large ships occur. Oil leakages, cleaning detergents and ballast water discharges at this site can all affect water quality within the bay.

S 4 indicates sample site 4 which is an area within the Wilson's Wharf vicinity, where many boats and yachts dock. There are a number of stormwater drain outlets in this area. It is assumed that general waste from the recreatioanl activities that go on daily at this site as well as storm water from their drainage outlets can impact the quality of the bay water.

S 5 implies Sample site 5 which basically surrounded by offices of Transnet, the National Sea Rescue Institute (NSRI), construction and port consultants. In the period of the research, some construction works were ongoing at this site. These include the demolition of the north groin of the bay and the building of a new pier. Such activities could also have effects on the water quality of the bay.

3.9.2 Collection of Samples

Water sampling was done between the months of April 2009 and March 2010. Samples were collected at the pre-selected sites in sterile one liter bottles, stored on ice and transported to the laboratory for analysis. Three samples were taken at each sampling site, each at mid-depth. On subsequent visits samples were taken as close as possible to the original site. All samples were analyzed within twenty four hours after collection.

3.9.3 Data Analysis and Collation

The Yellow Springs Instrument, YSI 6920 MDS Sonde instrument was used to analyze the water samples. The instrument is a robust multi parameter instrument for measuring water quality. It measures the following physical and chemical indicators at a go when in operation; temperature, depth, total dissolved solids, total suspended solids, turbidity, salinity, resistivity, dissolved oxygen percentage, dissolved oxygen concentration, specific conductivity, conductivity, pH, ammonium-N, nitrates-N and ammonia-N. The instrument was recalibrated the day before samples were taken to ensure accurate readings. Files were opened and saved on the sonde menu for all the sampling sites and discrete readings were logged unto the files and saved. For each sample logged, within ten seconds, fifteen readings were taken. The EcoWatch Software was used to download the analyzed data from the YSI sonde component and onto a computer. The sets of data were transported to

Microsoft Excel. The mean for each set of fifteen values were calculated to represent absolute values for sampling sites on specific sampling day. Univariate values for each sampling site were deduced by finding the averages of the calculated means for each sampling day. The individual means and overall (univariate) averages were extrapolated into graphs and tables for easy analysis and discussions. The data obtained were then compared with the DWAF South African Water Quality Guidelines (DWAF, 1996 (a), (b), (c)) and on some occasions, with previous data obtained by CSIR. For discussion purposes, the following indicators were selected; temperature, dissolved oxygen (saturation and concentration), pH, salinity, turbidity, total dissolved solids, ammonium-N, ammonia-N, nitrate-N, chloride, conductivity and specific conductivity.

3.1.1 CHALLENGES

It was initially proposed that 8 sites would be sampled but due to challenges of accessibility and restrictions, only 5 sample sites were practically realised. This was primarily due to the fact that the bay is now a private property (belonging to Transnet) These restrictions were imposed ad hoc depending on the intensity or sensitivity of operations within the port. This challenge compromised the sampling programme as originally planned. Under these conditions, sampling had to be rescheduled. Further, whilst a more comprehensive sampling coverage was desired, approval for these was not forthcoming from authorities, hence the researcher worked within allowable areas and those that would give the overall best coverage of the bay. In order to ensure that the samples taken in a day were all reflective of a neap tide or spring tide, the five sites chosen was most practical.

The restricted area status of the study site as well as the roughness of the sea on some days made it impossible to collect samples some distances from one another at the same preselected site.

It was almost impossible to follow the plan of samplying every fortnight due to bad weather conditions especially during the spring season.

CHAPTER 4

PRESENTATION OF RESEARCH RESULTS

This chapter is a presentation of tables and graphs compiled from the data acquired by the researcher during the sampling period. The appendix has the raw data of all the sites on all the sampling days throughout the sampling period. Sampling was done on seven occasions at five selected sampling sites. Below is a presentation of the sampling dates and the temporal periods:

S1 - Sample day 1 was on the 30th April, 2009, autumn season

S2 - Sample day 2 was on the 12th June, 2009, winter season

S3 - Sample day 3 was on the 30th June, 2009, winter season

S4 - Sample day 4 was on the 15th July, 2009, winter season

S5 - Sample day 5 was on the 29th July, 2009, winter season

S6 - Sample day 6 was on the 10th October, 2009, late spring; early summer season

S7 - Sample day 7 was on the 26th March, 2010, late summer; autumn season.

Data are not available for site 2 on sampling day 1 and for site 5 on sampling days 6 and 7. These data gaps were due to accessibility problems encountered by the researcher during field surveys.

Table 4.1 Mean temperature values of individual sites during the sampling period

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Summer)	18.96	-	18.88	19.1	18.81
2 (Winter)	19.3	18.51	19.76	19.1	19.43
3 (Winter)	16.86	13.75	15.71	13.89	16.38
4 (Winter)	14.97	14.93	14.46	14.62	15.07
5 (Winter)	15.26	15.24	15.5	15.12	15.25
6 (Late Spring)	16.01	15.26	15.82	15.64	-
7 (Early Summer)	19.42	19.28	19.42	19.14	-
OVERALL AVERAGE	17.25	16.16	17.08	16.66	16.99

Overall average = Sampling sessions divided by 7.

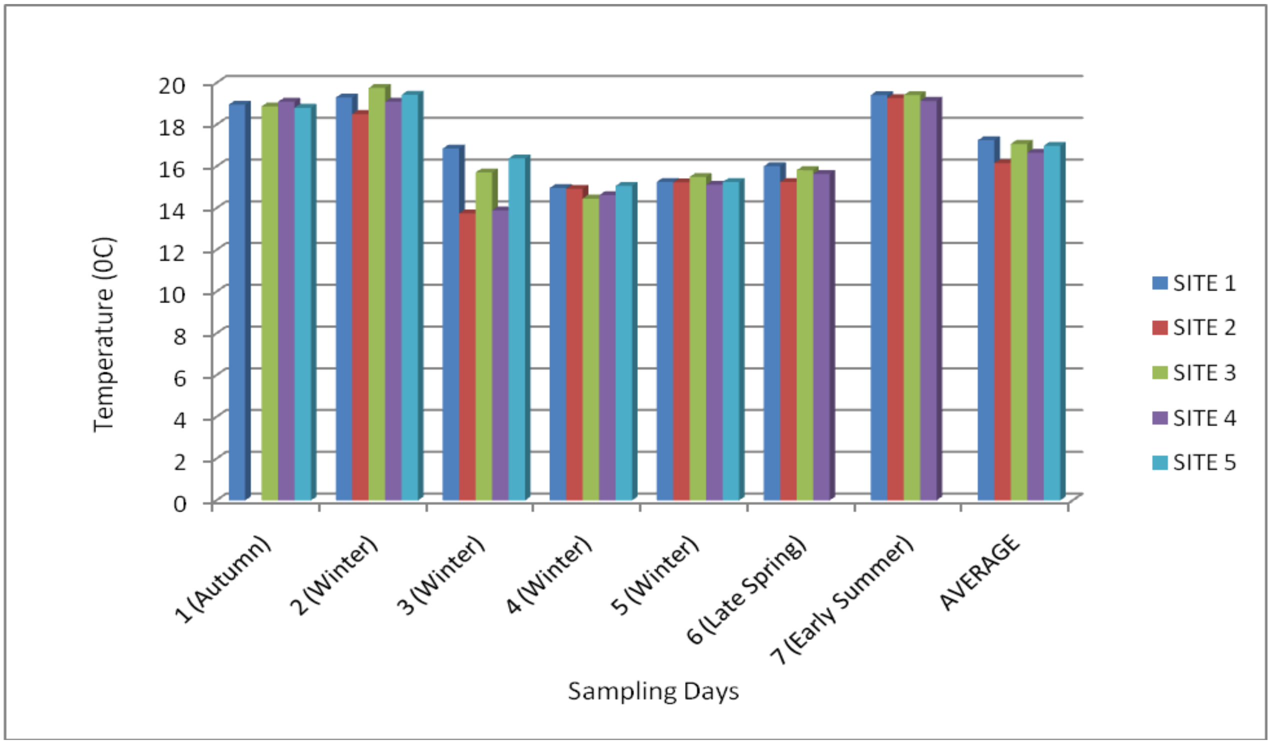


FIGURE 4.1 Graph of mean temperature values and overall averages for sample sites during the sampling period.

Table 4.2 Mean DO (%) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	18.41		35	21	30.87
2 (Winter)	49.42	252.65	57.57	51.58	68.68
3 (Winter)	89.27	69.87	96.89	40.63	83.82
4 (Winter)	19.09	20.3	26.23	23.67	18.29
5 (Winter)	98.53	123.08	95.87	97.16	97.94
6 (Late Spring)	59.75	97.81	51.77	58.91	
7 (Early Summer)	0.6	52.4	10.3	12.1	
OVERALL AVEARAGE	47.87	102.69	53.38	43.58	59.92

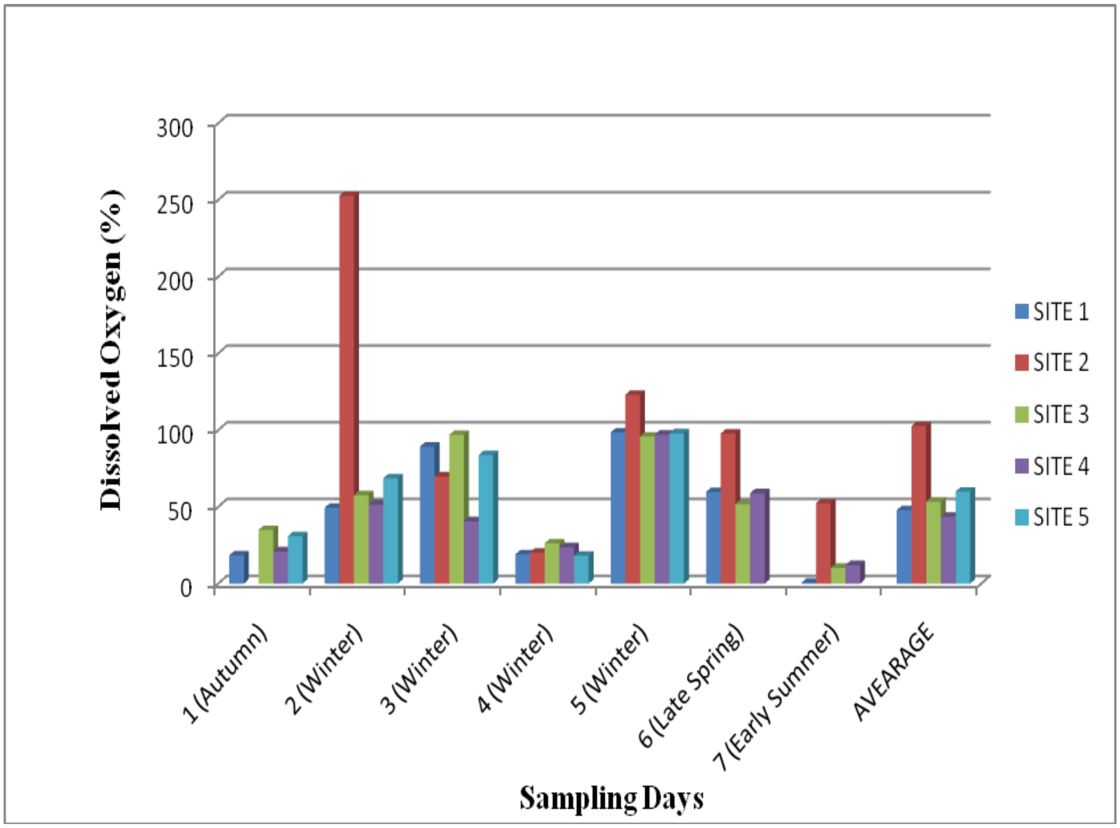


FIGURE 4.2 Graph of mean dissolve oxygen values and overall averages for sample sites during the sampling period.

Table 4.3 Mean DO (mg/L) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	1.41		2.87	1.73	2.23
2 (Winter)	3.54	23.63	4.14	3.81	4.89
3 (Winter)	7.61	7.22	7.67	3.24	6.71
4 (Winter)	1.47	2.05	2.07	1.85	1.41
5 (Winter)	8.35	12.32	7.34	8.16	7.47
6 (Late Spring)	5.89	9.8	4.51	4.69	
7 (Early Summer)	0.04	4.9	0.78	0.92	
OVERALL AVERAGE	4.04	9.99	4.20	3.49	4.54

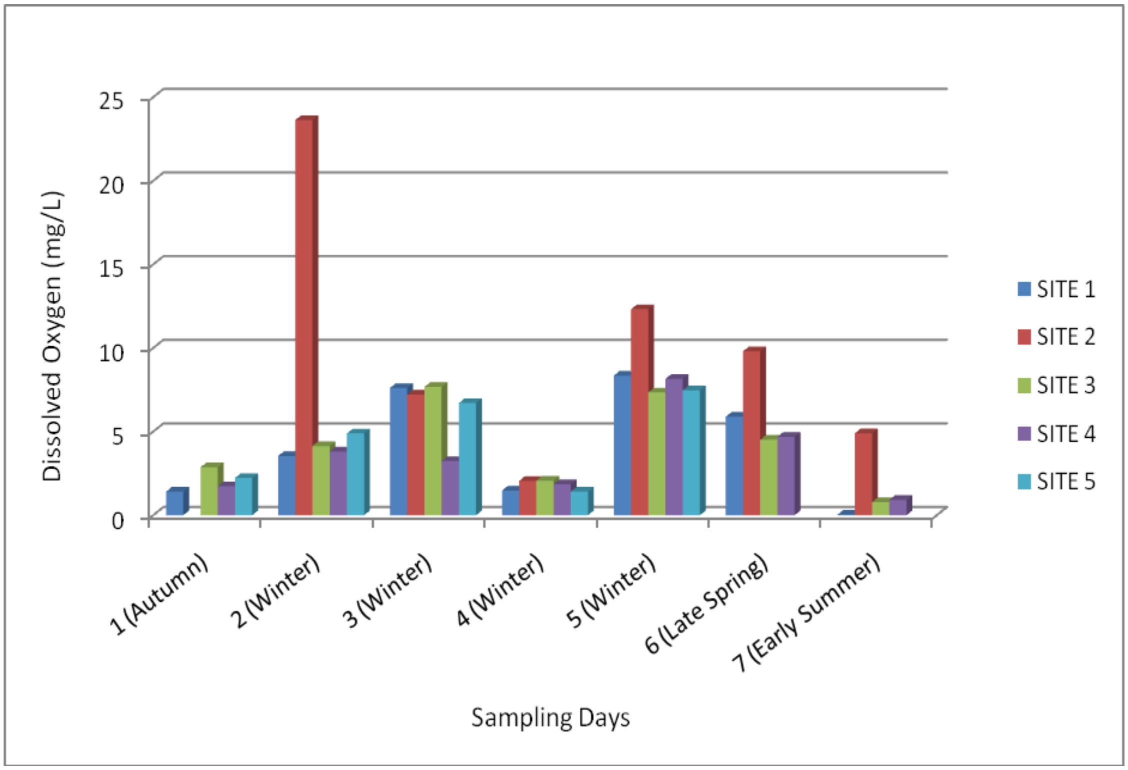


Figure 4.3 Graph of mean dissolved oxygen concentration values and overall averages of sites during the sampling period.

Table 4.4 Mean pH values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	6.92		7.28	7.13	7.51
2 (Winter)	6.93	7.62	6.01	7.06	6.74
3 (Winter)	7.17	7.81	6.49	6.73	7.34
4 (Winter)	6.93	5.92	7.01	6.94	6.39
5 (Winter)	6.32	6.66	6.23	5.47	5.79
6 (Late Spring)	7.17	8.21	7.26	7.16	
7 (Early Summer)	6.63	7.76	7.03	6.83	
OVERALL AVERAGE	6.87	7.33	6.76	6.76	6.75

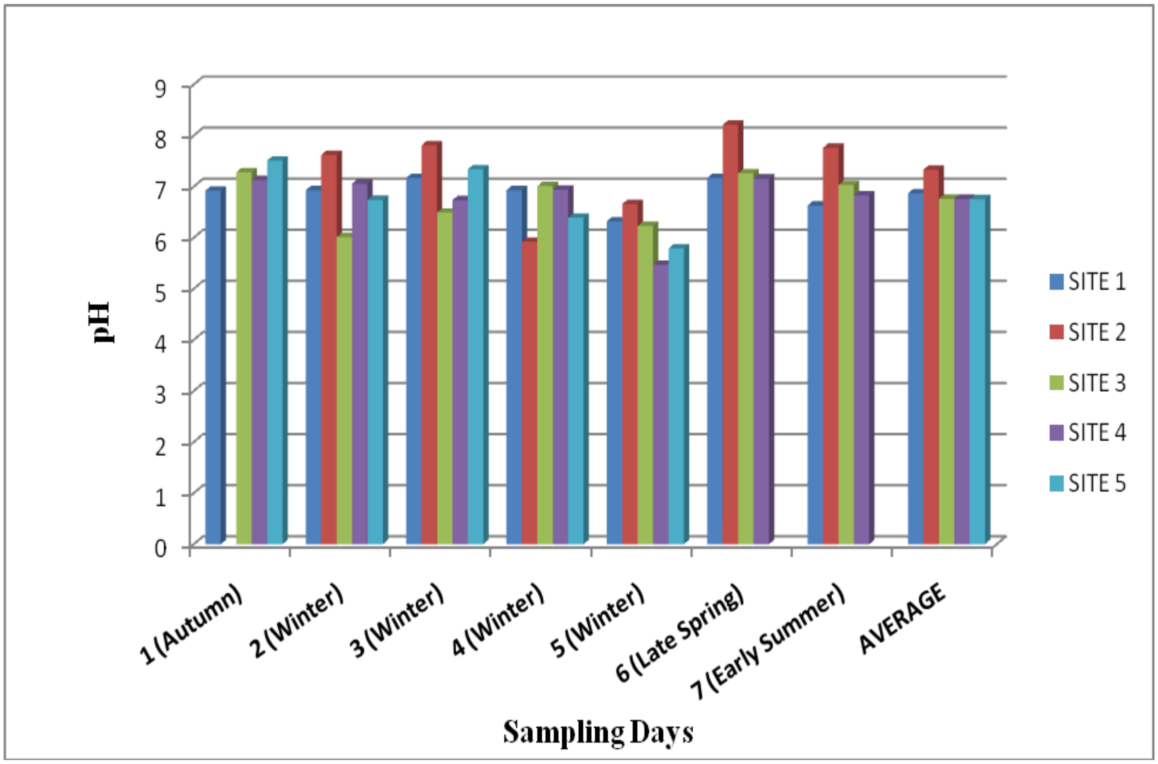


FIGURE 4.4 Graph of mean pH values and overall averaged of sample sites during the sampling period

Table 4.5 Mean salinity (ppt) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	32.25		21.49	19.38	42.5
2 (Autumn)	42.42	0.29	40.45	38.24	43.12
3 (Winter)	32.24	0.45	37.24	41.70	33.07
4 (Winter)	44.23	0.3	41.78	43.1	44.18
5 (Winter)	27.51	0.35	43.41	29.59	44.69
6 (Late Spring)	0.12	0.26	21.06	36.6	
7 (Early Summer)	31.45	0.26	31.51	33.68	
OVERALL AVERAGE	30.03	0.32	33.85	34.61	41.51

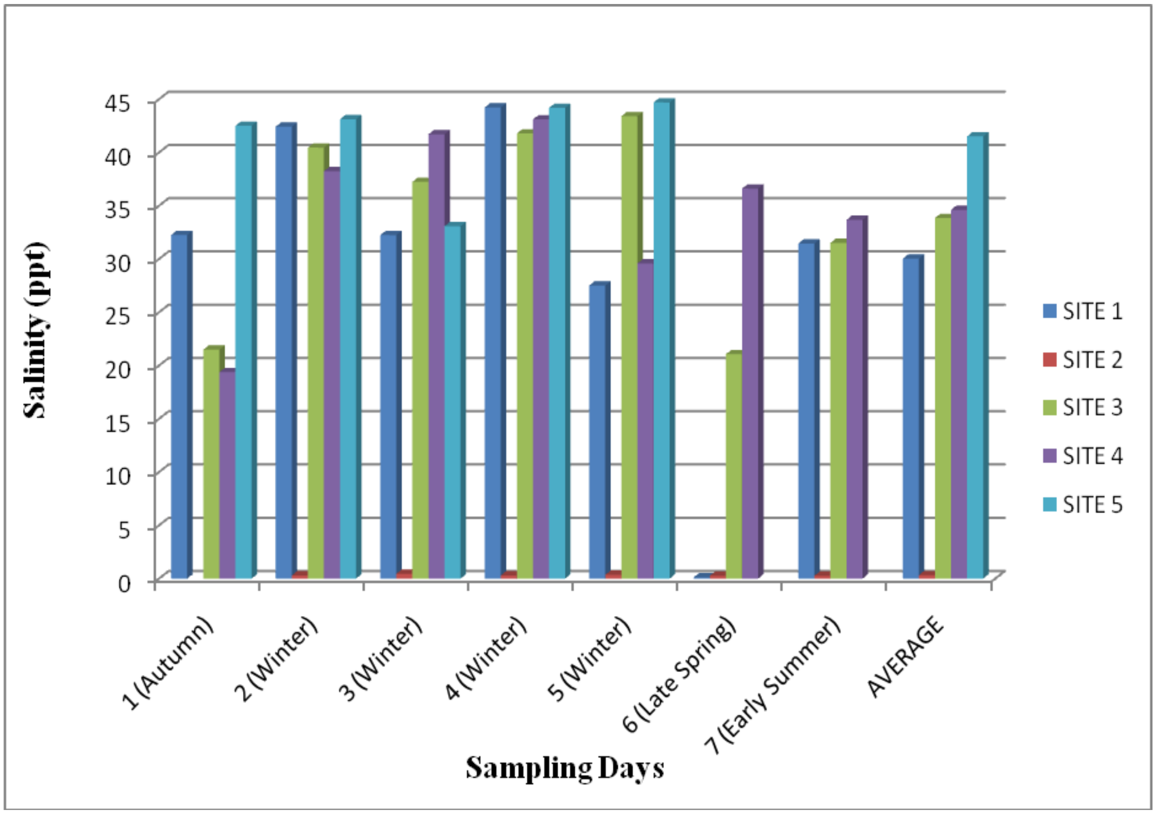


FIGURE 4.5 Graph of mean salinity values and averages of sample sites during the sampling period.

Table 4.6 Mean total dissolved salts (g/L) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	32.01		22.19	20.2	40.9
2 (Winter)	40.85	0.39	39.15	37.25	41.43
3 (Winter)	21.95	0.59	36.43	40.34	32.75
4 (Winter)	42.45	0.4	40.38	41.5	42.4
5 (Winter)	27.77	0.46	41.74	29.66	42.83
6 (Late Spring)	0.17	0.35	21.79	35.87	
7 (Early Summer)	31.23	0.35	31.34	33.27	
OVERALL AVERAGE	28.06	0.42	33.29	34.01	40.06

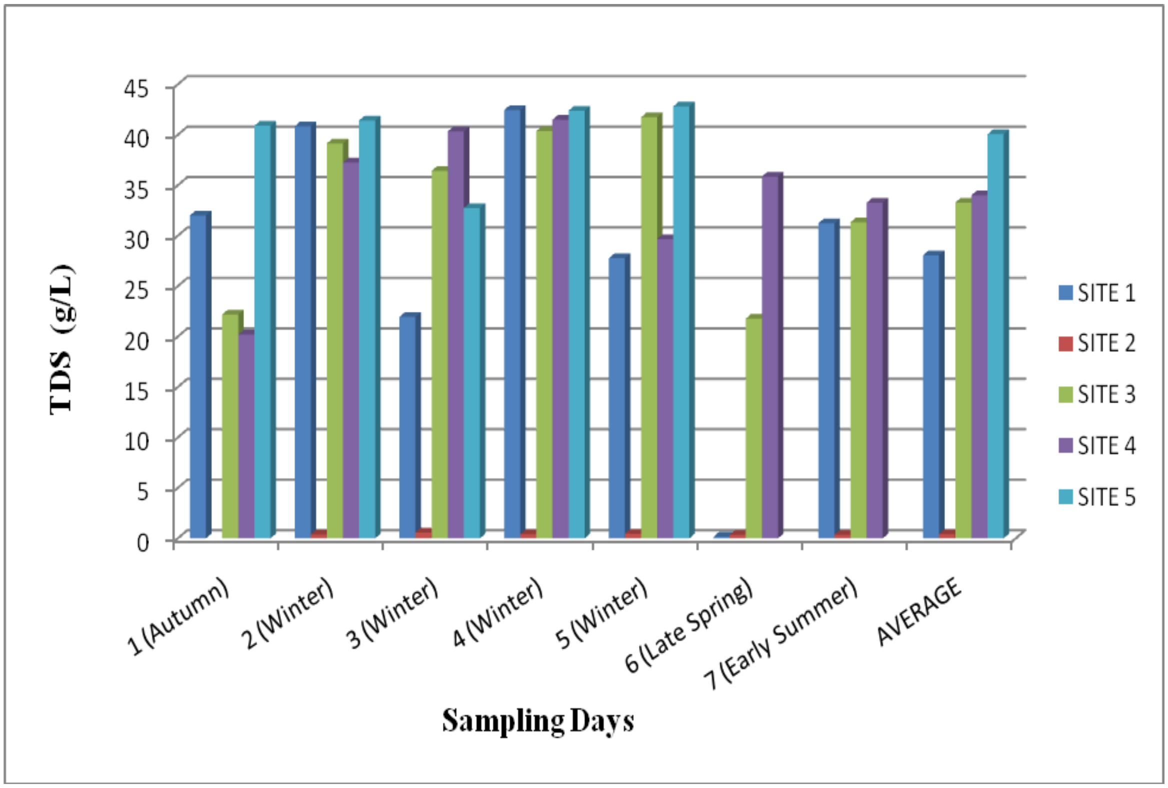


FIGURE 4.6 Graph of mean TDS values and averages of sample sites during the sampling period.

Table 4.7 Mean turbidity (NTU) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	4.2	-	5.56	4.8	5.47
2 (Winter)	7.9	21.53	12.95	4.81	7.38
3 (Winter)	5	6.84	4.5	4.06	5.35
4 (Winter)	5.41	7.5	4.58	5.4	5.89
5 (Winter)	8.23	6.48	4.7	6.2	5.01
6 (Late Spring)	4.54	4.81	4.07	4	-
7 (Early Summer)	6.1	6.9	4.8	4	-
OVERALL AVERAGE	5.91	9.01	5.88	4.75	5.82

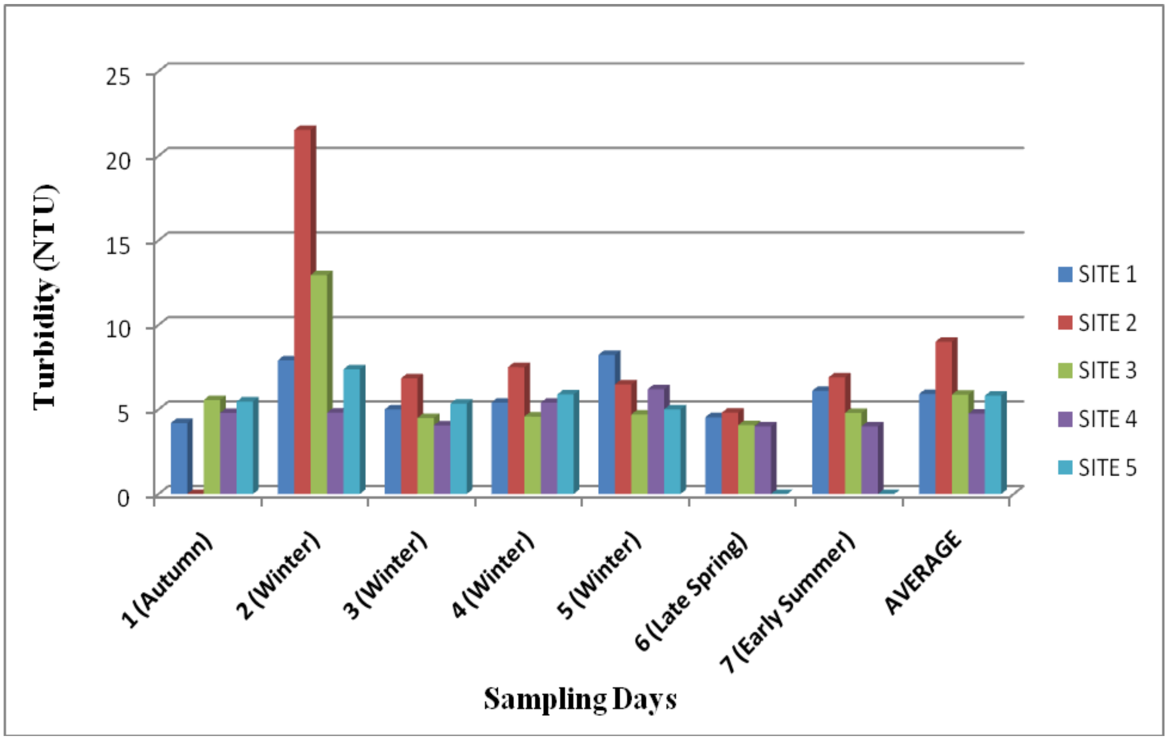


FIGURE 4.7 Graph of mean turbidity values and averages of sample sites during the sampling period.

Table 4.8 Mean nitrate-N (mg/L) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	20.67	-	24.98	21.78	23.12
2 (Winter)	16.02	61.75	16.15	15.79	15.93
3 (Winter)	11.48	64.35	8.52	13.02	12.4
4 (Winter)	15.16	90.59	15.29	13.52	13.07
5 (Winter)	14.15	87.91	8.92	7.15	11.19
6 (Late Spring)	13.68	111.87	22.2	19.32	-
7 (Early Summer)	9.85	36.8	12.18	11.98	-
OVERALL AVERAGE	14.43	75.55	15.46	14.65	15.14

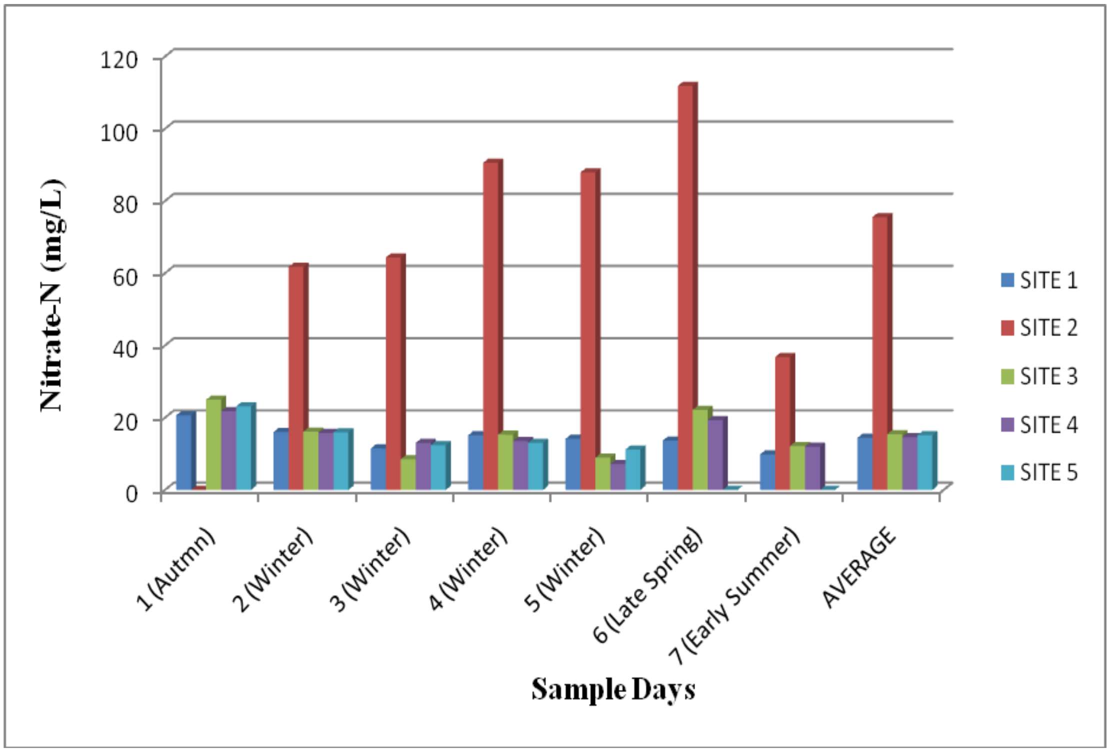


FIGURE 4.8 Graph of mean nitrate-N values and averages of sample sites during the sampling period.

Table 4.9 Mean ammonium-N (mg/L) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	409.97	-	230.22	353.41	232.43
2 (Winter)	172.41	183.05	206.73	201.59	201.74
3 (Winter)	213.37	166.89	264.53	317.14	214.91
4 (Winter)	211.07	408.79	273.2	271.73	215.59
5 (Winter)	243.18	217.46	262.34	778.37	218.35
6 (Late Spring)	74.24	78.55	106.08	130.28	-
7 (Early Summer)	72.6	139.1	216.5	292.5	-
OVERALL AVERAGE	199.55	198.97	222.80	335.00	216.60

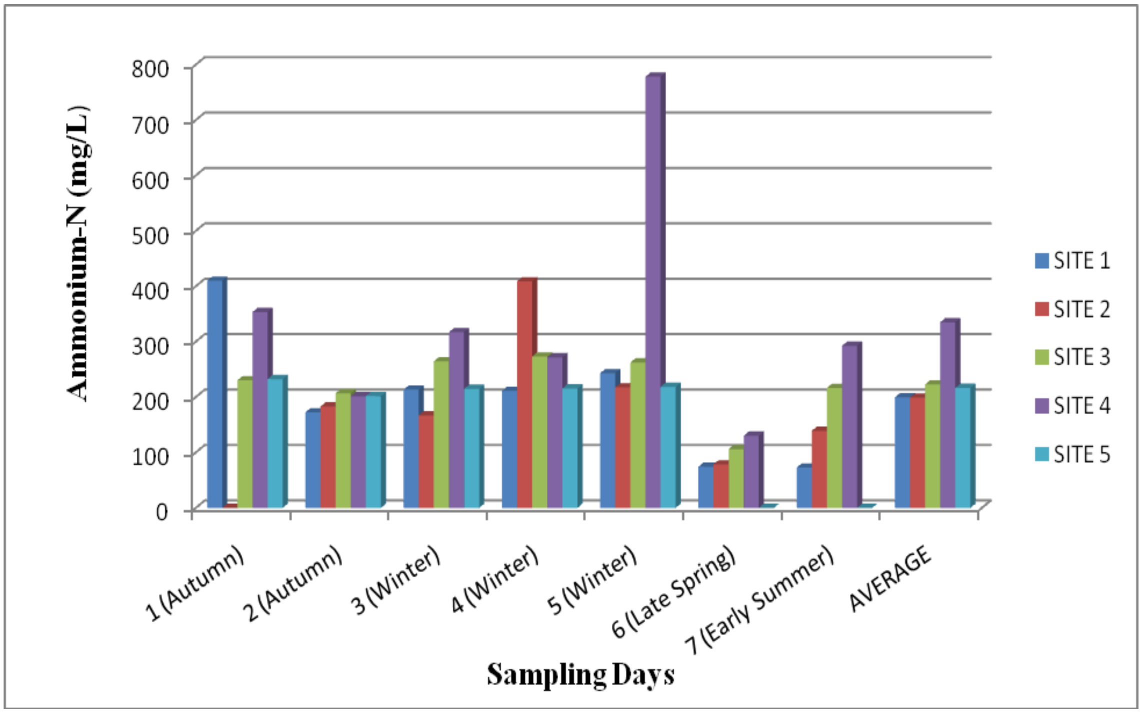


FIGURE 4.9 Graph of mean ammonium-N values and averages of sample sites during the sampling period.

Table 4.10 Mean ammonia-N (mg/L) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	1.09	-	1.47	1.61	2.23
2 (Winter)	0.45	2.72	0.07	0.72	0.34
3 (Winter)	0.9	2.67	0.2	0.36	1.21
4 (Winter)	0.4	0.09	0.6	0.51	0.12
5 (Winter)	0.13	0.26	0.1	0.06	0.03
6 (Late Spring)	0.33	3.58	0.51	0.46	-
7 (Early Summer)	0.1	3.02	0.77	0.61	-
OVERALL AVERAGE	0.49	2.06	0.53	0.62	0.79

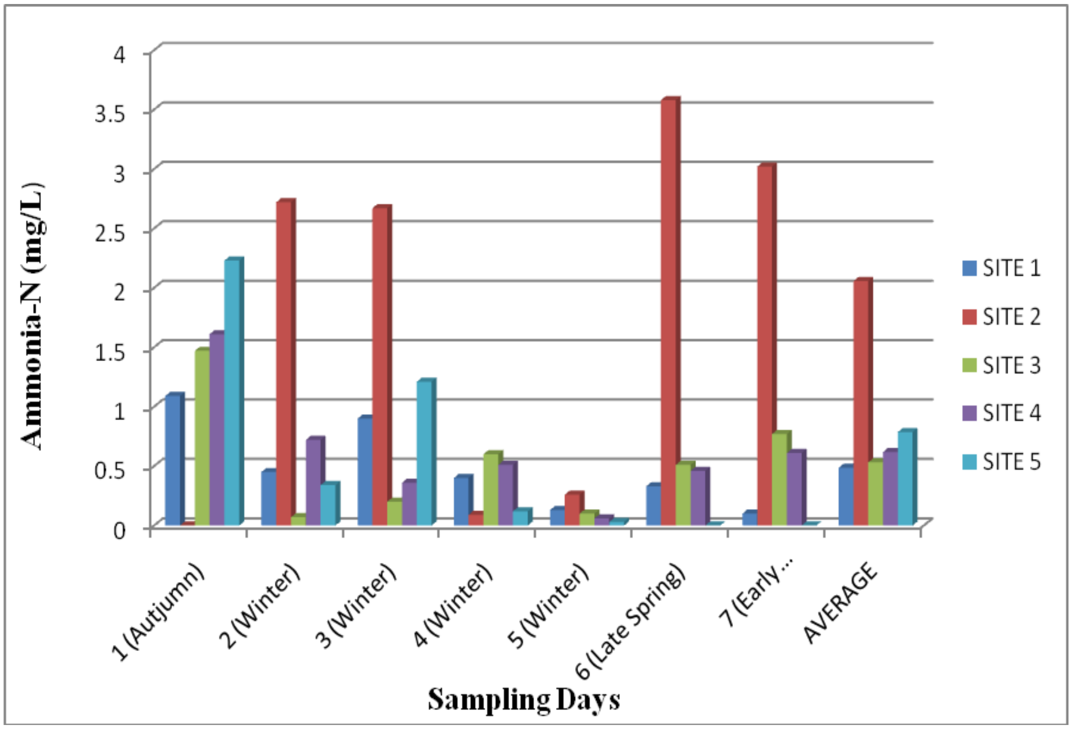


FIGURE 4.10 Graph of mean ammonia-N values and averages of sample sites during the sampling period.

Table 4.11 Mean chloride (mg/L) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	9309.48	-	11883.59	7936.24	11073.22
2 (Autumn)	7150.1	1156.87	7823.04	6906.9	8397.31
3 (Winter)	6354.64	1325.72	6569	5056.63	6031.14
4 (Winter)	6289.93	169.88	5722.16	5236.1	6186.09
5 (Winter)	6399.91	1121.6	4915.24	3856.95	5302.9
6 (Late Spring)	5453.52	1178.84	8189.25	6759.44	-
7 (Early Summer)	2093	399.6	2466	2428	-
OVERALL AVERAGE	6150.08	892.09	6795.47	5454.32	7398.13

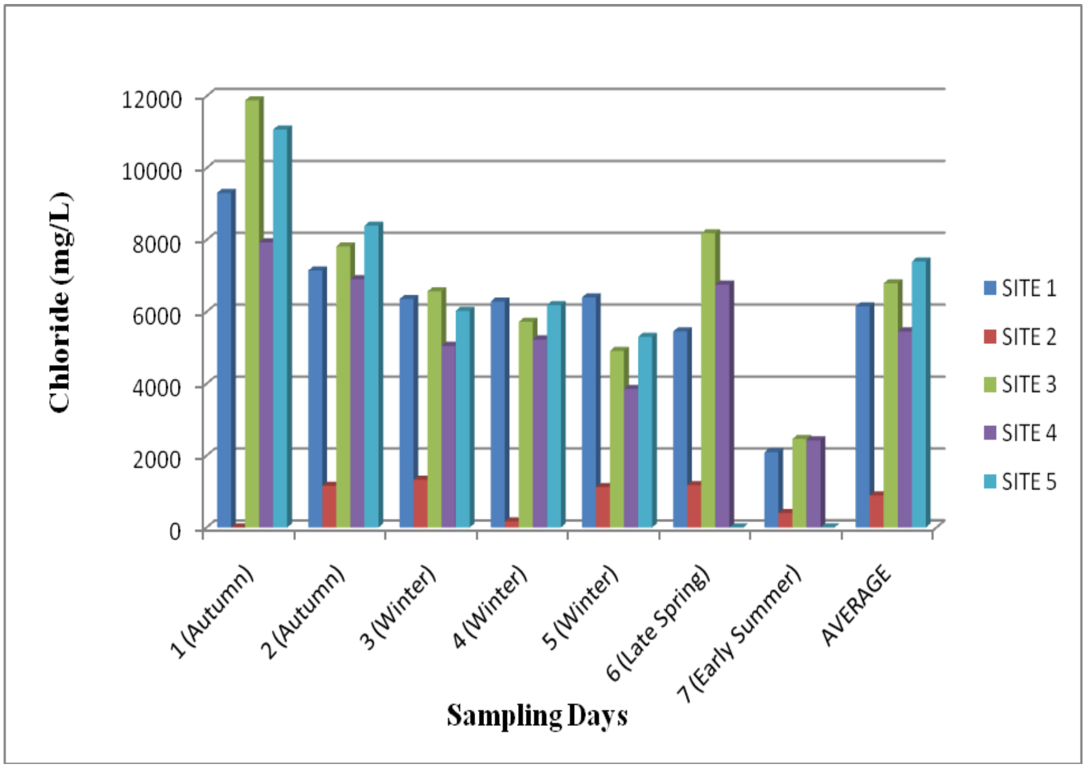


FIGURE 4.11 Graph of mean chloride values and averages of sample sites during the sampling period

Table 4.12 Mean conductivity (mS/cm) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	43.56	-	30.14	27.58	55.48
2 (Winter)	56	0.52	54.2	50.86	56.96
3 (Winter)	28.52	0.71	46.1	48.89	42.08
4 (Winter)	52.8	0.5	49.62	51.2	52.86
5 (Winter)	34.78	0.58	52.56	37.02	53.63
6 (Later Spring)	0.22	0.44	27.65	45.32	-
7 (Early Summer)	43.9	0.47	43.16	45.46	-
OVERALL AVERAGE	37.11	0.54	43.35	43.76	52.20

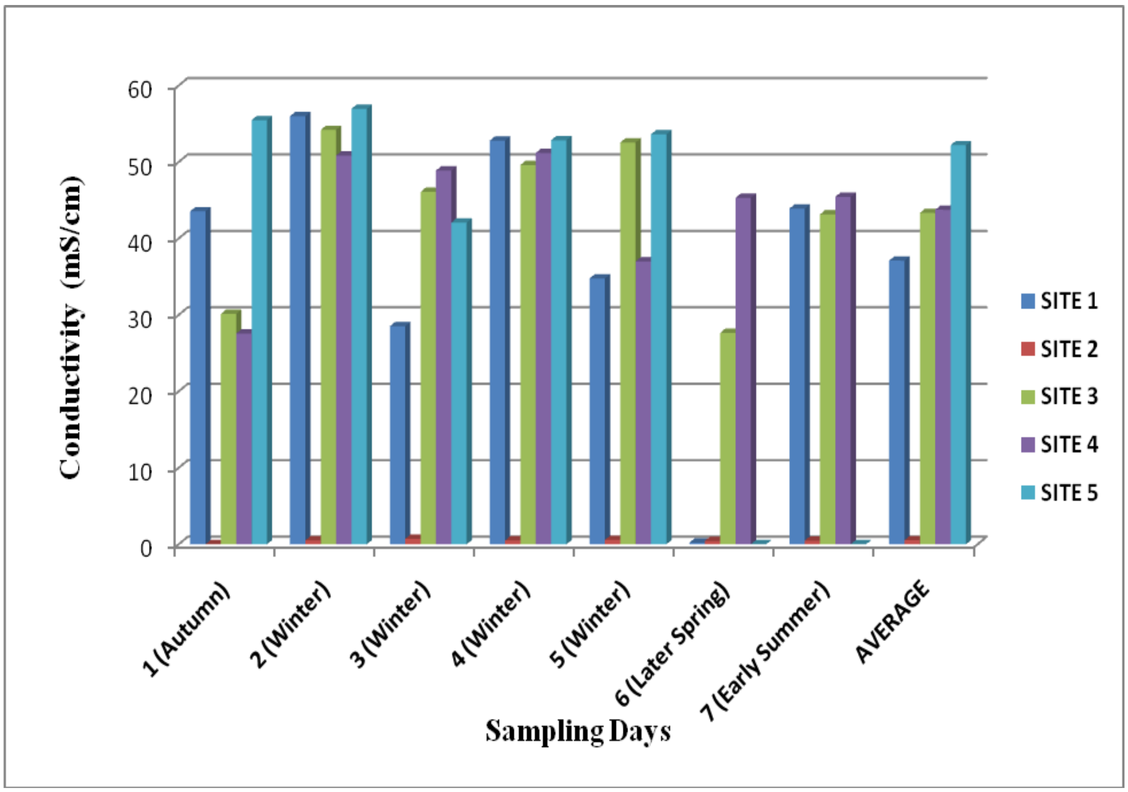


FIGURE 4.12 Graph of mean conductivity values and averages of sample sites durimg the sampling period

Table 4.13 Mean specific conductivity (mS/cm) values of individual sites during the sampling period.

SESSION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
1 (Autumn)	49.24	-	34.14	31.08	62.93
2 (Winter)	62.85	0.59	60.23	57.31	63.73
3 (Winter)	33.78	0.9	56.04	62.06	50.38
4 (Winter)	65.31	0.62	62.13	63.85	65.23
5 (Winter)	42.72	0.71	64.21	45.63	65.89
6 (Late Spring)	0.26	0.54	33.53	55.18	-
7 (Early Summer)	48	0.53	48.22	5.17	-
OVERALL AVEARGE	43.17	0.65	51.21	45.75	61.63

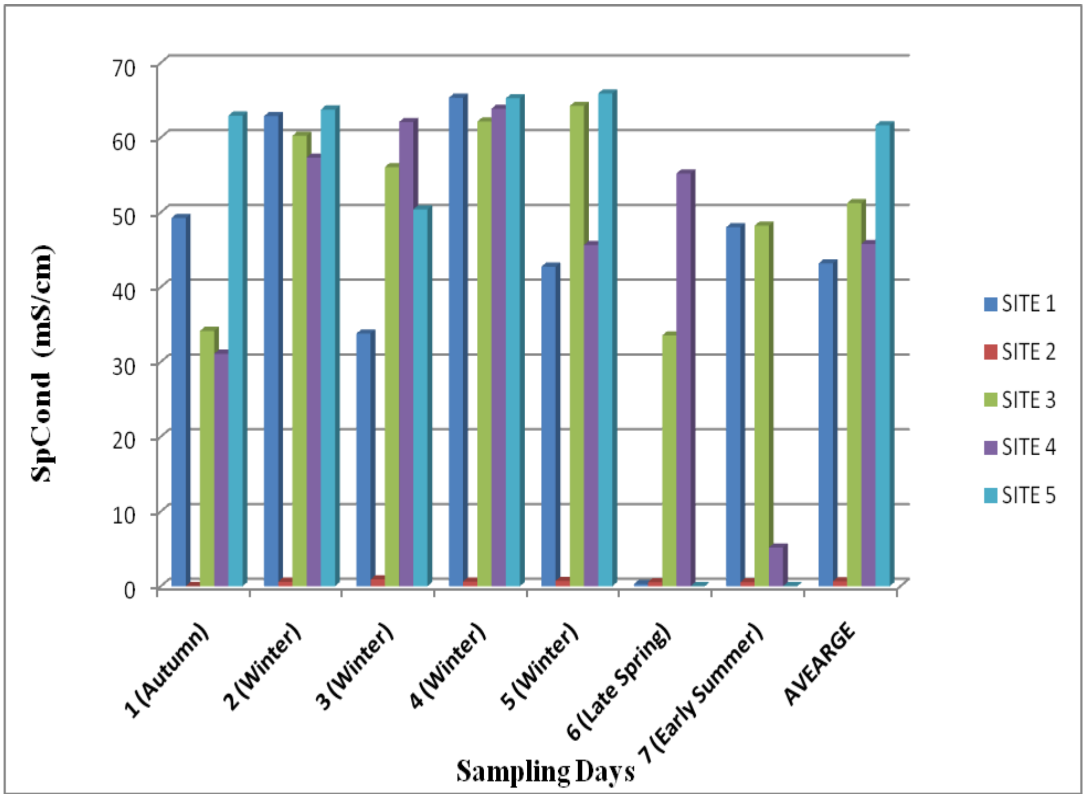


FIGURE 4.13 Graph of mean specific conductivity values and averages of sample sites during the sampling period

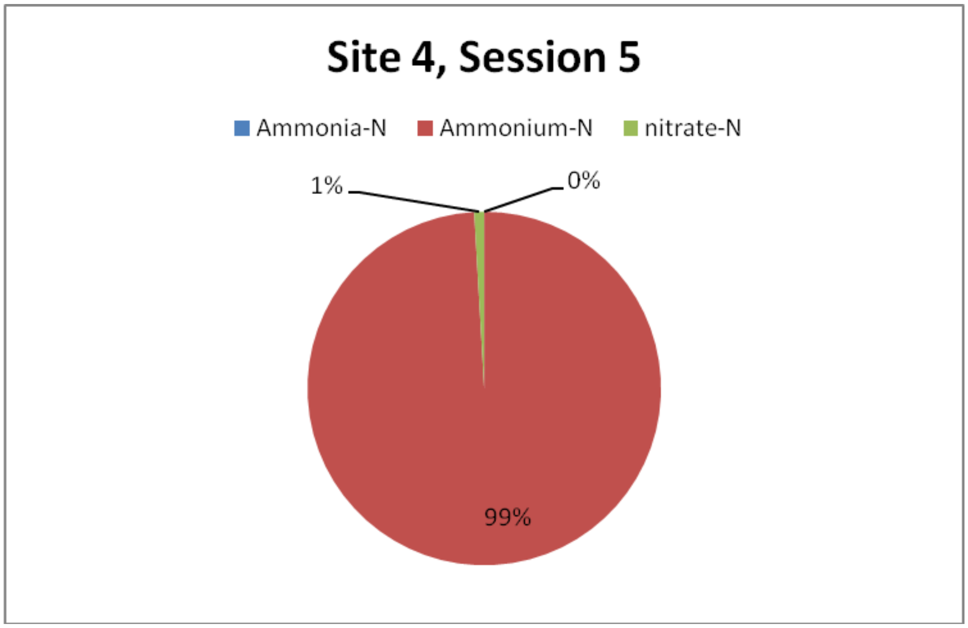


FIGURE 4.14 Graph of components of nitrogen in percentage at site 4 on sampling session 5.

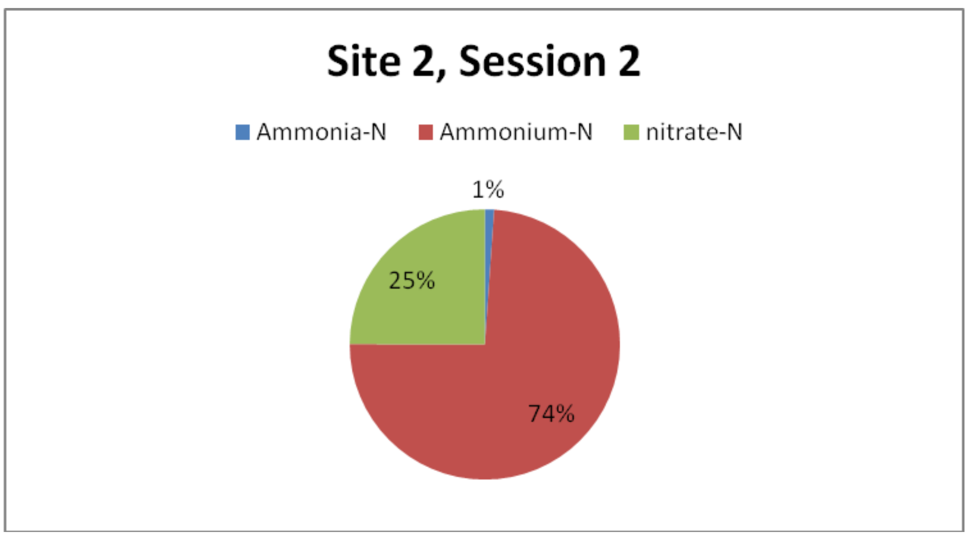


FIGURE 4.15 Graph of components of nitrogen in percentage at site 2 on sampling session 2.

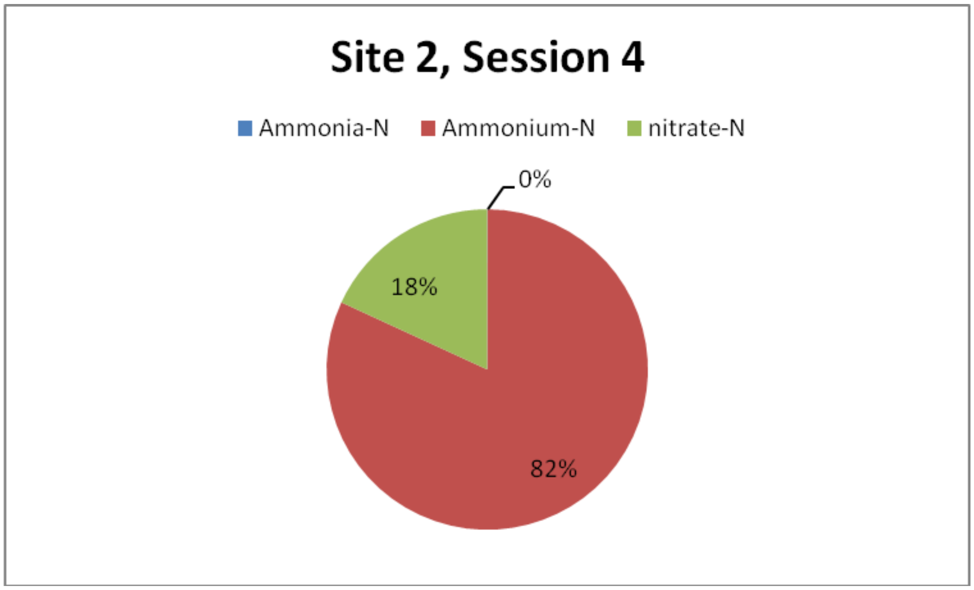


FIGURE 4.16 Graph of components of nitrogen in percentage at site 2 on sampling session 4.

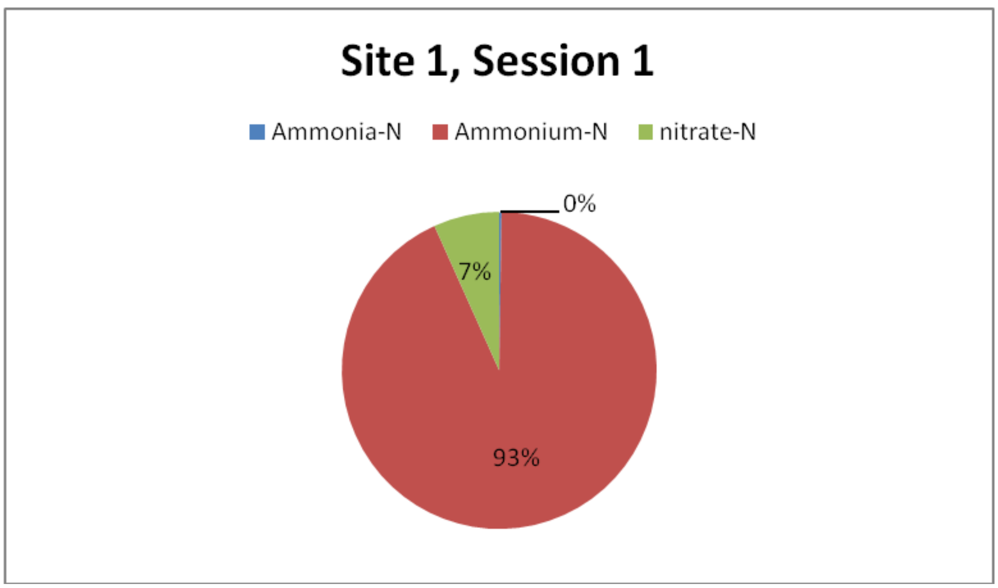


FIGURE 4.16 Graph of components of nitrogen in percentage at site 1 on sampling session 1

CHAPTER FIVE: ANALYSIS AND DISCUSSION OF RESULTS

5.0 INTRODUCTION

Defining water quality standards for ecosystems is difficult and involving as compared to defining water quality standards for human consumption and other domestic purposes. Based on the contribution of natural events which also create physico-chemical changes, it is sometimes difficult to draw a line of distinction between human induced stress and nature induced stress. The results presented in chapter four are interpreted and discussed in detail in this chapter. The discussions are done in comparison with the second edition of the South African Water Quality Guidelines (SAWQG) document issued by the Department of Water Affairs and Forestry (DWAF, 1996). There are 2 sets of different guidelines, one for fresh water and one for coastal marine waters. Each is further divided into series or volumes according to the type of use being applied to the water body. There are as yet no guidelines specific for estuaries and river mouths, reviews and researches are on going to include the above and update current information. Volumes of the SAWQG relevant to the selected sites of the research were used to compare with the data acquired during the sampling period. The volumes most referred to are:

- The South African water quality guidelines for coastal marine waters, volume 1 (Natural Environment),
- The South African water quality guidelines, volume 7 (Aquatic Ecosystems),
- The South African water quality guidelines, volume 8 (Field Guide) and
- The South African water quality guidelines, volume 1 (Domestic Use).

These volumes were selected with the understanding that sites 1, 3, 4 and 5 are in areas of the bay with little freshwater influence and almost entirely seawater dominated whereas site 2 located in the Umhlatuzana canal is dominantly freshwater. The data are also compared with the data acquired with reported water quality data within the bay according to a research report by the centre for scientific and industrial research in Newman *et al*.'s (2007) document.

5.1 TEMPERATURE

Temperature is among the key indicators when assessing the physico-chemical quality of a water body although it is not a chemical constituent. Temperature is not influenced by the most chemical indicators, even though most chemical constituents and physiological processes are directly or indirectly influenced by temperature values. Recording temperature values assist in giving appropriate meaning and interpretations to physico-chemical conditions. It is stipulated by DWAF in the SAWQG document that east coast waters have maximum temperatures averaging 25^0C, with winter temperatures being about 4^0C less (DWAF, 1996b). Temperature values recorded during the sampling period reflected seasonal variation characteristics (Figure 4.1). As expected, the winter samples were generally lower than the summer, autumn and spring samples, they all fell within the SAWQG stipulations (See Table 4.1 and figure 4.1). Temperature monitoring records set the platform for assessing and making detailed analysis of water quality data because they impact on a great number of water quality chemical parameters. Temperature ranges above or below target qualities may cause or contribute to problems such as eutrophication, retardation in growth, hampered respiration and reproduction patterns in the aquatic organisms (DWAF, 1996a).

5.2 DISSOLVED OXYGEN (As percent saturation and as concentration in mg/L)

Unpolluted surface waters usually show close to saturation dissolved oxygen levels. According to the DWAF (1996a), the acceptable range for almost all aquatic organisms is within the range of 80 -120%. The dissolved oxygen levels recorded in percentage and mg/L showed some degree of seasonal variation characteristics with some scattered unexpected results. CSIR reports on a research of the Durban bay concluded through modeling outcomes that; at the same temperatures, the freshwater portions of the bay register about 2mg/L concentration values above those of the seawater dominated portions (Newman, 2007). This pattern was realized in the results obtained although not all round. About 60% of the set of results obtained showed site 2 samples giving higher values than all the other sites. Generally, autumn, summer and spring samples showed lesser dissolved oxygen than the winter samples. A quick glance at dissolved oxygen levels (Figure 4.2) shows low levels, mostly outside the DWAF range. The overall averages of all the sites were approximately 60% and below, except for site 2 which recorded an overall average of

102.69 (Table 4.2). It is obvious that the extremely high value recorded on the second sampling day contributed to the high overall average for this site. Only sampling day five reveals a good set of values for dissolved oxygen status at all sites. The seventh sampling day gave the worst set of data for dissolved oxygen with averages in percentages of 0.6, 52.4, 10.3 and 12.1 for sites 1, 2, 3 and 4 respectively. Although these values represent summer values, they are unacceptably low to be attributed to the weather conditions only and it is indicative of potential serious deleterious biological processes initiated or in progress at that time.

The set of values within acceptable range at site 1 were 98.53% (table 4.2) recorded during winter on the 5th sampling day and 89.27% recorded on the third sampling day. The other sampling times recorded very low dissolved oxygen with some values indicating hypoxic conditions at site 1. The lowest dissolved oxygen saturation, for site 1, 18.42% was recorded on the first day of sampling. As much as these low values can be attributed to summer, spring and autumn weather conditions, anthropogenic factors like the dredging activities (Ohimain *et al*., 2008) due to the ongoing harbour entrance widening project also played a major part in lowering dissolved oxygen in the surface waters. During dredging, sediments are stirred up and phytoplankton ecosystem interactions are increased due to the stirred up nutrients in the form of decaying organic matter. A study by Ohimain *et al*., (2008) reveals that dredging decreases dissolved oxygen and pH while increasing conductivity, TDS and sulphate values. Site 5 and site 1 are about 250 meters apart, and as such, they experience almost the same conditions with all things being equal; this explains the similarities in the pattern of their dissolved oxygen values (See figures 4.2 and 4.3).

As stated earlier, Site 2 gave an unusual super saturation value of 252.65%, on the second sampling day which is unexpectedly high for an autumn sample (Table 4.2). This high value reflects the rapid flow of water through the canal on the day of sampling. The rapid flow, mixing and turbulence created, aided and contributed to the high saturation level. Photosynthesis by algae and aquatic plants is another major source of dissolved oxygen; therefore, super-saturation levels can be associated with excessive photosynthesis. Due to the sewage treatment plants and factories upstream, it could be that there had been significant release of nutrients into the influent streams which had aggravated processes and resulted in the super saturation. Super saturation due to this chain of occurrences is usually followed after some time by extended periods of hypoxic or even worse, anoxic conditions. It is believed that an extended period of dissolved oxygen less than 80% saturation can have acute behavioral and physiological stress on aquatic fauna. The lowest dissolved oxygen value, for site 2, of 20.3%, was recorded in summer on the seventh sampling day. Only one sampling day recorded a comfortably acceptable saturation value for site 2 which was 97.81% dissolved oxygen. The inconsistent records of extremely low and extremely high dissolved oxygen concentrations confirms that site two experiences an influx of organic material every now and then thus creating a cycle of dissolved oxygen highs and lows. The organic content originates from sewage treatment plant effluent, agriculture runoff and industrial discharges. Other human activities that can lead to low dissolved oxygen include warm water discharge from factory boiler makers and removal of vegetation from along the water body's channel. Sites 3 and 4 also showed similar patterns of levels oscillating from moderate to hypoxic to anoxic conditions as discussed for all the sites above.

Although low dissolved oxygen cannot be concluded straight away to have disastrous effects on aquatic organism, abrupt depletion will absolutely cause shocks in fish species and disturb the heath status of aquatic ecosystems or cause migration of species to move to oxygen enriched parts of the bay. Low dissolved oxygen levels need to be recorded over a period of time to determine the frequency of occurrence, how long the conditions last and at what times during the day they occur, after which mitigation measures can be taken. Both conditions of super-saturation and low dissolved oxygen are not acceptable for the good health of ecosystems.

5.3 PH

PH is a very important constituent in water quality analysis because most aquatic organisms are adapted to certain pH levels and slight variation for some can cause harmful effects. Natural factors like geological influences, atmospheric constituents, seasonal variations, and biological activities of the aquatic organisms (rate and proportions of photosynthesis and respiration), can impact on pH values. Although temperature also has an influence on pH values, in most cases when dealing with water bodies, it is ignored since its influence is negligible in aquatic ecosystems. For example, at a temperature rise of as much as 20^0C, pH values may decrease by just 0.1 in freshwater bodies (DWAF, 1996a).

The pH value of seawater typical of South Africa is in the range of 7.3 and 8.2 and that for freshwater is between 6 and 8 (DWAF, 1996b). A previous research by CSIR on the bay reported pH values within a close range of 7.50 and 8.30 which are higher than the results obtained in this research. PH values obtained showed slight implications of seasonal variability with winter samples seemingly lower than the other seasons. The average mean pH of sites 1, 3, 4, and 5 were almost of the same value, that is, within 6.75 and 6.87. These values are rather acidic for typical seawater samples which are normally more alkaline.

Under normal circumstance, the high inorganic carbon concentrations in seawater serves as a buffer thus resisting pH changes even upon introduction of acidic or alkaline substances (Hansen, 2002). This buffering ability is to the advantage of the resident organisms since they do not experience vast deviations in pH as compared to those organisms in the freshwater zones. PH fluctuations however, were rather high for seawater samples. Site 1 showed the set of values with the least fluctuations (Figure 4.4), ranging from 6.32 to 7.17 (Table 4.4). Sites 3, 4, and 5 showed high fluctuating pH values of between 6.01 – 7.28, 5.47 – 7.16 and 5.79 – 7.51 respectively. Such high variations imply that material being disposed into the bay from internal and external sources have high pH extremes, to the extent as to upset the buffering capability of seawater.

In general, mean pH value for site 2 (almost freshwater in nature) was within the DWAF target range for fresh water. (See table 4.4). The issue of concern though was the degree of fluctuation of values between sampling days. Site 2 pH results show the variations clearly (See figure 4.4). The average pH value for site 2 was 7.33 but pH values as low as 5.92 and as high as 8.21 from the average value were recorded on the 4th and 6th sampling times respectively, all during the winter season. The fluctuations are as a result of the discharge of waste and industrial effluent from the upper catchments of the Umbilo and Mhlatuzana rivers. The degree of deviation from background values can be used to determine the severity of the impact on the ecology. In addition, pH variations can cause acute and chronic effects on the physiology of aquatic organisms and also lead to breakdown in the ecological structure and function (Hansen, 2002). The differences in values between these sites on various sampling days can be attributed to localized activities like biological processes.

Fluctuation of pH values creates an unbearable environment for aquatic organisms especially the residents in the near-freshwater and less saline regions (Hansen, 2002). It also creates conditions for competition among members of an ecosystem, whereby undue advantage may be created for high pH tolerant or low pH tolerant species.

5.4 SALINITY

Salinity is influenced by factors such as tidal movements, evaporation, rainfall and freshwater inputs (Joyce and Viola, 2007). These factors account for the highly dynamic salinity levels that characterize estuaries. Knowledge of salinity levels helps to predict the distribution and welfare of aquatic life within a water body. Fish species are physiologically sensitive to salinity levels and sharp or gradual changes may be detrimental to their survival. The salinity regime of the east coast shoreline of South Africa which the bay falls within has salinity levels of 35ppt and above (DWAF, 1996a). Considering those of the south and west coasts which do not exceed 35ppt, the east salinity levels are relatively high. This is due to the almost all year round warm tropical weather in the east coast, which induces evaporation, thus making the sea water more concentrated.

As anticipated for estuarine environments, salinity levels varied widely within and between sites, with the seawater dominated sites recording higher levels than the freshwater dominated site (see figure 4.5). Winter levels are expected to be lower than summer, autumn and spring samples because the latter three seasons cause evaporation of water thereby creating concentration of salinity. This was not greatly reflected in the data obtained since no clear-cut temporal characterization can be identified from the results obtained. The salinities of site 3 and 4 on the first sampling day were unexpectedly low, (21.49ppt and 19.38ppt respectively) for seawater-dominated areas. These can be attributed to the fact that sampling was done after a heavy rainfall and storm water outlets had drained large volumes of rainfall runoff directly into those regions. Salinities of sites 1 and 5 were however not equally impacted by the rainfall event due to the presumed fewer (or absence of) storm water drainage outlets (See table 4.5). The presumption is made because, a technical survey of storm water outlets within the bay was not done during the research; although quite a number were observed in the vicinities of site 3 and 4. The outcomes of urbanization made the impact on salinity worse. Many square meters of pavement, structures and concrete works (driveways, shopping centre parking lots, rooftops, etc) has reduced seepage of rain into the soil during rainfall events, and rather increased surface runoff. Minimized concreting and paving in the upper catchment area would reduce the volume of runoff flowing into the bay thus reducing the impact that rainfall can have on salinity levels. The 0.12 record for salinity at sample site 1 on the 6th sampling occasion (Table 4.5) was unexpected; a logical explanation could be reading error of the sampling instrument. Site 3's low level recorded (21.06ppt) on the same day can also be either linked to reading error or to release of water into the bay by cleaning and repairs activities that occur at that point. The average mean of salinity at site 2 of 0.32ppt is within the DWAF target range for fresh water. Its low salinity gives empirical proof that at that point, interactions between freshwater and seawater is at a minimal. Continuous occurrences of fluctuations in salinity levels can aggravate problems related to ecosystems such as general growth deficiency and reduction in rate of reproduction in primary and secondary consumers, as well as changes in the ecdysis patterns of arthropods most especially, lobsters (DWAF, 1996a).

5.5 TOTAL DISSOLVED SALTS (TDS)

The strong correlation between TDS and salinity makes it somewhat possible to use one result in place of the other in situations where only one of them has been assessed, most especially when dealing with seawater (DWAF, 1996b). This is because salinity is almost like a measure of sodium chloride salt, a substance that seawater has a high content of. That is why data for seawater TDS patterns can neatly be superimposed on salinity levels (See figures 4.5 and 4.6) and as such liken the salinity discussions above to the TDS data obtained. This may be the reason why most researchers of seawater and estuarine bays do not include TDS as an indicator of water quality. In fact, the DWAF SAWQG for coastal marine waters does not discuss TDS nor include its target range (DWAF, 1996b). In addition, the freshwater target values that DWAF provides for TDS are designated for human consumption and not for ecosystems. The target range of TDS levels stipulated for safe human consumption is between 0 to 10g/L. Comparing the DWAF target ranges with the data from site two gives the impression that the water at site 2 with regards to TDS levels is safe for human consumption. Not much comparison could be done with the CSIR (2007) research results on the bay since TDS was not considered as a parameter in that research.

5.6 TURBIDITY

Although there are no available target ranges in the SAWQG for turbidity in terms of coastal marine water and freshwater ecosystems, the target range stipulated for domestic use (1 NTU) and for recreational purposes (3 NTU) (DWAF, 1996 f) are all below the data compiled, most especially for site 2 which is freshwater. The average turbidity values for sites 1, 3, 4 and 5 were 5.91 NTU, 5.88 NTU, 4.75 NTU and 5.82 NTU respectively, while that of site 2 was 9.01 NTU. These show the overall highly turbid status of the bay water. The chemical properties of the seawater dominated sites combine with specific ions and form coagulates thereby reducing the number of matter in suspension (DWAF, 1996b) and this accounts naturally for the lower turbidity values. On the whole, the overall average turbidity values of the seawater dominated sites were almost the same (See figure 4.6) and relatively high (i.e. within 5.82 and 5.91 NTU), except site 4 which registered a slightly lower value of 4.75 NTU (See table 4.6).

It has been earlier explained that seawater values are expected to be lower than freshwater values, site 2 would most probably have had the highest turbidity values, should even the salinities been the same at all pre-selected sites, based on its spatial location and human pressures that area receives. This assertion is based on the number of industries, waste water treatment plants and some farms which have links to site 2. Sources of high turbidity caused by humans include industrial waste raw sewage, and fertilizer waste (gypsum). Apart from sewage treatment discharge and industrial waste, there have been several reports of sewage flowing into the Umbilo and Umhlatuzana rivers (Carnie, 2008; Enviroadmin, 2008). Vegetation filters soil particles and particulate matter during rainfall, thus cleared vegetation within the catchment loosens up soil particles and increases turbidity especially during and after rainfall. This is the situation created due to the high urbanization and industrialization along the site. The highest turbidity value during sampling period for site 2; 21.53 NTU was recorded on the same day that the highest dissolved oxygen saturation was recorded. This correlation confirms the reasons given for the high dissolved oxygen incurred assertion earlier made, that the super saturation at site 2 could be linked firstly to river flow dynamics causing high turbulence and mixing and secondly to an increase in algae as a result of a rise in organic matter (turbidity), which are nutritive substrates for algae growth. The occurrence of either situation will increase turbidity as well.

High turbidity reduces light penetration which connotes low rate of photosynthesis by primary producers. This will in turn lower available dissolved oxygen, thereby creating dire consequences for secondary and tertiary producers. The suspended solids can also get clogged in the gills of fish during filter feeding and lead to suffocation and dead. According SAWQG of DWAF, turbidity values between 5-10 NTU have the probability of bearing disease carrying microorganisms on the suspended solids. The document also asserts that turbidity of 10 NTU and above has high risk of being infectious because of pathogenic microbes and toxic chemical bindings on the particulate matter.

5.7 NUTRIENTS

The nutrient analyzed was nitrogen in the forms of nitrates, ammonium and ammonia. Due to the complex nature of the chemical interactions that occur between the forms of nitrogen in solution and the other parameters like organic carbon, dissolved oxygen, pH and temperature, it is almost impossible to give straightforward interpretations to values obtained during monitoring.

5.7.1 Nitrate-N

According to the DWAF document on SAWQG, the average nitrate-N concentration along the east coast ranges between 38 and 47µg l^{-1} and, Durban's average is fixed at 47µg l^{-1}. These averages are comparatively low when considered alongside those of the south and west coast which are 81 µg l^{-1} and 280 +/- 56 µg l^{-1} (DWAF, 1996b). The data collated for nitrate-N did not show clear cut characteristics of temporal variations. The overall nitrate-N averages recorded were over and above the averages stipulated for the east coastal waters. This is a signal that the productivity within the bay is more than normally expected in waters in tropical zones. The set of results obtained for the first sampling day showed the highest nitrate-N values for sites 1, 3, 4 and 5. (See figure 4.8). As revealed earlier, the first sampling session was done after a heavy rainfall; and this could be the reason for the high concentrations recorded (Adams and Matsumoto, 2007). Influx of fresh water into the bay during rainfall carries high concentration of nutrients from the urbanized and industrialized upper catchments.

Much as expected, site 2 on each sampling during the entire sampling period gave the highest records of nutrients and gave the overall average of 75.55 mg/L (Table 4.8). Even the lowest nitrate-N value for site 2, 36.8 mg/L, was over and above the target range of 0.5 – 10 mg/L for fresh water. It is generally accepted that nitrate-N levels are relatively higher in freshwater than in seawater both with uncontaminated status. It was therefore not surprising that site 2 gave higher values of nitrate-N on all sampling occasions. However, because the values were extremely high, it is believed that human factors also contribute immensely. The presence of sessile and floating mat-like green algae characteristic within the area of site 2, gives physical proof of nutrient overload in the Mhlatuzana and Umbilo rivers. The nutrients originate from burst sewage treatment plant pipes, fertilizer runoff from the small isolated farms, and industrial effluent discharged into the rivers. Storm water drainage pipes which drain the densely polluted areas within the upper catchment also contribute a substantial amount of nutrients into the bay during heavy rainfall. Even when the sewage treatment plants are put into good shape, there would still be the problem of nutrient overload intermittently because no matter how well sewage is treated; there are always substantial amounts of nitrates in the effluent.

5.7.2 Ammonium-N

Ammonium-N concentrations were over and above target values, just as nitrate-N. The graphs (Figures 4.8 and 4.9) show that the portions of ammonium-N make up a far greater portion of total nitrogen in the samples collected than nitrate-N (See also figures 4.1.4 through to 4.17). Most marine phytoplankton prefer to utilize ammonium as a source of nutrient, since it requires less energy for metabolism than nitrates (Wheeler and Kokkinakis, cited in Li *et al*., 2005). High ammonium-N levels thus imply high fertility levels. It can also be speculated that there are not enough phytoplankton to utilize the abundant nutrients as a result of the low dissolved oxygen status identified. The low pH values also contribute to ammonium-N being far greater than the ammonia-N species of the total nitrogen content. At low pH, the equation $NH_3 + H_2O \leftrightarrow NH_4^+ + OH$, shifts more towards the right since ammonium ions are basic in nature (DWAF 1996 a). When pH rises towards alkaline, then more ammonia species will be formed in solution. Levels of ammonium were mostly higher in the near-seawater sites than at site 2 for the entire sampling period (Table 4.9).

The maximum ammonium value of 778.37 mg/L was recorded at site 4 on sampling session 5 (Table 4.9). The cause for this outrageous maximum value cannot be explained accurately or be traced to a specific activity that might occur within site 4. The value however corresponds with the overall lowest pH value for the entire sampling period, which was also recorded at site 4 on the 5^{th} sampling session as well as the lowest nitrate-N value ever recorded. This confirms the assertion made earlier that low pH creates conditions for higher ammonium levels, thus lowering nitrate-N and ammonia-N (Figure 4.14)

It was expected that site 1 and 5 would give similar results of nutrients because they are just about 250 meters apart (Figure 4.10) meanwhile the difference in values between the two on the first day of sampling were rather vast. Site one recorded 409.97mg/L while site 5 recorded 232.43, almost two times smaller. This unexpected variation cannot be accurately accounted for, although speculations can be made that an activity of some sort at the coal terminal had occurred to shoot the value up to such a high. During chemical breakdown of coal, ammonia is released (DWAF, 1996a) which in solution, dissociates into ammonium ions and un-ionized ammonia. The acidic nature at that point, 6.92, (see table 4.4) then gave room for more ammonium to be formed as opposing unionized ammonia.

It was only on the fourth sampling session that site 2 ammonium values exceeded those of the near-seawater sites. It is also the only time that ammonia value of site 2 was lower than the other sites (See figures 4.9 and 4.10). This trend further confirms that in water bodies, ammonium and ammonia which are all part of the total nitrogen in solution are inversely proportional. That is to say; the greater the ammonia content, the lesser the ammonium content and vice versa. Although ammonium is not as toxic to aquatic life as ammonia, exceeding levels are capable of creating rife conditions for eutrophication and its attendant problems (DWAF, 1996a).

5.7.3 Ammonia-N

There is empirical evidence that ammonia concentrations in seawater are about 5 times less than in freshwater, even at equal temperature and pH (DWAF, 1996b), this trend was observed in the data acquired (Figure 4.10) during the research except for the anomaly discussed in the preceding section. The target value of ammonia-N in the South African water quality documents for ecosystems in marine and coastal water bodies is 0.6 mg/L. The values for freshwater are as follows; target value is 0.007 mg/L, chronic effect value is 0.015mg/L and acute effect value is 0.1mg/L (DWAF, 1996a). Ammonia values captured for all sites were over and above the target values (See figure 4.10). Although it is not clearly visible, comparing the results of dissolved oxygen and ammonia-N (Figures 4.2 and 4.10), it appears that the lower the dissolved oxygen, the higher the ammonia-N values. This could be linked to the fact that at low dissolved oxygen or anoxic conditions, denitrifying bacteria breakdown existing organic matter anaerobically and release toxic ammonia as a result. Site 2 gave the overall highest mean average of 3.58 mg/L which was recorded on the sixth sampling day. The overall average ammonia of site two 2.06 mg/L, falls above the DWAF stipulated value for chronic effects. This means that chronic effects of ammonia levels like general growth deficiencies, eutrophication, and mortalities are being experienced at site 2. The higher pH values of site 2 could have influenced the higher levels of ammonia (Li *et al*., 2005) but that is not the only reason for such results. Other known causes of ammonia concentration increases are sewage discharge, industrial effluent and atmospheric discharge of gaseous ammonia which eventually get dissolved into water bodies (Wassman and Olli, 2004). Excessive use of fertilizers is also a cause because, commercial fertilizers have high contents of ammonia and ammonium salts and when the plants are not able to utilize all of these salts, they end up as leachates and flow downstream into water bodies. As established earlier, ammonia is highly toxic to aquatic life and is supposed to be kept at the barest minimum as much as possible (Newman *et al*., 2007)). High ammonia values can cause chronic effects such as pathological effects in fish organs, reduction in growth rate, retarded morphological development and higher percentages of unsuccessful hatching (DWAF, 1996a). Acute impacts of ammonia concentration can cause respiratory problems and lead to death. Aquatic fauna are more susceptible to ammonia toxicity than aquatic fauna. Nutrient contents, in all the nitrogen forms analyzed give proof of the fact that the bay is heavily burdened with nutrients.

5.8 CHLORIDE

Analysis of chloride ions is much more relevant and critical when studying freshwater for domestic purposes than it is for embayments and marine environments. Chloride value analyses for marine waters are quite insignificant since the ecosystems within the waters are already accustomed to living in high chloride concentration environments. As such, the SAWQG gives TWQV for domestic use and there are yet no target values available for ecosystems in marine, freshwater, and estuarine environments. According to the DWAF document on freshwater for domestic use, chloride range from 0 to 600 mg/L are potable (DWAF, 1996c). Records of chloride concentration for site 2 (See Table 4.11) confirm the not-potable state of the water with regards to chloride ions. Although chloride levels at the moment cannot be used to quantify the degree of impact on aquatic ecosystems it is worth noting that the highly soluble nature of chloride and its ability to accumulate in solution, has the potential of posing a threat to the normal physiological functioning of ecosystems living in freshwater portions that influent into the bay. According to the DWAF water quality guide, chloride concentrations are approximately 19,800 mg/L for typical sea waters (DWAF 1996b). Comparing this with the mean chloride results for sites 1, 3, 4 and 5 (Table 4.11) indicates that freshwater from the rivers have some impact on the embayment, no matter how small.

5.9 CONDUCTIVITY AND SPECIFIC CONDUCTIVITY

Specific conductivity is a more favoured choice for discussing electrical conductivity than conductivity. This is due to the temperature specific (25^0C) attribute of specific conductivity. In place of TDS and salinity, specific conductivity can be used to assess the amount of dissolved salts in solution. Neither conductivity nor specific conductivity however gives a hint of breakdown of the concentration of individual salts, e.g., carbonates, bicarbonates, chlorides and nitrates in solution. Due to the high ionic contents of water in sites 1, 3, 4 and 5, their average conductivity levels (37.11, 43.35, 43.76 and 52.20 mS/cm) were equally high compared with site 2, with an average of 0.54 mS/cm (See table 4.12 and figure 4.12). High TDS and salinity values gave high conductivities (Figures 4.6 and 4.5) The DWAF water quality standards documents gives no target range for conductivity and specific conductivity for ecosystems occurring both in freshwater and coastal marine waters. Just as discussed for the previous parameter (chloride), conductivity and specific conductivity values are of more concern in analyzing water for domestic use than they are for aquatic ecosystems.

5.1.1 CONCLUSION

Although a substantive number of indicators have not yet been assigned with target values and others are quite ambiguous, thus making discussions and comparisons with baseline values a rather arduous task, an overall outlook of the data acquired proves that the water quality within the bay needs to be tackled with more concern, especially, for the ecosystems which make their living in and around the bay. The results obtained for the basic indicators of water quality, dissolved oxygen contents and nutrient contents, all gave cause for concern.

On the whole, dissolved oxygen levels fell outside the DWAF target values. Factors like routine dredging within the bay, nutrient overload from sewage treatment plants, factory effluents and disproportionate discharge of freshwater volumes facilitate the outcomes of dissolved oxygen. Concerning the sporadic instances of super-saturation, the main factor is the release of treated sewage effluent upstream.

For typical seawater pH, values in the range of 6.75 – 6.87 are rather high for sites 1, 3, 4 and 5. Terminal operations at some nodes (e.g. Coal terminal and ship maintenance) contribute to the characteristic high pH values. Nutrient overload via human activities also contribute to such effect.

Nutrient values obtained were highly variable, ranging from too high through to extremely low. The greatest contributors to the out-of-target-range nutrient values are sewage disposal, in the form of treated effluent discharge or raw sewage, accidentally discharged or leaked into the bay waters. Routine dredging to rid the bay of excess sand also cause upsets in both settled nutrients and in the composition of the species of varying trophic levels.

Clearly, anthropogenic influences in the forms of the harbor and industrial operations as well as recreational activities have contributed greatly to the poor water quality data obtained.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The aim of this research was to evaluate the impacts that various socioeconomic activities have on the water quality standards that are appropriate for the survival of ecosystems within the bay. The main water quality indicators analyzed during the research were temperature, dissolved oxygen, pH, salinity, total dissolved salts (TDS), turbidity, nitrate-N, ammonium-N, ammonia-N, chloride and conductivity. The conclusions made in this chapter were based on the researcher's observations, samples taken, data obtained, and analysis of data, interpretations and discussions presented in previous chapters.

6.2 Key Findings

6.2.1 Socioeconomic Activities

Regarding the aim to identify some specific anthropogenic activities occurring within the bay, the following observations were made. The Durban bay is positioned in the midst of diverse socioeconomic activities, the major one being the Durban harbour with 24hour operations occurring at many terminals like the coal terminal, car terminal, sugar terminal and container terminal, and an oil and petroleum complex which is directly connected to oil refineries by pipes. The bay also houses all the three main marinas for yachting purposes namely the Royal Natal Yacht Club, Wilson's wharf and the Bluff Yacht Club. All the yacht clubs have facilities such as restaurants, bars, lounges, toilets and libraries. Further inland, towards the freshwater side of the bay are other economic endeavours like factories whose main connection with the bay is the releasing of their effluent into the rivers influent into the bay.

6.2.2 Water quality data Obtained and Their Effects on Ecosystems

The interdependence relationships between water quality indicators are very strong. The indicators observed were connected to one another and a rise in one implied a rise or a decrease in another. Nutrient contents for example influenced dissolved and turbidity levels and vice versa while salinity and the conductivity measures were also similar. The fact that the periodic influx of fresh seawater from the bay entrance into the bay could not completely buffer or overshadow hypoxic conditions is proof that the effects of dredging activities for example are severe and long-lived (Patel and Holtzhausen, 2008 and Pithakpol, 2007).

Temperature results on all sampling occasions were within the expected values for the survival of most ecosystem species dwelling in tropical water bodies. Temperatures on the average were lower during winter than in summer, as expected. One winter collection gave summerlike values due to the occurrence of striking summer-like weather during winter season, typical of Durban weather pattern.

The dissolved oxygen values, both of concentration (mg/L) and saturation levels (%) and including turbidity values mostly fell outside DWAF's target ranges for ecosystems stability, in terms of species growth and reproduction rate and survival at large. The sampling sites had overall averages below 50% dissolved oxygen levels with the exception of site 1. Dissolved oxygen levels corresponded with high turbidity, and all the nitrogen forms measured. The main activity that upset dissolved oxygen is the dredging activities as a result of the ongoing harbor (bay) entrance widening project during the period of research. Dissolved oxygen values at site 2 swayed between supersaturated levels and hypoxic levels because of the intermittent inputs of organic matter, which is in fact a representation of high turbidity. The bulk of the organic matter could have originated from sewage treatment effluent and industrial effluent all present in the upper catchment of the bay. Sporadic releases from these sources created eutrophic conditions which lead to low dissolved oxygen contents. The boats and yachts which dock at sites 3 and 4 minimized the flow of flushing water at these areas, thereby reducing the ability of oxygen to dissolve.

On the whole, the pH values recorded within the bay were too acidic for values for expected seawater values. The fluctuating values were the outcome of the biological and chemical actions as a result of anthropogenically aided inorganic influx.

Salinity, TDS, conductivity and specific conductivity were observed to be directly proportional to one another since they all are indirect or direct measurements of ionic contents in different forms. The salinity values obtained between the sites were greatly variable, as it is expected of estuarine environments. Values at sites 3 and 4 were on some occasions much lower than expected due to the influx of high volumes of rainfall runoff via storm water drainage outfalls after rains. The salinity values correlated with TDS and conductivities measured on all occasions during the sampling period with high salinity also giving high TDS and high conductivities. Site 2 with the least amount of seawater intrusion recorded the lowest salinity, TDS and conductivity averages. The overall average of site 2 TDS values were within the DWAF target range.

DWAF does not yet have target turbidity ranges for aquatic systems, however, the turbidity values obtained can be said to be relatively high on most occasions, most especially at site 2. These results are attributed to the highly urbanized catchment area of the bay, the factories and sewage treatment effluent.

The data acquired for nutrient content within the bay were very dynamic, ranging from very low to very high and to moderate. This was also attributed to the diversity of socio-economic activities scattered throughout the bay. The highest ammonium-N level recorded for the entire sampling period was at site 1 (Coal terminal). The specific reason for this outcome could not be identified although it was suspected that probably a certain activity or process during operations at the coal terminal could have increased ammonium-N contents on that day.

6.2.3 Water Quality Effects on Ecosystems

Dissolved oxygen is one of the most critical water quality indicators for ecosystem survival. When it is not readily available it can lead to significant alterations in the species composition within a water body thereby collapsing the integrity and resilience of species within the ecosystem. This parameter is being critically affected by numerous activities within the bay. Under such circumstances, the species that cannot tolerate low dissolved oxygen move to more favourable conditions and the anoxic loving ones thrive for a while after which, the water body becomes classified as dead due to the absence of aquatic life. This explains why aquatic life within the area of site 2 is almost non-existent. On all the days of sampling, only tadpoles and threads and mats of green algae were found in the water with no visible signs of any fish species observed.

Due to the marine water dominant nature of the bay, the resident ecosystems are more adapted to saline marine conditions. Dilution of salinity through stormwater outfalls and effluent from ship repairs and cleaning exercises are detrimental to the normal physiological functions. Conditions of low available nutrients are scattered all over the bay and are greatly influenced by the activities occurring within the surroundings. Despite the tidal influence with its ability to flush the water within the bay and reduce eutrophication effects, persistent episodic eutrophication within the bay can stress some species and lead to their migration. The effects of water quality on ecosystems can be summarized as follows; respiratory and feeding problems, reduction in general growth and development, perturbation in reproduction cycles, and ultimately, death.

6.3 Conclusion

Activities within the bay and its catchment are diverse; from terminal operations to ship repairs, industrial and recreational endeavors. These activities and processes, initiated by humans, to a large extent are responsible for high non-standard outcomes. These occurrences were striking enough to cause the distortions observed in the expected temporal variations of the parameters analyzed. Summarizing the outcome of this research, the researcher concludes that socio-economic activities indeed have depreciating degrees of impact on the water quality standards which are favorable for estuarine ecosystems. The resultant chemical and physical conditions created due to these ongoing activities within the bay are not suitable for proper feeding, growth and reproduction of species within the ecosystems (Pithakpol, 2007, Paul and Meyer, 2008, and Smart, 2008). This has caused many species within the bay to migrate; this situation is likely to worsen if stringent measures are not taken in the near future.

6.4 RECOMMENDATIONS

Based on the knowledge and experience gained in the conducting of this research, the following recommendations are made:

More voluntary programs and community based monitoring programs for the bay need to be launched to create general awareness of the significance and prestige of the bay as well as give understanding of the implications of water quality degradation within the bay not only on the resident ecosystems, but also on the booming socioeconomic activities established on the bedrock of the bay’s resources.

Further research need to be done with the help of GIS and remote sensing technology to identify and map out the exact locations of the various socioeconomic activities within the bay’s catchment.

After tracing the exact sources of pollution into the bay, control programs must be developed to mitigate their impacts and where possible, eradicate them completely.

The bay is very unique with regards to its geomorphology, flow dynamics and physiological resilience, therefore, literature that will assist in predicting the responses of ecosystems to changes in water quality parameters; most especially, response to nutrient dynamics need to be compiled through several other researches in the same direction. The link between eutrophication and its effects on marine ecosystem and estuarine bays at large and specific to the Durban bay need to be understood and if possible, quantified in order to assist estuarine managers and policy makers in their decision makers.

Succeeding research should include the hydrological dynamics within the bay and their ability to thin out or lesson the incoming pollution effects on the water quality.

REFERENCES

Able, K.W., 2005: A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats, *Estuarine, Coastal and Shelf Science*, 64, 5-17.

Adams, J. and McGwynne, L., 2004: Protocols Contributing to the management of estuaries in South Africa, with a particular emphasis on the Eastern Cape province, Volume II, Report E, *A Monitoring Protocol for South African Estuaries*.

Adams, L.G. and Matsumoto, G.I., 2007: Investigating coastal processes and nitrate levels in the elkhorn slough using real-time data *Oceanography,* 20, (1), 200-204.

Anderson, G., 2003: Marine ecosystems, www.marinebio.net.

Andersen, J., SchluTer, L., and Ærtebjerg, G., 2006: Coastal Eutrophication: Recent developments in definitions and implications for monitoring strategies, *Journal Of Plankton Research*, 28, (7) 621–628.

Aubry, A., and Elliott, M., 2006: The use of environmental integrative indicators to assess seabed disturbance in estuaries and coasts: Application to the Humber Estuary, UK, *Marine Pollution Bulletin*, 53, 175–185.

Baird, R.C., 2005: On sustainability, estuaries, and ecosystem restoration: the art of the practical, *Restoration Ecology*, vol. 13, (1) 154–158.

Bailey, T., 2000: Durban Metro: Deep sea sewage outfalls, *WISA 2000 conference, Sun City, South Africa, 28 May-1 June 2000*.

Bansal, P., 2002: The corporate challenges of sustainable development, Academy of Management Executive, 2002, Vol. 16, No. 2, 122-131.

Bartone, S., 2005: Estuarine indicators, Proceedings of the *Estuarine Indicators Workshop*, CRC Press, Boca Raton, FL.

Basnyat, P., Teeter, L.D., Flynn, K.M., Lockaby, G., 1999: Relationships between landscape characteristics and nonpoint source pollution inputs to coastal estuaries, *Environmental Management* Vol. 23, No. 4, 539–549

Beck, M.W., Heck Jr., K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B.S., Hays, C.G., Hoshino, K., Minello, T.J., Orth, T.J., Sheridan, P.F., Weinstein, M.P., 2003: The role of near shore ecosystems as fish and shellfish nurseries; Issues in ecology, *Ecological Society of America*, 11, 1-12.

Beckley, L.E., Fennessy, S.T., and Everett, B.I., 2008: Few fish but many fishers: a case study of shore-based recreational angling in a major South African estuarine port, *African Journal of Marine Science*, 30(1): 11–24.

Berry, P.F. 1971: The spiny lobsters of the east coast of southern Africa, distribution and ecological notes, *oceanographic research institute*, 27.

Bishop, M. J., Sean P. Powers, S.P., Porter, H.J., Charles H. Peterson, C.H., 2006: Benthic biological effects of seasonal hypoxia in a eutrophic estuary, predate rapid coastal development, Estuarine, Coastal and Shelf Science 70, 415-422.

Breetzke, T., Celliers L., and Moore, L., 2009: From white paper to national coastal management programme and beyond, *SSI Engineers and Environmental Consultants*, Durban.

Breitburg, D., 2002: Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries, *Estuaries*, 25, (4), 767-781.

Bowen, R.E. Riley, C., 2003: Socio-economic indicators and integrated coastal management, *Ocean & Coastal Management* 46, 299–312.

Cameron, W. M. and Pritchard, D. W., 1963: Estuaries, in Hill, M. N. (Ed.), *The Sea*, Wiley Interscience, New York, 2, 306 – 324.

Carnie, T., 2008: Durban Sewage killed fish, says CSIR's report http://www.ioi.co.za.

Chilli, N. S., 2008: *A study of the environmental impacts (natural and anthropogenic) on the estuaries of KwaZulu Natal, South Africa: Implications for management*, Ph.D. thesis, Durban: University of KwaZulu Natal.

Chris, C., Bricker, S.B. and Pirhalla, D.E., 2001: Eutrophic conditions in estuarine waters, In: NOAA's State of the Coast Report. Silver Spring, MD: National Oceanic and Atmospheric Administration. URL: http://state-of coast.noaa.gov/bulletins/html/eut.html. Accessed on 8th December, 2009.

Common Ground, 2004: *Draft synthesis of specialist findings for incorporation into environmental impact assessment report;* Proposed small craft harbour development: Durban point precinct, EIA reference no.: 4451.

Cooper, J.A.G., 1991: *Sedimentary Models and Geomorphological Classification of River Mouths on a Subtropical, Wave-Dominated Coast, Natal, South Africa*, Ph.D. thesis, University of Natal, Durban.

Cooper J.A.G., Ramm, A.E.L., Harrison, T.D., 1994: The estuarine health index: a new approach to scientific information transfer, *Ocean and Coastal Management*, 25:103–41.

Cooper, S.R., McGlothlin, S.K., Madritch, M., and Jones, D.L., 2004: Paleoecological evidence of human impacts on the Neuse and Pamlico Estuaries of North Carolina, USA, *Estuaries*, 27, 617–633.

Costanza, R., d'Arge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., Oneil, R.V., Paruelo, J., Raskin, R., Sutton, P., vandenBelt, M., 1997: The value of the world's ecosystem services and natural capital, *Nature*, 387, 253–260.

Courrat, A., Lobry, J., Nicolas, D., Laffargue, P., Amara, R., Lepage, M., Girardin, M., Le Pape, O., 2009: Anthropogenic disturbance on nursery function of estuarine areas for marine species, *Estuarine, Coastal and Shelf Science*, 81, 179–190.

Custodio, D., Von., 2009: Examples of how to describe a river basin, *CRBOM, small publications*, series No. 13, Central Java, I*ndonesia*.

Damassa, T., 2006: The value of coastal ecosystems, *Earthtrends; World Resource Institute*, accessible online at www.earthtrends.wri.org.

Davies-Coleman and Cook, B.A., 2000: The status of the genetic and biochemical analysis of marine organisms in south Africa, In: Summary Marine Biodiversity Status Report for South Africa, Durham, B.D. & Pauw, J.C. (eds). National Research Foundation, Pretoria.

Day, J. H., 1980: What is an estuary? *South African Journal of Science*, 76: 198.

Day, J. H. (ed.) 1981. Estuarine ecology, with particular reference to southern Africa. AA Balkema, Cape Town, 411.

Day, J. W., Hall, C. A. S., Kemp, W. M. & Yanez-Aranciba, A., 1989: *Estuarine Ecology*. John Wiley, New York.

De Jonge, V.N., Elliott, M., 2002: Causes, historical development, effects and future challenges of a common environmental problem: eutrophication, *Hydrobiologia*, 475/476, 1–19.

Department of Environmental Affairs and Tourism (DEAT), 2005, State of the environment, Climate change, www.soer.deat.gov.za.

Department of Environmental Affairs and Tourism, 2001: South African estuaries land cover; Durban bay catchment.

Department of Environmental Affairs and Tourism (DEAT) (2000): *White Paper for Sustainable Coastal Development in South Africa*, *Coastal Management Policy Programme*, Pretoria.

Department of Water Affairs and Forestry (DWAF), 1996 (a): *South African Water Quality Guidelines,* Vol 7 *Aquatic Ecosystems*, Pretoria.

DWAF, 1996 (b): South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment. Pretoria, South Africa.

Dictionary of Environmental Sciences and Engineering, 2008, 2nd Edition, Routledge.

De Wolf, H. U., Backeljaua, T., Blust, R., 2000: Heavy metal accumulation in the periwinkle *Littorina littorea,* along a pollution gradient in the Scheldt estuary, *The Science of the Total Environment*, 262, 111 – 121.

Durban government, 2007: Biodiversity Report, Durban, 2007. www.durban.gov.za.

Durham, B.D. & Pauw, J.C. (eds). In: Summary Marine Biodiversity Status Report for South Africa, National Research Foundation, Pretoria.

Ecological Society of America, (Undated): Hypoxia, www.esa.org, *accessed on 11th December, 2009*.

Edgar, G.J., Barrett, N.S., Graddon, D.J., 1999: A classification of Tasmanian estuaries and assessment of their conservation significance using ecological and physical attributes, population and land use, *Tasmanian Aquaculture and Fisheries Institute*, Technical Series report 2, 205pp.

Elliott, M., and Quintino, V., 2007: The Estuarine Quality Paradox, Environmental Homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas, *Marine Pollution Bulletin*, 54, 640–645.

Elliot, M and McLusky, D.S., 2002: The need for definitions in understanding estuaries, Estuarine, *Coastal and Shelf Science*, 55, 815-827.

Enviroadmin, 2008: http://www.buanews.gov.za, *accessed on 16th December, 2009*.

eThekwini Municipality (Environmental Management Department), 2008: Sustainability Best Practice Portfolio Special edition, *Water 2007/08* for the eThekwini Municipality.

eThekwini Municipality, 2009: Durban estuaries, Environmental Management Department.

Evans, G.W. and English, K., (2002): The environment of poverty: Multiple stressor exposure, psychophysiological stress, and socio-emotional adjustment. *Child Development*, 73(4), 1238-1248.

Fuel Firing Systems (FFS) 2000: http://www.ffs-refiners.com.

Fialho, A.P., Oliveira, L.G., Tejerina-Garro, F.L., de Merona, B., 2008: Fish-habitat relationship in a tropical river under anthropogenic influences, *Hydrobiologia*, 598:315–324.

Forbes, A.T., Demetriades, N.T., and Cyprus, D.P., 1996: Biological significance of harbours as coastal habitats in KwaZulu-Natal, South Africa, *Aquatic conservation: marine and freshwater ecosystems*, Vol. 6. 331 - 341.

Forbes, A. T. and Demetriades, N. T., 2008: Estuaries of Durban; Report for the Environmental Management Department, eThekwini municipality.

Foster, E., Haward, M., Coffen-Smout, S., 2005: Implementing integrated oceans management: Australia's south east regional marine plan (SERMP) and Canada's eastern Scotian shelf integrated management (ESSIM) initiative, *Marine Policy* 29, 391–405.

Fox, S. and Bourne, S., 2008: Analytical Framework for Coastal and Estuarine Study.

Freeman, A.M., 2003: Economic evaluation, what and why? In *A Primer on Non-market Valuation*, edited by Champ, P.A., Boyle, K.J. and Brown, T.C., Dordrecht: Kluwer Academic Publishers, chapter 1 pg 8.

Garden, S.E., and Garland, G.G., 2005: Spit development in the Mdloti River estuary, KwaZulu-Natal, *South African journal of ecology*, l, 257-270.

Gibb, 2004: Environmental Impact Assessment for the Widening and Deepening of the Port of Durban Entrance Channel, final scoping report; National Port Authority (Port of Durban).

Glavovic, B.C., 2006: The evolution of coastal management in South Africa: Why blood is thicker than water, *Ocean & Coastal Management* 49, 889–904.

Grime J.P., (1989): The stress debate: symptom of impending synthesis? *Biol J Linn Soc*; 37:3-17.

Hale, S.S., Paul, J.F., and Heltshe, J.F., 2004: Watershed landscape indicators of estuarine benthic condition, *Estuaries*, 27, 283– 295.

Hansen, P.J., 2002: Effect of high pH on the growth and survival of marine phytoplankton: implications for species succession, *Aquatic Microbial Ecology*, 28, 279–288, 2002.

Harris, S.A. and Cyrus, D.P., 2000: Comparison of laval fish Assemblages in 3 large estuarine systems, KwaZulu Natal, South Africa, Marine Biology, 137: 527-541.

Harrison, T.D., Cooper, J.A.G., Ramm, A.E.L., 2000. State of South African estuaries. Geomorphology, Ichthyofauna, water quality and aesthetics. Department of Environmental Affairs and Tourism. State of the Environment Series Report 2, 1-127.

Harding, W.R., Archibald, C.G.M. and Taylor, J.C., 2005: The relevance of diatoms for water quality assessment in South Africa, A position paper, *Water SA*, 31, (1), 41-46.

Hill, N. E. T., and Maharaj, B., 2003: "Durban's pursuit of economic development in the post-apartheid era", *Urban Forum*, 14(2-3): 223-243.

Hindmarch, J.A., Griffiths, A.L., Officer A.K., and Wittneben, G., 2008: Durban Harbour tunnel—first use of a slurry tunnel boring machine in South Africa, *The Journal of The Southern African Institute of Mining and Metallurgy* VOLUME 108 1-8.

Hofmann, A. F., Middelburg, J.J., Soetaert, K., and Meysman, F.J.R., 2009.: PH modeling in aquatic systems with time-variable acid-base dissociation constants applied to the turbid, tidal Scheldt estuary. *Biogeosciences*, 6, 1539–1561.

Hosking, S.G., Wooldridge, T.H., Dimopoulos. G., Mlangeni, M., Lin, C-H., Sale, M., and Du Preez, M., 2004: The valuation of changes to estuary services in South Africa as a result of changes to freshwater inflow; Report to the Water Research Commission, WRC report no: 1304/1/04.

Hounslow, A.W., 1995: *Water Quality Data: Analysis and Interpretation*, Boca Raton Lewis Publishers.

Hume, T.M., Snelder, T., Weatherhead, M., Liefting, R., 2007: A controlling factor approach to estuary classification, *Ocean & Coastal Management*, 50, 905–929.

Hutson, T., 2003: The port that needs to expand, Ports and Shops, Oct 26, 2006.

Hutson, T., 2007 (a): Harbour project; a massive boost for KZN, *The Mercury*, May 2007.

Hutson, T., 2007 (b): The changing face of Durban Bay, Ports and Ships Jan 31, 2007.

IEC, 2009: Electoral Commission of South Africa, 2009 elections report.

Johnson, A.M., 2004: *Estuary use planning and the application of terrestrial zoning principles in an estuarine system: A case study of the Guana Tolomato Matanzas National Estuarine Research Reserve*, Ph.D. thesis, University of Florida.

Joyce, C. and Viola, T., 2008: *Monitoring estuarine water quality*, National Oceanic and atmospheric, Administration.

Jones, K.S., 1970: Some thoughts on classification for retrieval, *Journal of Documentation* 1970; 26:89–101.

Kennish, M. J., (editor) 2001: Barnegat Bay–Little Egg harbor, New Jersey: estuary and watershed assessment, *Journal of Coastal Research Special*, 32:1–280.

Kennish, M.J., Bricker, S.B., Dennison, W.C., Gilbert, P.M., Livingston, R.J., Moore, K.A., Noble, R.T., Paerl, H.W., Ramstack, J.M., Seitzinger, S., Tomasko, D.A. and Valiela, V., 2007: Barnegat bay–little egg harbor estuary: case study of a highly eutrophic coastal bay system, *Ecological Applications*, 17(5) 3–16.

Kjerfve, B., 1994: Coastal lagoon processes, *Elsevier Oceanography Series*, 60, Elsevier Science Publishers.

Lamberth, S.J. and Turpie, J.K., 2003: *The role of estuaries in South African fisheries: Economic importance and management implication,* Water Research Commission Report, No. 756/2/03.

LeMarie, M., Van der Zaag, P., Menting, G., Baquete, E., Schotanus, D., 2006: The use of remote sensing for monitoring environmental indicators: The case of the Incomati estuary, Mozambique, *Physics and Chemistry of the Earth*, 31 (2006) 857–863.

Li, Q. P., Zang, J-Z., Millero, F.J., Hansell, D.A., 2005: Continuous colorimetric determination of trace ammonium in seawater with a long-path liquid waveguide capillary cell, Marine Chemistry 96, 73– 85

Li, J., Li, L., Zheng, L., Xian, Y., Jin, Z., 2006: Determination of chemical oxygen demand values by a photocatalytic oxidation method using nano-TiO2 film on quartz, *Talanta*, 68, 765–770.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H. and Jackson, J.B.C.,: 2006: Depletion, degradation, and recovery potential of estuaries and coastal seas, *Science* 312:1,806–1,809.

Maltby, l., 1999: Organism-level responses, *Ecological Applications*, 9(2), 431–440.

Mardon, D. W., and Stretch, D. D., 2002: The effects of wind speed, direction and duration on crosscurrents at the port of Durban entrance, 1st International Conference on Heat Transfer, Fluid Mechanics, and Thermodynamics; 8-10 April 2002, Kruger Park, South Africa.

McComb, A. J. (Ed), 1995: Introduction, *Eutrophic shallow estuaries and lagoons*, CRC press.

McKenzie, M., 2005: Estuary management instruments: *A report to Centre for Environment and Development*, *University of KwaZulu-Natal*.

McGwynne, L. and McKenzie, M., 2006: Policies and procedures for incorporating information and knowledge on estuaries into the IDP and related processes are established through collaboration between researchers and authorities at local, district and provincial levels, *Water Research Commission Report*, July 2006.

Meire, P., Ysebaert, T., Van Damme, S., Van den Bergh, E., Tom Maris, T., and Struyf, E., 2005: The Scheldt estuary: A description of a changing ecosystem, *Hydrobiologia*, 540:1–11.

Meyer, J., Mulholland, P. J., Paerl, H. W., Ward, A. K., 2009: A Framework for Research Addressing the Role of Ammonia/Ammonium in the Sacramento-San Joaquin Delta and the San Francisco Bay Estuary Ecosystem, Submitted to: *The CALFED Science Program*.

Michaud, J.P. 1991: A Citizens' Guide to Understanding and Monitoring Lakes and – Streams, *Washington State Department of Ecology*.

Mitchell, S., 2005: Managing sedimentary processes in South African estuaries: A guide, *Water Research Commission*, WRC Report No. TT 241/04.

Morris, R., 2004: Concepts of recreational planning with reference to the Duiwenhoks estuary, southern cape, Pr Sci Nat. 2004.

Mouillot, D., Spatharis, S., Reizopoulou, S., Laugier, T., Sabetta, L., Basset, A., DoChi, T., 2006: Alternatives to taxonomic-based approaches to assess changes in transitional water communities. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16, 469–482.

Murphy, S., 2007: General information on Alkalinity, City of Boulder, Boulder Area Sustainable Information Network (BASIN) http://water.usgs.gov/nawqa/circ-1136.html. Assessed on the 11th December 2009.

NASA, 2010: Amateur scientists guide to water quality monitoring observations, www.disc.sci.gsfc.nasa.gov, accessed on 3rd March, 2010.

Newman, B., Weerts, S., Porter, S., Mackay, F., 2007: Specialist Studies for Transnet Capital Expansion Programme; Port of Durban, Prepared for *Transnet Projects*.

Nixon, S. W. 1995. Coastal marine eutrophication: a definition social causes, and future concerns, *Ophellia*, 41, 199-219.

Nomquphu, W., 2005: Overview of the Situation and Challenges for Water Quality Monitoring and Reporting in South Africa: Report for the *Department of Water Affairs and Forestry*, Pretoria, South Africa, Work Session on Water Statistics, Vienna , 20-22 June 2005.

NPA, 2009: http://ports.co.za/durban-harbour.php, *accessed on 5th December, 2010*.

O'Connor, M., 2006: The ''Four Spheres'' framework for sustainability, Ecological Complexity 3, 2 85 – 2 9 2.

Odum, E.P., 1985: Trends expected in stressed ecosystems, *Bioscience*, 35, 419–422.

Ohimain E.I., Imoobe, T. O., and. Bawo, D.D.S., 2008: Changes in water physico-chemical properties following the dredging of an oil well access canal in the Niger Delta, *World Journal of Agricultural Sciences* 4 (6): 752-758.

Ohrel, R.L. and Register, K.M., 2006: Voluntary Estuary Monitoring Manual, (2nd Ed) Chapter 9: Dissolved Oxygen and Biochemical Oxygen Demand, USEPA.

Olsen, S. B., Padma, T. V., and Richter, B.D., (2006): Managing freshwater inflows to estuaries: a methods guide, The Nature Conservancy USAID. Pennsylvania Avenue.

Parish, B., 2006: From poles to wholes: Facilitating an integrated approach to sustainable entrepreneurship, World review of entrepreneurship, management and sustainable development, 2, 4, 281-294.

Patel, S., and Anton Holtzhausen, A., 2008: The design of Durban harbour's new entrance channel, *Civil Engineering, Vol 16, No. 5*.

Patel, S. and Holtzausen, A., 2009: The design of Durban harbor's new entrance channel, *Port and harbor engineering*, IMESA, July, 2009.

Paul, M.J., and Meyer, J.L., 2008: Streams in the urban Landscape, Urban Ecology, Section 3, 207-231,

Paulay, G., Kirkendale, L., Lambert, G., Meyer, C., 2002: Anthropogenic biotic interchange in a coral reef ecosystem: A case study from Guam, *Pacific Science*, 11, 403-423.

Perillo, G.M.E., 1995: *Definitions and geomorphologic classifications of estuaries in geomorphology and sedimentology of estuaries,* Edited by Perillo, Elsevier Science.

Perillo, G.M.E. 1989: New geodynamic definition of estuaries; Review, *Geofisica*, 31:281-287.

Petrosillo, I., Valente, D., Zaccarelli, N., Zurlini, G., 2009: Managing tourist harbors: Are managers aware of the real environmental risks? *Marine Pollution Bulletin*, 58, 1454–1461.

Pinckney, J. L., Hans W. P., Tester, P., and Richardson, T.L., 2001: The role of nutrient loading and eutrophication in estuarine ecology, *Environmental health perspectives*, Vol 109, supplement 5, October, 2 001**.**

Pithakpol, S., 2007: The impact of maintenance dredging on water quality and phytoplankton standing stock in Kwan Phayao lake, Thailand, *School of Agriculture, Natural Resources and Environment*, *Naresuan University*, *Phayao Campus*, *Phayao* 56000, *Thailand*.

Ports and Ships, 2007: Big Success for Durban Bay Cleanup, May 21st 2007, www.port.co.za, *accessed 15th January, 2010*.

Ports & Ships Maritime News, 2007: Support for Operation Cleanup at Durban Bay May 8, 2007, www.port.co.za, *accessed 15th January*, *2010*.

Ports and Ships, 2003: To dig a new port, or not – that is the question.

Pradervand, P., Beckley, L.E., Mann, B. Q., Radebe, P.V., 2003: Assessment of the line fishery in two urban estuarine systems in KwaZulu-Natal, South Africa, *African journal of marine science*, Vol. 25 (1), 111-130.

Pritchard, D. W., 1952: Salinity distribution and circulation in the Chesapeake Bay estuarine system, *Journal of Marine Research*, 11, 106-123.

Rajkaran, A. and Adams, J., 2006: Current population structure of mangroves from Mlalazi to Mtamvuna estuaries in KwaZulu Natal, South Africa, *Department of Botany*, *Nelson Mandela Metropolitan University*, Port Elizabeth.

Rees, J.G., Setiapermana, D., Sharp, V.A., Weeks, J.M., Williams, T.M., 1999: Evaluation of the impacts of land-based contaminants on the benthic faunas of Jakarta Bay, Indonesia, *Oceanologica Acta*, 22 (6), 627–640.

Republic of South Africa (2008). *National Environmental Management: Integrated CoastalManagement Act.* Cape Town: Government Printer, pp. 64Restrepo, J.D., 2008: Applicability of LOICZ catchment-coast continuum in a major Caribbean basin: the Magdalena River, Colombia, *Estuarine, Coastal and Shelf Science*, 77 (2), 214-229.

Robinson, J., 2001: Economic value of Australia’s estuaries; a scoping study, *CRC for coastal zone estuary and waterway management*.

Roessig, J.M., Woodley, C.M., Cech, J.J., Hansen, L.J., 2005: Effects of global climate change on marine and estuarine fishes and fisheries, World Wide Fund for Nature, Gland, Switzerland.

Rosas, C., Martinez, *E.*, Gaxiola, G., Brito, R., Sanchez, A., Soto, L.A., 1999: The effect of dissolved oxygen and salinity on oxygen consumption, ammonia excretion and osmotic pressure of *Penaeus setiferus* (Linnaeus) juveniles, Journal of Experimental Marine Biology and Ecology, 234, 41-57.

Savides, M. M, 2007: Harbour pollution sparks fears for species, *The Mercury*, page 3; December 28, 2007.

SAWS, 2010: Climate Data for Durban". South African Weather Service. http://old.weathersa.co.za/Climat/Climstats/DurbanStats.jsp. Retrieved 6 March 2010.

Simon, M., Cabezas, O., Garcia, I., and Martinez, P., 1994: A new method for the estimation of total dissolved salts in saturation extracts of soils from electrical conductivity, *European Journal of Soil Science*, 45 (2) ,153 - 157.

Smart, K.A., Smart, H. L., and Jackson, C.R., 2008: The effects of fine scale environmental variation on microbial community structure and function in aquatic environments, In: *Environmental Microbiology Research Trends* Ed: George V. Kurladze, pp. 167-190, Nova Science Publishers, Inc.

Smith, L. M., Whithouse, S. and Oviatt, C.A., 2010: Impacts of climate change on Narragansett bay, *Northeastern Naturalist* 17(1):77-90.

Strom, T-E., and Klaveness, D., 2003: Hunnebotn: a seawater basin transformed by natural and anthropogenic processes. *Estuarine, Coastal and Shelf Science* 56, 11, 77–1185.

Subramanian, V., 2002: *A textbook in Environmental Science*, Narosa Publishing House: CRC Press, New Delhi.

Tanner-Tremaine, V. 2007: Yealm estuary environmental management plan, Action Programme, 2007- 2012, www.southdevonaonb.org.uk.

The Star, 2008: Durban streams run red with pollution, 18 February 2008 www.thestar.co.za.

The Mercury, 2008: Bad whiff about fish kill reports, *6 March 2008.*

Trade and Investment, KwaZulu Natal: www.tikzn.co.za, *accessed 26th January, 2010.*

Turpie, J. k., 2004(a): Current Status of Estuaries, their Protection and Threats to their Biodiversity, Proposed Goals for Conservation and Guidelines for a Strategy for the Protection of Estuarine Biodiversity: A report for Water research Commision by the Institute of Natural Resources.

Turpie. J.K., 2004(b): South African National Spatial Biodiversity Assessment 2004: Technical Report, Volume 3: Estuarine Component, *South African National Biodiversity Institute, Pretoria*.

Turpie, J.K., 2007: Birds of the Berg River estuary and their relationship to freshwater inflow. *Unpublished report to DWAF*; *Anchor Environmental Consultants*.

Turpie, J.K., Sihlophe, N., Carter, A., Maswime, T., and Hosking, S., 2006: Maximising the socio-economic benefits of estuaries through integrated planning and management: a rationale and protocol for incorporating and enhancing estuary values in planning and management, *Anchor Environmental Consultants*, for *Water Research Commission*.

Turpie, J.K., Adams, JB., Joubert, A., Harrison, T.D., Colloty, BM., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. and Van Niekerk, L., 2002: Assessment of the conservation priority status of South African estuaries for use in management and water allocation, *Water SA*, 28, 2.

UNEP, 2001: Disposal of waste from land, *UN Atlas of the Oceans*, UNEP – GPA.

UNEP, 2006: Challenges to International Waters – Regional Assessments in a Global Perspective, United Nations Environment Programme, Nairobi, Kenya.

Van Coller, J., Maasdorp, G., Mavundla, K., 2007: Durban Maritime Industry, A Value-Chain Analysis.

Van der Meij, S.E.T., Moolenbeek, R.G., Hoeksema, B.W., 2009: Decline of the Jakarta Bay molluscan fauna linked to human impact, *Marine Pollution Bulletin*, 59 (2009) 101–107.

Van Niekerk, L. V. (2007): *A framework for regional estuarine management: A South African case study*, published MSc, University of Stellenbosch.

Van Niekerk, L., Taljaard, S., Schonegevel, L. 2006: Introductory course to estuarine management in South Africa, Training Course Manual, *Water Research Commission Report No. 1485/1/07*.

Van Niekerk, L. and Taljaard, S., *2003*: A framework for effective cooperative governance of South African estuaries, *CSIR report, ENV-S-C 2003-077.*

Vasconcelos, R.P., Reis-Santos, P., Fonseca, V., Maia, A., Ruano, M., França, S., Vinagre, C., Costa, M.J., Cabral, A., 200: Assessing anthropogenic pressures on estuarine fish nurseries along the Portuguese coast: A multi-metric index and conceptual approach.

Wannamaker, C.M. and Rice, J.A., 2000: Effects of hypoxia on movements and behavior of selected estuarine organisms from the southeastern United States, *Journal of Experimental Marine Biology and Ecology*, 249, 145–163.

Wassman, P. and Olli, K., 2004: Drainage basin nutrient and eutrophication: An integrated approach, *Norwegian College of Fishery Sciences, University of Trosmo*, Norway.

Watson, J.M., 2008: Coastal change, http://pubs.usgs.gov/circ/c1075/change.html, *accessed on 14th December, 2009.*

Weilgart, L.S. (ND) The impact of ocean noise pollution on marine biodiversity, *Department of Biology Dalhousie University Halifax*, Nova Scotia Canada.

Whitfield, A.K., 1998: Biology and ecology of fishes in southern African estuaries, *Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology* 2, 1-223.

Whitfield, A.K. 1992: A characterization of southern African estuarine systems. *South African Journal of Aquatic Science*, 12 89-103.

Whitefield, A. K., Elliot, M., 2004: Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future, *Journal of Fish Biology* (2002) 61, 229–250.

Whitefield, A.K. and Elliot, M., 2005: Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future, *Journal of Fish Biology*, 61, 229-250.

Widdows, J., Donkina, P., Staffa, F.J., Matthiessen, P., Law, R.J., Allen, Y.T., Thain, J.E., Allchin, C.R., and Jones, B.R., 2002: Measurement of stress effects (scope for growth and contaminant levels in mussels (Mytilusedulis) collected from the Irish Sea, *Marine Environmental Research* 53, 327–356.

Wilkinson, M., Wood, P., Wells, E., Scanlan, C., 2007: Using attached macroalgae to assess ecological status of British estuaries for the Water Framework Directive, *Marine Pollution Bulletin*, 55, 136–150.

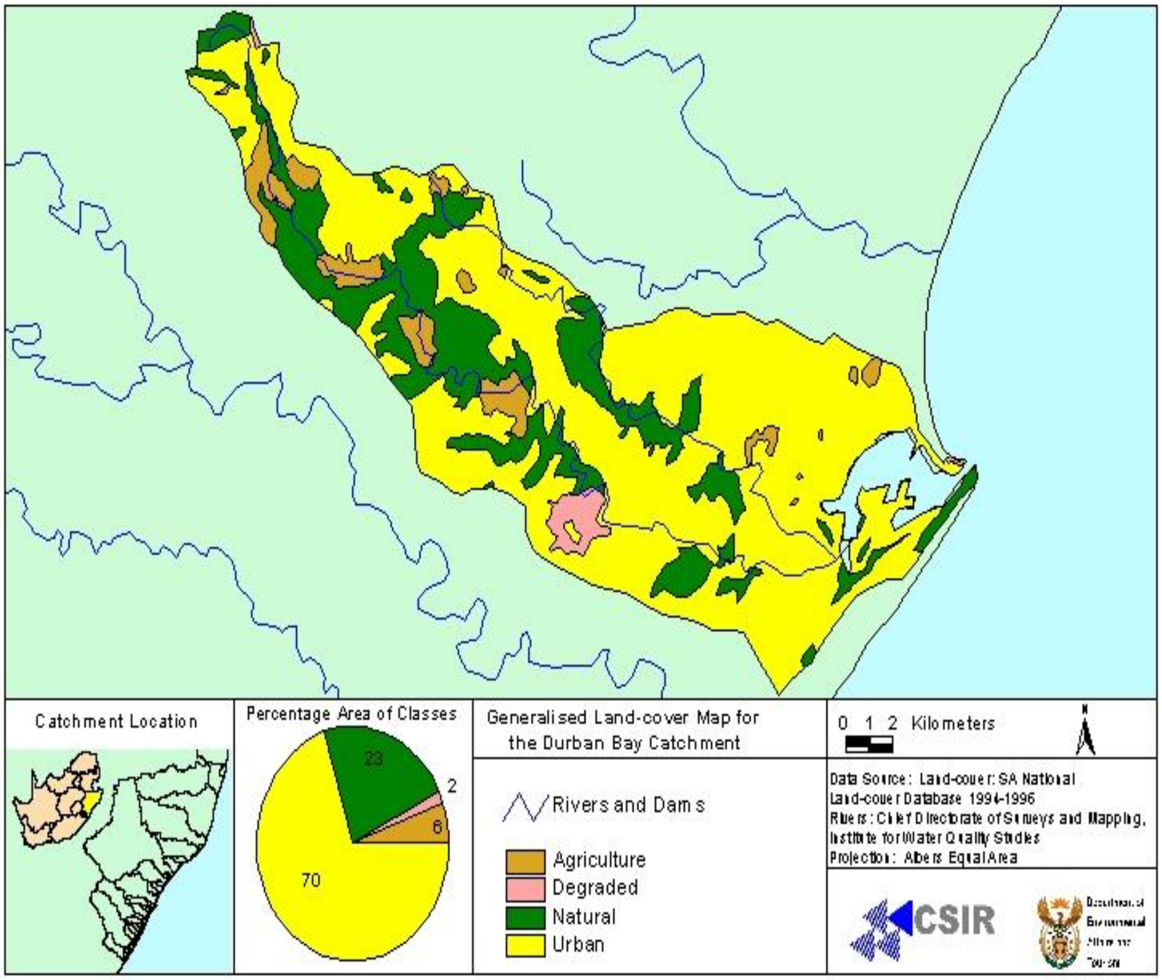
Willard, D. A., Cronin, T. M., (2007): Paleecology and ecosystem restoration: case studies from Chesapeake Bay and the Florida Everglades, *Frontiers in Ecology and the Environment*: Vol. 5, No. 9, 491-498.

Williams, W.D., 1966: Conductivity and the concentration of total dissolved solids in Australian lakes, *Australian Journal of Marine and Freshwater Research*, 17(2) 169 - 176

Wilson, M.A., Costanza, R., Boumans, R., and Liu, S., 2002: Integrated Assessment and Valuation of Ecosystem Goods and Services provided by Coastal Systems *Proceedings of the Royal Irish Academy* 2002, Dublin, Ireland.

World Health Organization (WHO), 2003: Total dissolved solids in drinking-water; Background document for development of WHO *Guidelines for Drinking-water Quality* WHO/SDE/WSH/03.04/16.

APPENDIX I



Map of the the Durban bay catchment area

APPENDIX II

SITE 1 SAMPLING DAY ONE

Date	Temp	SpCond	Cond	TDS	Salinity	DO%	DO Conc	pH	AmmoniumN	AmmoniaN	NitrateN	Chloride	Turbidity
M/D/Y	C	mS/cm	mS/cm	g/L	ppt	%	mg/L		mg/L	mg/L	mg/L	mg/L	NTU
4/30/2009 12:14	18.96	49.241	43.564	32.007	32.25	18.8	1.44	6.91	411.95	1.05	20.5	9328.25	4.2
4/30/2009 12:14	18.96	49.243	43.563	32.008	32.25	18.5	1.41	6.92	410.78	1.08	20.64	9310.25	4.2
4/30/2009 12:14	18.96	49.242	43.563	32.007	32.25	18.5	1.41	6.92	411.71	1.08	20.61	9299	4.2
4/30/2009 12:14	18.96	49.242	43.563	32.007	32.25	18.4	1.41	6.92	410.84	1.08	20.67	9326.5	4.2
4/30/2009 12:14	18.96	49.24	43.562	32.006	32.25	18.4	1.41	6.92	409.34	1.09	20.72	9346.5	4.2
4/30/2009 12:14	18.96	49.242	43.563	32.007	32.25	18.4	1.41	6.92	410.63	1.09	20.65	9306.75	4.2
4/30/2009 12:14	18.96	49.242	43.563	32.008	32.25	18.4	1.41	6.92	411.27	1.09	20.63	9294.5	4.2
4/30/2009 12:14	18.96	49.242	43.563	32.008	32.25	18.4	1.41	6.92	409.96	1.09	20.7	9320.5	4.2
4/30/2009 12:14	18.96	49.243	43.563	32.008	32.25	18.4	1.41	6.93	408.08	1.09	20.77	9339.25	4.2
4/30/2009 12:14	18.96	49.243	43.563	32.008	32.25	18.4	1.41	6.93	409.23	1.09	20.68	9296.5	4.2
4/30/2009 12:14	18.96	49.245	43.563	32.009	32.26	18.4	1.41	6.93	409.98	1.09	20.67	9283.25	4.2
4/30/2009 12:14	18.96	49.243	43.563	32.008	32.25	18.3	1.4	6.93	408.97	1.1	20.72	9307.25	4.2
4/30/2009 12:14	18.96	49.243	43.563	32.008	32.25	18.3	1.4	6.93	407.59	1.1	20.77	9328	4.2
4/30/2009 12:14	18.96	49.244	43.563	32.009	32.26	18.3	1.4	6.93	408.98	1.1	20.68	9284.75	4.2
4/30/2009 12:14	18.96	49.244	43.563	32.009	32.26	18.3	1.4	6.93	410.3	1.1	20.65	9271	4.2
MEAN	18.96	49.24	43.56	32.01	32.25	18.41	1.41	6.92	409.97	1.09	20.67	9309.48	4.20

APPENDIX II

SITE 1 SAMPLING DAY TWO

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/12/2009 12:00	19.31	62.861	56.03	40.86	42.45	49.5	3.55	6.92	172.83	0.44	15.91	7107.25	7.9
6/12/2009 12:00	19.3	62.856	56.015	40.856	42.45	49.5	3.55	6.92	172.89	0.45	15.95	7123.88	7.9
6/12/2009 12:00	19.3	62.856	56.014	40.857	42.45	49.5	3.55	6.92	172.35	0.45	16.01	7146	7.9
6/12/2009 12:00	19.3	62.855	56.012	40.856	42.45	49.4	3.54	6.93	172.11	0.45	16.05	7160.63	7.9
6/12/2009 12:00	19.3	62.853	56.009	40.855	42.45	49.4	3.54	6.93	172.56	0.45	15.98	7129.63	7.9
6/12/2009 12:00	19.3	62.852	56.007	40.854	42.44	49.4	3.54	6.93	173.02	0.45	15.98	7133.5	7.9
6/12/2009 12:00	19.3	62.85	56.005	40.853	42.44	49.4	3.54	6.93	172.45	0.45	16.04	7155.75	7.9
6/12/2009 12:00	19.3	62.85	56.004	40.853	42.44	49.4	3.54	6.93	172.06	0.45	16.07	7172.88	7.9
6/12/2009 12:00	19.3	62.848	56.001	40.851	42.44	49.4	3.54	6.93	172.27	0.45	16.01	7144.25	7.9
6/12/2009 12:00	19.3	62.846	55.999	40.85	42.44	49.4	3.54	6.93	172.6	0.45	16.01	7146.13	7.9
6/12/2009 12:00	19.29	62.842	55.992	40.847	42.44	49.4	3.54	6.93	172.73	0.45	16.03	7153.25	7.9
6/12/2009 12:00	19.29	62.841	55.99	40.847	42.44	49.4	3.54	6.93	172.17	0.45	16.08	7175.88	7.9
MEAN	19.30	62.85	56.00	40.85	42.44	49.42	3.54	6.93	172.41	0.45	16.02	7150.10	7.90

APPENDIX II

SITE ONE SAMPLING DAY THREE

Date M/D/Y	**Temp C**	**SpCond mS/cm**	**Cond mS/cm**	**TDS g/L**	**Salinity ppt**	**DO% %**	**DO Conc mg/L**	**pH**	**AmmoniumN mg/L**	**AmmoniaN mg/L**	**NitrateN mg/L**	Chloride mg/L	Turbidity NTU
6/30/2009	16.86	33.779	28.527	21.956	21.24	89.6	7.64	7.16	214.01	0.88	11.4	6358.38	5
6/30/2009	16.86	33.778	28.525	21.956	21.24	89.5	7.63	7.16	213.96	0.89	11.43	6353	5
6/30/2009	16.86	33.778	28.525	21.956	21.24	89.5	7.63	7.16	213.32	0.89	11.47	6372.88	5
6/30/2009	16.86	33.778	28.524	21.956	21.24	89.3	7.62	7.17	212.46	0.89	11.52	6393.88	5
6/30/2009	16.86	33.776	28.522	21.954	21.24	89.3	7.62	7.16	214.02	0.89	11.43	6343.25	5
6/30/2009	16.86	33.777	28.523	21.955	21.24	89.3	7.62	7.17	213.86	0.89	11.45	6347.38	5
6/30/2009	16.86	33.776	28.522	21.955	21.24	89.3	7.62	7.17	213.36	0.9	11.49	6362.38	5
6/30/2009	16.86	33.776	28.522	21.955	21.24	89.2	7.61	7.17	212.73	0.9	11.53	6383.63	5
6/30/2009	16.85	33.775	28.521	21.954	21.24	89.2	7.61	7.17	213.97	0.9	11.45	6333	5
6/30/2009	16.85	33.775	28.521	21.954	21.24	89.2	7.61	7.17	213.55	0.9	11.47	6337.25	5
6/30/2009	16.85	33.777	28.521	21.955	21.24	89.2	7.61	7.17	212.84	0.9	11.51	6355.63	5
6/30/2009	16.85	33.776	28.52	21.955	21.24	89.1	7.6	7.17	212.22	0.9	11.55	6375.25	5
6/30/2009	16.85	33.775	28.519	21.954	21.24	89.1	7.6	7.17	213.86	0.9	11.47	6326.13	5
6/30/2009	16.85	33.776	28.519	21.954	21.24	89.1	7.6	7.17	213.55	0.9	11.49	6330.13	5
6/30/2009	16.85	33.776	28.519	21.954	21.24	89.1	7.6	7.17	212.84	0.9	11.53	6347.38	5
MEAN	16.86	33.78	28.52	21.95	21.24	89.27	7.61	7.17	213.37	0.90	11.48	6354.64	5

APPENDIX II

SITE 1 SAMPLING DAY FOUR

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/15/2009 10:44	14.98	65.283	52.788	42.434	44.21	19	1.46	6.91	213.63	0.39	15.03	6265	5.6
7/15/2009 10:45	14.97	65.304	52.795	42.448	44.23	19.1	1.47	6.93	211.89	0.4	15.1	6275.38	5.4
7/15/2009 10:45	14.97	65.306	52.795	42.449	44.23	19.1	1.47	6.93	211.48	0.4	15.13	6283.13	5.4
7/15/2009 10:45	14.97	65.306	52.795	42.449	44.23	19.1	1.47	6.93	211.2	0.4	15.16	6294.63	5.4
7/15/2009 10:45	14.97	65.307	52.796	42.449	44.23	19.1	1.47	6.93	210.65	0.4	15.15	6290.88	5.4
7/15/2009 10:45	14.97	65.308	52.796	42.45	44.23	19.1	1.47	6.93	211.48	0.4	15.12	6278.88	5.4
7/15/2009 10:45	14.97	65.309	52.797	42.451	44.23	19.1	1.47	6.93	211.06	0.4	15.15	6289.5	5.4
7/15/2009 10:45	14.97	65.311	52.797	42.452	44.23	19.1	1.47	6.94	210.73	0.4	15.18	6301.75	5.4
7/15/2009 10:45	14.97	65.312	52.798	42.453	44.23	19.1	1.47	6.94	210.26	0.4	15.19	6296.88	5.4
7/15/2009 10:45	14.97	65.313	52.798	42.454	44.23	19.1	1.47	6.94	211.06	0.4	15.15	6285.63	5.4
7/15/2009 10:45	14.97	65.313	52.798	42.454	44.23	19.1	1.47	6.94	210.67	0.4	15.19	6295.5	5.4
7/15/2009 10:45	14.97	65.315	52.799	42.455	44.24	19.1	1.47	6.94	210.4	0.4	15.22	6305.75	5.4
7/15/2009 10:45	14.97	65.316	52.799	42.455	44.24	19.1	1.47	6.94	209.93	0.4	15.22	6302	5.4
7/15/2009 10:45	14.97	65.317	52.8	42.456	44.24	19.1	1.47	6.94	210.93	0.4	15.19	6288	5.4
7/15/2009 10:45	14.97	65.316	52.799	42.455	44.24	19.1	1.47	6.94	210.63	0.41	15.21	6296	5.4
MEAN	14.97	65.31	52.80	42.45	44.23	19.09	1.47	6.93	211.07	0.40	15.16	6289.93	5.41

APPENDIX II

SITE ONE SAMPLING DAY FIVE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/29/2009	15.27	42.691	34.758	27.749	27.49	98.9	8.38	6.27	247.84	0.11	14.24	6330.13	8.7
7/29/2009	15.27	42.649	34.721	27.722	27.46	98.7	8.36	6.3	244.84	0.12	14.16	6362.63	8.7
7/29/2009	15.26	42.699	34.759	27.754	27.49	98.6	8.35	6.31	242.52	0.12	14.19	6407.25	8.7
7/29/2009	15.26	42.706	34.764	27.759	27.5	98.6	8.35	6.32	241.91	0.12	14.13	6375.63	8.7
7/29/2009	15.26	42.714	34.771	27.764	27.51	98.6	8.35	6.32	242.71	0.12	14.13	6386.13	8.3
7/29/2009	15.26	42.709	34.766	27.761	27.5	98.6	8.35	6.32	242.85	0.12	14.15	6402	8.3
7/29/2009	15.26	42.692	34.752	27.75	27.49	98.5	8.35	6.32	242.77	0.13	14.18	6422.38	8.3
7/29/2009	15.26	42.695	34.754	27.752	27.49	98.5	8.35	6.33	242.2	0.13	14.11	6389.88	8.1
7/29/2009	15.26	42.75	34.799	27.788	27.53	98.5	8.35	6.33	242.79	0.13	14.11	6396.75	8.1
7/29/2009	15.26	42.745	34.795	27.784	27.53	98.5	8.35	6.33	242.93	0.13	14.14	6412.13	8
7/29/2009	15.26	42.756	34.803	27.791	27.54	98.4	8.34	6.33	242.98	0.13	14.17	6430.63	8
7/29/2009	15.26	42.751	34.799	27.788	27.53	98.4	8.34	6.33	242.32	0.13	14.11	6398.25	7.9
7/29/2009	15.26	42.756	34.803	27.791	27.54	98.4	8.34	6.34	243.06	0.13	14.11	6408.88	7.9
7/29/2009	15.26	42.765	34.81	27.797	27.54	98.4	8.34	6.34	243.14	0.13	14.14	6427.13	7.9
7/29/2009	15.26	42.772	34.815	27.802	27.55	98.4	8.33	6.34	242.79	0.13	14.18	6448.88	7.8
MEAN	15.26	42.72	34.78	27.77	27.51	98.53	8.35	6.32	243.18	0.13	14.15	6399.91	8.23

APPENDIX II

SITE ONE SAMPLING SIX

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
10/2/2009	16.01	0.263	0.218	0.171	0.13	59.7	5.89	7.18	72.37	0.33	13.98	5596.25	4.6
10/2/2009	16.01	0.262	0.217	0.17	0.13	59.7	5.89	7.17	73.68	0.33	13.77	5503.75	4.6
10/2/2009	16.01	0.262	0.217	0.171	0.13	59.7	5.89	7.17	73.71	0.33	13.74	5485.13	4.6
10/2/2009	16.01	0.262	0.217	0.17	0.13	59.7	5.89	7.17	74.59	0.33	13.64	5441.63	4.6
10/2/2009	16.01	0.262	0.217	0.17	0.12	59.7	5.89	7.17	74.13	0.33	13.69	5458.25	4.6
10/2/2009	16.01	0.261	0.217	0.17	0.12	59.7	5.89	7.17	74.01	0.33	13.71	5467	4.6
10/2/2009	16.01	0.262	0.217	0.17	0.13	59.7	5.89	7.17	74.04	0.33	13.68	5449.5	4.5
10/2/2009	16.01	0.262	0.217	0.17	0.12	59.7	5.89	7.17	74.93	0.33	13.58	5414.63	4.5
10/2/2009	16.01	0.261	0.216	0.17	0.12	59.7	5.89	7.17	74.5	0.33	13.64	5434.5	4.5
10/2/2009	16	0.261	0.216	0.17	0.12	59.8	5.9	7.17	74.36	0.33	13.67	5449.38	4.5
10/2/2009	16	0.262	0.217	0.17	0.12	59.8	5.9	7.17	74.36	0.33	13.65	5435.63	4.5
10/2/2009	16	0.261	0.216	0.17	0.12	59.8	5.9	7.17	75.18	0.33	13.56	5397.88	4.5
10/2/2009	16	0.261	0.216	0.17	0.12	59.8	5.9	7.17	74.7	0.33	13.62	5419.13	4.5
10/2/2009	16	0.261	0.216	0.169	0.12	59.9	5.9	7.17	74.51	0.33	13.65	5431.63	4.5
10/2/2009	16	0.261	0.216	0.17	0.12	59.9	5.9	7.17	74.47	0.33	13.63	5418.5	4.5
MEAN	16.01	0.26	0.22	0.17	0.12	59.75	5.89	7.17	74.24	0.33	13.68	5453.52	4.54

APPENDIX II

SITE TWO SAMPLING DAY TWO

DateTime M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/12/2009	18.53	0.594	0.52	0.386	0.29	254.1	23.75	7.62	184.72	2.8	61.05	1149.03	21.6
6/12/2009	18.52	0.594	0.521	0.386	0.29	253.5	23.7	7.62	183.13	2.76	61.65	1156.13	21.6
6/12/2009	18.52	0.594	0.521	0.386	0.29	253.5	23.71	7.62	183.07	2.76	61.79	1158.38	21.6
6/12/2009	18.52	0.595	0.521	0.386	0.29	252.9	23.66	7.62	181.78	2.75	62.18	1165.19	21.6
6/12/2009	18.51	0.594	0.521	0.386	0.29	252.9	23.66	7.62	184.98	2.74	61.23	1149.25	21.5
6/12/2009	18.51	0.595	0.521	0.386	0.29	253	23.66	7.62	182.99	2.73	61.71	1156.25	21.5
6/12/2009	18.51	0.595	0.521	0.386	0.29	253	23.66	7.62	182.84	2.73	61.87	1158.56	21.5
6/12/2009	18.51	0.595	0.521	0.387	0.29	252.4	23.61	7.62	181.49	2.72	62.27	1165.19	21.5
6/12/2009	18.51	0.595	0.521	0.387	0.29	252.4	23.61	7.61	184.68	2.71	61.31	1149.5	21.5
6/12/2009	18.5	0.594	0.521	0.386	0.29	252.4	23.61	7.62	182.8	2.71	61.79	1156.59	21.5
6/12/2009	18.5	0.595	0.521	0.387	0.29	252.4	23.62	7.61	182.77	2.7	61.92	1158.75	21.5
6/12/2009	18.5	0.595	0.521	0.387	0.29	251.8	23.56	7.62	181.36	2.7	62.32	1165.41	21.5
6/12/2009	18.5	0.595	0.521	0.387	0.29	251.8	23.56	7.61	184.42	2.69	61.35	1149.53	21.5
6/12/2009	18.49	0.595	0.521	0.387	0.29	251.8	23.56	7.61	182.46	2.68	61.83	1156.41	21.5
6/12/2009	18.49	0.595	0.521	0.387	0.29	251.8	23.57	7.61	182.29	2.67	61.98	1158.81	21.5
MEAN	18.51	0.59	0.52	0.39	0.29	252.65	23.63	7.62	183.05	2.72	61.75	1156.87	21.53

APPENDIX II

SITE TWO SAMPLING DAY THREE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/30/2009	13.73	0.931	0.73	0.605	0.46	70.2	7.26	7.87	155.03	2.86	68.35	1432.75	8.1
6/30/2009	13.74	0.917	0.72	0.596	0.45	70	7.23	7.83	162.66	2.76	65.55	1361.34	6.8
6/30/2009	13.74	0.914	0.718	0.594	0.45	69.9	7.22	7.83	163.23	2.74	65.38	1356.19	6.8
6/30/2009	13.74	0.912	0.716	0.593	0.45	69.9	7.22	7.82	165.91	2.73	64.48	1336.59	6.8
6/30/2009	13.75	0.91	0.714	0.591	0.45	69.9	7.22	7.81	165.76	2.71	64.48	1333.91	6.7
6/30/2009	13.75	0.907	0.712	0.59	0.45	69.9	7.22	7.81	166.56	2.69	64.36	1328.81	6.7
6/30/2009	13.75	0.905	0.71	0.588	0.45	69.8	7.21	7.81	166.68	2.68	64.39	1326.56	6.8
6/30/2009	13.76	0.903	0.709	0.587	0.45	69.8	7.21	7.8	169.08	2.67	63.63	1310.44	6.8
6/30/2009	13.76	0.9	0.707	0.585	0.45	69.8	7.21	7.8	168.57	2.65	63.75	1310.16	6.8
6/30/2009	13.76	0.898	0.705	0.584	0.44	69.8	7.21	7.79	168.97	2.64	63.75	1307.31	6.8
6/30/2009	13.76	0.896	0.703	0.582	0.44	69.8	7.21	7.79	168.88	2.62	63.81	1307.34	6.8
6/30/2009	13.77	0.894	0.702	0.581	0.44	69.8	7.21	7.78	171.03	2.61	63.12	1292.78	6.7
6/30/2009	13.77	0.892	0.7	0.58	0.44	69.8	7.21	7.78	170.3	2.59	63.31	1294.28	6.7
6/30/2009	13.77	0.889	0.699	0.578	0.44	69.8	7.21	7.78	170.46	2.58	63.36	1293.06	6.7
6/30/2009	13.77	0.887	0.697	0.577	0.44	69.8	7.21	7.78	170.21	2.57	63.5	1294.34	6.6
MEAN	13.75	0.90	0.71	0.59	0.45	69.87	7.22	7.81	166.89	2.67	64.35	1325.72	6.84

APENDIX II

SITE TWO SAMPLING DAY FOUR

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/15/2009	14.94	0.619	0.5	0.402	0.3	20.3	2.05	5.92	408.33	0.09	90.7	169.89	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	407.45	0.09	90.84	170.36	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	408.76	0.09	90.56	169.8	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	409.89	0.09	90.34	169.42	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	409.27	0.09	90.57	169.76	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	407.72	0.09	90.88	170.33	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	408.89	0.09	90.57	169.78	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	410.06	0.09	90.37	169.41	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	409.43	0.09	90.54	169.82	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	407.77	0.09	90.85	170.32	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	408.9	0.09	90.55	169.77	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	409.98	0.09	90.34	169.45	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	409.21	0.09	90.5	169.85	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	407.61	0.09	90.78	170.39	7.5
7/15/2009	14.93	0.619	0.5	0.402	0.3	20.3	2.05	5.92	408.61	0.09	90.5	169.79	7.5
MEAN	14.93	0.62	0.50	0.40	0.30	20.30	2.05	5.92	408.79	0.09	90.59	169.88	7.50

APPENDIX II

SITE TWO SAMPLING DAY FIVE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/29/2009	15.24	0.709	0.577	0.461	0.35	122.9	12.3	6.65	201.45	0.26	87.75	1126.78	6.4
7/29/2009	15.24	0.71	0.578	0.462	0.35	123	12.32	6.66	202	0.26	88.15	1130	6.4
7/29/2009	15.24	0.711	0.578	0.462	0.35	123.1	12.32	6.66	202.44	0.26	88.03	1124.34	6.5
7/29/2009	15.24	0.711	0.578	0.462	0.35	123	12.32	6.66	201.45	0.26	88.42	1128.31	6.5
7/29/2009	15.24	0.711	0.578	0.462	0.35	123	12.32	6.65	210.73	0.27	87.42	1115.94	6.4
7/29/2009	15.24	0.71	0.578	0.462	0.35	123	12.32	6.65	395.01	0.49	87.63	1120.44	6.5
7/29/2009	15.24	0.71	0.578	0.461	0.35	123	12.32	6.65	299	0.38	87.8	1122.16	6.5
7/29/2009	15.24	0.71	0.578	0.461	0.35	123.1	12.33	6.65	160.15	0.2	88.38	1127.06	6.5
7/29/2009	15.24	0.711	0.578	0.462	0.35	123.1	12.33	6.67	196.17	0.26	87.35	1114.72	6.5
7/29/2009	15.24	0.71	0.578	0.462	0.35	123.1	12.33	6.67	186	0.24	87.8	1118.88	6.5
7/29/2009	15.24	0.71	0.578	0.461	0.35	123.1	12.33	6.67	199.22	0.26	88	1120.72	6.5
7/29/2009	15.25	0.71	0.577	0.461	0.35	123.2	12.33	6.66	198.54	0.26	88.43	1124.84	6.5
7/29/2009	15.25	0.711	0.578	0.462	0.35	123.2	12.33	6.66	204.28	0.26	87.46	1112.84	6.5
7/29/2009	15.25	0.71	0.578	0.462	0.35	123.2	12.33	6.66	202.65	0.26	87.89	1117.38	6.5
7/29/2009	15.25	0.71	0.578	0.461	0.35	123.2	12.33	6.66	202.76	0.26	88.11	1119.59	6.5
MEAN	15.24	0.71	0.58	0.46	0.35	123.08	12.32	6.66	217.46	0.28	87.91	1121.60	6.48

APPENDIX II

SITE TWO SAMPLING DAY SIX

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
10/2/2009	15.26	0.55	0.447	0.357	0.27	97.3	9.74	8.23	76.28	3.62	111.57	1209.22	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.5	9.76	8.22	77.65	3.6	111.57	1190	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.7	9.78	8.22	77.34	3.59	112.23	1193.66	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.7	9.78	8.21	78.57	3.59	110.96	1179.22	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.7	9.78	8.21	78.23	3.59	111.55	1181.44	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.7	9.78	8.21	78.33	3.58	111.8	1181.53	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.8	9.8	8.21	78	3.58	112.45	1185.34	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.8	9.8	8.2	79.22	3.58	111.18	1171.63	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.8	9.8	8.21	78.89	3.57	111.72	1173.72	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	97.8	9.8	8.21	78.99	3.57	112.02	1173.84	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	98	9.82	8.21	78.63	3.57	112.67	1177.59	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	98	9.82	8.2	79.87	3.57	111.42	1163.81	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	98	9.82	8.2	79.5	3.56	111.96	1165.97	4.8
10/2/2009	15.26	0.538	0.438	0.35	0.26	98	9.82	8.2	79.56	3.56	112.16	1166.03	4.9
10/2/2009	15.26	0.538	0.438	0.35	0.26	98.3	9.84	8.2	79.21	3.57	112.78	1169.66	4.9
MEAN	15.26	0.54	0.44	0.35	0.26	97.81	9.80	8.21	78.55	3.58	111.87	1178.84	4.81

APPENDIX II

SITE THREE SAMPLING DAY ONE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
4/30/2009	18.89	34.157	30.171	22.202	21.5	34.8	2.85	7.29	230.28	1.49	24.85	11857.75	5.6
4/30/2009	18.88	34.144	30.153	22.193	21.49	34.9	2.86	7.29	229.98	1.48	24.94	11884.25	5.6
4/30/2009	18.88	34.143	30.151	22.193	21.49	34.9	2.86	7.29	230.09	1.48	24.99	11897.25	5.6
4/30/2009	18.88	34.141	30.149	22.192	21.49	35	2.86	7.29	229.92	1.47	24.94	11863.25	5.6
4/30/2009	18.88	34.14	30.148	22.191	21.49	35	2.86	7.29	230.45	1.47	24.96	11867.25	5.6
4/30/2009	18.88	34.139	30.146	22.19	21.49	35	2.86	7.28	230.54	1.47	24.98	11883.25	5.6
4/30/2009	18.88	34.137	30.144	22.189	21.49	35	2.87	7.28	230.45	1.47	25.02	11907.75	5.6
4/30/2009	18.88	34.135	30.142	22.188	21.48	35	2.87	7.28	230.04	1.47	24.97	11872.5	5.5
4/30/2009	18.87	34.134	30.141	22.187	21.48	35	2.87	7.28	230.48	1.47	24.98	11877	5.5
4/30/2009	18.87	34.131	30.138	22.185	21.48	35	2.87	7.28	230.46	1.47	25	11891.5	5.5
4/30/2009	18.87	34.13	30.137	22.185	21.48	35.1	2.87	7.28	230.27	1.47	25.04	11907.75	5.5
4/30/2009	18.87	34.129	30.135	22.184	21.48	35.1	2.87	7.28	229.84	1.46	24.99	11876	5.5
4/30/2009	18.87	34.126	30.133	22.182	21.48	35.1	2.87	7.28	230.18	1.46	24.98	11884.75	5.6
4/30/2009	18.87	34.125	30.131	22.181	21.48	35.1	2.87	7.28	230.07	1.46	25.02	11900	5.6
MEAN	18.88	34.14	30.14	22.19	21.49	35.00	2.87	7.28	230.22	1.47	24.98	11883.59	5.56

APPENDIX II

SITE THREE SAMPLING DAY TWO

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/12/2009	19.77	60.178	54.165	39.116	40.41	61.9	4.45	6.15	180.5	0.08	18.43	8860.5	9.9
6/12/2009	19.76	60.208	54.185	39.135	40.43	58.2	4.18	6.06	200.21	0.07	16.7	8076.38	9.9
6/12/2009	19.76	60.215	54.189	39.14	40.44	58.2	4.18	6.05	202.41	0.07	16.49	7974.75	9.9
6/12/2009	19.76	60.218	54.192	39.142	40.44	58.2	4.18	6.04	203.99	0.07	16.36	7911.13	9.9
6/12/2009	19.76	60.222	54.195	39.145	40.44	58.2	4.18	6.03	205.38	0.07	16.26	7866.13	9.9
6/12/2009	19.76	60.226	54.198	39.147	40.44	57.3	4.12	6.02	206.57	0.07	16.17	7828.38	14.5
6/12/2009	19.76	60.231	54.202	39.15	40.45	57.3	4.12	6.01	208.3	0.07	16.02	7759.75	14.5
6/12/2009	19.76	60.236	54.205	39.153	40.45	57.3	4.12	6	209.32	0.07	15.93	7721.38	14.4
6/12/2009	19.76	60.239	54.208	39.155	40.45	57.3	4.12	5.99	210.11	0.07	15.87	7697.88	14.4
6/12/2009	19.76	60.243	54.211	39.158	40.46	56.7	4.08	5.98	210.6	0.07	15.83	7679.88	14.4
6/12/2009	19.76	60.248	54.215	39.161	40.46	56.7	4.08	5.98	211.63	0.06	15.72	7627.25	14.4
6/12/2009	19.76	60.252	54.218	39.164	40.46	56.7	4.08	5.97	212.17	0.06	15.66	7606.38	14.5
6/12/2009	19.76	60.255	54.221	39.166	40.47	56.7	4.08	5.96	212.69	0.06	15.63	7595.88	14.5
6/12/2009	19.76	60.259	54.223	39.168	40.47	56.4	4.06	5.95	213.05	0.06	15.61	7591	14.5
6/12/2009	19.76	60.264	54.228	39.172	40.47	56.4	4.06	5.95	214	0.06	15.52	7549	14.6
MEAN	19.76	60.23	54.20	39.15	40.45	57.57	4.14	6.01	206.73	0.07	16.15	7823.04	12.95

APPENDIX II

SITE THREE SAMPLING DAY THREE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/30/2009	15.72	56.031	46.097	36.42	37.23	96.8	7.66	6.47	266.59	0.19	8.33	6519	4.5
6/30/2009	15.71	56.034	46.095	36.422	37.24	96.9	7.67	6.48	266.06	0.2	8.42	6536.13	4.5
6/30/2009	15.71	56.036	46.096	36.423	37.24	96.9	7.67	6.49	264.91	0.2	8.45	6554.5	4.5
6/30/2009	15.71	56.036	46.096	36.423	37.24	96.9	7.67	6.49	263.99	0.2	8.5	6582.63	4.5
6/30/2009	15.71	56.037	46.096	36.424	37.24	96.9	7.67	6.49	263.39	0.2	8.54	6608.63	4.5
6/30/2009	15.71	56.038	46.096	36.425	37.24	96.9	7.67	6.49	265.89	0.2	8.46	6541.13	4.5
6/30/2009	15.71	56.039	46.097	36.426	37.24	96.9	7.67	6.49	264.48	0.2	8.5	6559.5	4.5
6/30/2009	15.71	56.041	46.098	36.426	37.24	96.9	7.67	6.5	263.67	0.2	8.55	6589.63	4.5
6/30/2009	15.71	56.039	46.097	36.426	37.24	96.9	7.67	6.5	263.27	0.2	8.59	6612.13	4.5
6/30/2009	15.71	56.041	46.098	36.426	37.24	96.9	7.67	6.5	265.73	0.2	8.51	6545.88	4.5
6/30/2009	15.71	56.042	46.099	36.427	37.24	96.9	7.67	6.5	264.31	0.2	8.55	6564.13	4.5
6/30/2009	15.71	56.042	46.099	36.427	37.24	96.9	7.67	6.5	263.43	0.2	8.59	6592.88	4.5
6/30/2009	15.71	56.042	46.099	36.427	37.24	96.9	7.67	6.5	262.84	0.2	8.63	6614.38	4.5
6/30/2009	15.71	56.043	46.099	36.428	37.24	96.9	7.67	6.5	265.34	0.2	8.55	6547	4.5
6/30/2009	15.71	56.044	46.1	36.429	37.24	96.9	7.67	6.51	264.05	0.2	8.58	6567.5	4.5
MEAN	15.71	56.04	46.10	36.43	37.24	96.89	7.67	6.49	264.53	0.20	8.52	6569.00	4.50

APPENDIX II

SITE THREE SAMPLING DAY FOUR

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/15/2009	14.43	62.152	49.609	40.399	41.8	25.4	2	7	275.75	0.6	15.15	5662.25	4.6
7/15/2009	14.46	62.127	49.621	40.382	41.78	26	2.05	7.01	273.55	0.6	15.28	5715	4.6
7/15/2009	14.46	62.125	49.621	40.382	41.78	26.2	2.06	7.01	273.19	0.6	15.3	5727	4.6
7/15/2009	14.46	62.127	49.622	40.382	41.78	26.2	2.06	7.01	273.56	0.6	15.26	5713.25	4.6
7/15/2009	14.46	62.125	49.622	40.381	41.78	26.2	2.06	7.01	273.45	0.6	15.27	5716.75	4.6
7/15/2009	14.46	62.125	49.622	40.381	41.78	26.2	2.06	7.01	273.25	0.6	15.3	5722.13	4.5
7/15/2009	14.46	62.125	49.622	40.381	41.78	26.3	2.07	7.01	272.96	0.6	15.32	5732.25	4.5
7/15/2009	14.46	62.125	49.622	40.381	41.78	26.3	2.07	7.01	273.33	0.6	15.28	5720.5	4.5
7/15/2009	14.46	62.127	49.623	40.382	41.78	26.3	2.07	7.01	273.31	0.6	15.28	5722.38	4.6
7/15/2009	14.46	62.125	49.623	40.381	41.78	26.3	2.07	7.01	273.05	0.6	15.3	5728.25	4.6
7/15/2009	14.46	62.127	49.623	40.382	41.78	26.4	2.08	7.01	272.55	0.6	15.33	5737.38	4.6
7/15/2009	14.46	62.127	49.623	40.382	41.78	26.4	2.08	7.01	272.96	0.6	15.3	5723.88	4.6
7/15/2009	14.46	62.125	49.623	40.381	41.78	26.4	2.08	7.01	272.72	0.6	15.3	5728.75	4.6
7/15/2009	14.46	62.125	49.623	40.381	41.78	26.4	2.08	7.01	272.38	0.6	15.32	5735.75	4.6
7/15/2009	14.46	62.127	49.623	40.382	41.78	26.5	2.09	7.01	272.02	0.6	15.35	5746.88	4.6
MEAN	14.46	62.13	49.62	40.38	41.78	26.23	2.07	7.01	273.20	0.60	15.29	5722.16	4.58

APPENDIX II

SITE THREE SAMPLING DAY FIVE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/29/2009	15.52	64.189	52.562	41.723	43.39	96.2	7.36	6.21	266.13	0.1	8.82	4894.25	4.7
7/29/2009	15.5	64.206	52.562	41.734	43.41	96	7.35	6.22	261.64	0.1	8.87	4895.25	4.7
7/29/2009	15.5	64.207	52.562	41.735	43.41	96	7.35	6.22	262.77	0.1	8.88	4904.38	4.7
7/29/2009	15.5	64.206	52.56	41.734	43.41	96	7.35	6.22	263.16	0.1	8.89	4910	4.7
7/29/2009	15.5	64.209	52.56	41.736	43.41	95.9	7.34	6.22	262.45	0.1	8.92	4923.75	4.7
7/29/2009	15.5	64.21	52.56	41.737	43.41	95.9	7.34	6.22	261.44	0.1	8.89	4902.25	4.7
7/29/2009	15.5	64.212	52.56	41.738	43.41	95.9	7.34	6.22	262.75	0.1	8.91	4913	4.7
7/29/2009	15.5	64.213	52.559	41.739	43.41	95.9	7.34	6.23	262.9	0.1	8.92	4917.38	4.7
7/29/2009	15.5	64.215	52.559	41.739	43.41	95.8	7.33	6.23	262.17	0.1	8.95	4931.63	4.7
7/29/2009	15.49	64.217	52.559	41.741	43.42	95.8	7.33	6.23	261.09	0.1	8.93	4912	4.7
7/29/2009	15.49	64.22	52.559	41.743	43.42	95.8	7.33	6.23	262.25	0.1	8.94	4921.13	4.7
7/29/2009	15.49	64.222	52.558	41.744	43.42	95.8	7.33	6.23	263.23	0.1	8.95	4924.5	4.7
7/29/2009	15.49	64.223	52.558	41.745	43.42	95.7	7.32	6.24	261.44	0.1	8.98	4937.63	4.7
7/29/2009	15.49	64.226	52.558	41.747	43.42	95.7	7.32	6.24	260.41	0.1	8.96	4915.63	4.7
7/29/2009	15.49	64.227	52.558	41.748	43.42	95.7	7.32	6.24	261.31	0.1	8.97	4925.88	4.7
MEAN	15.50	64.21	52.56	41.74	43.41	95.87	7.34	6.23	262.34	0.10	8.92	4915.24	4.70

APPENDIX II

SITE THREE SAMPLING DAY SIX

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
10/2/2009	15.82	33.52	27.643	21.788	21.06	51.7	4.51	7.26	106.4	0.51	22.1	8167.75	4
10/2/2009	15.82	33.523	27.646	21.79	21.06	51.7	4.51	7.26	105.78	0.51	22.18	8175.38	4
10/2/2009	15.82	33.525	27.647	21.791	21.06	51.7	4.51	7.26	106.35	0.51	22.17	8178.13	4
10/2/2009	15.82	33.525	27.647	21.791	21.06	51.7	4.51	7.26	106.41	0.51	22.18	8180.88	4
10/2/2009	15.82	33.525	27.648	21.791	21.06	51.8	4.51	7.26	106.11	0.51	22.24	8207.25	4.1
10/2/2009	15.82	33.525	27.647	21.791	21.06	51.8	4.51	7.26	105.72	0.51	22.21	8183.88	4.1
10/2/2009	15.82	33.526	27.648	21.792	21.06	51.8	4.51	7.26	106.25	0.51	22.18	8184.88	4.1
10/2/2009	15.82	33.527	27.649	21.793	21.06	51.8	4.51	7.26	106.33	0.51	22.19	8188.5	4.1
10/2/2009	15.82	33.528	27.649	21.793	21.06	51.8	4.51	7.26	106.02	0.51	22.25	8208.5	4.1
10/2/2009	15.82	33.527	27.649	21.793	21.06	51.8	4.51	7.26	105.7	0.51	22.21	8187.13	4.1
10/2/2009	15.82	33.528	27.65	21.793	21.06	51.8	4.51	7.26	106.22	0.51	22.19	8189	4.1
10/2/2009	15.82	33.529	27.65	21.794	21.06	51.8	4.51	7.26	106.28	0.52	22.2	8190.13	4.1
10/2/2009	15.82	33.529	27.651	21.794	21.06	51.8	4.51	7.26	105.95	0.52	22.26	8213.25	4.1
10/2/2009	15.82	33.528	27.65	21.793	21.06	51.8	4.51	7.26	105.56	0.51	22.22	8190.88	4.1
10/2/2009	15.82	33.528	27.65	21.793	21.06	51.8	4.51	7.26	106.08	0.52	22.2	8193.25	4.1
MEAN	15.82	33.53	27.65	21.79	21.06	51.77	4.51	7.26	106.08	0.51	22.20	8189.25	4.07

APPENDIX II

SITE FOUR SAMPLING DAY ONE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
4/30/2009	19.11	31.062	27.568	20.19	19.37	21	1.73	7.12	354.8	1.6	21.66	7888.5	4.8
4/30/2009	19.11	31.072	27.574	20.197	19.37	21	1.73	7.12	353.94	1.61	21.73	7925.5	4.8
4/30/2009	19.1	31.073	27.574	20.198	19.37	21	1.73	7.13	353.42	1.61	21.77	7939.63	4.8
4/30/2009	19.1	31.074	27.575	20.198	19.37	21	1.73	7.13	352.5	1.61	21.79	7943.13	4.8
4/30/2009	19.1	31.075	27.575	20.199	19.37	21	1.73	7.12	354.63	1.61	21.68	7906.13	4.8
4/30/2009	19.1	31.075	27.575	20.199	19.37	21	1.73	7.13	353.88	1.61	21.75	7927.38	4.8
4/30/2009	19.1	31.076	27.576	20.199	19.38	21	1.73	7.13	353.15	1.61	21.79	7942	4.8
4/30/2009	19.1	31.076	27.576	20.199	19.38	21	1.73	7.13	352.27	1.61	21.82	7947.5	4.8
4/30/2009	19.1	31.077	27.576	20.2	19.38	21	1.73	7.13	354.37	1.61	21.73	7914.88	4.8
4/30/2009	19.1	31.077	27.576	20.2	19.38	21	1.73	7.13	353.61	1.61	21.8	7940.25	4.8
4/30/2009	19.1	31.078	27.577	20.201	19.38	21	1.74	7.13	353.05	1.62	21.84	7957	4.8
4/30/2009	19.1	31.078	27.577	20.201	19.38	21	1.74	7.13	352.06	1.61	21.86	7961.5	4.8
4/30/2009	19.1	31.079	27.577	20.201	19.38	21	1.74	7.13	354.03	1.61	21.75	7928.38	4.8
4/30/2009	19.1	31.079	27.577	20.202	19.38	21	1.74	7.13	353.13	1.62	21.83	7951.5	4.8
4/30/2009	19.1	31.08	27.578	20.202	19.38	21	1.74	7.13	352.32	1.61	21.87	7970.38	4.8
MEAN	19.10	31.08	27.58	20.20	19.38	21.00	1.73	7.13	353.41	1.61	21.78	7936.24	4.8

APPENDIX II

SITE FOUR SAMPLING DAY TWO

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/12/2009	19.13	57.298	50.877	37.244	38.23	51.9	3.83	7.06	202.89	0.72	15.73	6864.5	4.8
6/12/2009	19.12	57.305	50.866	37.248	38.24	51.7	3.81	7.06	202.45	0.72	15.77	6890.75	4.9
6/12/2009	19.11	57.307	50.865	37.25	38.24	51.7	3.81	7.06	201.98	0.72	15.79	6895	4.8
6/12/2009	19.11	57.309	50.865	37.251	38.24	51.6	3.81	7.06	201.31	0.72	15.81	6906.13	4.8
6/12/2009	19.11	57.311	50.864	37.252	38.24	51.6	3.81	7.06	200.59	0.71	15.8	6898.75	4.8
6/12/2009	19.11	57.313	50.863	37.253	38.24	51.6	3.81	7.06	201.27	0.72	15.78	6895.38	4.8
6/12/2009	19.11	57.313	50.861	37.253	38.24	51.6	3.81	7.06	201.28	0.72	15.79	6901.38	4.8
6/12/2009	19.1	57.314	50.859	37.254	38.24	51.5	3.8	7.06	201.37	0.72	15.82	6916.13	4.8
6/12/2009	19.1	57.315	50.858	37.255	38.24	51.5	3.8	7.06	201.41	0.72	15.8	6912.13	4.8
6/12/2009	19.1	57.317	50.857	37.256	38.24	51.5	3.8	7.06	202.38	0.72	15.78	6908	4.8
6/12/2009	19.1	57.319	50.856	37.257	38.25	51.5	3.8	7.06	202.18	0.72	15.8	6915	4.8
6/12/2009	19.09	57.32	50.854	37.258	38.25	51.5	3.8	7.06	201.7	0.72	15.82	6926	4.8
6/12/2009	19.09	57.322	50.854	37.259	38.25	51.5	3.8	7.06	201	0.72	15.81	6923.75	4.8
6/12/2009	19.09	57.323	50.853	37.26	38.25	51.5	3.8	7.06	201.26	0.72	15.8	6921.13	4.8
6/12/2009	19.09	57.324	50.852	37.261	38.25	51.5	3.8	7.06	200.77	0.72	15.82	6929.5	4.8
MEAN	19.10	57.31	50.86	37.25	38.24	51.58	3.81	7.06	201.59	0.72	15.79	6906.90	4.81

APPENDIX II

SITE FOUR SAMPLING DAY THREE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/30/2009	13.89	62.052	48.879	40.334	41.7	40.8	3.25	6.74	321.16	0.36	12.87	5000	4.1
6/30/2009	13.89	62.057	48.883	40.337	41.7	40.7	3.25	6.74	317.55	0.36	12.93	5019.38	4.1
6/30/2009	13.89	62.057	48.883	40.337	41.7	40.7	3.25	6.74	316.65	0.36	12.96	5031.38	4.1
6/30/2009	13.89	62.058	48.884	40.338	41.7	40.6	3.24	6.74	316.4	0.36	12.99	5043.5	4.1
6/30/2009	13.89	62.06	48.885	40.339	41.7	40.6	3.24	6.74	317.61	0.36	12.96	5033.5	4.1
6/30/2009	13.89	62.059	48.886	40.339	41.7	40.6	3.24	6.73	318.45	0.36	12.98	5040.88	4.1
6/30/2009	13.89	62.059	48.886	40.339	41.7	40.6	3.24	6.73	319.04	0.36	13	5052.5	4.1
6/30/2009	13.89	62.058	48.886	40.338	41.7	40.6	3.24	6.74	318.98	0.36	13.03	5066	4.1
6/30/2009	13.89	62.059	48.887	40.339	41.7	40.6	3.24	6.73	319.26	0.36	13.01	5057.25	4.1
6/30/2009	13.89	62.061	48.888	40.339	41.7	40.6	3.24	6.73	318.19	0.36	13.03	5065	4.1
6/30/2009	13.89	62.062	48.889	40.34	41.7	40.6	3.24	6.73	316.41	0.35	13.07	5078.38	4
6/30/2009	13.89	62.06	48.889	40.339	41.7	40.6	3.24	6.73	314.67	0.35	13.12	5091.38	4
6/30/2009	13.89	62.063	48.891	40.341	41.71	40.6	3.24	6.73	314.48	0.35	13.09	5081.13	4
6/30/2009	13.89	62.064	48.891	40.342	41.71	40.6	3.24	6.73	314.04	0.35	13.1	5088.25	4
6/30/2009	13.89	62.065	48.892	40.343	41.71	40.6	3.24	6.73	314.21	0.35	13.13	5100.88	3.9
MEAN	13.89	62.0596	48.8866	40.33893	41.702	40.62667	3.242	6.734	317.14	0.36	13.018	5056.627	4.06

APPENDIX II

SITE FOUR SAMPLING DAY FOUR

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/15/2009	14.62	63.804	51.159	41.473	43.06	24.2	1.89	6.93	267.93	0.5	13.4	5201.63	5.4
7/15/2009	14.62	63.841	51.19	41.497	43.09	23.8	1.86	6.94	271.28	0.51	13.48	5221.75	5.4
7/15/2009	14.62	63.844	51.192	41.499	43.09	23.8	1.86	6.94	271.26	0.51	13.5	5231	5.4
7/15/2009	14.62	63.846	51.194	41.5	43.1	23.7	1.85	6.94	271.09	0.51	13.52	5240.88	5.4
7/15/2009	14.62	63.849	51.196	41.502	43.1	23.7	1.85	6.94	271.85	0.51	13.49	5226.25	5.4
7/15/2009	14.62	63.851	51.198	41.503	43.1	23.7	1.85	6.94	271.66	0.51	13.51	5232	5.4
7/15/2009	14.62	63.854	51.2	41.505	43.1	23.7	1.85	6.94	271.59	0.51	13.53	5237.88	5.4
7/15/2009	14.62	63.856	51.202	41.506	43.1	23.6	1.84	6.94	271.62	0.52	13.55	5243.75	5.4
7/15/2009	14.62	63.859	51.204	41.508	43.11	23.6	1.84	6.94	272.41	0.52	13.51	5228	5.4
7/15/2009	14.62	63.86	51.205	41.509	43.11	23.6	1.84	6.94	272.37	0.52	13.53	5237.75	5.4
7/15/2009	14.62	63.862	51.207	41.51	43.11	23.6	1.84	6.94	272.39	0.52	13.55	5245.38	5.4
7/15/2009	14.62	63.863	51.208	41.511	43.11	23.5	1.84	6.94	272.3	0.52	13.58	5252.88	5.4
7/15/2009	14.62	63.866	51.21	41.513	43.11	23.5	1.84	6.94	272.96	0.52	13.54	5238.5	5.4
7/15/2009	14.62	63.87	51.212	41.515	43.11	23.5	1.84	6.94	272.66	0.52	13.57	5247.75	5.4
7/15/2009	14.62	63.871	51.213	41.516	43.12	23.5	1.84	6.95	272.58	0.52	13.59	5256.13	5.4
MEAN	14.62	63.85	51.20	41.50	43.10	23.67	1.85	6.94	271.73	0.51	13.52	5236.10	5.40

APPENDIX II

SITE FOUR SAMPLING DAY FIVE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/29/2009	15.13	45.51	36.931	29.581	29.51	97.6	8.2	5.4	793.02	0.05	6.94	3767.06	6.2
7/29/2009	15.12	45.592	36.99	29.635	29.57	97.3	8.17	5.45	782.25	0.05	7.08	3824.19	6.2
7/29/2009	15.12	45.599	36.995	29.639	29.57	97.3	8.17	5.45	781.7	0.05	7.12	3845.25	6.2
7/29/2009	15.12	45.605	37	29.643	29.58	97.2	8.16	5.46	778.38	0.05	7.15	3861.63	6.2
7/29/2009	15.12	45.613	37.006	29.649	29.58	97.2	8.16	5.46	783.53	0.05	7.07	3818.25	6.2
7/29/2009	15.12	45.623	37.014	29.655	29.59	97.2	8.16	5.46	776.36	0.05	7.13	3845.94	6.2
7/29/2009	15.12	45.63	37.02	29.66	29.59	97.2	8.16	5.47	774.77	0.05	7.17	3865.88	6.2
7/29/2009	15.12	45.636	37.024	29.663	29.6	97.1	8.15	5.47	773.22	0.06	7.2	3880.56	6.2
7/29/2009	15.12	45.643	37.029	29.668	29.6	97.1	8.15	5.47	780.92	0.06	7.12	3835.63	6.2
7/29/2009	15.12	45.65	37.035	29.673	29.61	97.1	8.15	5.48	774.75	0.06	7.18	3863.94	6.2
7/29/2009	15.12	45.656	37.039	29.676	29.61	97.1	8.15	5.48	773.53	0.06	7.21	3886.31	6.2
7/29/2009	15.12	45.662	37.044	29.68	29.62	97	8.14	5.49	771.67	0.06	7.24	3903.69	6.2
7/29/2009	15.12	45.669	37.049	29.685	29.62	97	8.14	5.49	779.56	0.06	7.17	3858.69	6.2
7/29/2009	15.12	45.674	37.053	29.688	29.63	97	8.14	5.49	776.09	0.06	7.22	3888.13	6.2
7/29/2009	15.12	45.68	37.057	29.692	29.63	97	8.14	5.5	775.73	0.06	7.26	3909.06	6.2
MEAN	15.12	45.63	37.02	29.66	29.59	97.16	8.16	5.47	778.37	0.06	7.15	3856.95	6.20

APPENDIX II

SITE FOUR SAMPLING DAY SIX

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
10/2/2009	15.65	55.119	45.273	35.828	36.55	59	4.7	7.16	131.21	0.46	19.2	6697.88	4
10/2/2009	15.64	55.159	45.302	35.853	36.58	58.9	4.69	7.16	130.96	0.46	19.27	6728.5	4
10/2/2009	15.64	55.175	45.313	35.864	36.59	58.9	4.69	7.16	130.23	0.46	19.29	6741.5	4
10/2/2009	15.64	55.179	45.316	35.866	36.6	58.9	4.69	7.16	130.65	0.46	19.3	6749.75	4
10/2/2009	15.64	55.18	45.317	35.867	36.6	58.9	4.69	7.16	130.57	0.46	19.31	6760	4
10/2/2009	15.64	55.182	45.318	35.869	36.6	58.9	4.69	7.16	130.3	0.46	19.35	6775.38	4
10/2/2009	15.64	55.186	45.321	35.871	36.6	58.9	4.69	7.16	129.83	0.46	19.31	6754.63	4
10/2/2009	15.64	55.19	45.323	35.873	36.61	58.9	4.69	7.16	130.19	0.46	19.32	6761	4
10/2/2009	15.64	55.191	45.324	35.874	36.61	58.9	4.69	7.16	130.24	0.46	19.34	6770.13	4
10/2/2009	15.64	55.192	45.325	35.875	36.61	58.9	4.68	7.16	130.05	0.46	19.39	6786	4
10/2/2009	15.64	55.195	45.328	35.877	36.61	58.9	4.68	7.16	129.68	0.46	19.34	6762.63	4
10/2/2009	15.64	55.198	45.329	35.879	36.61	58.9	4.68	7.16	130.19	0.46	19.34	6768	4
10/2/2009	15.64	55.199	45.33	35.879	36.61	58.9	4.68	7.16	130.31	0.46	19.36	6775.75	4
10/2/2009	15.64	55.2	45.331	35.88	36.61	58.9	4.68	7.16	130.13	0.46	19.4	6790.88	4
10/2/2009	15.64	55.204	45.333	35.882	36.62	58.9	4.68	7.16	129.73	0.46	19.34	6769.5	4
MEAN	15.64	55.18	45.32	35.87	36.60	58.91	4.69	7.16	130.28	0.46	19.32	6759.44	4.00

APPENDIX II

SITE FIVE SAMPLING DAY ONE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	Ammonium N mg/L	Ammonia N mg/L	Nitrate N mg/L	Chloride mg/L	Turbidity NTU
4/30/2009	18.82	62.913	55.491	40.894	42.49	31.6	2.29	7.54	223.72	2.3	24.14	11545.75	5.1
4/30/2009	18.81	62.92	55.485	40.898	42.49	31.1	2.25	7.52	230.84	2.25	23.33	11173	5.1
4/30/2009	18.81	62.922	55.484	40.899	42.49	30.9	2.24	7.51	231.27	2.24	23.28	11148.25	5.1
4/30/2009	18.81	62.923	55.484	40.9	42.5	30.9	2.24	7.51	231.45	2.24	23.18	11104	5.1
4/30/2009	18.81	62.926	55.485	40.902	42.5	30.9	2.24	7.51	232.26	2.24	23.14	11085.5	5.6
4/30/2009	18.81	62.927	55.484	40.902	42.5	30.9	2.24	7.51	232.65	2.23	23.11	11072.5	5.6
4/30/2009	18.81	62.929	55.484	40.904	42.5	30.8	2.23	7.51	232.87	2.23	23.09	11067	5.6
4/30/2009	18.8	62.932	55.484	40.905	42.5	30.8	2.23	7.51	232.85	2.22	23.02	11029	5.6
4/30/2009	18.8	62.933	55.484	40.906	42.5	30.8	2.23	7.51	233.57	2.22	22.99	11014	5.6
4/30/2009	18.8	62.933	55.483	40.906	42.5	30.8	2.23	7.51	233.82	2.22	22.96	11005.25	5.6
4/30/2009	18.8	62.933	55.482	40.906	42.5	30.7	2.22	7.5	233.9	2.22	22.96	11000.75	5.6
4/30/2009	18.8	62.933	55.482	40.906	42.5	30.7	2.22	7.5	233.86	2.21	22.9	10965.5	5.6
4/30/2009	18.8	62.936	55.482	40.908	42.5	30.7	2.22	7.5	234.37	2.21	22.88	10961.5	5.6
4/30/2009	18.8	62.936	55.481	40.908	42.5	30.7	2.22	7.5	234.52	2.21	22.87	10961	5.6
4/30/2009	18.8	62.937	55.481	40.909	42.51	30.7	2.22	7.5	234.5	2.21	22.88	10965.25	5.6
MEAN	18.81	62.93	55.48	40.90	42.50	30.87	2.23	7.51	232.43	2.23	23.12	11073.22	5.47

APPENDIX II

SITE FIVE SAMPLING DAY TWO

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/12/2009	19.46	63.712	56.966	41.413	43.1	71.4	5.09	6.78	178.14	0.34	18.09	9498.25	7.9
6/12/2009	19.44	63.723	56.96	41.42	43.11	69.9	4.98	6.75	195.94	0.34	16.44	8653.75	7.3
6/12/2009	19.44	63.723	56.958	41.42	43.11	68.9	4.91	6.74	197.24	0.34	16.32	8589.25	7.2
6/12/2009	19.44	63.727	56.959	41.422	43.12	68.9	4.91	6.74	199.21	0.34	16.12	8490	7.2
6/12/2009	19.44	63.729	56.959	41.424	43.12	68.9	4.91	6.74	200.52	0.34	16.01	8432	7.2
6/12/2009	19.44	63.73	56.957	41.424	43.12	68.9	4.91	6.74	201.59	0.34	15.92	8387.5	7.3
6/12/2009	19.43	63.732	56.956	41.426	43.12	68.4	4.87	6.74	202.55	0.34	15.85	8354.5	7.3
6/12/2009	19.43	63.735	56.956	41.428	43.12	68.4	4.87	6.73	204.09	0.34	15.71	8283.25	7.3
6/12/2009	19.43	63.737	56.956	41.429	43.12	68.4	4.87	6.73	204.91	0.34	15.64	8251.75	7.3
6/12/2009	19.43	63.739	56.955	41.43	43.12	68.4	4.87	6.73	205.53	0.35	15.6	8233.75	7.4
6/12/2009	19.43	63.74	56.953	41.431	43.13	68	4.84	6.74	205.95	0.35	15.57	8219.25	7.4
6/12/2009	19.42	63.743	56.953	41.433	43.13	68	4.84	6.73	207.05	0.35	15.47	8161.38	7.4
6/12/2009	19.42	63.745	56.953	41.434	43.13	68	4.84	6.73	207.55	0.35	15.43	8142	7.5
6/12/2009	19.42	63.749	56.952	41.437	43.13	68	4.84	6.74	207.82	0.35	15.41	8133.25	7.5
6/12/2009	19.42	63.751	56.951	41.438	43.13	67.7	4.82	6.74	208.07	0.35	15.41	8129.75	7.5
MEAN	19.43	63.73	56.96	41.43	43.12	68.68	4.89	6.74	201.74	0.34	15.93	8397.31	7.38

APPENDIX II

SITE FOUR SAMPLING DAY THREE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
6/30/2009	16.38	50.357	42.062	32.732	33.05	84	6.73	7.33	214.29	1.19	12.32	5993.13	5.8
6/30/2009	16.38	50.372	42.075	32.742	33.06	83.9	6.72	7.33	215.4	1.21	12.39	6031.25	5.4
6/30/2009	16.38	50.372	42.075	32.742	33.06	83.8	6.72	7.33	215.17	1.21	12.43	6048.25	5.4
6/30/2009	16.38	50.376	42.078	32.744	33.06	83.8	6.72	7.33	214.41	1.2	12.36	6008.63	5.3
6/30/2009	16.38	50.378	42.08	32.746	33.07	83.8	6.72	7.33	215.52	1.21	12.37	6016.75	5.3
6/30/2009	16.38	50.38	42.082	32.747	33.07	83.8	6.72	7.33	215.58	1.21	12.4	6034.25	5.3
6/30/2009	16.38	50.383	42.084	32.749	33.07	83.8	6.71	7.34	215.23	1.21	12.45	6052.75	5.3
6/30/2009	16.38	50.385	42.086	32.75	33.07	83.8	6.71	7.34	214.25	1.21	12.38	6014.63	5.3
6/30/2009	16.38	50.386	42.087	32.751	33.07	83.8	6.71	7.33	215.33	1.21	12.39	6020.5	5.3
6/30/2009	16.38	50.387	42.088	32.752	33.07	83.8	6.71	7.34	215.36	1.21	12.42	6037.25	5.3
6/30/2009	16.38	50.388	42.089	32.752	33.07	83.8	6.71	7.34	214.93	1.21	12.46	6057.25	5.3
6/30/2009	16.38	50.39	42.09	32.753	33.07	83.8	6.71	7.34	213.94	1.21	12.4	6019.38	5.3
6/30/2009	16.38	50.391	42.091	32.754	33.08	83.8	6.71	7.34	214.93	1.21	12.4	6025.13	5.3
6/30/2009	16.38	50.39	42.091	32.753	33.08	83.8	6.71	7.34	214.88	1.21	12.43	6043.38	5.3
6/30/2009	16.38	50.39	42.091	32.753	33.08	83.8	6.71	7.34	214.44	1.21	12.47	6064.63	5.3
MEAN	16.38	50.38	42.08	32.75	33.07	83.82	6.71	7.34	214.91	1.21	12.40	6031.14	5.35

APPENDIX II

SITE FIVE SAMPLING DAY FOUR

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/15/2009	15.08	65.223	52.865	42.395	44.17	18.4	1.42	6.36	218.11	0.11	12.88	6122.13	5.9
7/15/2009	15.07	65.229	52.863	42.399	44.17	18.3	1.41	6.38	215.86	0.12	13.02	6164.75	5.9
7/15/2009	15.07	65.231	52.863	42.4	44.18	18.3	1.41	6.38	216.87	0.12	12.98	6150.75	5.9
7/15/2009	15.07	65.231	52.863	42.4	44.18	18.3	1.41	6.38	215.88	0.12	13.05	6179.88	5.9
7/15/2009	15.07	65.23	52.862	42.399	44.17	18.3	1.41	6.39	214.96	0.12	13.1	6205.63	5.9
7/15/2009	15.07	65.231	52.862	42.4	44.18	18.3	1.41	6.39	215.31	0.12	13.06	6182	5.9
7/15/2009	15.07	65.23	52.861	42.399	44.17	18.3	1.41	6.39	216.31	0.12	13.03	6165.63	5.9
7/15/2009	15.07	65.229	52.86	42.399	44.17	18.3	1.41	6.39	215.32	0.12	13.09	6195	5.9
7/15/2009	15.07	65.23	52.86	42.399	44.17	18.3	1.4	6.4	214.5	0.12	13.15	6220	5.9
7/15/2009	15.07	65.231	52.86	42.4	44.18	18.3	1.4	6.4	214.93	0.12	13.1	6195.38	5.9
7/15/2009	15.07	65.231	52.86	42.4	44.18	18.3	1.4	6.4	215.97	0.12	13.07	6176.13	5.9
7/15/2009	15.07	65.232	52.859	42.4	44.18	18.3	1.4	6.4	215.17	0.12	13.13	6205.5	5.9
7/15/2009	15.07	65.232	52.859	42.4	44.18	18.2	1.4	6.41	214.41	0.12	13.18	6231.63	5.9
7/15/2009	15.07	65.232	52.858	42.401	44.18	18.2	1.4	6.41	214.66	0.12	13.14	6206	5.9
7/15/2009	15.07	65.232	52.858	42.401	44.18	18.2	1.4	6.41	215.59	0.12	13.11	6191	5.8
MEAN	15.07	65.23	52.86	42.40	44.18	18.29	1.41	6.39	215.59	0.12	13.07	6186.09	5.89

APPENDIX II

SITE FIVE SAMPLING DAY FIVE

Date M/D/Y	Temp C	SpCond mS/cm	Cond mS/cm	TDS g/L	Salinity ppt	DO% %	DO Conc mg/L	pH	AmmoniumN mg/L	AmmoniaN mg/L	NitrateN mg/L	Chloride mg/L	Turbidity NTU
7/29/2009	15.26	65.876	53.62	42.819	44.68	98.3	7.5	5.83	213.21	0.03	11.4	5443.38	4.5
7/29/2009	15.25	65.888	53.624	42.827	44.69	98	7.48	5.8	216.84	0.03	11.26	5353.75	5
7/29/2009	15.25	65.889	53.625	42.828	44.69	98	7.48	5.8	218.48	0.03	11.19	5312.63	5
7/29/2009	15.25	65.891	53.625	42.829	44.69	98	7.48	5.79	218.46	0.03	11.19	5309.38	5
7/29/2009	15.25	65.891	53.625	42.829	44.69	98	7.48	5.79	217.98	0.03	11.21	5317.25	5
7/29/2009	15.25	65.892	53.626	42.83	44.69	97.9	7.47	5.79	217.54	0.03	11.23	5324.63	5
7/29/2009	15.25	65.894	53.627	42.831	44.69	97.9	7.47	5.79	219.21	0.03	11.14	5283	5.1
7/29/2009	15.25	65.894	53.627	42.831	44.69	97.9	7.47	5.78	218.96	0.03	11.15	5281.5	5.1
7/29/2009	15.25	65.894	53.627	42.831	44.69	97.9	7.47	5.78	218.47	0.03	11.17	5289.38	5.1
7/29/2009	15.25	65.894	53.627	42.831	44.69	97.9	7.47	5.78	218.15	0.03	11.19	5300.38	5.1
7/29/2009	15.25	65.896	53.627	42.832	44.69	97.9	7.47	5.78	219.86	0.03	11.11	5261.75	5.1
7/29/2009	15.25	65.896	53.627	42.832	44.69	97.9	7.47	5.78	219.57	0.03	11.12	5262.88	5.1
7/29/2009	15.25	65.897	53.627	42.833	44.69	97.9	7.47	5.77	219.09	0.03	11.15	5272.75	5.1
7/29/2009	15.25	65.897	53.627	42.833	44.69	97.8	7.46	5.77	218.94	0.03	11.18	5284	5
7/29/2009	15.25	65.9	53.628	42.835	44.7	97.8	7.46	5.77	220.52	0.03	11.1	5246.88	5
MEAN	15.25	65.89	53.63	42.83	44.69	97.94	7.47	5.79	218.35	0.03	11.19	5302.90	5.01