THE ENVIRONMENTAL AND HEALTH STATUS OF THE MNGENI ESTUARY IN KWAZULU-NATAL, SOUTH AFRICA

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Submitted in partial fulfillment of the academic requirements for the degree of Masters of Science, in the School of Life and Environmental Sciences, Department of Geography, University of KwaZulu-Natal (Westville Campus – Durban)

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DECLARATION

I, Natasha Brijlal hereby declare that this dissertation and title: THE ENVIRONMENTAL AND HEALTH STATUS OF THE MNGENI ESTUARY, is a result of my own investigation and research and that it has not been submitted in part or in full for any other degree or to any other institution or university.

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20 MAY 2005

Date

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ABSTRACT

The Mngeni River system, referred to as the lifeline of the Durban Metropolitan Area, serving as estimated population of more than two million, is the most intensively utilized fluvial system in KwaZulu-Natal. The river is characterized by human activities, especially industrialization, from its source in the Drakensburg down to the point of discharge at Beechwood within the Durban Metropolitan Area. Anthropogenic influences within the catchment derive from dam construction and water abstraction, diverse settlements, commercial and subsistence agriculture, industrial and urban land use, and recreational uses. In this study, aspects of the physical, chemical and biological characteristics (pH, turbidity, total dissolved solids, total suspended solids, conductivity, temperature, calcium, chloride, sulphate, nitrate, nitrite, ammonia) of the lower Mngeni river and the Mngeni Estuary were monitored seasonally to ascertain the general health status of this environment.

All of these parameters measured demonstrated distinct seasonal variability whilst some parameters (ammonia, calcium, chloride, nitrate, nitrite, phosphate and total dissolved solids) fall well within the DWAF critical limits for estuarine/fresh water bodies. The study reveals that several others (sulphate, calcium, E.coli) occur in concentrations that are significantly higher than the DWAF general standards. Of particular concern is the extremely high level of E.coli measured in the estuary (5- 10 times of DWAF limits). This study determined that the major sources of pollutants derive from five possible sources. These are industries, the Northern Wastewater Treatment plant, informal settlements along the river banks, rural settlements downstream of the Inanda Dam, vagrants and other indiscriminate polluters.

This study therefore confirms that the lower Mngeni River and the estuary is particularly susceptible to pollution. To help alleviate this problem and aid policy development, recommendations to aid improved management of the system are also presented.

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THE ENVIRONMENTAL AND HYDROLOGICAL STATUS OF THE MNGENI RIVER

CHAPTER 1

INTRODUCTION AND CONTEXTUALIZATION OF THE PROBLEM

1.1 Preamble

We live on a water planet, or we can say, we live on a blue planet. Our earth's green colours are not possible without water, and its brown colours are water – scarce areas that cannot support much vegetation. Water covers about 71% of the earth's surface. The world's oceans help regulate the planets climate, dilute and degrade some of our wastes, and are a major habitat for many of the planet's living creatures. The earth's organisms are made mostly of water, for example, a tree is about 60% water. In the human population women are about 50% water and men about 60% water by weight. Each of us needs only a dozen or so cupfuls of water per day to survive, but huge amounts of water are needed to supply us with food, shelter and our other needs and wants (Miler, 1996).

It is the general perception of many developing countries that there are enough water resources to meet prevailing demands and this is highlighted by the fact that economic development outweighs environmental concerns. A watercourse that is polluted can cause a serious threat to the natural environment, endangering human life and aquatic flora and fauna. Therefore, to achieve and maintain an acceptable standard of living, access to a safe and reliable resource of clean drinking water is essential. This will become a viable objective only by keeping our valuable water resources as pollution-free as possible. Water pollution control and water resource management is vital for the protection of water resources. Not only does this require vast amounts of money but must be conducted in a socially acceptable and sustainable manner (Howards, 1995).

Many cities refuse to see water as a precious and finite resource and continue to squander and contaminate supplies. In Manila for example, 58% of water channeled into city pipes disappear unaccounted for. Contaminated water already causes over 80% of all diseases and more than a third of the number of deaths in developing countries. Water related disease (cholera, typhoid, etc.) also account for an estimated 10% of each person's working life, and the urban poor suffer more than most. For example, in Soweto Township, South Africa, cholera is one hundred times more common than in the adjoining high income communities (Water Quality Information, 1991).

Innovative approaches and new methodologies for protecting public health, recovering nutrient resources and protecting water resources from pollution are necessary (Howards, 1995).

Integrated, zero-discharge, and wastewater re-use strategies are the emerging concept in municipal wastewater re-use at this time and the development and dissemination of viable alternatives for urban wastewater re-use is essential (Bouwer, 1993b).

Rapid industrialization, urbanization and population growth in different countries resulted in the generation of large quantities of waste materials, some of which are toxic, carcinogenic or mutagenic causing problems of their disposal into the environment (Miller, 1996).

As industrialization, urbanization and population grows, so does the demand for freshwater. The availability of freshwater limits the number of people that an area can support. In turn, population growth and density typically affect the availability and quality of resources in an area, as people attempt to assure their water supply by digging wells, constructing reservoirs and dams, and diverting the flow of rivers (Kiernan, 1996; Kraemer, 1998). If water needs consistently outpace available supplies, at some point overuse of water leads to the depletion of surface and groundwater resources, triggering chronic water shortages (Merla, 1998).

1.2 Water as a resource

Water is one of the most important natural resources that sustains life, and invaluable for the operation of industries. While population and industrialization in South Africa is growing at a phenomenal rate, the demands on water resources are enormous. Neither the individual nor the organized community can survive without water. Modern industrial development would not have been possible without an adequate supply of water. It is therefore not surprising that water has occupied an important position in the activities of human beings (Miller, 1986).

Many rivers in Eastern Europe, Latin America and Asia that are used as a source of drinking water are severely polluted as are some rivers in more developed countries. In China, 41% of large cities obtain their drinking water from polluted groundwater. In Russia half of all tap water is unfit to drink and a third of the aquifers are too contaminated for drinking purposes (Miller, 1996).

According to the World Health Organization (WHO), 1.2 billion people – over one fifth of humanity doesn't have a safe supply of drinking water and 1.8 billion people lack adequate sanitation facilities. At least five million people, most of them children under the age of 5, die every year from water borne diseases that could be prevented by clean drinking water and better sanitation (Howards, 1995).

Only a tiny portion of the planet's abundant water is available to us as fresh water. About 97% is found in the oceans and is too salty for drinking, irrigation or industry. The remaining 3% is fresh water. About 2.997% of it is locked up in ice caps or glaciers or is buried so deep that it costs too much to extract. Only about 0.003% of the earth's total volume of water is easily available to us as soil moisture, exploitable groundwater, water vapour, and in lakes and streams. If the world's water supply were only 100 litres our usable supply of fresh water would be only about 0.003 litres (one and a half teaspoons), (Miller, 1996).

Fortunately, the available fresh water amounts to a generous supply that is continuously collected, purified and distributed in the hydrologic cycle. This natural recycling and purification process provides plenty of fresh water so long as we don't either overload it with slowly degradable and non-degradable wastes or withdraw it from underground supplies faster than it is replenished. Unfortunately, we are doing both (Miller, 1986).

1.2.1 Water availability

Only one-hundredth of one percent of the world's total supply of water is considered easily accessible for human use (Lefort, 1996). Globally, between 12.5 and 14 billion cubic metres of water (12 500 to 14 000 cubic kilometers) are considered available for human use on an annual basis. This amounts to about 9 000 cubic metres per person per year, as estimated in 1989. (Lean and Hinrichsen, 1994). (Note: 1 cubic metre equals 1 000 litres). By the year 2025 global per capita availability of freshwater is projected to drop to 5 100 cubic metres per person as another 2 billion people join the world's population. Even then, this amount would be enough to meet human needs if it were distributed equally among the world's population (UNESCO, 1996).

Global figures on water availability give a skewed picture. The world's available freshwater supply is not distributed evenly around the globe, throughout the seasons, or from year to year. In some cases water is not where we want it, nor in sufficient quantities. In other cases we have too much water, in the wrong place, at the wrong time. We "live under the tyranny of the water cycle", observes hydrologist Falkenmark (1993), referring to the earths hydrological cycle.

The earth's hydrological cycle acts like a giant water pump that continually transfers freshwater from the oceans to the land and back again. (See Fig. 1.1).

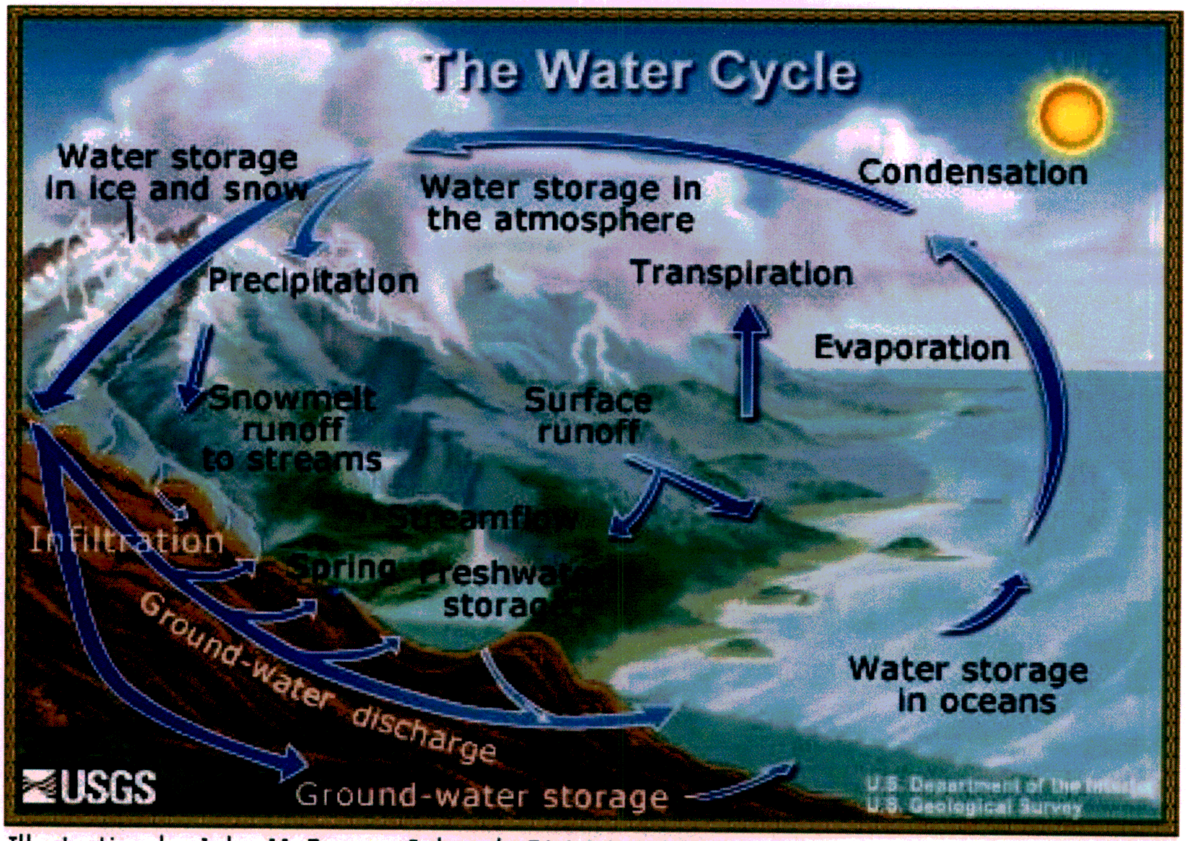

Illustration by John M. Evans, Colorado District, USGS

<u>Figure 1.1</u>: The Water Cycle

Source: http://ga.water.usgs.gov/edu/watercycle.html **(2004).**

In this solar-driven cycle, water evaporates from the earth's surface into the atmosphere and is returned as rain or snow. Part of this precipitation evaporates back into the atmosphere. Another part flows into streams, rivers and lakes, commencing a journey back to the sea. Still another part sinks into the soil and becomes soil moisture or groundwater. Plants incorporate soil moisture into their tissues and release it into the atmosphere in the process of evapo-transpiration (UN, 1997). Much of the groundwater eventually works its way back into the flow of surface waters (UN, 1977).

1.2.2 Water scarcity and explosive population growth

The world's population, at nearly 6 billion, is increasing by about 80 million people each year. This number implies an increased demand for freshwater of about 64 billion cubic metres a year – an amount equivalent to the entire annual flow rate of the Rhine River (Clarke, 1991). While population growth rates have slowed, the absolute number of people added to the population each year, remains near historic highs. For example, because nearly 2 billion people have been added to the planet since 1970, the availability of water is one-third lower now than it was then (Pastel, 1997).

China and India, the world's first and second most populous countries, provide examples of how even modest population growth rates translate into large absolute numbers when the population base is large. In China the population growth rate is about 1% per year, estimated in 1998 (PRB, 1998). Nevertheless, because China's population is over 1.2 billion people, even a low population growth rate means 12 million additional people each year. India's population growth rate which is substantially higher than China's, at about 1.9% per year, means about 18 million people added each year to India's current population of about 970 million (UNFPA, 1977).

In the two regions of the world that already face the most serious absolute or seasonal shortages of water – Africa and near the East – population growth rates remain amongst the highest in the world. In sub-Saharan Africa population is growing by an average 2.6% a year; in the Near East and North Africa, by 2.2% (PRB, 1988). These population growth rates have ominous implications for water supply in the countries of these regions.

As their populations grow, more and more countries are facing water shortages (Falkenmark, 1993). A country is said to experience *water stress* when annual water supplies drop below 1,700 cubic meters per person. At levels between 1

700 and 1 000 cubic metres per person periodic or limited water shortages can be expected. When annual water supplies drop below 1 000 cubic meters per person, the country faces water scarcity (Gardner-Outlaw, 1977).

Once a country experiences water scarcity, it can expect chronic shortages of freshwater that threaten food production, hinder economic development and destroy ecosystems. According to Falkenmark (1993), based on an index of per capita freshwater needs, estimated a minimum need of 100 litres per day per person for household use and from 5 to 20 times as much for agricultural and industrial uses.

It is very difficult to present population-related data on South Africa because there is no efficient method of data collection yet. (Green Paper on Population Policy, 1995). The Durban Metropolitan Area (DMA) has a large and rapidly growing population due to increasing urbanization, natural growth and migration (Durban Metro Webpage, 1999). The Durban area has a population of 2 523 601 people according to the 1998 census. This is a phenomenal increase since 1991 which had only 716 000 residents (Durban Metro Webpage, 1999).

Human population is one of the main causes of environmental degradation. A growing population and increasing standards of living has created increased demands for goods and services (including housing, water and electricity), increased production of waste, increased use of the environment for economic and recreational activities and increased transportation needs (Durban Metro Webpage, 1999).

The issue of water in South Africa is a good example of these interactions. Water is in very short supply in South Africa. This is partly because there is little rainfall, but it is also because of bad water management in terms of building and maintaining boreholes, dams and so on, and the inequitable distribution of the water that there is. Most resources are not absolute; access to them depends on levels of technology, and countries can decide how important any resource is and how much money to spend on making it available. So, for example, in the 1995 budget, water supply was allocated to more of the budget because the new government wanted to make it a priority (CSIR, 2002).

In all countries, rich people consume more than poor people do. Thus the impact of a more affluent section of the population on resources and the environment, even if their numbers are few, may be greater than that of the poorer sections of the population. South Africa is an extreme example of this: while some South Africans, and the industrial sector, use up a lot of South Africa's limited water supply, most South Africans use very little. The recent government decision to charge a higher price for water to those who use most of it indicates recognition of the importance of challenging consumption patterns in a context of the need to conserve a resource, in this case water (Greenpaper on Population Policy, 1995).

The Durban Metropolitan Area's (DMA) population has a range of impacts on the natural environment as a result of demand for goods and services (including housing, water and electricity supply), production of waste products, undertaking economic and recreational activities and moving around the city. As the population of the DMA continues to grow, due to the birthrate and people moving to the city, these pressures on the environment will continue to increase.

Table 1.1 Population Needs and Associated Environmental Impacts

The Needs	The Impact
Safe drinking water	Modification of river systems
Regular food supply	Increase in agricultural productivity with subsequent increase in pesticide and fertilizer use and vegetation changes
Waste Disposal	Provision of landfill sites. Illegal dumping of waste. Pollution of land, air and water through poor waste disposal
Housing	Informal and formal settlements developing on valuable open spaces
Transportation	Operation of motor vehicles causes air and noise pollution
Employment	Economic activity can result in air, water, land and noise pollution as well as the destruction of natural habitats
Services and Infrastructure	The provision of services and infrastructure may result in encroachment into natural ecosystems and/or pollution of the natural environment.

(Durban Metro Webpage, 1999).

1.3 Contextualization of the problem

Water, a life sustaining resource, is currently experiencing degradation at an unprecedented rate. Overutilisation and pollution of this natural resource, a consequence of human activities, apart from having a detrimental effect on quality and quantity also impacts negatively on the hydrology of fluvial systems and certain ecosystems that are dependent on fresh water systems. In some instances the water bodies are unable to assimilate themselves to their original status. Reference in this regard can, *inter alia*, be made to the Yangtze Basin in China, the Ganges River in India and the Vistula River in Poland.

The water situation in South Africa is further exacerbated by geographical distribution. More than 80% of the rainfall occurs on the eastern part of the country. One such fresh water system that is potentially susceptible to the influence of human activities on water quality and quantity is the Mngeni River. The river systems in South Africa are in urgent need of conservation and management since the mean annual precipitation of 480mm is below the world average of 850mm per annum.

The Mngeni River system, referred to as the lifeline of the Durban Metropolitan Area, serving an estimated population of more than two million, is the most intensively utilized fluvial system in KwaZulu-Natal. This river is characterized by human activities virtually from its source in the Drakensberg down to the point of discharge at Beachwood within the Durban Metropolitan Area. Anthropogenic influences within the catchments derive from dam construction and water abstraction, diverse settlements, commercial and subsistence agriculture, industrial and urban land use, sand winning and recreational uses. The impacts of these myriad of activities upon the physical, chemical and biotic condition of the Mngeni Estuary have not been conclusively determined in studies thus far conducted in this environment. Past researches on this estuary have, thus far, focused exclusively on either physical or biotic factors. It is within this context that this investigation is being executed. The primary focus will be on a presentation of a holistic analysis of the influence of human activities on the environmental and health status of the estuary and the immediate environment. This investigation is expected to contribute significantly to a comprehensive understanding of the dynamic mechanisms affecting the optimum functioning of the Mngeni Estuary and will consequently present the basis for improved management of the system.

1.4 Aims, Objectives and Hypothesis of Study

1.4.1 The aim of the study/investigation

The aim of the study is to establish the environmental and health status of the Mngeni Estuary according to accepted national protocols such as those adopted by the River Health Programme (RHP) and commonly accepted procedures for determining the health status of estuaries.

1.4.2 The objectives of the study is/are

Major objectives include:

- To outline the current human utilization of the Mngeni catchment and estuary;
- To trace the historical changes of the main ecosystems of the Mngeni Estuary;
- To quantify the major factors determining estuarine health status including estuarine habitats, invertebrate organisms, mangrove communities and riparian vegetation;
- To evaluate the chemical status of the estuarine waters to ascertain pollution levels, their sources and effects and;
- To provide an overall assessment of the state of the estuary and recommendations for improved management of the system.

1.5 Chapter Formation and Sequence

The focus in chapter two will is a review of literature pertaining to water pollution. Case studies will also be highlighted here.

The third chapter of the study encompasses a description of the study area followed by the methodology employed to execute the investigation. Results of the study in the form of tables and graphs together with the analysis are presented in chapter four.

The fifth and final chapter provides the reader with discussion and evaluation of the results presented in the previous chapter. This is followed by recommendations and an overall conclusion of the investigation.

1.6 Conclusion

No matter how water is used – whether for agriculture, industry, or municipalities – there is great potential for better conservation and management. Water is wasted nearly everywhere. Until actual scarcity hits, most countries and most people take access to fresh water for granted.

“We have to stop living as if we had unlimited water supplies and start recognizing that we must deal with serious water constraints”. The relevant question about freshwater is not “how much water do we need and where do we get it?” rather, it is “how much water is there and how can we best benefit from it?” (Falkenmark, 1989).

CHAPTER 2

THE ENVIRONMENTAL AND HEALTH STATUS OF RIVERS: A THEORETICAL REVIEW

2.1 Introduction

Of all the planet's renewable resources, fresh water may be the most unforgiving. Difficult to purify, expensive to transport and impossible to substitute, water is essential to produce food, for economic development and life itself. Its importance to human health and well-being was underlined in mid-1993 when the United Nations' new Commission on Sustainable Development made improvement of water quality one of the first priorities for technology transfers from wealthy (First World) countries to poorer (Third World) ones.

Only when taps run dry, as happened for a time in 1993 in places as far apart as Des Moines, Loa, and Sarajevo, are those who live in the industrialized world were reminded how critical access to water is to all aspects of life. In less prosperous countries, millions of people, most of them women, need no such reminder. They walk miles each day to find the water they need and carry it home.

Yet water availability has not received the attention it deserves in global discussions of the sustainable use of natural resources. It has been examined even less in the context of population growth. On a planet whose surface is more than two thirds covered by water, the illusion of abundance has clouded the reality that renewable fresh water is an increasingly scarce commodity (World Resource Institute, 1988).

While the world's oceans may seem abounded, the amount of fresh water actually available to people is finite, and a mere fraction of the water visible from outer space. Over the long term, the water humanity can count on for use year after year is the planet's *renewable* supply. That is the water that falls from the sky, seeps into the ground or collects in rivers and lakes and flows back to the sea, from which it was first drawn up by the sun. To be used sustainably, water cannot be withdrawn from reservoirs and other sources faster than it is replenished through the natural hydrological cycle (Edwards, 1997).

Our capacity for capturing and storing fresh water has expanded throughout history, and we are learning how to use it more efficiently. But no technology can significantly expand the basic resource. The use of desalination may suggest the world's oceans are potentially inexhaustible sources of fresh water, but the process of extracting salt from seawater remains expensive and dependent on polluting and non-renewable fossil fuels (Stokes, 1983).

Life is tied to water as it is tied to air and food. And food is tied to water since plant growth depends on its flow from roots to foliage. Throughout history, secure access to water has been essential to social and economic development and the stability of cultures and civilizations. Since ancient times, agriculture has depended on fortuitous combinations of good soils and predictable water supplies, and dependable water sources of abundant water played a prominent role in the industrialization of Europe and North America. Even if less developed nations pursue new development paths that avoid the errors of the past, it is difficult to imagine how we will proceed if renewable fresh water is in short supply (Arnell, 1996).

Efforts to encourage water conservation face special challenges not encountered with other natural resources. In much of the world, water is not controlled by market mechanisms because it is either free for the taking or unmetered. Nor is water a global resource that can be traded like petroleum or given in aid like food or medicine. Overexploitation and pollution of water in one river basin may be of little or no relevance to those living in another. But, ultimately the need for clean, drinkable water is in close proximity to households is a basic requirement for all human beings (Stokes, 1983).

Rivers are important to humans because they supply fresh drinking water, serve as home for important fisheries, provide transportation routes, and are the source for irrigation water and hydroelectric power. Humans have used rivers since the beginning of civilization. In Asia, people have revered the life-giving importance of rivers for thousands of years. Many ancient temples are located near streams and rivers that needed protection to ensure high quality water for society. The Chinese written characters for the word *politics* express the sense of responsibility for waterways – the literal interpretation of the characters includes the meaning of "protection of water." Many of the ancient, legendary leaders in China were respected because of their ability to control water so that fields could be irrigated and floods prevented. The first great African civilization began along the banks of the Nile around 5000 BC. The agricultural wealth along the valley of the Nile River gave the pharaohs in ancient Egypt their power. Many pyramids and shrines stood along the banks of the Nile (Stokes, 1983).

Other important aspects of rivers are the ecological characteristics of river channels and floodplains. These areas provide a zone between land and water environments. Floodplains and channels are diverse habitats that support the world's largest wetlands, which are home to innumerable species of plants and animals. Most of the fish that live in rivers use the channel and floodplain and in some rivers, the deltas and estuaries, during their life cycle (Leal and Mertes, 2002).

Fresh water plays an integral role in the functioning of all environments and societies. Since its earliest inception, human society has seen fresh water bodies as a vital resource, and entire ancient 'hydraulic civilizations' developed on certain rivers, notably those of the Tigris-Euphrates, the Nile and the Indus Valley. Society is no less reliant on this fundamental resource today. Fresh water from lakes, rivers and wetlands is utilized for municipal, agricultural, industrial, recreational and power generation uses; it forms a convenient medium for transport and a sink for wastes. Society's use of fresh water, its availability and quality, have thrown up numerous issues of controversy and these issues will become more acute as global water withdrawals continue to increase. An estimate of the gross global withdrawal for the year 2000 is 5200km3, a nine-fold increase over the 1900 level, and this increase continues to accelerate (Shiklomanov, 1993).

Humanity currently uses just over half of all reasonably accessible global runoff and about a quarter of total terrestrial evapotranspiration (Postel *et al.*, 1996). Global data mask regional differences, however, which are essentially functions of climatic influences. All countries suffer from periodic excesses of fresh water in the form of floods, while others also experience perennial shortages, in some cases due to a complete absence of permanent rivers (e.g. Malta and Saudi Arabia). An idea of the wide variety of ways in which human activity can adversely affect freshwater ecosystems is given by noting the effects upon freshwater fish, a biological indicator of ecosystem health (Refer to Table 2.1) (Middleton, 1999).

2.2 How is water used?

It is difficult to estimate the amount of water needed to maintain acceptable or minimum living standards. Moreover, different sources use different figures for total water consumption and for water use by sector of the economy (European Schoolbooks (ES), 1994).

A range of 20 to 40 litres of freshwater per person per day is generally considered to be a necessary minimum to meet needs for drinking and sanitation alone. If water for bathing and cooking is included as well, this figure varies between 27 and 200 litres per capita per day (Gleick, 1996).

The amount of water that people in a country actually use depends not only on minimum needs and how much water is available for use but also on the level of economic development and the extent of urbanization. Globally, of the three standard categories of freshwater use – for agriculture, industry, and domestic (personal, household, and municipal) – agriculture dominates. On a worldwide basis, agriculture accounts for about 69% of all annual water withdrawals; industry, about 23%; and domestic use, about 8% (Engelman and Leroy, 1993).

TABLE 2.1: Summary of main pressures facing freshwater fish and their habitats temperate areas.

Danger	Effects
Industrial and domestic effluents	Pollution, elimination of stocks, blocking of migratory species
Acid deposition	Elimination of stocks in poorly buffered areas
Land use (farming and forestry)	Eutrophication, acidification, sedimentation
Eutrophication	Algal blooms, deoxygenation, changes in species
Industrial development (including roads)	Sedimentation, obstructions, transfer of species
Warm water discharge	Deoxygenation, temperature gradients
River obstruction (dams)	Blocking of migratory species
Fluctuating water levels (reservoirs)	Loss of habitat, spawning, food supply
Infilling, drainage and canalisation	Loss of habitat, shelter, food supply
Water transfer	Transfer of species and disease
Water abstraction	Loss of habitat and spawning grounds, transfer of species

Fish farming	Eutrophication, introductions, diseases, genetic changes
Angling and fishery management	Elimination by piscicides, introductions
Commercial fishing	Overfishing, genetic changes
Introduction of new species	Elimination of native species, diseases, parasites
Water recreation	Disturbance, habitat loss

***Source:* Middleton (1999).**

Sources of water pollution can be traced to all sorts of human activity, including agriculture, industry, urbanization and mining. Most forms of water pollution can be classified into three categories:

- Excess nutrients from sewage and soil erosion;
- Pathogens from sewage; and
- Heavy metals and synthetic organic compounds from industry, mining and agriculture.

Three other forms should also be mentioned:

- Thermal pollution from power generation and industrial plants;
- Radioactive substances; and
- Turbidity problems caused by increased sediment loads or decreased water flow.

Organic liquid wastes can be broken down by bacteria and other micro-organisms in the presence of oxygen, and the burden of organics to be decomposed is measured by the biochemical oxygen demand (BOD). Liquid organic wastes include sewage, many industrial wastes (particularly from industries processing agricultural products) and runoff which picks up organic wastes from land. As a river's dissolved oxygen decreases with increasing organic loads of organic wastes, so fish and aquatic plant life suffer and may

eventually die. Heavy volumes of organic wastes can overload a riverine system to the point at which all dissolved oxygen is exhausted.
Pollution of water due to temperature increase, so-called ‘thermal pollution,’ also reduces its dissolved oxygen content. This occurs in two ways. An increase in water temperature decreases the solubility of oxygen on the one hand, and on the other, increases the rate of oxidation, thereby imposing a faster oxygen demand on a smaller content. Thermal pollution also has a number of more direct adverse effects on river ecology, including a general increase in undesirable forms of algae and reduced reproduction and growth of some species of fish (Langford, 1990).

Inorganic liquid wastes become dangerous when not adequately diluted. Even in very small concentrations, however, some heavy metals (such as cadmium, lead and mercury) are particularly dangerous and can bioaccumulate up the food chain, ultimately damaging human health. Pathogens from human waste spread disease and represent the most widespread contamination of water (Table 2.1). Water-related diseases can be classified into those that are waterborne (e.g. diarrhoea, cholera and polio); those that are related to the lack of personal cleanliness (e.g. trachoma and typhoid); and those that are related to water as a habitat for certain disease vectors (e.g. schistosomiasis, malaria and onchocerciasis), (UNEP/WHO, 1988).

Data for freshwater quality are generally sparse, cover limited periods, and are subject to changes in analytical methods and the movement of gauging stations, but a coordinated effort at worldwide monitoring has been made within the framework of UNEP’s Global Environmental Monitoring System, or GEMS (UNEP/WHO, 1988). The network, launched in 1977, comprises 240 river stations, 43 lake stations and 61 groundwater stations.

Meybeck *et al.* (1989) showed how particular sources of water pollution have ebbed and flowed with time in the highly industrialized countries. The growth of urban areas during the Industrial Revolution created the first wave of serious water pollution, from domestic sources, around the turn of the century. These have been superseded by industrial pollutants and, during the second half of the century, by nutrient pollution (particularly from agricultural sources), and by micro-organisms towards the end of the 1990s. A similar pattern of peaks in serious pollution problems is being experienced in the rapidly industrializing countries, but compressed into the post-war decades, and it is here that some of the most serious water pollution problems are being faced today. The other regions where water pollution has reached crisis proportions are in the countries of the former Soviet bloc. As with many other pollution issues, it is often the poorer sectors of society that suffer most from the detrimental effects of poor water quality (Meybeck *et al*, 1989).

It is easy to dispose of waste by dumping it into a river or lake. In large or small amounts, dumped, intentionally or accidentally, it may be carried away by the current, but will never disappear. It will reappear downstream, sometimes in changed form, or just diluted. Freshwater bodies have a great ability to break down some waste materials, but not in the quantities discarded by today's society. This overload that results, called pollution, eventually puts the ecosystem out of balance. Sometimes nature itself can produce these imbalances. In some cases, the natural composition of the water makes it unfit for certain uses: e.g. water flowing in the highly saline terrain of the prairies or gushing from highly mineralized springs in some parts of the country cannot sustain fish populations. But most often our waterways are being polluted my municipal, agricultural and industrial wastes, including many toxic synthetic chemicals which cannot be broken down at all by natural processes. Even in tiny amounts, some of these substances can cause serious harm (Garcia, 1998).

2.3 Pollution and water

In the last 20 years, developed countries have made enormous strides in cleaning up water supplies that had become heavily polluted. Despite this progress, there is still along way to go. In the United States, some of the surface and groundwater is still dangerously polluted in 40 states, and the lack of clean water restricts economic development in many areas (Arms, 1994).

Water pollution in less-developed countries remains a huge and growing problem. The former Soviet-bloc countries are probably the most polluted area on Earth because pollution from industry and agriculture was never controlled. The Polish Academy of Sciences reports that more than half of Poland's water is too polluted for even industrial use. The very poor countries are not generally troubled by industrial pollution. Here the problem is that the population has outgrown the water supply so that water used for drinking is often polluted with sewage and agricultural runoff, leading to a terrible death toll from water-borne diseases (Arms, 1994).

Water pollution is the introduction into fresh or ocean water of chemical, physical, or biological material that degrades the quality of water and affects the organisms living in it. Water pollution has two underlying causes: industrialization and the human population explosion. Both produce waste products that we cannot dispose of or cannot dispose of as fast as we produce them (Batkin and Keller, 1995).

According to Batkin and Keller (1995) and Miller (1997), there are several classes of pollutants. These include:

1. **Pathogens**

   These are organisms that cause diseases such as bacteria, viruses, protozoa, and parasitic worms, and many live only in water. Pollution with pathogens is usually caused by domestic sewage and untreated human and animal wastes.

A good indicator of the quality of drinking water is the number of colonies of *coliform bacteria* present in a 100ml sample of water:

The World Health Organization (WHO) recommends a *coliform* count of 0cfu/100ml for drinking water, and the Environmental Protection Agency (EPA) recommends 200cfu/100ml for swimming water.

Since the average human excretes 2 billion such organisms per day, its easy to see how untreated sewage can contaminate water.

2. **Nutrients and biodegradable organic matter**

   Biodegradable organic matter includes the remains of animals and plants, including faeces, leaves, wood waste, fat, and debris from food processing plants. These substances are broken down by decomposers into mineral nutrients that plants take up.

3. **Oxygen Demanding Wastes**

   Organic wastes that can be decomposed by aerobic bacteria degrade water quality by depleting water of diffused oxygen (DO) and therefore fish and other organisms die. The Biological Oxygen Demand (BOD) is a measure of the quantity of oxygen available in contaminated water.

4. **Physical Agents**

   Physical agents, refer, amongst other things, to like heat and suspended solids such as insoluble particles of soil and other matter (driftwood, material from human activities, etc.) Clouds of sediment hinders photosynthesis, disrupts aquatic food webs, carries bacteria and other harmful substances, clogs gills, diminishes light penetration; fills in lakes, dams, estuaries and destroys spawning grounds.

5. **Toxic Chemicals**

These are many chemicals that are poisonous to organisms. They include acids, salts, and compounds of toxic metals such as mercury and lead, where high concentrations of these can render water as unfit to drink, harm fish and other aquatic life, depress crop yields, increase corrosion of equipment that use water, etc. Other toxic chemicals are organic compounds such as some pesticides and waste products of the petrochemical industry and radioactive waste, which threaten human and aquatic life. The water that is polluted by water soluble radioactive isotopes which concentrate in tissues and organs, causing birth defects, cancer and genetic disorders.

6. **Inorganic Plant Nutrients**

Water soluble nitrates and phosphates promote excessive growth of algae and other aquatic plants. These in turn reduce light penetration resulting in death and decay of such plants. The overall impact is a significant reduction or even depletion of dissolved oxygen.

7. **Thermal Pollution**

Water drawn from rivers to cool industrial and power plants are returned to the river at higher temperatures causing a lowering of dissolved oxygen, habitat changes, and makes aquatic organisms more vulnerable to diseases.

According to Arms (1994), the thousands of points that serve as sources of pollution can be broadly categorized into:

- **Point sources** are individual locations such as a factory, a sewage treatment plant, or an oil tanker. Pollution from point sources is relatively easy to control because the source can be identified and regulated.

- **Non-point sources**, sources that occupy large areas and have many routes into the water supply. Non-point sources include streets, highways, construction sites, farmland, forests, and residential areas. Fertilizers, pesticides, oil, animal faeces, salts, and other pollutants from non-point sources trickle into our water supply by way of the soil, storm drains, and runoff into marshes and streams.

Garcia (1998) indicates that the types of water pollutants can be grouped as:

a) Non-persistent (degradable)

- domestic sewage
- fertilizers
- some industrial wastes

These compounds can be broken down by chemical reactions or by natural bacteria into simple, non-polluting substances such as carbon dioxide and nitrogen. The process can lead to low oxygen levels and eutrophication if the pollution load is high. But this damage is reversible.

b) Persistent (degrade slowly)

- some pesticides (e.g. DDT, dieldrin)
- some leachate components from landfill sites (municipal, industrial)
- petroleum and petroleum products
- PCBs, diotoxins, polyaromatic hydrocarbons (PAHs)
- radioactive materials such as strontium-90, cesium-137, radium-226, and uranium
- metals such as lead, mercury, cadmium

This is the most rapidly growing type of pollution and includes substances that degrade very slowly or cannot be broken down at all; they may remain in the aquatic environment for years or longer periods of time. The damage they cause is either irreversible or reparable only over decades or centuries.

c) Other

- warm water from cooling towers (thermal pollution)
- floating debris
- garbage
- foam

The above examples are not of chemical pollution, but of physical pollution which interferes mainly with the usability and/or aesthetic appeal of the water. In certain cases, thermal pollution can kill fish.

2.4 The Health Dimension

Water-related diseases are a human tragedy, killing millions of people each year, preventing millions more from leading healthy lives, and undermining development efforts (Nash, 1993). About 2.3 billion people in the world suffer from diseases that are linked to water (Kristof, 1997).

Some 60% of all infant mortality is linked to infectious and parasitic diseases, most of them water-related (Rowley, 1990). In some countries water-related diseases make up a high proportion of all illnesses among both adults and children. In Bangladesh, for example, an estimated three-quarter of all diseases are related to unsafe water and inadequate sanitation facilities. In Pakistan, one-quarter of all people attending hospitals are ill from water-related diseases (Ali, 1992).

Providing clean water supplies of water and ensuring proper sanitation facilities would save millions of lives by reducing the prevalence of water-related diseases (United Nations Commission on Sustainable Development, 1997). Thus, finding solutions to these problems should become a high priority for developing countries and assistance agencies.

While water-related diseases vary substantially in their nature, transmission, effects, and management, adverse health effects related to water can be organized into three categories: **water-borne** diseases, including those caused by both faecal-oral organisms and those caused by toxic substances; **water-related vector** diseases (Bradley, 1994). Another category, **water-scarce** (also called water-washed) diseases consists of diseases that develop where clean fresh water is scarce (Kjellen and McGranahan, 1997).

2.4.1 Water-Borne Diseases

Water-borne diseases are "dirty-water" diseases – those caused by water that has been contaminated by human, animal, or chemical wastes. Worldwide, the lack of sanitary waste disposal and of clean water for drinking, cooking, and washing has resulted in over 12 million deaths a year (Davidson and Chakraborty, 1992).

Water-borne diseases include cholera, typhoid, shigella, polio, meningitis, and hepatitis A and E. Human beings and animals can act as hosts to the bacterial, viral, or protozoal organisms that cause these diseases. Globally, millions of people have little access to sanitary waste disposal or to clean water for personal hygiene. An estimated 3 billion people lack a sanitary toilet, for example. Over 1.2 billion people are at risk because they lack access to safe freshwater (Khan, 1997).

Where proper sanitation facilities are lacking, water-borne diseases can spread readily. Untreated excreta carrying disease organisms wash or leach into freshwater sources, contaminating drinking water and food. The extent to which disease organisms occur in specific freshwater sources depends on the amount of human and animal excreta that they contain (Bowman, 1994).

Diarrhoeal disease, the major water-borne disease, is prevalent in many countries where sewage treatment is inadequate. Instead, human wastes are disposed of in open latrines, ditches, canals, and water courses or they are spread on cropland. Worldwide an estimated 4 billion cases of diarrhoeal disease occur every year, causing 3 million to 4 million deaths, mostly among children (Olshansky *et al.*, 1997).

Using contaminated sewage for fertilizer can result in epidemics of such diseases as cholera. These diseases can even become chronic where clean water supplies are lacking. In the early 1990s, for example, raw sewage water that was used to fertilize vegetable fields caused outbreaks of cholera in Chile and Peru (United nations Commission on Sustainable Development, 1997). In Buenos Aires, Argentina, a slum neighbourhood faced continual outbreaks of cholera, hepatitis, and meningitis because only 4% of homes had either water mains or proper toilets, while poor diets and little access to medical services aggravated the health problems (Ainstein, 1996).

Toxic substances that find their way into freshwater are another cause of water-borne diseases. Increasingly, agricultural chemicals, fertilizers, pesticides, and industrial wastes are being found in freshwater supplies. Such chemicals, even in low concentrations, can build up over time and, eventually, can cause chronic diseases such as cancer among people who use the water (Silfverberg, 1994).

Health problems from nitrates in water sources are becoming a serious problem almost everywhere. In over 150 countries nitrates from fertilizers have seeped into water wells, fouling the drinking water (Maywald *et al.*, 1988). Excessive concentrations of nitrates cause blood disorders. Also, high levels of nitrates and phosphates in water encourage growth of blue-green algae, leading to deoxygenation (eutrophication). Oxygen is required for metabolism by the organisms that serve as purifiers, breaking down organic matter, such as human wastes, that pollute the water. Therefore the amount of oxygen contained in water is a key indicator of water quality (Bowman, 1994).

Pesticides such as DDT and heptachlor, which are used in agriculture, often wash off in irrigation water. Their presence in water and food products has alarming implications for human health because they are known to cause cancer and also may cause low sperm counts and neurological disease (Maywald *et al.*, 1988). In Dhaka, Bangladesh, heptachlor residues in water sources have reached levels as high as .789 micrograms per litre – more than 25 times the WHO-recommended maximum of .03 micrograms per litre (Xinhua Chinese News Agency, 1998). In Venezuela water collected during the rainy season found that the water was contaminated with a number of pesticides. Examination of pregnant women in the area found that they all had breast milk containing DDT residues – toxins that can be passed to an infant (Brunetto *et al.*, 1996).

The seepage of toxic pollutants into ground and surface water reservoirs used for drinking and household use causes health problems in industrialized countries as well. In Europe and Russia the health of some 500 million people is at risk from water pollution. For example, in northern Russia half a million people on the Kola Peninsula drink water contaminated wit heavy metals, a practice that helps explain high infant mortality rates and endemic diarrhoeal and intestinal diseases (Edwards, 1997).

2.4.1.1 Prevention and Solutions

Improving public sanitation and providing a clean water supply are the two steps needed to prevent most water-borne diseases and deaths. In particular, constructing sanitary latrines and treating waste water to allow for biodegradation of human wastes will help curb diseases caused by pollution. At the least, solids should be settled out of waste water so that it is less contaminated. It is important that a clean water supply and the construction of proper sanitary facilities be provided together because they reinforce each other to limit the spread of infection (Vanderslice and Briscoe, 1998).

Many studies link improvements in sanitation and provision of potable water with dramatic reductions in water-related morbidity and mortality. A review in 1991 of over 100 studies of the effects of clean water and sanitation on human health found that the median reduction in deaths from water-related diseases was 69% among people with access to potable water and proper sanitation (Esry *et al.*, 1998).

Providing clean water and sanitation greatly reduces child mortality. According to a review of 144 studies from the 1980s, infant and child deaths fell by an average of 55% as a result of providing clean water and sanitation (USAID, 1990). In a study of countries where infant mortality rates dropped dramatically – as in Costa Rica, where the decline was from 68 deaths per 1,000 live births in the 1970s to just 20 per 1,000 in the 1980s – researchers attributed three-quarters of the mortality decline to water and sanitation projects provided as part of rural community health programs (Yacoob *et al.*, 1989).

While the cost of building freshwater supply systems and sanitation facilities is high, the cost of *not* doing so can become staggering. In Karachi, Pakistan, for example, a study found that poor people living in areas without any sanitation or hygiene education spent six times more on medical care than people who lived in areas with access to sanitation and who had a basic knowledge of household hygiene (Khan, 1997).

2.4.2 Water-Based Diseases

Water-based diseases are caused by aquatic organisms that spend part of their life cycle in the water and another part as parasites of animals. These organisms can thrive in either polluted or unpolluted water. As parasites, they usually take the form of worms, using intermediate animal vectors such as snails to thrive, and then directly infecting humans either by boring through the skin or by being swallowed (Bradley, 1994).

Water-based diseases include guinea worm (dracunculiasis), paragonimiasis, clonorchiasis, and schistosomiasis (bilharzia). These diseases are caused by a variety of flukes, tapeworms, roundworms and tissue nematodes, often collectively referred to as helminths, which infect humans (Muller and Morera, 1994). Although these diseases usually are not fatal, they can be extremely painful, preventing people from working and sometimes even making movement impossible.

The prevalence of water-based diseases often increases when dams are constructed, because the stagnant water behind dams is ideal for snails, the intermediary host for many types of worms. For example, the Akosombo Dam, on the Volta Lake in Ghana, and the Aswan High Dam, on the Nile in Egypt, has resulted in huge increases of schistosomiasis in these areas (Basch, 1990). Also in Mali a survey conducted in 225 villages in different ecological settings found that the prevalence of urinary schistosomiasis was five times greater in villages with small dams (67%) than in the drier savanna villages (13%) (Hunter *et al.*, 1993).

2.4.2.1 Prevention and Solutions

Individuals can prevent infection from water based diseases by washing vegetables in clean water and thoroughly cooking food. They can refrain from entering infected rivers, because many parasites bore through the feet and legs. In areas where guinea worm in endemic, people can use a piece of cloth or nylon gauze to filter out guinea worm larvae, if clean water is unavailable (Yacoob *et al.*, 1989). As with water-washed diseases, providing hygienic disposal of human wastes helps control water-based diseases. Also, for irrigation channels and other constructed waterways, building fast-flowing steams makes it more difficult for snails to survive, thus eliminating the intermediary host (Bradley, 1994).

Some water-development schemes have started disease control programs along with construction of facilities. In the Philippines, for example, where the development of water resources is a high priority, the National Irrigation System Improvement Project in Layte, begun in 1979, included specific provisions and funding to control schistosomiasis. As a result of these measures, the prevalence of water-based diseases dropped from 24% in 1979 to 9% in 1985. Because fewer people fell ill, the average increase in productivity was an estimated 19 days of work per person per year, worth an additional US$1 million in wages ((Hunter *et al.*, 1993).

2.4.3 Water-related Vector Diseases

Millions of people suffer from infections that are transmitted by vectors – insects or other animals capable of transmitting an infection, such as mosquitoes and tsetse flies – that breed and live in or near both polluted and unpolluted water. Such vectors infect humans with malaria, yellow fever, dengue fever, sleeping sickness, and filariasis. Malaria, the most widespread, is endemic in about 100 developing countries, putting some 2 billion people at risk (Chatterjee, 1995; World Bank, 1993).

The incidence of water-related vector diseases appears to be increasing (WHO, 1997). There are many reasons: people are developing resistance to antimalarial drugs; mosquitoes are developing resistance to DDT, the major insecticide used; environmental changes are creating new breeding sites; migration, climate change, and creation of new habitats mean that fewer people build up natural immunity to the disease; and many malaria control programs have slowed or been abandoned (WHO, 1996).

Lack of inappropriate water management, along with failure to take preventive measures, contributes to the rising incidence of malaria, filariasis, and onchocerciasis. Construction projects often increase the mosquito population, as pools of stagnant water, even if they exist only briefly, become breeding grounds (Hunter *et al.*, 1993). For example, in West Africa an epidemic of Rift Valley fever in 1987 has been linked to the Senegal River Project. The project, which flooded the lower Senegal River area, enabled the type of mosquito that carries the virus to expand so much that the virus was transmitted to humans rather than remaining in the usual animal hosts (Olshansky *et al.*, 1997).

2.4.3.1 Prevention and Solutions

The solution to water-related vector diseases would appear to be clear – eliminate the insects that transmit the diseases. This, however, is easier said than done as pesticides themselves may be harmful to health if they get into drinking or irrigation water. Also, many insects develop resistance to pesticides, and diseases can re-emerge in new forms (Olshanksy *et al.*, 1997).

Alternative techniques to control these diseases include the use of bednets and introducing natural predators and sterile insects. In Gujarat, India, for example, an important part of an integrated project to control disease vectors was breeding guppies – fish that eat mosquito larvae – in bodies of water, while eliminating the use of insecticides altogether (WWFC and WWF, 1998). An inexpensive approach to controlling insect vectors involves the use of polystyrene spheres floating on the top of bodies of static water. Because the spheres cover the surface of the water, the mosquito larvae die from lack of air (Bradley, 1994).

Another way to control the vectors is species sanitation – using biological methods and habitat management to reduce or eliminate the natural breeding grounds of the disease vectors (Bowman, 1994). Such methods can include: filling and draining unneeded bodies of stagnant water; covering water storage containers; eliminating mosquito breeding sites by regularly clearing canals, reservoirs, and fish ponds of weeds; installing sprinkler and trickle irrigation instead of canals; and lining canals to prevent silt deposits from forming and impeding the flow of water (Hunter *et al.*, 1993). The integration of education about disease prevention into health services and encouraging community discussion of prevention would help people to control vectors and to identify and eliminate inconspicuous breeding sites (Hunter *et al.*, 1993).

2.4.4 Water-Scarce Diseases

Many other diseases – including trachoma, leprosy, tuberculosis, whooping cough, tetanus, and diphtheria – are considered water-scarce (also known as water-washed) in that they thrive in environments where freshwater is scarce and sanitation is poor. Infections are transmitted when too little fresh water is available for washing hands. These diseases, which are uncontrolled throughout most of the world, can be effectively controlled with better hygiene, for which adequate freshwater is necessary. Some parasitic diseases not usually considered water-related and previously limited in their reach have been rapidly increasing as populations grow and water supplies become more polluted. For example, cysticerosis, a disease usually produced by tapeworms found in undercooked pork and limited to rural areas, expanded rapidly in Mexico City in the early 1980s. As the city's population soared, the parasite multiplied in the highly polluted water of the Tula River, which supplies much of the drinking water for the makeshift settlements on the city's outskirts. Tens of thousands of people downstream from the city sewage system were infected (Garrett, 1994).

2.4.4.1 Prevention and Solutions

Addressing problems of water supply and sanitation can be part of improving maternal and child health care (Evans and Stephenson, 1995). If such problems are not addressed, they can undercut other health measures. For example, a study in Nigeria found that, even though guinea worm was common and known to affect many mothers and small children, primary health care providers did not focus on provision of safe water as a health measure (Yacoob *et al.*, 1989).

In general, public health and disease control programs have not been concerns of water resources development projects, which typically focus on potential economic benefits. Municipal authorities do not take into account the community health benefits to be achieved from water-related projects, in addition to such benefits as power generation, irrigation, flood control, and water supply (Hunter *et al.*, 1993).

2.5 THE PHYSICAL, CHEMICAL, NUTRIENT AND BIOLOGICAL CHARACTERISTICS OF WATER

Water quality is taken to be the combined effect of the physical, chemical and biological constituents of a sample of water for a particular use. For convenience, variables can be grouped in a number of ways. Perhaps the simplest, is to divide them into *physical* attributes such as temperature, turbidity, solids, biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO). *Chemical* constituents are the alkalinity, nitrogen, phosphorous, etc. content of a sample of water. And finally, the *biological* characteristic of water is the total coliforms, *E.coli* content, etc.

2.5.1 The Chemical and Physical Characteristics of Water

Water quality measure can be classified in a number of ways but at most are grouped as physical, chemical and biological. Examples of physical factors are suspended solids, alkalinity, turbidity, hardness, biological oxygen demand (BOD), total oxygen demand (TOD), etc. Chemical measures of water quality include the analysis for the presence of specifications such as calcium, magnesium, lead, chemical oxygen demand (COD), etc.

2.5.1.1 pH (Acidity and Alkalinity)

The concentrations of hydrogen (H+), hydroxyl (OH^-), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions are some of the most important attributes determining the composition and quality of water. Furthermore, these ions are in dynamic equilibrium in most water samples, and a change in the concentration of any one will have an effect on all of the others (WRC, 2004).

The pH value is a measure of the hydrogen ion activity in a water sample. It is mathematically related to hydrogen ion activity according to the expression:

pH = -log10 [H+]

Pure water (i.e. water containing no solutes) ionizes very slightly to produce a small proportion of hydrogen and hydroxyl ions:

$H2O \leftrightarrow H+ + OH^-$

As the concentration of hydrogen ions increases, pH decreases and the solution becomes more acidic. As [H+] decreases, pH increases and the solution becomes more basic.

2.5.1.2 Turbidity

Turbidity is the water quality characteristic most obvious to the casual observer. Its immediate visual effect is to decrease the clarity of water. This factor, together with water colour, leads to impeded light penetration, an effect that may have far-reaching ecological consequences (Gippel, 1989). The major components and properties affecting light penetration of natural waters are tabulated in Table 2.2.

Table 2.2: The major components and properties affecting light penetration in natural waters (modified from Gippel 1989).

Major components of stream loads	**Examples**	**Properties affecting light penetration**
Dissolved organic matter	Fulvic acid, humic acid, lingo-sulphonic acid, tannic acid	Some organic acids give water a yellow-brown colouration: affect colour of water.
Dissolved inorganic matter	Ionic forms of minerals	Concentrations are usually too low to affect light penetration: no effect.
Suspended organic matter	Pollen, micro-organisms, seeds and other fine to coarse particles	Variations in colour, shape, size, fluorescence and refractive index: affect turbidity of water.
Suspended inorganic matter	Products of weathering (e.g. kaolinite, quartz, illite, smectite, mica) and speciation (e.g. hydroxides)	Variations in colour, shape, size, fluorescence and refractive index: affect turbidity of water.

Light penetration is normally measured either *in situ* by visual observation or using a light probe, or *in vitro* using a spectrophotometer or turbidimeter.

2.5.1.3 Total Suspended Solids (TSS)

The total suspended solids (TSS) concentration is a measure of the amount of material suspended in water. The concentration of suspended solids increases with the discharge of sediment washed into rivers due to rainfall and re-suspension of deposited sediment. Natural variations in rivers often result in changes in the TSS, the extent of which is governed by the hydrology and geomorphology of a particular region. Increases in total suspended solids may also result from anthropogenic sources, including:

- Discharge of domestic sewage,
- Discharge of industrial effluents (such as pulp/papermill, china-clay, and brick and pottery industries),
- Discharge from mining operations,
- Fish-farm effluents (mostly organic suspended solids) and
- Physical perturbations from road, bridge and dam construction.

(DWAF, 1996).

Suspended solids may be measured by mass. The total suspended solids (TSS) concentration of a water sample is measured gravimetrically and expressed as mg/l.

2.5.1.4 Total Dissolved Solids (TDS)

The total dissolved solids concentration is a measure of the quantity of all compounds dissolved in water. Natural waters contain varying quantities of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material. The TDS concentration also depends on physical processes such as evapouration and rainfall. The TDS concentrations are generally:

- Low in rainwater, less than 1 mg/l;
- Low in water in contact with granite, siliceous sand and well-leached soils;

- Greater than 65 mg/l in water in contact with Precambrian shield areas; and
- In the range of 200 – 1 100 mg/l in water in contact with Palaeozoic and Mesozoic sedimentary rock formations.

(Dallas and Day, 1993).

2.5.1.5 Conductivity

(Electrical) conductivity is another measure of dissolved material and is often used as a surrogate for TDS particles. Since the electrical conductivity of water is a function of the number of charged particles (ions) in solution, it is also a measure of the total quantity of salts. "Conductivity" in water quality terminology, is thus a measure of the ability of a sample of water to conduct an electrical current: the higher the conductivity, the greater the number of ions in solution.

2.5.1.6 Temperature

Temperature may be defined as the condition of a body that determines the transfer of heat to, or from, other bodies. Temperature plays an important role in water by affecting the rates of chemical reactions and therefore also the metabolic rates of organisms. Temperature is therefore one of the major factors controlling the distribution of aquatic organisms (Duffus, 1980).

Natural thermal characteristics of running waters are dependent on hydrological, climatological and structural features of the region and catchment's area (Table 2.3). Hydrologically, factors such as the source of water (snow melt, surface runoff, lake outlet, etc), the relative contribution of groundwater, and the rate of flow or discharge, will influence the temperature regime (Ward, 1985). The latitude and longitude of the river, as well as climatic factors such as air temperature, cloud cover, wind speed, vapour pressure and precipitation events, all influence the thermal conditions in rivers. Structural characteristics of the river and catchment area, including topographic features, vegetation cover, channel form, water volume, depth and turbidity, affect the amount of solar radiation reaching and heating the water, and thus its thermal regime (Reid and Wood, 1976).

Table 2.3: Major factors affecting the thermal regime of rivers.

FEATURE	**FACTOR**
HYDROLOGICAL	Source of water (snow melt, surface runoff, etc).
	Groundwater contribution
	Flow rate and discharge
CLIMATOLOGICAL	Latitude and altitude of river
	Air temperature
	Cloud cover
	Wind speed
	Vapour pressure
	Precipitation events
STRUCTURAL	Catchment and river topography
	Vegetation cover
	Channel form
	Water volume, depth
	Turbidity

2.5.1.7 Calcium

Calcium is one of the key elements essential for living organisms. As well as being found as a structural material in, for example, bones, teeth, mollusc shells and crustacean (e.g. crab) exoskeletons, it is fundamental for muscle contraction, nervous activity, energy metabolism and an enormous variety of other biochemical interactions (Day and King, 1995).

It is clear, mainly from empirical evidence, that waters low in calcium may be unable to support molluscs and crustaceans, both of which require calcium for the construction of shells and exoskeletons.

2.5.1.8 Chloride

Chloride is a major anion in sea water and in many inland waters. Chloride ions are essential components of living systems, being involved in the ionic, osmotic and water balance of body fluids. Except where they have an effect by increasing the total dissolved solids, the exhibit no toxic effects on living systems (Ward, 1998).

Chlorine itself, on the other hand, is gaseous element that dissolves in water to form hydrochloric acid, which is a strong acid that dissociates to form Cl^- and H+ ions. Free chlorine in water is toxic and is often used as a disinfectant in swimming pools and in water purification works. Total residual chlorine concentrations of <1mg/l^{-1} can significantly affect aquatic ecosystems (Truter, 1990).

2.5.1.9 Sulphate

Sulphur in water occurs largely as the sulphate (SO_4^{2-}) ion. In living systems, sulphur is an essential component of proteins and is thus an essential element. In most natural waters, sulphate ions tend to occur in lower concentrations than chloride ions. Sulphate themselves are not toxic. In excess, however, they form sulphuric acid, which is a strong acid that reduces pH and can have devastating effects on aquatic ecosystems. This is particularly problematic in water seeping from mines, where sulphate levels can be extremely high. Sulphur dioxide, the gaseous precursor of sulphate, is a major component of acid precipitation. In regions where the rivers are poorly buffered, sulphate levels can increase significantly, causing sharp drops in pH (Neal, 2001).

2.5.1.10 Magnesium

Magnesium is an essential element, being found in chlorophyll and in a variety of enzymes and being involved in the process of muscle contraction and the transmission of nervous impulses. Since it is usually found in relatively high concentrations, it is unlikely to act as a limiting nutrient or a toxin (Walsh, 2000).

2.5.1.11 Sodium

Sodium is ever-present in natural waters and is the major cation in sea water. It is the major cation involved in ionic, osmotic, and water balance in all organisms and is also involved in the transmission of nervous impulses and in muscle contraction. Sodium is probably the least toxic metal cation and it effects on aquatic ecosystems are almost entirely as a major contributor to TDS (Hellawell, 1986).

2.5.2 Nutrient Enrichment of water

Plant nutrients are any elements required for normal plant growth and reproduction. In this sense, plant nutrients include carbon, nitrogen, phosphorous, etc., as well as other elements termed "micro-nutrients", which are required in much smaller quantities (Addiscott *et al.*, 1991). Of the major nutrients listed above, nitrogen (N) and phosphorous (P) are the most commonly implicated in excessive plant growth resulting from nutrient enrichment of aquatic ecosystems (Hart *et al.*, 1992; Correll, 1998).

Nutrient enrichment is termed eutrophication and it can lead to an imbalance in biological communities, particularly to an increase in plant communities and associated water quality problems.

2.5.2.1 Phosphorous

Phosphorous can occur in numerous organic and inorganic forms, and may be present in waters as dissolved and particulate species. Phosphorous plays a major role in the structure of nucleic acids (e.g. DNA) and in molecules (e.g. ATP) involved in the storage and use of energy in cells (Addiscott *et al.*, 1991). It occurs most commonly in dissolved form as the inorganic PO_43^- ion. Soluble Reactive Phosphorous (SRP), i.e. immediately available phosphorous and phosphorous that can be transformed into an available form by naturally occurring processes, is seldom found in quantity in non-polluted water as it is utilized by plants and sequestered in cells. Knowledge of the role of processes and mechanisms that control the supply of phosphate is essential for the management of catchments, rivers and lakes to avoid eutrophication (Webster *et al.*, 2001).

2.5.2.2 Nitrate

Nitrates are the ends products of the aerobic stabilization of organic nitrogen and may enter water via fertilizers, agricultural runoff, etc. In spite of their many sources, nitrates are seldom abundant in natural surface waters because photosynthetic action is constantly converting them to organic nitrogen in plant cells. They are, however, often found in high concentrations in groundwater. Nitrate is not normally toxic but high concentrations can be toxic to very young infants because NO_3^- binds with foetal haemoglobin to form a non-functional molecule, methaemoglobin (Porter, 1975).

2.5.2.3 Nitrite

Nitrite is a naturally occurring anion in fresh and saline waters. Human activities that increase nitrite concentrations in aquatic environments include industrial production of metals, dyes and celluloids, sewage effluents and certain types of aquaculture (Lewis and Morris, 1986). Toxic effects of nitrite are modified by water chemistry, particularly by chloride concentration (nitrite toxicity increases as Cl^- concentrations decrease); in fact there is an inverse linear relationship between nitrite toxicity and chloride concentration.

2.5.2.4 Ammonia

Ammonia is a common pollutant generally associated with sewage and industrial effluents and occurs in either the free, un-ionized form (NH_3) or as ammonium ions (NH_4+). It has been well established that the toxicity of ammonia is directly related to the concentration of the un-ionized form and that the ammonium ion has little or no toxicity, although it does contribute to eutrophication (Williams *et al.*, 1986).

In the surface or ground water ammonium generally results from the decomposition of nitrogenous organic matter, and is one of the constituents of the nitrogen cycle (McKee and Wolf, 1963).

2.5.3 Biological Characteristics of Water

Bacterial contamination of a water body may be caused by human waste discharged or entering a river as untreated sewage or from livestock waste.

2.5.3.1 *Escherichia coli*

Escherichia coli are a non-pathogenic bacterium that occurs universally in the intestinal tracts of humans and many other mammals. Its presence in water bodies is used as an indicator of faecal pollution (Davies and Day, 1998). It is likely that many South African rivers, both urban and rural, are severely contaminated by faecal pathogens, particularly where informal settlements house poverty-stricken communities with no waterborne sanitation and meagre water supplies. Where water supplies are contaminated by *E.coli* and untreated, the bacterium may change its nature, causing health problems such as diarrhoea and gastroenteritis (Davies and Day, 1998).

The theory thus far focused on fresh water systems with respect to it being a life sustaining resource. Overutilization and exploitation of this resource with subsequent impact were also reviewed. This study apart from concentrating on the above, also hinges on the estuarine environment.

2.6 The Estuarine Environment

Estuaries are places where freshwater rivers and streams flow into the ocean, mixing with the seawater. A wide variety of birds, fish, and other wildlife make estuaries their home. People also live, fish, swim, and enjoy nature in estuaries and the lands surrounding them. From the largest landscape features to the smallest microscopic organisms, an estuary is a fascinating place. When viewing an estuary from the air, for example, one is awed by striking river bends as freshwater finds its way back to the sea, the vast expanse of marsh grasses, mangroves, or mudflats, extending out into the calm waters, or perhaps the elegant curve of an expansive barrier beach. Wherever there are estuaries, there is a unique beauty, as rivers meet the sea, and both ocean and land contribute to a unique ecosystem of specialized plants and animals (Estuary Net Project, 2004).

2.6.1 Estuaries and their importance

An estuary is a partially enclosed body of water formed where freshwater from rivers and streams flows into the ocean, mixing with the salty sea water. Estuaries and the lands surrounding them are places of transition from land to sea, and from fresh to salt water. Although influenced by the tides, estuaries are protected from the full force of ocean waves, winds, and storms by the reefs, barrier islands, or fingers of land, mud, or sand that define an estuary's seaward boundary (National Estuarine Research, 1998).

Estuaries come in all shapes and sizes and go by many different names, often known as bays, lagoons, harbours, inlets, or sounds. However, not all water bodies by those names are necessarily estuaries. The defining feature of an estuary is the mixing of fresh and salt water, not the name.

The tidal, sheltered waters of estuaries support unique communities of plants and animals, specially adapted for life at the margin of the sea. Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably-sized areas of forest, grassland, or agricultural land. Many different habitat types are found in and around estuaries, including shallow open waters, freshwater and salt marshes, sand beaches, mud and sand flats, rocky shores, oyster reefs, mangrove forests, river deltas, tidal pools, sea grass and kelp beds, and wooded swamps (National Estuarine Research, 1998).

The character of an estuary is determined by rainfall, geology and the interaction between the river water and the salt water of the sea – each rise and fall of the tide causes changes. During floods, an estuary can be transformed overnight from tranquil waters to raging muddy torrents. Or, when an estuary is separated from the sea by a sandbar, making it a lagoon, it may become abnormally saline or even completely dry (CoastCARE, 2004).

According to the National Estuarine Research Reserves (1998), the productivity and variety of estuarine habitats foster a wonderful abundance and diversity of wildlife. Shore birds, fish, crabs and lobsters, marine mammals, clams and other shellfish, marine worms, sea birds, and reptiles are just some of the animals that make their homes in and around estuaries. These animals are linked to one another and to an assortment of specialized plants and microscopic organisms through complex food webs and other interactions.

Estuaries are among the most important coastal features, both ecologically and with respect to human settlement and use (Environment Canada, 1987). Estuaries are semi enclosed bodies of water formed when fresh water from rivers and coastal streams flows into and mixes with salt water of the ocean. Estuaries are unique places, strongly affected by tidal action, where land and river and sea merge into a dynamic natural complex (Harvey *et al.*, 1998).

Most definitions of estuaries do not reflect the uniqueness of these waters as habitats. They fail to convey the vibrant nature of the physical processes operating in estuaries, or to explain the roles that these processes play in shaping the character of aquatic and terrestrial life in and around estuaries (Lippson *et al.*, 1979).

Estuaries are critical for the survival of many species. Tens of thousands of birds, mammals, fish, and other wildlife depend on estuarine habitats as places to live, feed, and reproduce. Estuaries provide ideal spots for migratory birds to rest and refuel during their journeys. And many species of fish and shellfish rely on the sheltered waters of estuaries as protected places to spawn, giving them the nickname "nurseries of the sea." Hundreds of marine organisms, including most commercially valuable fish species, depend on estuaries at some point during their development (National Estuarine Research, 1998).

2.6.2 Estuarine Habitat

Habitat is the combination of physical features and living organisms that provide food, nesting and resting areas, and shelter for fish and wildlife (Lippson *et al.*, 1979).

The plants and animal habitats supported by an estuarine system are determined by the conditions within the watershed and in the adjacent marine realm. The rate at which fresh water enters the estuary, the amount and type of water-borne and bottom sediments, the degree of tidal flushing, and water depth (with temperature and sunlight infiltration), combine to produce habitat and food. Combinations of these factors can produce several estuarine habitats within a single estuary. A significant physical change in any of the factors can cause alterations in the biological estuarine community, greatly enlarging or reducing the size of various species populations (US EPA, 1992).

While every species has unique needs that must be served by its habitat, there a number of general habitat types in estuaries which define the ecology of each estuary. These classes of habitat are: fresh/brackish marsh and water; dunes and vegetated beach ridges; sand flats; salt marsh and salt ponds; mudflats; oyster and mussel bars; rockweed (found on bedrock); beaches (sand, gravel, cobble and boulder); sea bottom (mud, sand, gravel, cobble, boulder, or bedrock); shallows (ledges, bars, reefs, shallow bays); seaweed beds (i.e. kelp) and eelgrass beds. All these different types of estuary habitat support vital marine food chains and attract a vast array of fish, marine mammals and birds (Harvey *et al.*, 1998).

Marsh plants and grasses growing in estuarine waters are important to estuarine marine life. Salt marsh vegetation not only provides cover for many animals but also, through the normal life cycle of seasonal breakdown and decay, creates detritus that feeds and houses the minute species on which larger species depend. Blades of marsh grass, such as *spartina alterniflora*, are home to algae, snails and other food for larger species. Juveniles of many commercially valuable species, such as shrimp, reach maturity by hiding amid estuarine vegetation.

Estuarine marshes also provide homes for oysters, clams and other organisms that spend all of their lives in the estuary. Young shrimp, crabs and some fish use the estuary as a nursery ground. Marsh plants also help protect the shoreline from erosion and clean coastal waters by filtering out many pollutants (Berrill and Berrill, 1981).

Among the cultural benefits estuaries are recreation, scientific knowledge, education, and aesthetic ideals. Boating, fishing, swimming, surfing, and bird watching are just a few of the numerous recreational activities people enjoy in estuaries. Estuaries are often cultural centres of coastal communities, serving as the focal points for local commerce, recreation, celebrations, customs, and traditions (natural Resource Evaluation, 1997). As transition zones between land and water, estuaries are invaluable laboratories for scientists and students, providing countless lessons in biology, geology, chemistry, physics, history, and social issues. Estuaries also provide a great deal of enjoyment for the people who live, work, or recreate in and around them (National Estuarine Research, 1998).

The tangible and direct economic benefits of estuaries should not be ignored. Tourism, fisheries, and other commercial activities thrive on the wealth of natural resources estuaries supply. The protected coastal waters of estuaries also support important public infrastructure, serving as harbours and ports vital for shipping, transportation, and industry. For example, in America, estuaries provide habitat for more than 75% of America's commercial fish catch, and for 80-90% of the recreational fish catch (Coastal Challenges, 1998). Estuarine-dependent fisheries are among the valuable within regions and across the nation, worth more than $1.9 billion in 1990 (Estuaries of the United States, 1990). America's commercial and recreational fishing, boating, tourism, and other coastal industries provide more than 28 million jobs. There are 25, 500 recreational facilities along the U.S. coasts (Coastal Challenges, 1998). In short, estuaries provide us with a whole suit of resources, benefits, and services. Some of these can be measured in currency, others can not. Estuaries are an irreplaceable natural resource that must be managed carefully for the mutual benefit of all who enjoy and depend on them.

2.6.3 Biophysical Processes in Estuaries

Biophysical processes in estuaries can generally be divided into:

- Physical (or driving) components
- Biological (or response) component

2.6.3.1 Physical (or driving) Components

Physical components refer to the hydrodynamic (water movement patterns), sediment dynamic and water quality (biogeochemical and microbiological parameters) processes in estuaries. These components are often import driving forces (also referred to as stressors) in the changes observed in biological components, as well as effects on other beneficial uses (CSIR – Biophysical Processes in Estuaries, 2002).

The driving components in estuaries are mainly influenced by two forces, i.e. river inflow and the sea. It can be explained as follows:

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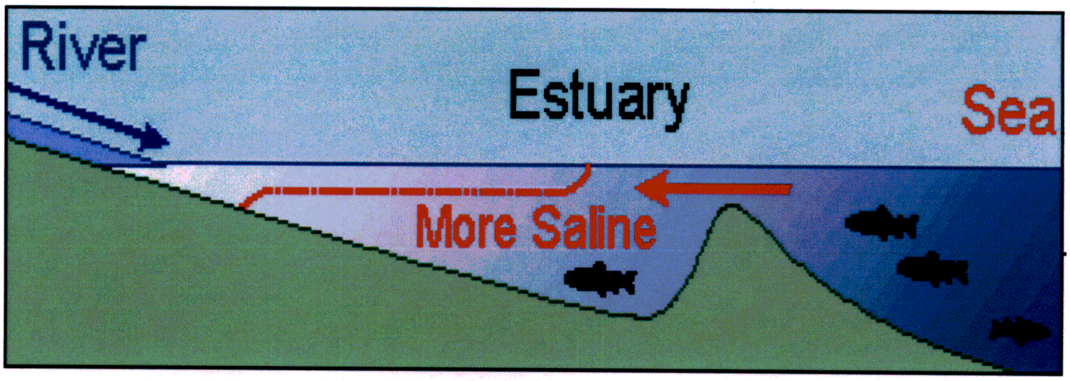


Figure 2.1 – Activity during high tide

During high tides, seawater pushes up into the estuary, introducing more saline water into the system and, at the same time, raising water levels in the estuary.

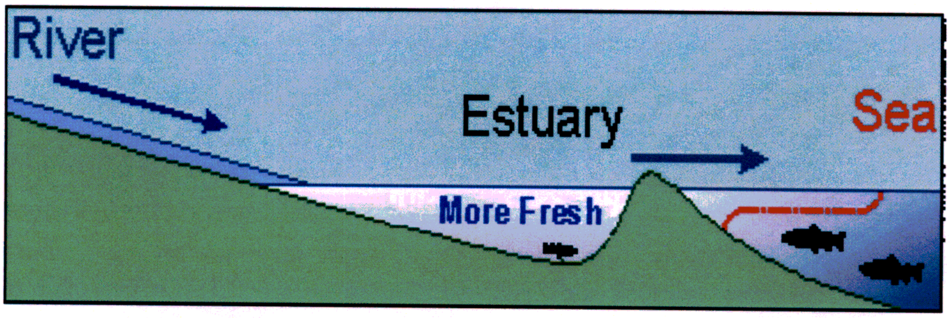


Figure 2.2 – Activity during low tide.

Source: **(CSIR, 2002).**

During low tides water drains from the estuary, usually resulting in the water becoming fresher, while the water level in the estuary drops.

The water quality features of an estuary are largely dependent on the type of water in the estuary at any time, i.e. seawater, freshwater or a mixture thereof. In addition, the retention time of water in an estuary (i.e. how long it stays in the system) also influences the water quality characteristics.

During periods of low flow (e.g. during dry seasons or drought), the sea's influence becomes very dominant, resulting in the system becoming increasingly more saline. Under intense conditions the salinities in an estuary can even become higher than that of seawater due to evaporation (referred to as hyper-salinity). Extended periods of these low flows could also cause premature closing of certain estuary mouths and/or lead to longer periods of mouth closure (CSIR – Biophysical Processes in Estuaries, 2002).

During floods most of the saline water in an estuary is flushed out to sea and the entire system usually becomes fresh. Floods also have the useful function of scouring sediment from estuaries and in doing so, it deepens the channel. All in all, the above imply that estuaries are highly variable environments in terms of hydrodynamics (e.g. water level variations and water velocities), water quality (e.g. salinity, temperature, pH and oxygen) and sediment dynamics (CSIR – Biophysical Processes in Estuaries, 2002).

2.6.3.2 Biological (or response) component

Biological components refer to estuarine vegetation, benthic invertebrates, fish, birds and mammals. Estuarine biotas are usually capable of tolerating highly variable environments of these systems.

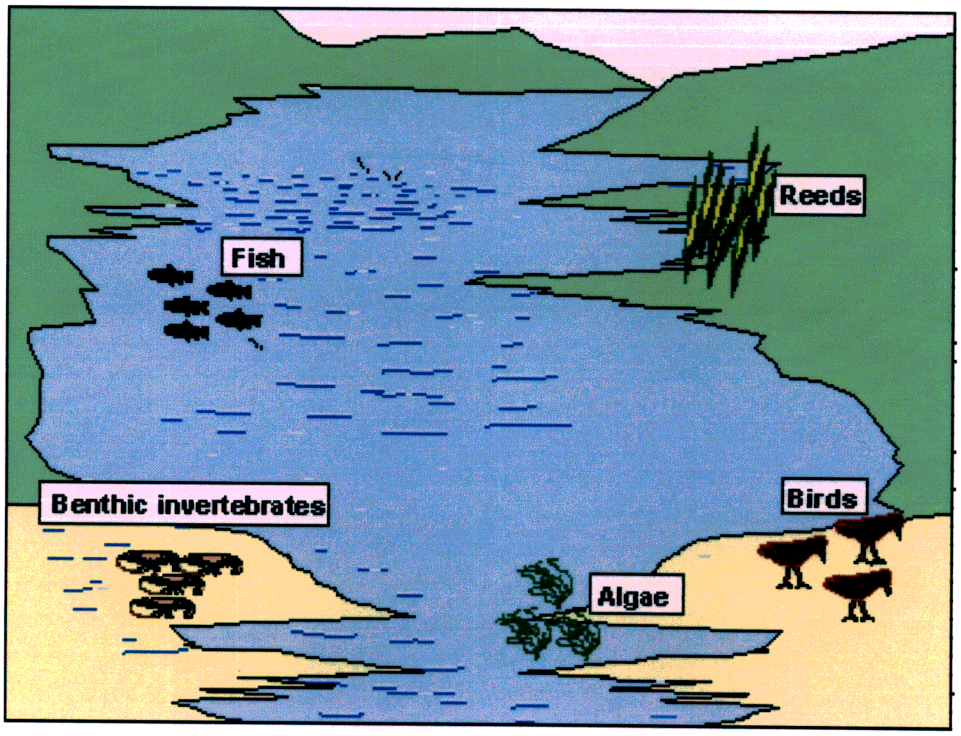


Figure 2.3 – Habitants of the estuary.

Source: **CSIR (2002).**

Estuarine vegetation includes mangroves, salt marshes, reeds, benthic micro-algae and phytoplankton. The vegetation provides both a safe habitat from predators and forms a crucial part of the food chain in estuaries.

Benthic invertebrates refer to organisms such as crabs, sand prawns, mud prawns, various mussel species and surface feeders. Crabs, for example, forage during low tide on the material deposited during the preceding high tide. These organisms provide an important food source to other estuarine inhabitants such as fish and birds.

A variety of **fish** species are found in estuaries. For example, fish (some estuarine mullet species) which are completely dependent on estuaries for their survival. On the other hand, there are species which only use estuaries as nursery grounds, when during spring and summer, juvenile fish enters the estuary to take advantage of its sheltered and food rich environment (CSIR – Biophysical Processes in Estuaries, 2002).

Estuaries are very important **bird** habitats, particularly in terms of breeding, roosting and feeding. The inter-tidal and flood plain areas of these systems usually support a wide variety of birds, such as herons, gulls, waders, terns and cormorants. Birds prey on prawns, marsh crabs, pencil bait and fish. Estuaries also provide protected habitats for some of our endangered Red Data species, such as the Black Oystercatchers (CSIR – Biophysical Processes in Estuaries).

2.6.4 Beneficial Uses of Estuaries

Beneficial uses usually require an estuary to be in a "good or acceptable condition" in terms of aspects such a water quality and biological functions.

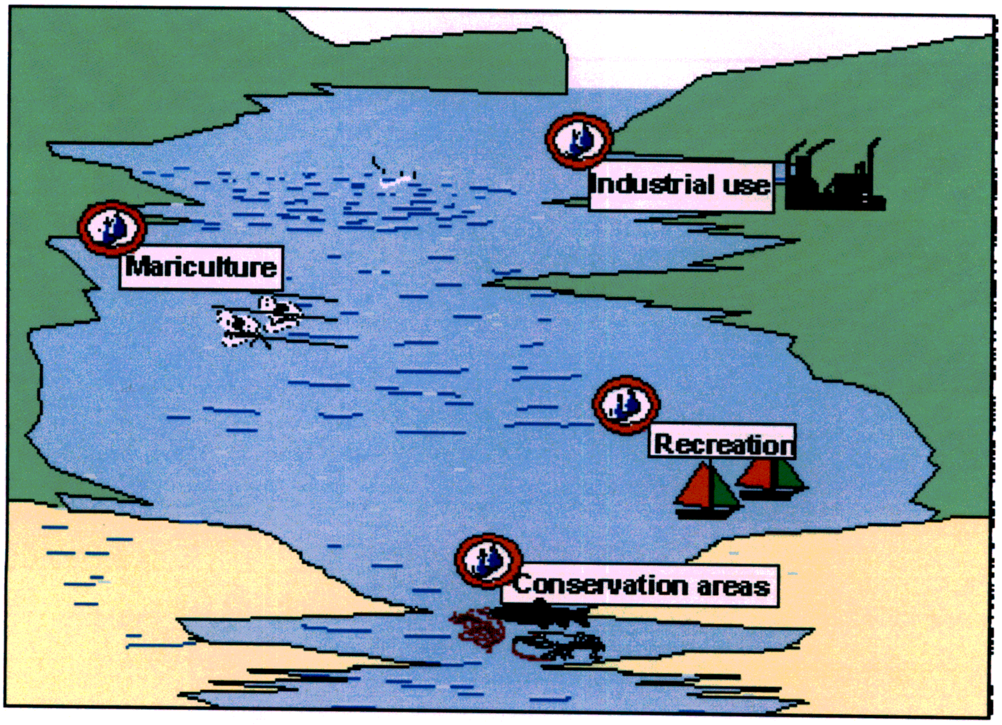


Figure 2.4 – The beneficial uses of estuaries
Source: **(CSIR, 2002).**

2.6.4.1 Conservation area

Estuaries are seen as ecologically sensitive areas and therefore have a high conservation status in South Africa. For example, estuaries provide a nursery for many marine and estuarine fish species and some are of international importance for migratory birds (e.g. Olifants Estuary). As a result many of our estuaries from part of national parks and coastal resorts.

2.6.4.2 Recreation

Estuaries are popular recreational and tourist destinations along the South African coast. In addition to their picturesque beauty, these systems also provide safe water areas for swimming, wind-surfing, boating and many other water sports.

2.6.4.3 Mariculture

Estuaries are increasingly used for commercial culturing of aquatic organisms. One of South Africa's largest mariculture industries, i.e. the oyster industry is situated in the Knysna Lagoon, one of our few estuarine bays.

2.6.4.4 Industrial use

The more important industrial uses of estuarine water are extraction of water for cooling purposes (e.g. power station on the Swartkops Estuary) and for salt production (e.g. on the Great Berg Estuary).

Adapted from (CSIR – Beneficial Uses of Estuaries, 2002).

2.6.5 Estuary Productivity and Function

Estuaries rank along with tropical rainforests and coral reefs as the world's most productive ecosystems, more productive than both the rivers and the ocean that influence them from either side (Harvey *et al.*, 1998).

In a healthy estuarine system, the interaction of tides, sediments and unplugged fresh water produce some of the densest concentrations of nutrients on the planet. Sheltered shallow waters and soft mud or sand flats regularly flooded by the tides provide ideal habitat for numerous organisms (NERRA, 2002). Also, in an estuary, nutrient-rich river waters combine with warmer, light infused shallow coastal waters and the outpouring of nutrient-rich deep ocean waters to generate primary productivity. The mixing of lighter fresh water and heavier salt water trap and circulate nutrients such that they are often retained and recycled by benthic (bottom dwelling) organisms to create a self-enriching system (NOAA, 1994).

According to Harvey and Abouchar (1998), estuaries can generate year-round primary production from macrophytes (seaweeds, sea grasses, and, marsh grasses), microphytes (mud algae) and the most important, but least understood estuarine species called phytoplankton. Like other green plants, phytoplanktons make the energy of sunlight available to animals as food. Phytoplanktons are consumed by microscopic, minute organisms called zooplankton. These tiny animals include the larvae of fish, crabs, shrimp, clams and other species, and are themselves part of the food supply for adults of their own and other species (NERRA, 2002).

This vast primary productivity is the cornerstone of the estuarine food chain, providing food for large populations of shellfish such as clams, mussels, oysters, or quahogs. In some estuaries, where productivity exceeds what can be used within the estuary, the action of regular tidal flushing moves nutrients and organic materials to adjacent coastal waters thereby balancing productivity. In areas of extremely high tides, this export of nutrients to adjacent waters does not seem to occur. Instead, the estuaries themselves use up everything they produce, making them incredibly efficient in their production of marine life (Environment Canada, 1987).

2.6.6 Activities and Developments Impacting on Estuaries

Many activities and development in and along estuaries impact of the natural functioning of these systems, in contrast, for example, to the requirements of the beneficial uses.

As estuaries are where sea and river meet, they are also a place where various different natural forces interact and are therefore particularly vulnerable to harm through human actions. Furthermore, compared to many other countries our estuaries are small in size and few in number, and many of these have already been extensively impacted on by man. A major threat to our estuaries is the deterioration of their catchment areas through, for example, the damming of rivers and removal of water, which results in a reduced input of freshwater as well as altered river5 flow patterns. This results in flood events (which are vital to the health of our estuaries) becoming smaller and less frequent, which in turn reduces the scouring of sediment from the estuary, so that it is not flushed out properly and could start to silt up. Over time the estuaries, starved of water, become shallower and more saline (CoastCARE, 2004).

Properties alongside estuaries are very popular development sites with high property values. However, development here means that the important shallow waters on the estuary margins are often lost when filled in with rubble and soil, or converted into marinas. Estuary mouths then have to be breached prematurely to prevent flooding of buildings situated too close to the water. This dramatically affects the dynamic nature of the estuary. Other negative impacts arise from agricultural practices that may lead to soil erosion; roads or railways which intrude into floodplains; the 'fixing' of mouths with retaining walls; various forms of pollution from land or sea; and dredging to remove excess sediment build-up (CoastCARE, 2004).

2.6.6.1 Point Source Waste Discharges

Waste discharged directly into South African estuaries mainly comprises of municipal waste (e.g. treated sewage) and channeled stormwater run-off. Industrial discharges into estuaries are limited. It mainly consists of the fish factory effluents discharge along the West Coast and discharges from sugar and paper mills into estuaries along the coast of KwaZulu-Natal. Problems associated with these discharges are mainly related to deterioration in the estuary's water quality resulting in, for example:

- Excessive algal and reed growth;
- Unacceptable aesthetics; and
- Human health risks (CSIR – Estuaries, 2002).

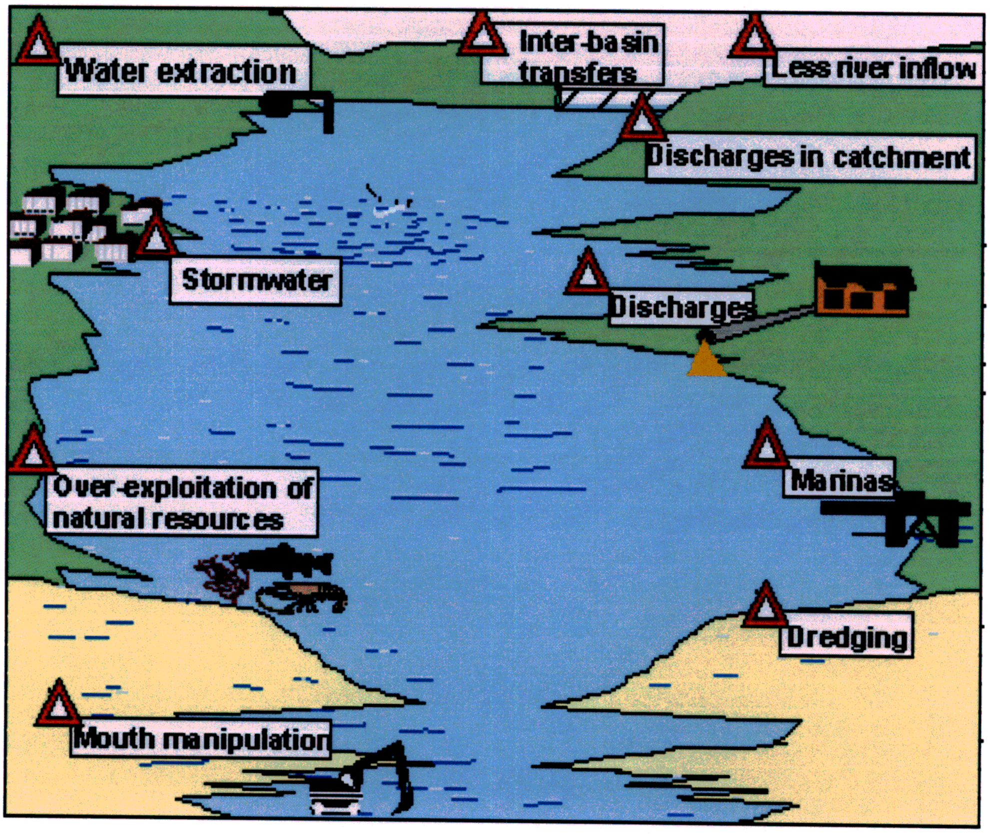


Figure 2.5 – Point source waste discharges in an estuary

Source: **(CSIR, 2002).**

2.6.6.2 Stormwater

In South Africa, contaminated stormwater run-off is the main source of diffuse waste discharges into estuaries. Problems associated with such discharges are mainly related to a decline in the estuary's water quality resulting in, for example:

- increased turbidity and toxicity affecting the biological functioning of the system;
- excessive algal and reed growth owing to nutrient enrichment;
- unacceptable aesthetics;
- human health risks; and
- clogging of equipment a result of litter (CSIR – Activities and Developments Impacting Estuaries, 2002).

2.6.6.3 Marinas, etc.

Constructions in estuaries include marinas, bank stabilization, breakwaters, jetties and bridges. Associated problems may include:

- interference with water circulation patterns;
- water quality problems caused by weak circulation; and
- increase or decrease in sedimentation due to changes in circulation patterns.

2.6.6.4 Dredging

Dredging operations usually occur in estuaries which are used as harbours e.g. the Great Berg Estuary, the Buffalo Estuary (East London), Durban Bay and St Lucia Estuary, or where reduced river flow has resulted in sedimentation and reed growth. Sand mining in estuaries has similar effects to dredging. Associated problems may include:

- poor water quality (mainly as a result of high silt loading);

- unacceptable aesthetics (silt loading, reduced clarity, possible odours);
- loss of biota (sand and mud prawns removed , die-off of vegetation); and
- dredged material not correctly removed (dumped on flood plain).

(CSIR – Activities and Developments Impacting Estuaries, 2002).

2.6.6.5 Mouth manipulation

Mouth breaching is a common practice in South Africa, particularly in estuaries where coastal developments have occurred at a level where inundation of low-lying properties will occur under the high water levels required for natural breaching. As a result, the mouth is breached artificially before these high levels are reached so as to prevent flood damage to properties.

Other reasons for artificial breaching include water quality deterioration, fishing interests (e.g. Bot Estuary) and compensatory action where substantial reductions in river flow have occurred (e.g. Great Brak Estuary). Problems which are associated with mouth breaching mainly relate to breaching at the wrong time of year, breaching at too low water levels, breaching at the wrong position or digging a too shallow initial trench, resulting in:

- increased sedimentation;
- no juvenile fish migration in spring or summer if closed;
- saltmarsh vegetation die-off due to long inundation; and
- decrease in flushing potential of sediment (CSIR, Activities and Developments Impacting Estuaries, 2002).

2.6.6.6 Water abstraction

Water abstraction is usually associated with cooling of power stations, processing of seafood, salt extraction and sand mining. Although these activities are often classified as beneficial uses, physical removal (abstraction) of water from an estuary, can cause numerous problems such as:

- an early and extended mouth closure (impact on juvenile fish migration, vegetation, migratory birds); and
- an increase in the salinity of an estuary.

2.6.6.7 Catchment activities

Activities in the catchment may influence the quantity and quality of river water entering an estuary. For instance, the construction of major dams, abstraction by local farmers, afforestation and infestation by alien vegetation can substantially reduce run-off to estuaries. On the other hand, inter-basin transfers (instances where water from one river basin is transferred to another where there is a water shortage) can result in reduced fresh water flows in the parent catchment and enhanced river flows in the receiving catchment.

The discharge of waste to rivers in the catchment of an estuary can occur both as point source discharges e.g. municipal waste, industrial effluent, and as diffuse discharges e.g. agricultural and pastoral run-off, the inflow of contaminated stormwater or groundwater (CSIR, 2002).

Major concerns associated with inter-basin transfer schemes are:

- non-natural salinity and temperature levels;
- nutrient enrichment;
- altered turbidity and/or siltation;
- interference with natural migration patterns and the introduction of alien species;
- an early and extended mouth closure, due to loss of river inflow;
- an increase in the salinities of an estuary;
- increase in sedimentation due to decrease in major floods (less scouring); and
- decrease in sedimentation due to major dams sometimes acting as sediment traps (CSIR, 2002).

2.6.6.8 Over-exploitation of natural resources

In some estuaries the uncontrolled exploitation of our living natural resources through fishing or bait collection has become a serious threat to these systems. These activities are subject to regulations set by the various provincial conservation authorities and the enforcement of these controls is therefore very important. Problems associated with over-exploitation include:

- loss of biodiversity (e.g. loss of fish and bait species);
- destruction of habitat; and
- loss of income (CSIR, 2002).

2.6.7 The need to protect estuaries

The economy of many coastal areas is based primarily on the natural beauty and bounty of estuaries. When those natural resources are imperilled, so too are the livelihoods of the many people who live and work there. Populations around coastal regions are growing three times faster than elsewhere in the world (Natural Resource Evaluation, 1997).

Unfortunately, the increasing concentration of people is upsetting the natural balance of estuarine ecosystems and threatening their integrity. Channels have been dredged, marshes and tidal flats filled, water polluted, and shorelines reconstructed to accommodate human housing, transportation, and agricultural needs (Estuaries of the United States, 1990).

As our population grows, the demands imposed on our natural resources increase. So too does the importance of protecting our resources for their entire natural, economic, and aesthetic values. It is our mission to restore and protect our estuaries for a sustainable future.

2.7 CONCLUSION

Water – the lifeblood of the ecosphere – is truly a wondrous substance that connects us to one another, to other forms of life, and to the entire planet. Despite its importance, water is one of our most poorly managed resources. We waste it and pollute it, and we also charge too little for making it available, thus encouraging still greater waste and pollution of this vital, potentially renewable resource.

Water is essential to human life and to the health of the environment. As a valuable natural resource, it comprises marine, estuarine, freshwater (river and lakes) and groundwater environments, across coastal and inland areas. Water has two dimensions that are closely linked - quantity and quality. Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. A healthy environment is one in which the water quality supports a rich and varied community of organisms and protects public health. Water quality is closely linked to the surrounding environment and land use. Other than in its vapour form, water is never pure and is affected by community uses such as agriculture, urban and industrial use, and recreation. The modification of natural stream flows by dams and weirs can also affect water quality. The weather too can have a major impact on water quality, particularly in a dry country like Australia which is periodically affected by droughts. Generally the water quality of rivers is best in the headwaters, where rainfall is often abundant. Water quality often declines as rivers flow through regions where land use and water use are intense and pollution from intensive agriculture, large towns, industry and recreation areas increases (EPA, 2004).

There are of course exceptions to the rule and water quality may improve downstream, behind dams and weirs, at points where tributaries or better quality groundwater enter the mainstream, and in wetlands. Rivers frequently act as conduits for pollutants by collecting and carrying wastewater from catchments and discharging it into the estuaries, and ultimately the ocean. This in turn has negative effects on the estuarine environment.

CHAPTER 3

STUDY AREA

3.1 INTRODUCTION

This chapter introduces the study area that underpins the study. It will discuss in some detail the description of the study area in terms of location, general characteristics and a brief historical description.

The Mngeni River catchment is situated in KwaZulu-Natal (Figure 3.1) and is the fundamental water source for both the Greater Durban and Pietermaritzburg Metropolitan areas in KwaZulu-Natal. The river enters the sea at a site just 5 km north of central Durban after passing through some of the northern suburbs and the Springfield Flats industries. It supplies water for approximately 45% of the Province's population in a region which produces 20% of South Africa's gross national product. With the population in the Greater Durban and Pietermaritzburg Metropolitan areas expected to expand to between 9 and 12 million by the year 2025, it was predicted over a decade ago that the rapidly accelerating water demand would exceed local raw water resources (Kienzle *et al.*, 1997). Some 1.5 million people live in the area upstream of the Inanda Dam, while a further 3 million are supplied by transfers of water captured in the Mngeni catchment to areas downstream of Inanda Dam in the Durban Functional Region. Apart from urban concentrations, areas within the former KwaZulu homelands are amongst the most densely populated areas in the catchment.
Figure 3.2 indicates the location of the Mngeni River from the estuary up to the Inanda Dam.

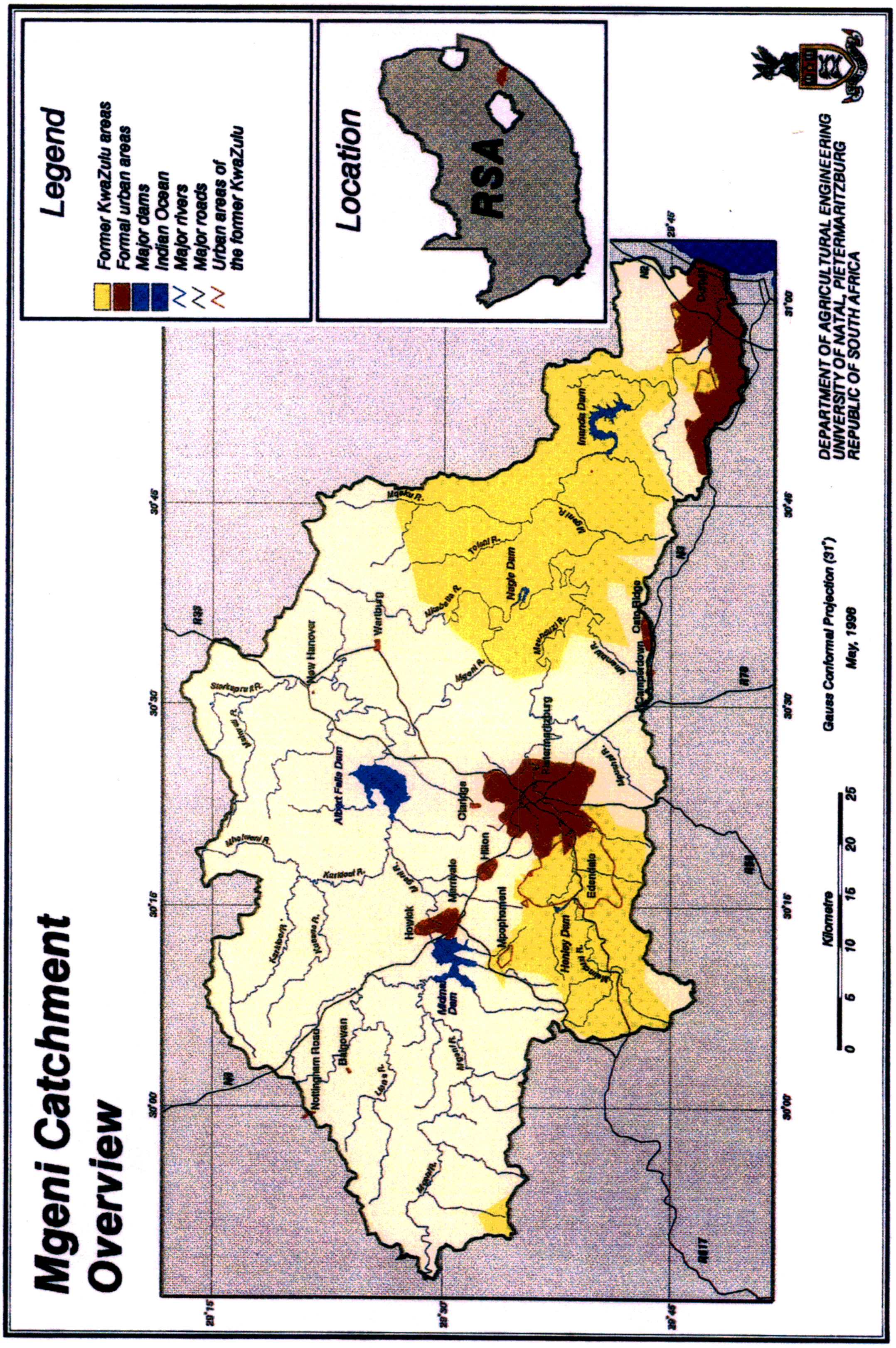


Figure 3.1: Mngeni Catchment Overview

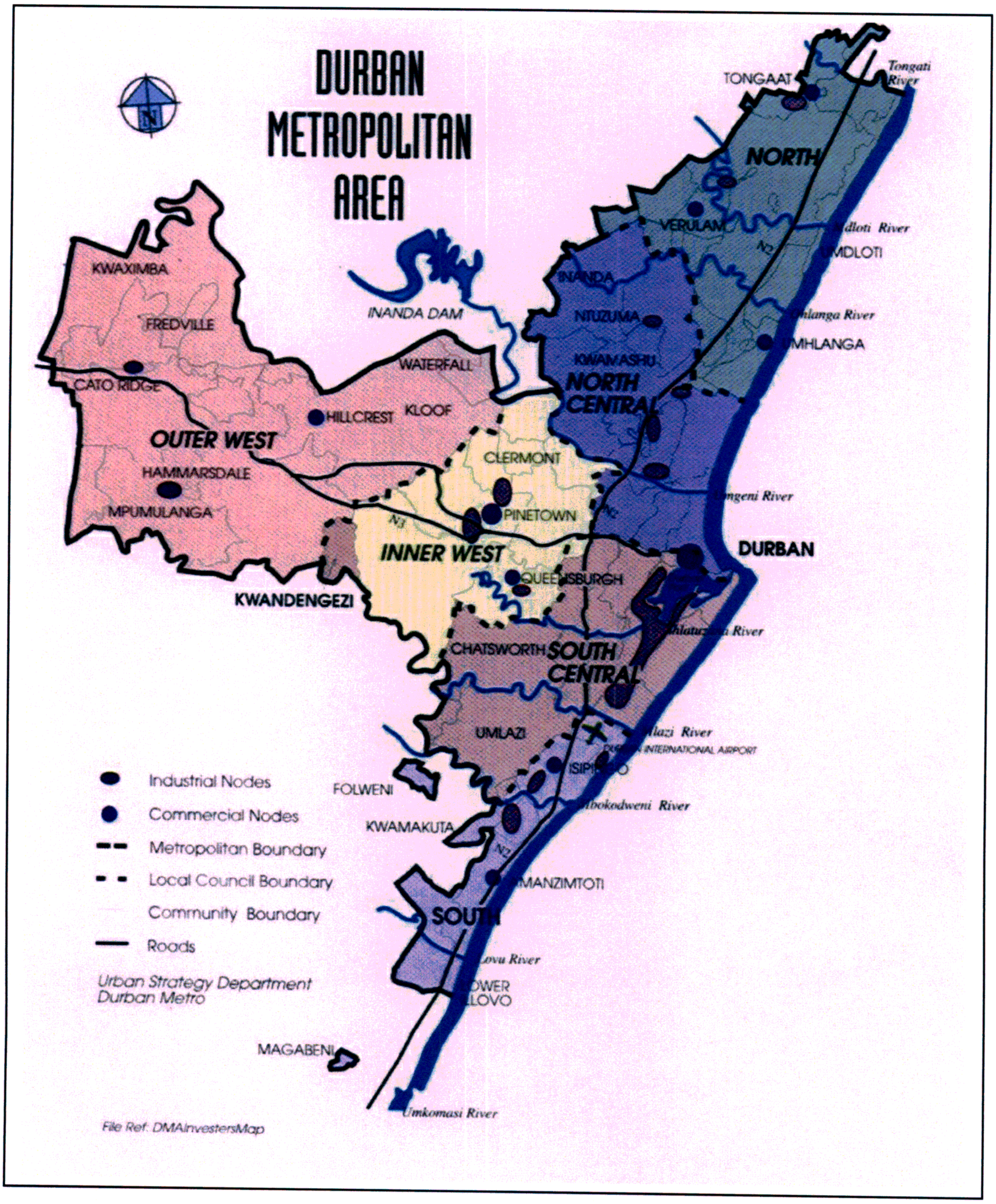


Figure 3.2: Mngeni River from the estuary up to the Inanda Dam.

Source: **DMA (2004).**

3.2 The Mngeni Catchment – A historical description of the Mngeni Estuary

Information on the meanderings of the Mngeni Estuary is confusing and scant. It appears that the position of the estuary has changed repeatedly; moving not only north and south along the coast, but at times the Mngeni River flowed directly into Durban Bay (WRC, 2002).

Russel (1889) noted that the name Mngeni means "River of Entrance" because the ancient Mngeni flowed into Durban Bay via a low-lying area known as "Eastern Vlei." However, a map of Durban drawn by Lt. King in 1823 (Plate 1) shows the river clearly entering the sea in approximately its current position, with little sign of a pathway to the Bay. A 1909 Mercury Pictorial (9th September) reported that the estuary had marched "three miles" from its present position towards Durban. Concern was expressed and the estuary was manually redirected towards its current position. This meandering of the inlet mouth probably occurred frequently.

From and old account written in the late 1600s (Bird, 1888), the author describes what is now Durban and where the mouth of the river is clearly the Bay itself: *"Neither is there any want of water, for every hill affords little brooks, which glide down several ways, some of which meet by degrees, which make up the river of Natal (Mngeni River), which dischargeth itself into the East Indian Ocean, in latitude 30° S, where it opens pretty wide, and is deep enough for small ships. But at the mouth of the river is a bar, which has not above 10 or 11 feet of water on it in a spring tide, though within there is water enough. This river is the principal of the country of Natal, and has lately been frequented by some of our ships, particularly by a small ship that Captain Rogers owned.* (Dampier's Voyages - British Museum - repeated in Bird 1888).

Cooper and Mason (1987) say the following of the meandering estuary: *"...the Mngeni flowed southward between the Berea Ridge and a line of coastal dunes* *before discharging into Natal Bay. This former course is marked by thick estuarine deposits beneath Durban."*

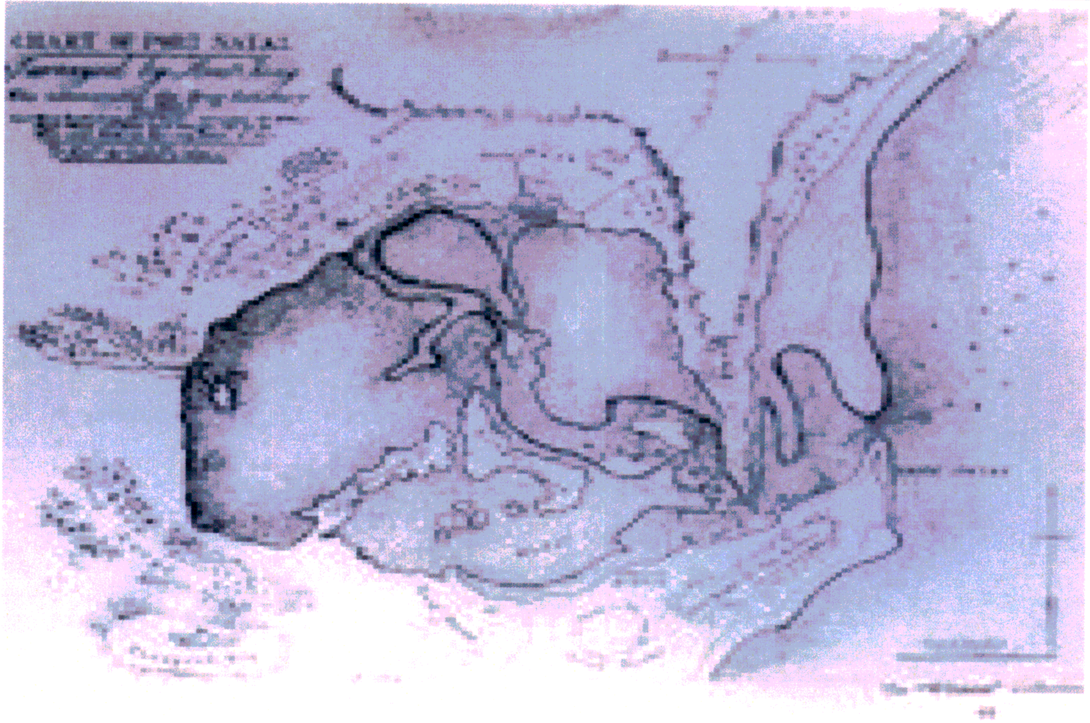


Plate 3.1 – Map of Durban Bay – 1823.
***Source:* CSIR (2002).**

The Mngeni River mouth lies adjacent to an extensive, low -lying area to the south on which is situated the main recreational zone of the city of Durban. In the early part of the 19th century the Mngeni was reported to flow south into Durban Bay when water levels rose (Begg, 1978). It appears that this may have been the end of an evolutionary phase. The late mid-Holocene Mngeni river may have been diverted southward behind a transgressive coastal barrier in the same way as the Nkomati River is in the Bay of Maputo. Evidence for this comes not only from the morphology of the Durban area but also from the fact that coarse-grained river sands are commonly encountered in the shallow subsurface of the low-lying area between the modern river- mouth and Durban Bay (King, 1962 and Francis, 1989). The modern river-mouth position had been assumed by the mid 19th century, either as a result of a particularly severe flood or by meander cutting of the inner margin of the barrier, or by formation of overwash channels. The inlet was fixed artificially in its present position by a groyne in the early 1930s.

There are several bridges across the Mngeni system in the study area. These are:

(a) the Ellis Brown viaduct, 450m from the mouth;
(b) the Athlone bridge, 1.4 km from the mouth (opened in 1927 (Stayt, 1971).
(c) the Connuaght bridge - opened in 1906 – (Stayt, 1971), 2.5 km from the mouth at the head of the estuary. (An old bridge in this position was washed away in 1869).
(d) A railway bridge, 150 m above the Connaught Bridge; and
(e) A footbridge over the Beachwood Creek.

Source: Begg (1978).

Plate 3.2 – Durban Bay around 1850. ***Source:*** **CSIR (2002).**

Plate 3.3 – Durban Today ***Source:*** **CSIR (2002).**

Plate 3.4 – The Connaught Bridge – 1870 ***Source*: CSIR (2002).**

Plate 3.5 – The Connaught Bridge today ***Source:* CSIR (2002).**

Contrast to plate 3.4, from virtually no inhabitants to a metropolis of over 1.3 million people and one of the largest parts in Africa.

3.3 The Mngeni River Catchment

The Mngeni Catchment is approximately 4 740 km² in areal extent of which 4 079 km² lies upstream of the Inanda Dam. The Mngeni catchment is divided into different sub-catchments (Figure 3.3). Some of the general biophysical characteristics of the river system are summarized in Table 3.1.

Table 3.1 – Biophysical characteristics of the Mngeni River

CHARACTERISTIC	**DETAILS**
Catchment size	4 740 km² (average)
River length	255km from source to mouth
Mean Annual Precipitation (MAP)	410 mm – 1 450 mm
Mean Annual Run-off (MAR)	72mm – 680mm
Mean Annual Evapouration (MAE)	1360mm – 2040mm

***Source:* Metro Water (2002).**

In the above table, the area of the catchment given is average. This is due to the various sizes measured by different researchers. Table 3.2 below shows the catchment areas measured by different researchers:

Table 3.2 – Changing areal extent of the Mngeni Catchment

RESEARCHER	**AREA**
Brand P.A.G. *et al.* (1967)	4 385 km²
Orme, A.R. (1974)	4 400 km²
Midgley, D.C. and Pitman, W.V. (1969)	4 639 km²
Oliff, W.D. *et al.* (1970)	5 084 km²
Cloete, C.E. and Oliff, W.D. (1976)	5 850 km²
Kienzle *et al.* (1997)	4 387 km²
AVERAGE	4 740 km²

Adapted from: Begg (1978).

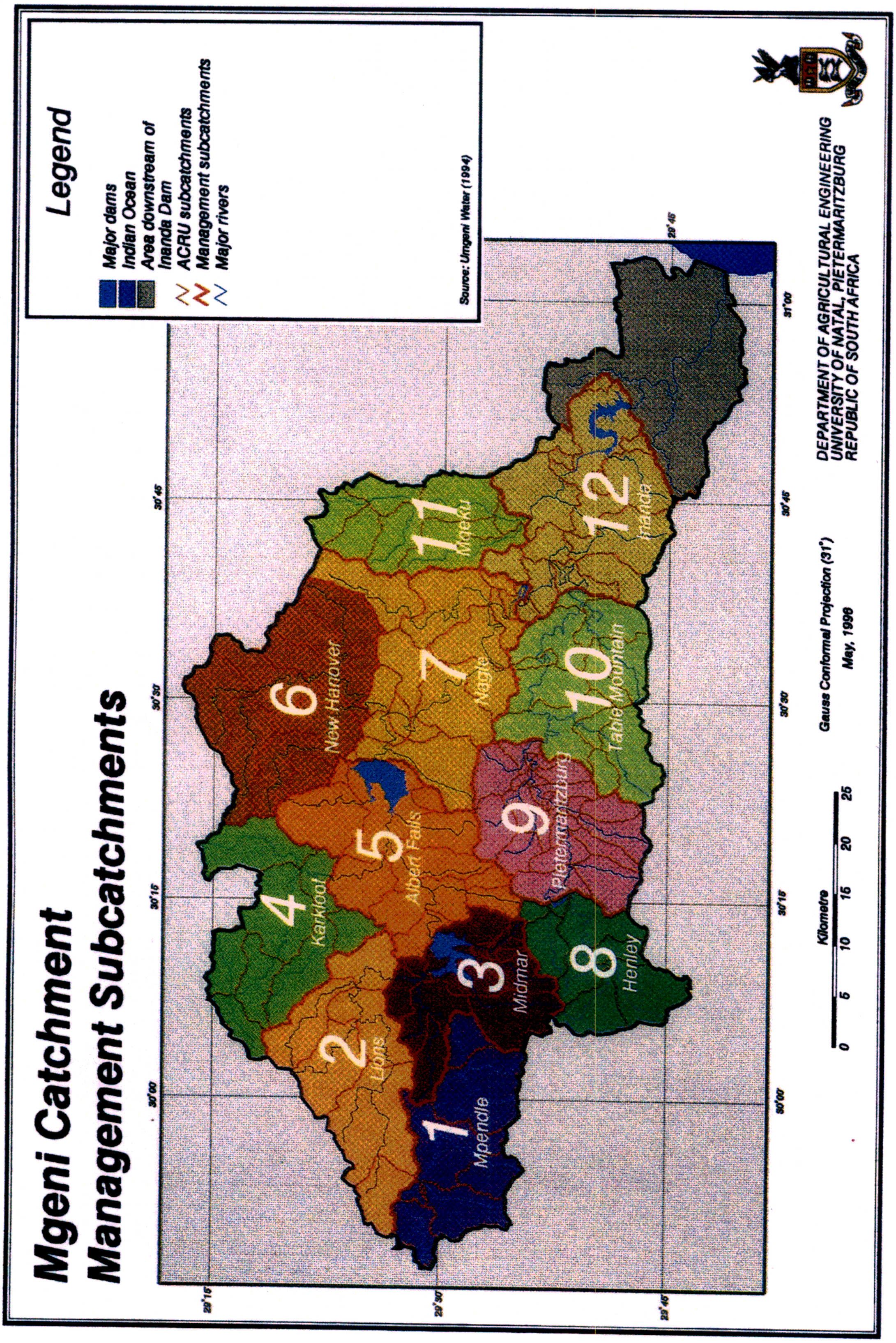


Figure 3.3: Mngeni Catchment Management Sub-Catchments.

The Mngeni River has its source in the foothills of the Drakensberg Mountains at an altitude of 1900 m and is approximately 255 km in length (Figure 3.4). The overall gradient of the river is therefore very steep (1: 132) but from the mouth to the upper reaches of its estuary, the gradient decreases to 1: 550 (Figure 3.5). This steep gradient affords the river considerable erosive potential – a fact evidenced by the deeply incised channels in the upper courses of the river and its tributaries. According to Orme (1974), mean discharge varies from 18.4 m^3s^{-1} in summer months to 6.5 m^3s^{-1} in winter whilst catastrophic floods such as that of September 1987 are capable of delivering estimated discharges of up to 17,000 m^3s^{-1} (Kovacs, 1988), (Plate 3.1 and 3.2).

The mean annual flow of the Mngeni catchment from 1958 to 1961 was 12.5 m^3/sec (Godbold, 1974). It has also been reported as 15.5 m^3/sec (Brand, 1967). The highest recorded flows are 532 m^3/sec. and the lowest 4.5 m^3/sec (Brand, 1967).

Over the past 10 years, a mean volume of 204 million m^3 of water was annually supplied to consumers living in and adjacent to the Mngeni catchment area, with the greatest annual supply reaching 270 million m^3 (Figure 3.7) in 1993/1994 (Umgeni Water, 1994). The mean annual volume supplied represents 37% of the long-term yearly water yield produced in the catchment area of the Mngeni upstream of, and including Inanda Dam. During the period 1960-1993 the mean annual precipitation (MAP) for the 4 079 km^2 catchment area upstream of Inanda Dam ranged between a low of 578 mm in 1992 and a high of 1 384 mm in 1987, averaging 902 mm per annum for that period (Umgeni Water, 1994).

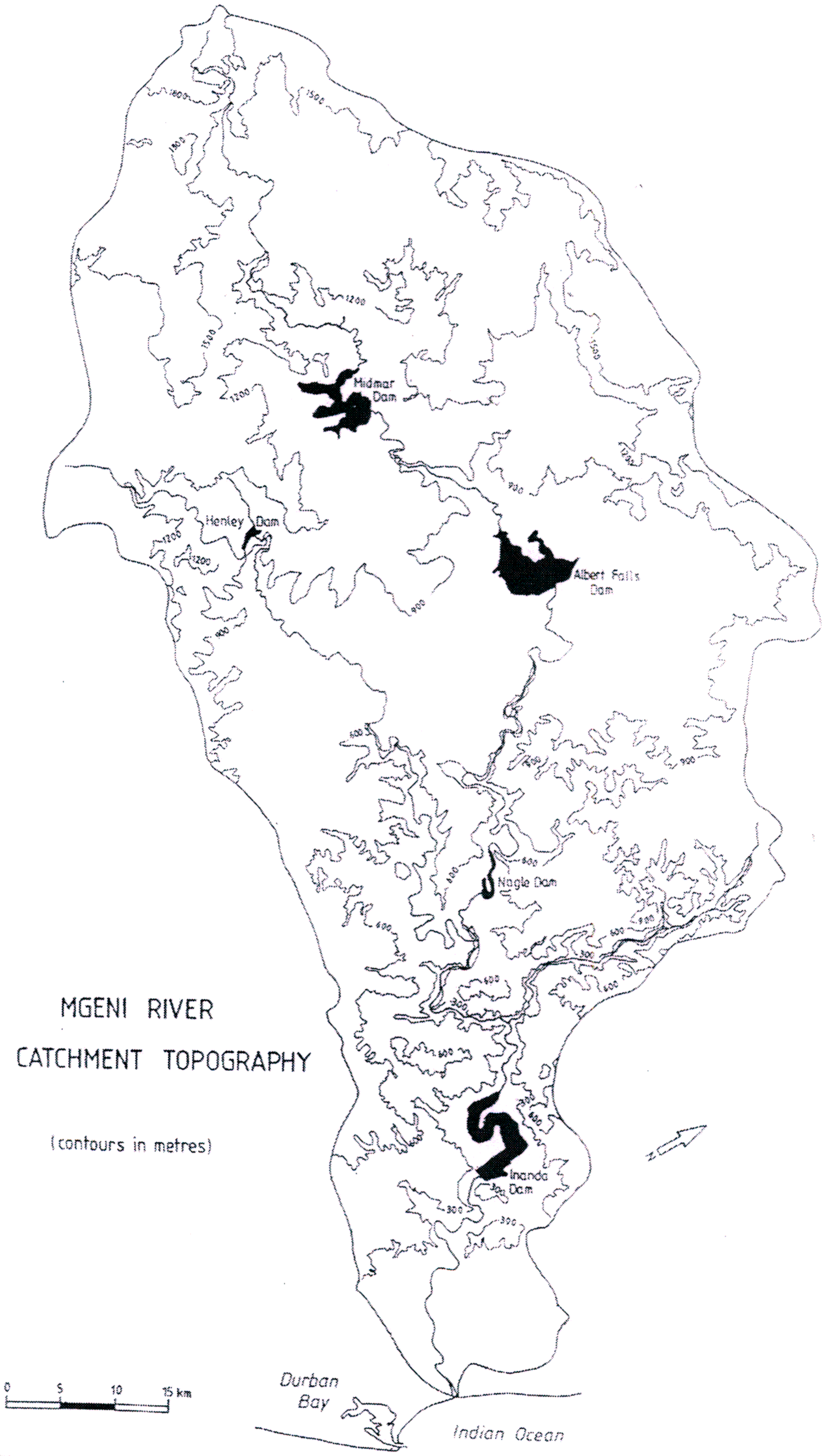


Figure 3.4: Major Dams along the Mngeni River.

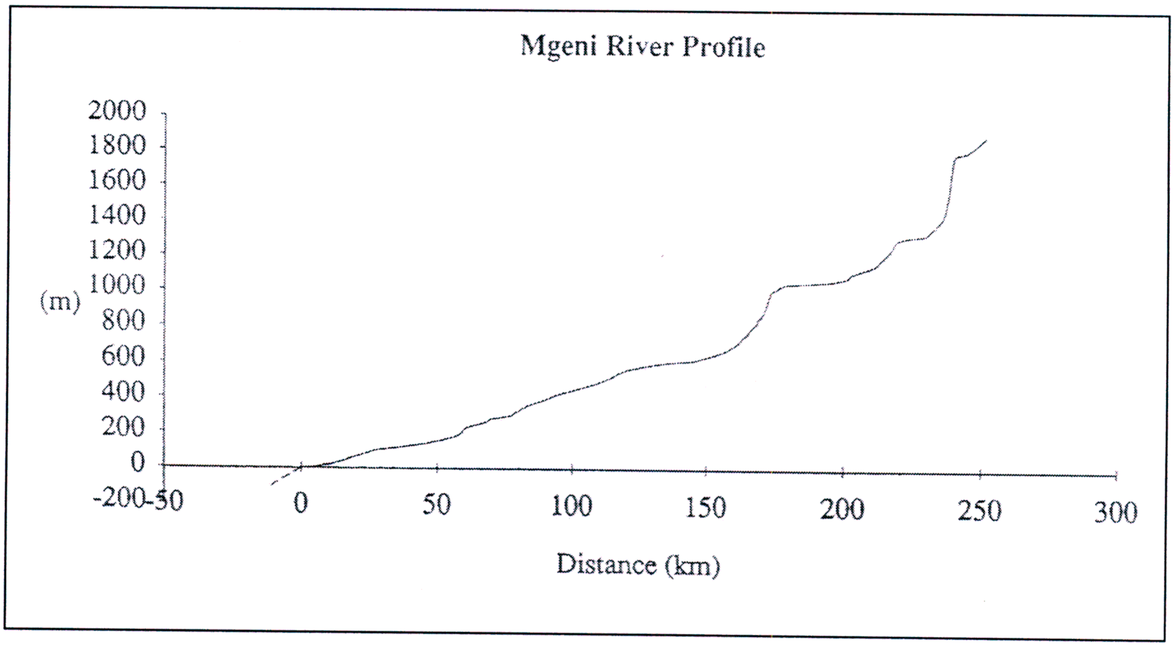


Figure 3.5 – The downstream river profile showing changes in gradient. The line represents the channel extension to the shelf edge during the last glacial maximum, assuming a straight river course.
Source: Kovacs, 1988.

3.3.1 Catchment Geology

A simplified geological map of the catchment is presented in Figure 3.6. The upper part of the catchment consists of Ecca and Beaufort Group sedimentary lithologies underlain by Dwyka Tillite and which have been intruded by Late Jurassic Karoo Dolerite. The central portion of the catchment traverses the deeply incised Proterozoic granite-gneiss complex of the Valley of a Thousand Hills and the lower portion of the catchment comprises downfaulted Ecca and Dwyka Tillite blocks. The floodplains of the Springfield flats and the estuarine area comprise Tertiary and Pleistocene deposits covered by several layers of alluvium deposited over several past flood events (Begg, 1978).

Orme described bedrock below the estuary as shale which was "fractured and weathered towards the surface with some dolerite intrusions …" At the Athlone

Bridge, bedrock was found to be 52 m below mean sea level (Orme, 1974 and 1975), although reported to be at 67 m below mean sea level at another locality (Maud, 1968). At the Connaught Bridge bedrock lay at a depth in excess of 28 m below mean sea level.

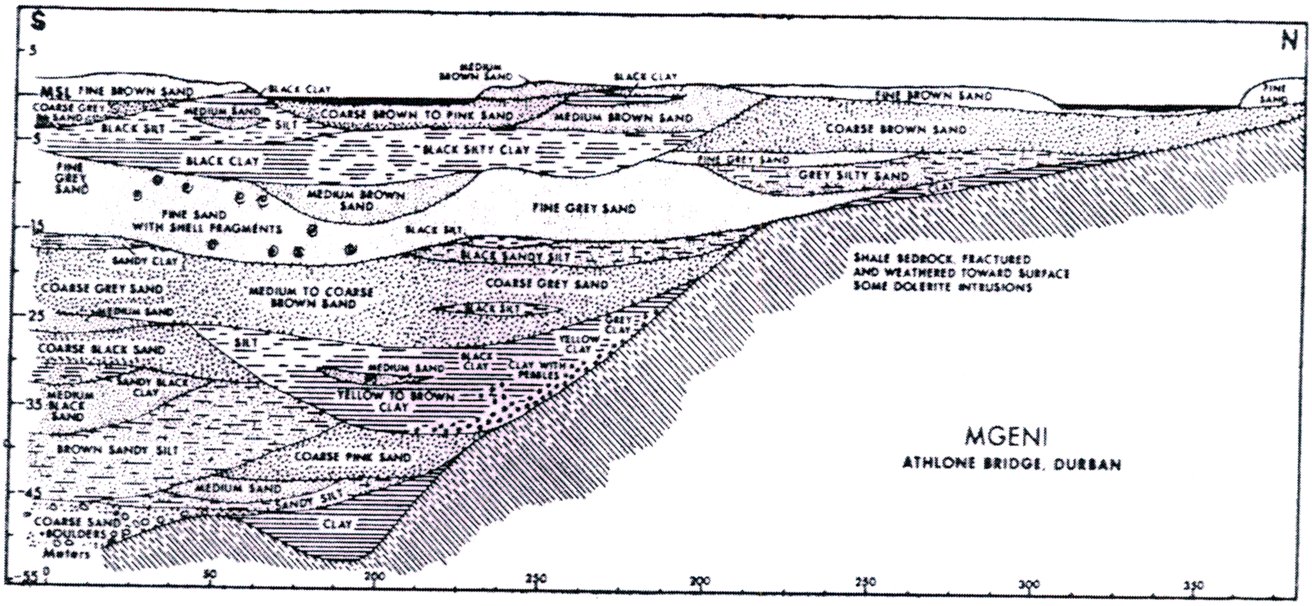
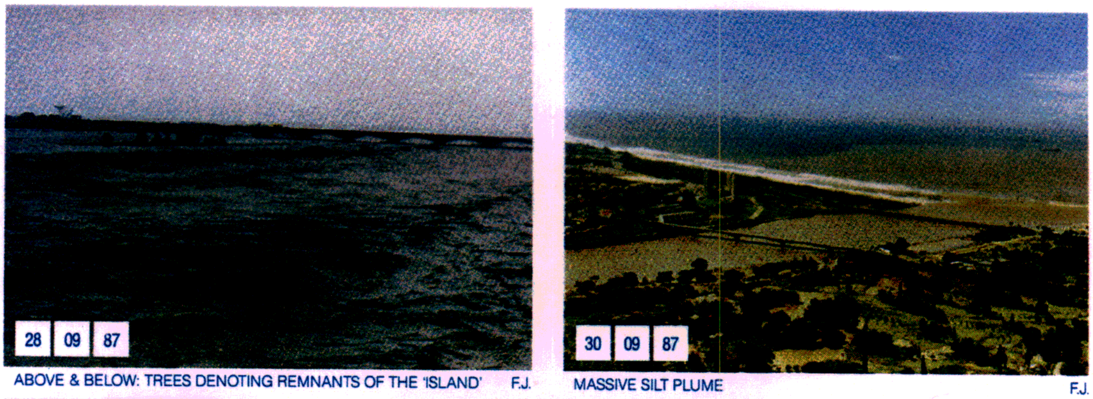


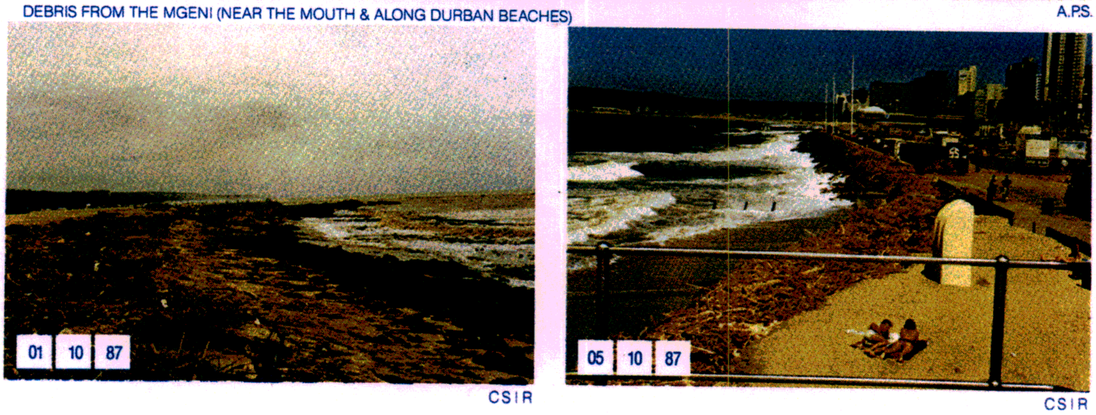
Figure 3.6 – A cross section through the Mngeni Estuary (Orme, 1974).



ABOVE & BELOW: TREES DENOTING REMNANTS OF THE 'ISLAND' F.J.

MASSIVE SILT PLUME F.J.

DEBRIS FROM THE MGENI (NEAR THE MOUTH & ALONG DURBAN BEACHES) A.P.S.



CSIR

CSIR

Plate 3.6 – Composite plates showing the 1987 flood event at the Mngeni Estuary. ***Source:*** **CSIR, 1989.**

Plate 3.7 – Pre-flood conditions can be seen in the smaller photo and the larger photo showing the ‘island’ being swept away by the raging waters.

Source: **CSIR, 1989.**

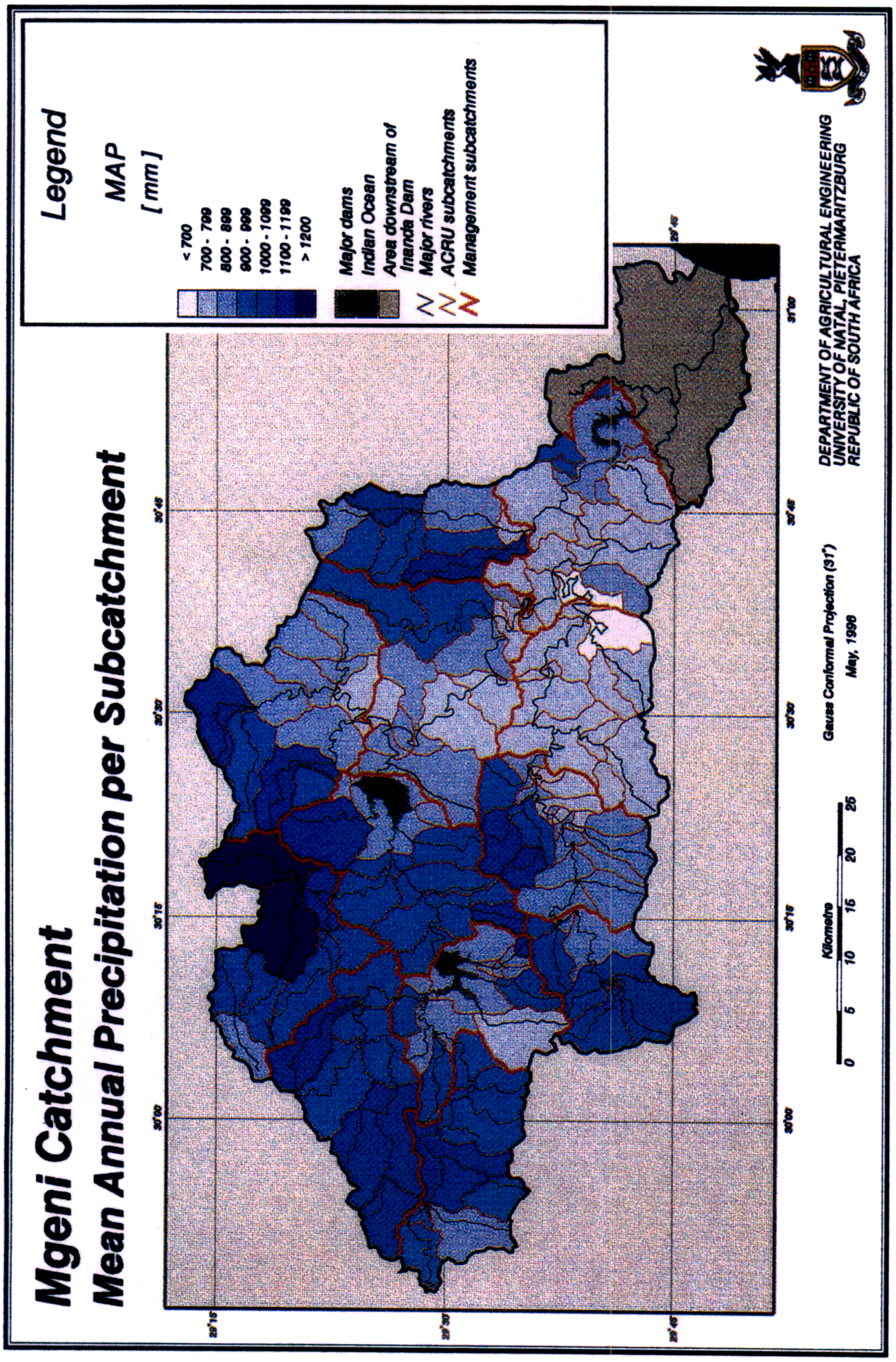


Figure 3.7: Mngeni Catchment Mean Annual Precipitation per Sub-Catchment.

3.3.2 Sediment Yield

The annual sediment yield of the Mngeni Catchment has been estimated at 1.6 x 10^6 tonnes (Rooseboom, 1975) whilst Pillay (1980) calculated an annual yield of 1.0 x 10^6 tonnes. These figures were calculated prior to the construction of the Inanda Dam (1988) which means that current yields may be significantly lower. In fact, there are four other large dams constructed on Mngeni River which implies that during pre-anthropogenic time's sediment yield of the river may have been significantly higher than modern day rates. However, significant population increases in those rural areas of the catchment downstream of the Inanda Dam have resulted in severe erosion in these areas leading to high sediment loads being supplied to the river during heavy rainfall events. Coupled with reduced flows downstream of Inanda Dam, this has caused considerable deposition of sediment in the estuarine environment. The actual amounts of sediment reaching the estuarine environment from these sources have not yet been quantified but given the sensitivity of estuarine ecosystems, it is important that future research focus on this problem.

3.4 The Mngeni Estuary

At present the Mngeni Estuary is situated 5.5km north of Durban Harbour (Figure 3.9 and plate 3.10) at 29°48'S; 30° 02'. Being surrounded by the northern suburbs of Durban, the estuary is easily accessible. There are roads along both banks, but down to the mouth on the southern bank only. It is funnel shaped and subject to tidal salinity fluctuations in its lowest 2.5km (Cooper, 1986). Beachwood Creek, a small tidal tributary, which runs parallel to the coastline for about 2km before connecting with the Mngeni system near the estuary mouth. The mangroves at Beachwood form extensive stands in the middle and upper reaches of the Creek and narrower strips in the lower reaches (Leuci, 1998).

Periodic flood events may remove a large amount of sediment from the estuary, but it appears to be replaced rapidly (Cooper, 1986; Badenhorst *et al.,* 1989). However, the Beachwood mangrove area is buffered from the scouring effect of the Mngeni floodwaters due to the stabilizing effect of the mangrove trees and its position away from the main flow channel. Consequently there is a progressive accumulation of fine grained organic-rich sediments there (Berjak *et al.,* 1977*;* Cooper, 1986).

There have also been significant changes in the estuary habitat. Between 1934 and 1984 the estuary has lost many of its intertidal and backwater habitats. Also, salt concentrations extended much further inland historically. Bridge construction, industrial and organic pollution and the damming of the rivers appear to exert the most significant impact on the estuary. Altered flows (due to upstream impoundment) have transformed the previously flood-dependent and permanently open estuary to a temporary open/closed system. In the absence of floods, sediment accumulates, changing the ecology of the system and thus the system's ability to provide a certain range of estuary-based goods and services CSIR, 2002).

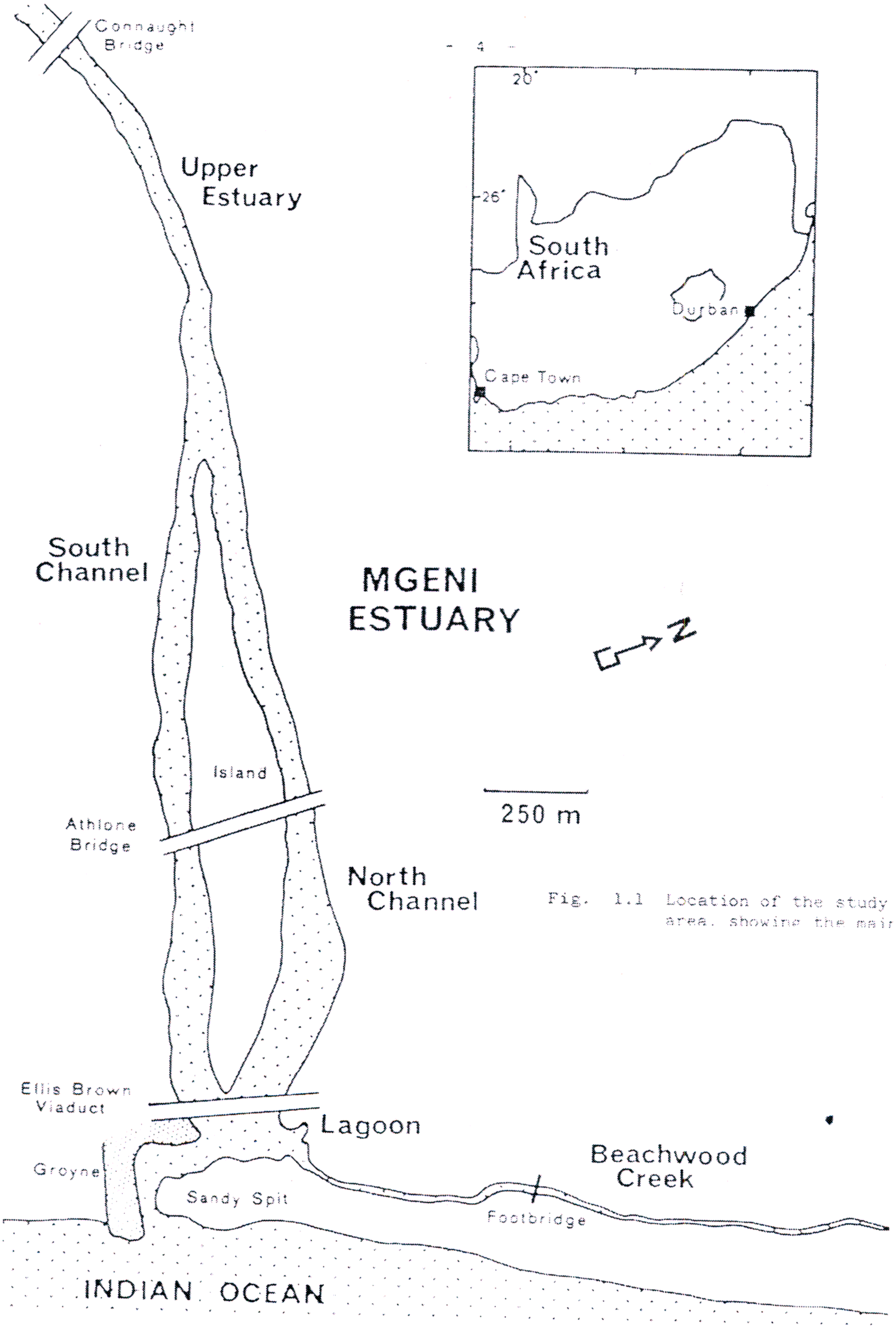


Figure 3.8 –The main physiographic units in the Mngeni Estuary.

Plate 3.8 – An aerial photo of the Mngeni Estuary. ***Source:*** **CSIR (2002).**

The present day Mngeni estuary. Ellis Brown Bridge in the foreground and the Athlone Bridge behind. Note the heavily populated north bank and the golf course to the left. The groyne on the left bank at the inlet mouth is clearly visible. Excessive sedimentation in the estuary due to poor catchment management has forced the main flow within the estuary along the left bank. The steep topography of the catchment hinterland is also clear in the background.

Plate 3.9 – An aerial photo of the cityscape at the Lower Mngeni Resource Unit in Durban.

Intensive urbanization and industrialization can be seen in the foreground; Connaught Bridge and the rail bridge spans across the estuary in the centre of the photograph.

Despite human impacts, the Mngeni remains a critically important estuary. The remaining 44ha of Beachwood mangroves in the estuary support a wide diversity of plants and animals. Recent studies have recorded 56 fish species, 13 prawn species and 11 crab species. The estuary also provides a habitat for juvenile marine fish. The Mngeni estuary also provides a variety of recreational opportunities. But, the Mngeni River will need to be managed carefully in order to maintain a desirable level of benefits from the estuary (CSIR, 2002).

In the estuary a tidal range of 0.4 m has been reported (Edwards and Moll, 1972). Moes (1975) provided details of sediment balance, velocity, flow and water levels in the Mngeni mouth over one tidal cycle. In the Beachwood Creek, tidal fluctuations were previously restricted to a few centimeters, by sand that had blown into the creek from unstable dunes and through obstruction by a concrete causeway (Moll. 1972). Once the causeway was removed (in August 1975) by the Durban Corporation, tidal fluctuation was restored to a range of +/- 1.1 m (Van der Riet, 1976).

Just upstream of the estuary is the industrial area of Springfield. On the southern bank of the estuary is a golf course and a model yacht pond, as well as a restaurant and other amusement facilities. The northern bank of the estuary has not been developed to the same degree. Near the mouth a tidal creek called Beachwood was declared a nature reserve in May 1977. However, on the western bank of Beachwood, the Department of Defence has established a rifle range which they intended on improving in the future by building a caretaker's flat, target sheds, rail system and canteen. This has now been turned into a museum (Metro Water, 2002).

The estuary is controlled by the NCS, formerly the Durban Corporation. The Beachwood nature reserve is under the joint control of the Natal Parks Board and the NCS.

The Mngeni estuary is a popular recreational centre (Brand, 1967) used for angling, bait collection (although now in 2004, it has become illegal to collect bait) and the occasional water sport event (such as the Mngeni raft race and the 'Duzi canoe marathon). Sand mining may feature as a use to which the estuary is put in the future. The estuary also functions as a means for effluent and storm-water disposal. The Beachwood nature reserve serves as a scientific and educational facility and nature trails through the swamps are planned.

Plate 3.10 - A portion of the Mngeni Estuary from Ellis Brown Bridge to the mouth. Note that the outlet is secured on the south side by a solid groyne that penetrates into the surf zone. A 25m wide barrier bar separates the lagoon area visible above from the sea. Note also a large flood tidal delta in the central portion of the photo.

Plate 3.11 – View of the Ellis Brown Bridge constructed over the estuary. High water marks during flood events are clearly evident on the bridge walls.

Plate 3.12 – Pollution found under the Ellis Brown Bridge. The sources of this pollution are from both vagrants that live under this bridge and from the pollution washed down by the tide.

Plate 3.13 & 3.14 – Beachwood Creek - This is an arm of the estuary extending to the north and parallel to the coast. Note the dense growth of mangroves lining the creek.

Plate 3.15 – A stand of *Avicennia Marina* (Beachwood Mangrove) on the north bank of the estuary.

3.5 Morphometry of the estuary:

3.5.1 Area: 48 ha

3.5.2 Axial length: although said to be less than 1.6 km (Brand, 1967), the axial length of the estuary is actually 2.5 km, this limit having been established after a salinity survey which was conducted on an incoming spring tide on 26 July 1972 (Simpson, 1972). The Beachwood Creek is 3 km long (Orme, 1974).

3.5.3 Shoreline length: Estuary = 8.2 km (including the perimeter of a largely centrally situated island). Beachwood = 6 km. TOTAL = 14.2 km.

3.5.4 Width: Maximum – At spring tide the estuary is 600 m wide near its mouth. In the Beachwood creek the entrance of the channel is 20 m wide (Van de Riet, 1976) – above which it varies from 2 m to 5 m in width. In places it splits into a series of channels, low islands and mud flats, where the overall width is 30 m to 40 m.

3.5.5 Channel – Normally 100 m wide.

3.5.6 Floodplain – In places over 1 km.

3.5.7 Shape – The main channel of the estuary splits around a large central island which is almost 2 km long and in places 300 m broad. The Beachwood creek runs in a northerly direction, at right angles to the Mngeni estuary itself.

3.5.8 Bathymetry – A spring tide in the estuary is 2.5 km deep. On an outgoing neap tide depths vary from 0.75 m to 2 m (Simpson, 1972). In the Beachwood creek the depth is said to be 0.5 m (Brown, 1971) – but more specific details (Van der Riet, 1976) have shown that, depending on the tide, depths at the entrance of the creek may range from 0.15 m to 1.25 m.

3.5.9 Nature of bottom materials - The nature of the Mngeni sediments was reported in 1969 to “vary a good deal at different places” as well as “not to alter greatly in a particular area'" (Oliff, 1970). The nature of the bottom was described as:

- Near the head of the estuary – fine sands;
- Near the middle reaches – sandy to gravelly substrates;
- Near the lower reaches – black anaerobic silt beneath deposits of sand or silt;
- In the Beachwood creek – sand and uniform composition; and
- In the mouth – sand.

3.5.10 Water clarity – The water in the Mngeni estuary is rarely clear (Edwards and Moll, 1972). Dredging at the Umgeni Sandworks upstream is constantly stirring the bottom seepage.

3.5.11 Pollution – Industrial areas on the Palmiet River have been known to pollute the system, but the chemistry of the estuary is dominated by the overpowering degree of pollution from the Zeekoe (or Piesang) river sewage discharge (Schoonbee, 1962).

3.5.12 Biotic characteristics: Flora – The mangrove community of the Beachwood nature reserve is the only feature of real botanical significance around the Mngeni Estuary.

3.5.13 Halophytes – The two common species are the White mangrove (*Avicennia marina*) and the Black mangrove (*Bruguiera*). Specimens of the Red mangrove (*Rhizophora)* from the Durban Bay and *Cerops* from the Kosi bay have been spotted (Berjak, 1977).

3.5.14 Fauna – A large variety of lower trophic level fauna, higher trophic level fauna, crustaceans and birds can be found in the Mngeni Estuary. A more detailed description of the fauna can be found in Berjak, 1977.

The Mngeni estuary, in its present degraded state, is still am important estuarine resource. The various problems apparent in the Mngeni system are:

In the estuary:	industrial pollution;
	Sewage pollution;
	Siltation; and
	Urbanization.
In Beachwood:	beach erosion; and
	Development/conservation conflicts.

3.6 Conclusion

The Mngeni River has undergone extensive modification, with riparian vegetation and the watercourse significantly altered to accommodate human habitation and development activities. The area is highly urbanized; with a population in excess of 1.3 million. Rising in the hills above Durban are a few smaller rivers, *viz.* the Mhlatuzana River and the Mbilo River, which drain large areas of the urban and industrial development sectors. Water entering the sea, however, is of poor quality, a result of the large volumes of urban pollutants (Metro Water, 2002).

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

This chapter introduces the methodology that underpins the study. It will discuss in some detail the fieldwork and data collection phases of the research as well as some specific methodological issues pertaining to these aspects of the research.

4.2 WATER QUALITY PARAMETERS

Water is one of the best solvents there is and there is almost an endless list of materials which could be present in a particular sample. When testing water quality it is often convenient to use “blanket parameters” which measure the presence of a group of contaminants or indicate a particular property. Various water quality standards depend on the nature of the water and its actual or potential use. There are three basic types of characteristics which are important (Chan, 1996).

These are:

- **PHYSICAL CHARACTERISTICS**
  These are parameters such as taste, odour, colour, temperature, suspended solids, etc. (Gray, 1994).

- **CHEMICAL CHARACTERISTICS**
  These are properties such as dissolved oxygen, organic content, alkalinity, hardness, etc. (Gray, 1994).

- **BIOLOGICAL CHARCACTERISTICS**

  Water forms a balanced ecosystem containing microorganisms such as bacteria, protozoa and algae. These microorganisms provide food for fish and other forms of life (WRC, 2004).

4.3 RESEARCH METHODOLOGY EMPLOYED IN THE CURRENT INVESTIGATION

The two common types of sample collection techniques are grab samples and composite samples. Composite sampling involves collecting individual samples at known time intervals. A grab sample involves taking a sample from the source by submerging sampling bottles into the water, taking the required amount, and thereafter immediately sealing the bottle. The following procedures were adopted in this study:

i) Firstly, a pilot survey of the study was undertaken in August 2002, when the estuary was comprehensively surveyed for a number of parameters. The pilot survey also included sampling of the parameters at the head of the estuary.

ii) From the initial survey, ten (10) sampling sites were identified and are shown in Fig 4.1. Sampling sites were identified on the basis of easy access to the area being surveyed, uniform distribution within the estuary, and water flow characteristics.

iii) Water and sediment samples were taken on a seasonal basis. The sampling surveys were thus conducted during July 2003 (winter), September 2003 (spring), January 2004 (summer), and March 2004 (autumn).

iv) Several surveys were made to the lower reaches of the Mngeni Catchment from the estuary mouth to 10km upstream, to map and record the different types of land uses occurring in this part of the study area. For the remainder of the catchment land uses were identified from aerial photographs.

v) It was not possible to accurately determine current velocities within the estuary as the water levels were very low and flows on flood and ebb tides took a number of different flow paths. These pathways were invariably separated by sandbar deposits within the estuary. A much larger study incorporating synoptic sampling of velocity would be required to adequately quantify this parameter.

4.3.1 Collection of water samples

a) All sampling was conducted at low tide. This was to avoid the backwash from influencing the concentration of the variables as well as providing accessibility to the sampling points. The South African Weather Bureau and tidal charts for Durban were consulted in this regard.

b) Sterile 500ml glass sampling bottles were used for all collections. The bottles were cleaned thoroughly beforehand with distilled water, as every sample would be subjected to microbiological examination, and thus the pre-treatment requirement to avoid contamination.

c) The samples were taken by immersing the sample bottle to mid-depth in the water column and were allowed to fill up completely (100% of volume of the sample bottle).

d) The sample bottles were filled to volume opposing to oxidation or chemical reactions in the samples attributed to the presence of atmospheric oxygen.

e) The bottles were then accurately labelled to indicate:

  a. GPS position at which sample was taken
  b. Sample number
  c. Time taken
  d. Depth of sample.

f) Note that each sample position was fixed using a GPS. On subsequent surveys, samples were taken as close as possible to the original GPS fixed positions (as per Fig 4.1).

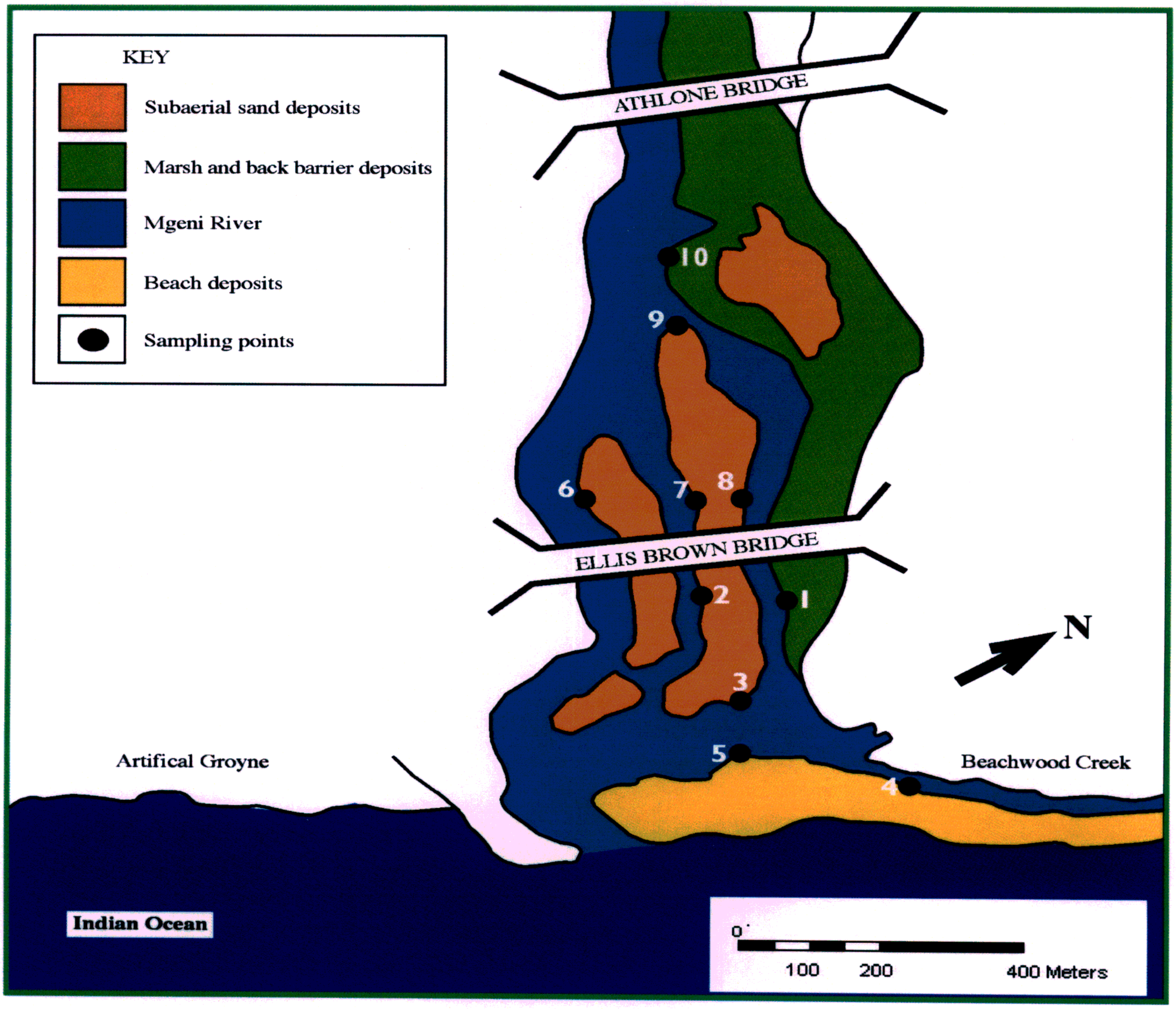


Figure 4.1 – Sampling points in the Mngeni Estuary.

4.3.2 Collection of sediment samples

a) At each sampling point, sediment samples were taken at depths of 30cm.

b) These samples were bottled in 500ml sterilized glass bottles and accurately labelled to indicate:

- GPS position (location of sample)
- Sample number
- Time taken
- Depth of sample.

On completion of the collection of all the water and sediment samples, they were placed on ice in a cooler box and transported immediately to the eThekwini Water Services Waste Water Laboratory in Prior Road, Durban for chemical analysis. It was of extreme importance to transport the samples immediately to the laboratory, as secondary (chemical) changes in the samples may produce incorrect results.

Plate 4.1 – The researcher in the process of taking a water sample at sample site 1. The Ellis Brown viaduct is in the background.

Plate 4.2 – Sediment samples being taken with a soil augur at sampling site 10. Note the Athlone Bridge in the background and the sparse riparian vegetation on the banks.

4.3.3 Laboratory Analysis

Examination of water in the laboratory (Raju, 1995) provides information regarding the presence and concentrations of the varying impurities in water. Water analysis is essential for the following reasons:

i. The results of analysis of treated effluents give the relative efficiencies of the different units of water treatment;

ii. The analysis aids in the determination of optimal chemical dosage to be used in the treatment process; and

iii. The analysis of the natural waters provides an indication of the waters' self-purifying capacity as well as its capability to withstand pollution.

The water samples collected as part of this investigation were taken to the eThekwini Wastewater Management Laboratory for analysis for determination of the concentrations of the indicators utilized in the assessment. For purposes of this investigation, the samples collected were analysed for the following variables:

- pH
- COD (Chemical Oxygen Demand)
- Calcium
- Chloride
- Phosphate
- Ammonia
- Nitrate/Nitrite
- Sulphate
- E.coli (*Escherichia coli*)

4.3.4 Instrumentation used for analysing samples

1) pH was measured using an electrode on a pH meter (Plate 4.3). As a standard practice, the instrument was properly calibrated prior to measurements being made. Calibration is as per manual instruction.

Plate 4.3 – pH meter being used to measure the pH of a sample.

2) COD (Chemical Oxygen Demand) was measured using the Microwave Digestion Method (Plate 4.4). For microwave digestion, the test portion is digested for 26 minutes in a strong acidic dichromate solution using silver sulphate as a catalyst and mercuric sulphate as a masking agent. The dichromate has partially reduced the oxidizable material present in the sample. The excess dichromate is titrated with ammonia iron II sulphate and the COD value is calculated from the amount of dichromate reduced.

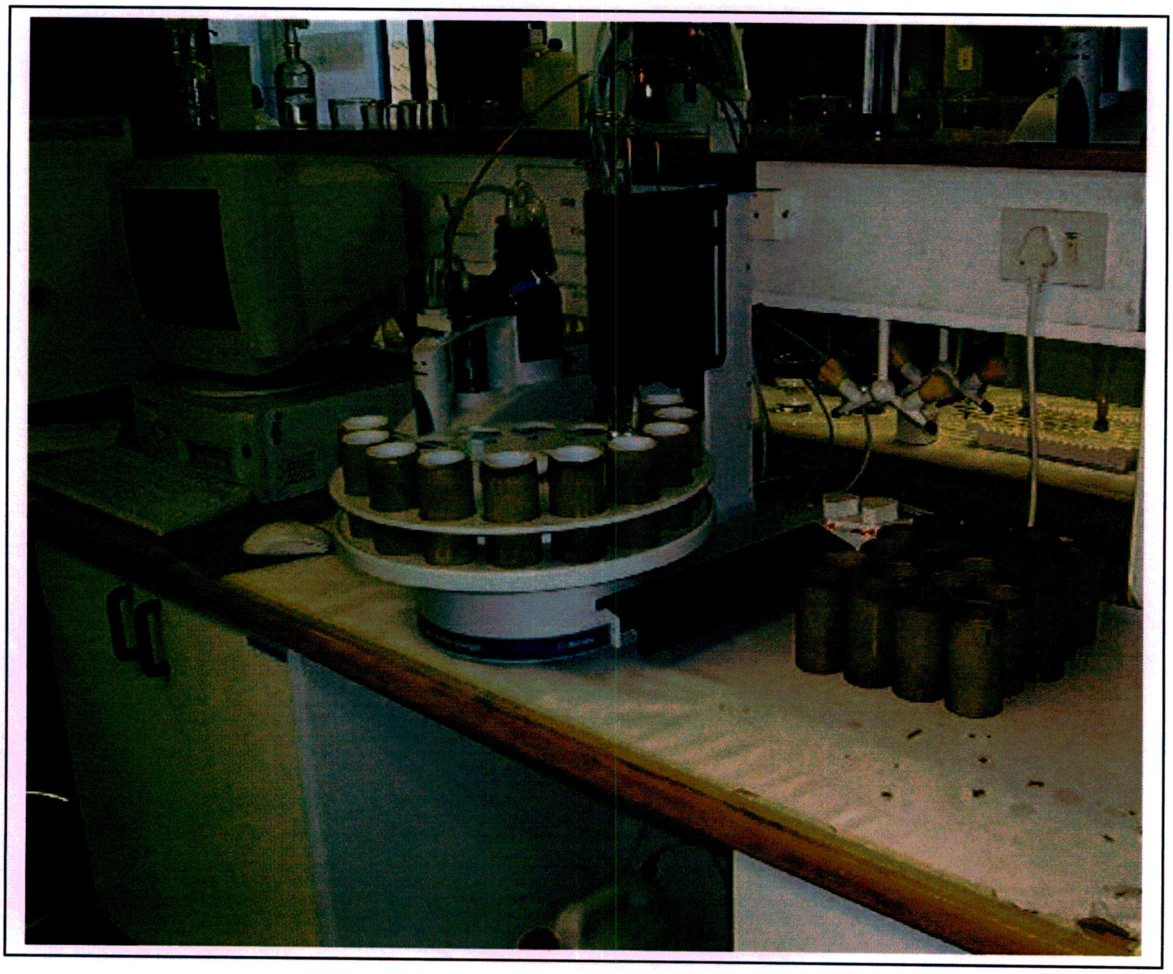


Plate 4.4 – Microwave Digestion Unit used for analyzing COD.

3) Chloride, phosphate, ammonia, nitrate/nitrite and sulphate concentrations were measured using the Flow Injection Analyzer manufactured by LACHAT (Plate 4.5 and 4.6). In the Flow Injection Analyzer, ammonium molybdate and potassium anitmonyl tartrate react in an acid medium with orthophosphate to form phosphomolybdic acid, which is reduced to an intensity coloured molybdenum blue ascorbic acid. A more detailed description of the instrument and technique can be found in the LACHAT Method Manual.

Plate 4.5 - Instrument, Flow Injection Analyzer (made by LACHAT) – used for determining chloride, phosphate, ammonia, nitrate/nitrite and sulphate.

Plate 4.6 – The Flow Injection Analyzer in action.

4) To measure E.coli, bacteria for the analysis of total coliform and E.coli, the membrane filter (MF) procedure is used. The direct MF technique is usually favoured for effluent examination due to its simplicity and minimal equipment, space, and supplies requirements. In this procedure, a known volume of water sample, after preparation of several dilutions, is filtered through a cellulose acetate or glass filter paper membrane with pores of less than 0.5 microns. The filter will thus retain bacterial cells on its surface. The filter paper is placed on suitable nutrient agar – on a pad saturated with a bacterial growth medium (MF-coliform broth) or on MF-coliform agar in a petri dish, covered, inverted, and incubated for 24 hours at 35°C (Curds *et al.,* 1990). After 24 hours the bacteria counts were then undertaken.

Plate 4.7 – Plates being made for bacteria counts.

5) Calcium and heavy metals were measured using the ICP (Inductively Coupled Plasma). Inductively coupled plasma (ICP) is a very high temperature (7000-8000K) excitation source that efficiently desolates, vaporizes, excites, and ionizes atoms. Molecular interferences are greatly reduced with this excitation source but are not eliminated completely. ICP sources are used to excite atoms for atomic-emission spectroscopy and to ionize atoms for mass spectrometry (Tissue, 1996). Refer to Plate 4.8.

A more detailed description of the ICP instrumentation technique can be found at http://elchem/icp.htm

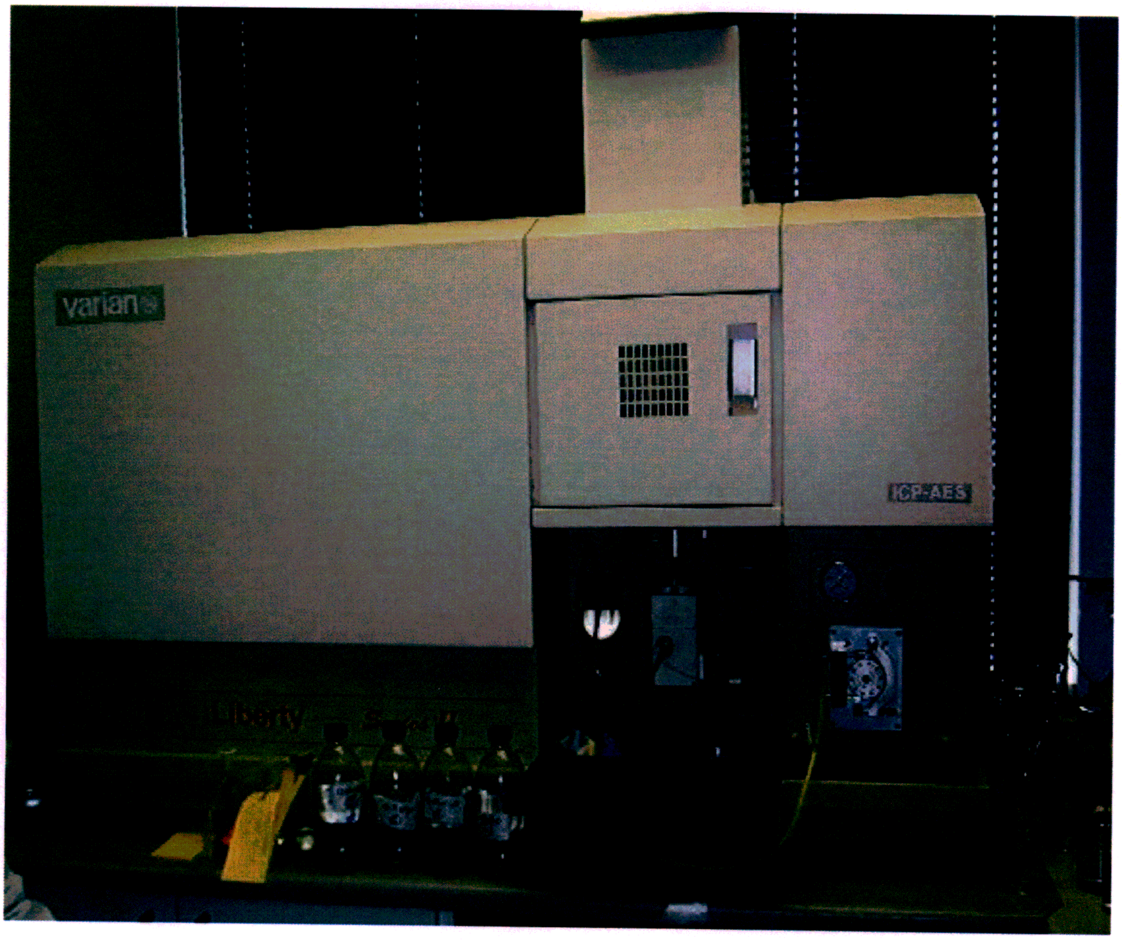


Plate 4.8 - Instrument, Inductively Coupled Plasma (ICP) used to measure concentrations of heavy metals.

4.4 Conclusion

Common analyses in the field of water quality are usually based on straightforward analytical principles. In order to obtain a true indication of the nature of the water, it is first necessary to ensure that the sample is actually representative of the source.

This chapter has therefore provided an introduction to some of the tools of research. It outlined the need for methodology and the various instruments required for water analysis.

CHAPTER 5

RESULTS AND DATA ANALYSIS

5.1 INTRODUCTION

The most challenging but rewarding task in research is the analysis and interpretation of the results obtained after sample collection. This chapter focuses on the practical steps in moving towards the final tabulations and graphical representation of data.

5.2 DATA ANALYSIS

The data obtained from analysis of water samples undertaken at the eThekwini Water and Wastewater Services for the ten samples collected during each of the four seasons will be examined in this chapter. The variables for which laboratory analysis were undertaken included pH, COD, sulphate, calcium, chloride, ammonia, nitrate/nitrite, phosphate, E.coli, and conductivity.

5.2.1 pH Concentration

TABLE 5-1: pH values for each of the four seasons.

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	6.8	7.1	7.1	6.8	7.1	7.2	7.6	7.5	7.0	7.4	**7.2**
AUTUMN	6.8	6.9	7.1	7.1	7.2	7.2	7.5	7.5	7.1	7.5	**7.2**
WINTER	6.8	6.87	7.55	7.29	7.44	7.3	7.7	7.5	7.0	7.4	**7.3**
SPRING	6.9	7.0	7.9	7.9	7.6	7.3	7.5	7.4	7.0	7.4	**7.4**

The above table represents the pH values for summer, autumn, winter and spring respectively. It appears that the average pH concentration is highest for spring, followed by winter, and the lowest pH being represented by summer and autumn.

The slight increase in alkalinity may be related to an increase in benthic/microbial activity during spring as water temperature raises and a number of organisms experience rapid growth and expansion of population.

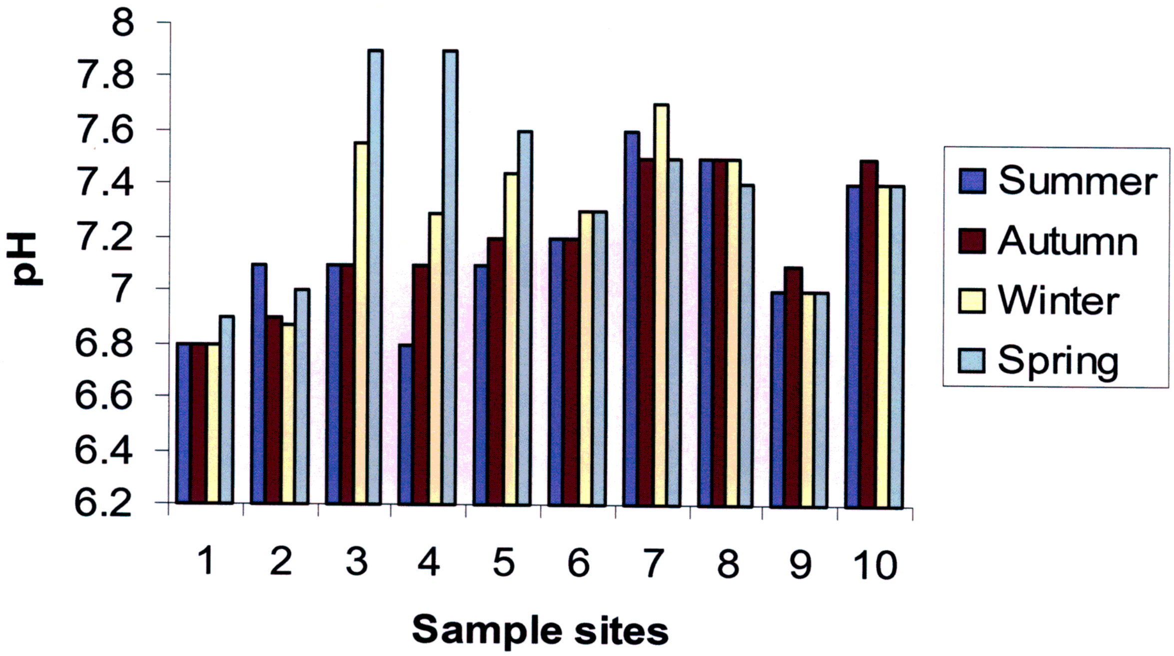


FIGURE 5-1 <u>pH VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES</u>

From the above figure, it can be seen that spring offers the highest pH values at sample sites 3 and 4 as compared to the other seasons. At sample site 1 the pH values remained constant except for spring. At sample sites 4 and 5 the pH values increased accordingly with the seasons. Summer and autumn values are the same at sample site 6 whereas winter and spring values are the same.

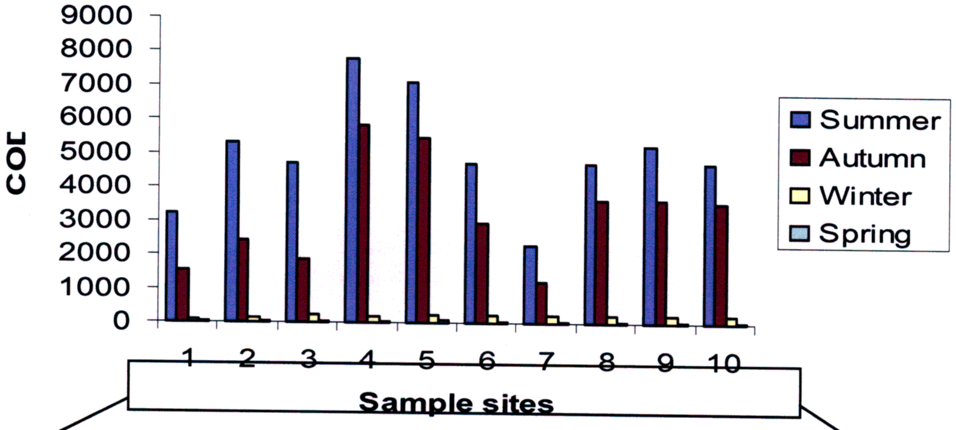
5.2.2 COD Concentration

TABLE 5-2: COD concentration for each of the four seasons (mg/l)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	3200	5300	4700	7800	7100	4700	2300	4700	5200	4700	**4970**
AUTUMN	1540	2410	1850	5830	5440	2950	1210	3630	3650	3550	**3206**
WINTER	110	125	230	196	214	211	251	244	234	250	**207**
SPRING	55	63	55	67	71	63	63	69	68	65	**64**

By examining the above table it can be seen that the COD values are highest for summer, followed by autumn, followed by winter, and finally spring.

FIGURE 5-2A **COD VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES**



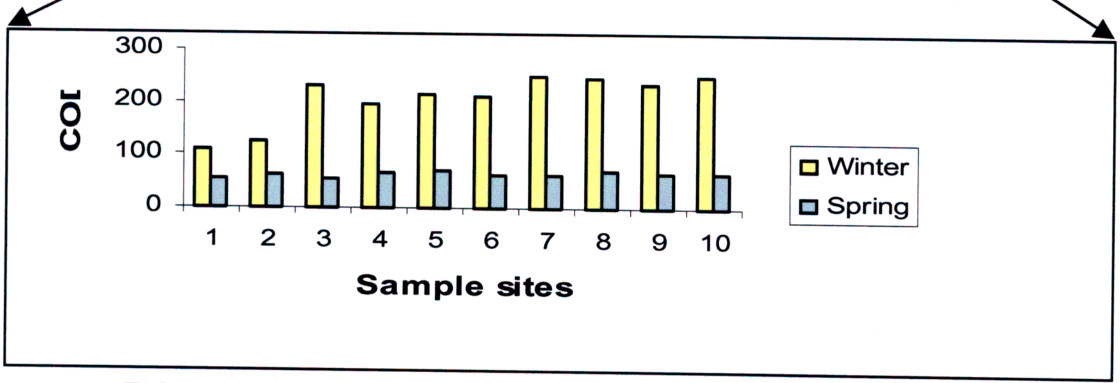


FIGURE 5-2B **COD VALUES FOR WINTER AND SPRING**

The summer values for COD from Figure 5-2A, are high throughout the four seasons. The autumn values are lower but remain fairly high as compared to winter and spring in Figure 5-2B. Figure 5-2B represents the winter and spring values for COD showing the winter COD concentration much higher than that of spring.

The high COD values for summer and autumn undoubtedly reflect high levels of microbial and other chemical reactions that occur in the estuarine environment during this time of increased solar energy input into the system.

Reduced temperatures during winter compelled with low discharge have reduced COD markedly from the summer highs. As the first spring rains occurred late in September, the COD levels were still in the low measures during this time. It is possible that the COD levels would increase once the system receive rains during late spring and early summer.

5.2.3 Ammonia Concentration

TABLE 5-3: Ammonia concentration for each of the four seasons (mg/l N)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	-	-	2.8	1.3	0.85	1.4	1.0	1.4	1.4	-	**1.5**
AUTUMN	<0.50	<0.50	<0.50	<0.50	<0.50	<0.5	<0.50	<0.50	<0.50	<0.50	**0.5**
WINTER	<0.50	<0.50	<0.50	<0.50	<0.50	<0.5	<0.50	<0.50	<0.50	<0.50	**0.5**
SPRING	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	**0.5**

The above table shows that the ammonia concentration for summer has been fairly high compared to those of the other seasons. In summer, at sample sites 1, 2 and 10 there was no ammonia present. The ammonia concentrations are constant for autumn, winter and spring.

These readings are consistent with the extremely high COD of the system during summer. These results confirm that the system is in its maximum phase of biochemical productivity at this time.

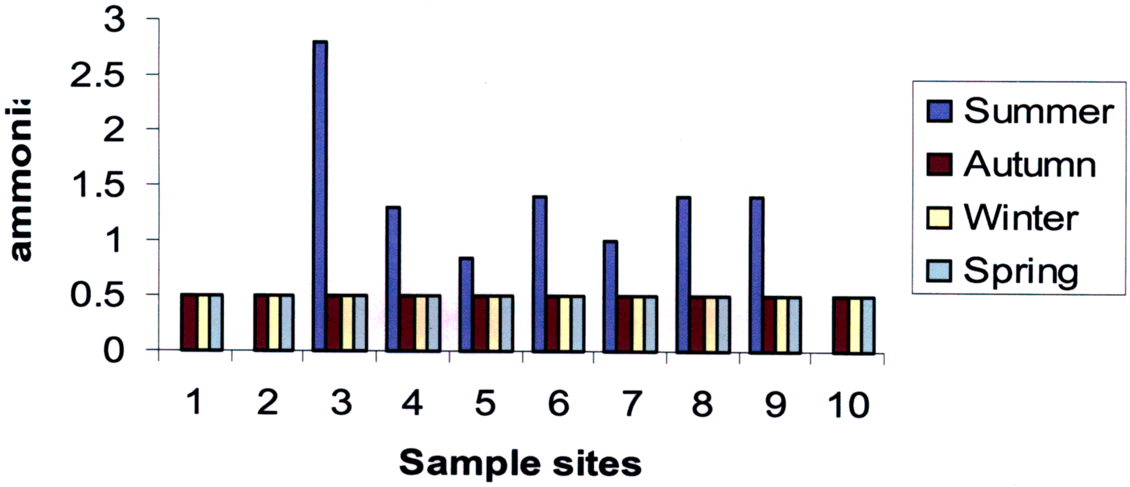


FIGURE 5-3 **AMMONIA VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES**

The above figure represents the ammonia concentration for the four seasons. It is clear that the ammonia concentration for summer is much higher than the other seasons. It is interesting that the ammonia concentration for autumn, winter and spring remain constant throughout the sampling sites.

5.2.4 Sulphate Concentration

TABLE 5-4: Sulphate concentration for each of the four seasons (mg/l)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	585	773	1799	1607	1472	2132	2503	2959	1970	795	**1659.5**
AUTUMN	521	621	918	1418	1220	1615	1818	1721	1721	718	**1229**
WINTER	510	585	680	1154	1160	950	1280	1150	1210	650	**933**
SPRING	1780	1890	1480	2150	1640	1520	1650	1550	1510	1610	**1678**

The above table shows the sulphate concentration at the different sampling points for the four seasons. On average, spring has the highest sulphate concentration and winter with the lowest. However, the summer concentration is close to spring. Sulphate concentration declines as temperature falls from summer to winter, but reaches up dramatically in spring as primary productivity increases in the system.

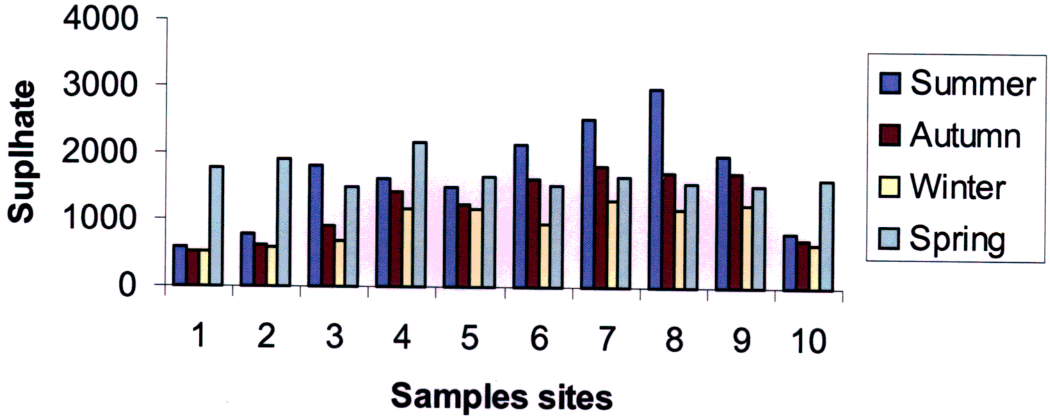


FIGURE 5-4 **AMMONIA VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES**

From the above figure, winter has the lowest concentration of sulphate throughout the seasons. Summer and spring have the highest sulphate concentration with autumn showing not too high or low concentrations.

5.2.5 Calcium Concentration

TABLE 5-5: Calcium concentration for each of the four seasons (mg/kg)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	206	747	129	640	188	457	24677	1371	137	12231	**5313**
AUTUMN	7200	<5.0	<5.0	3300	1000	990	1210	1200	1100	1210	**1722**
WINTER	156	54	32	21	52	86	54	10	52	44	**56**
SPRING	288	300	224	260	228	228	300	300	320	320	**277**

The above table shows that on average winter has the lowest concentration of calcium and summer has the highest concentration. On average spring has a lower concentration as compared to autumn. Autumn has the lowest concentration at sites 2 and 3. Winter has the lowest calcium concentration.

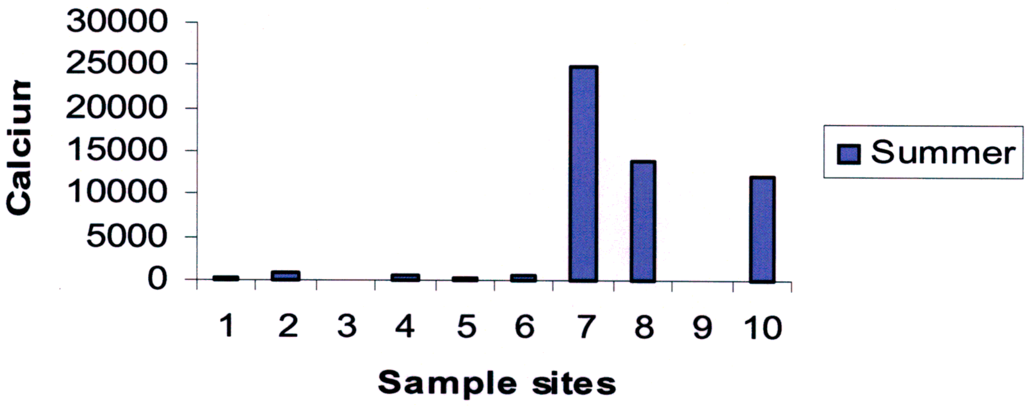


FIGURE 5-5A CALCIUM VALUES FOR SUMMER AT THE DIFFERENT SAMPLE SITES

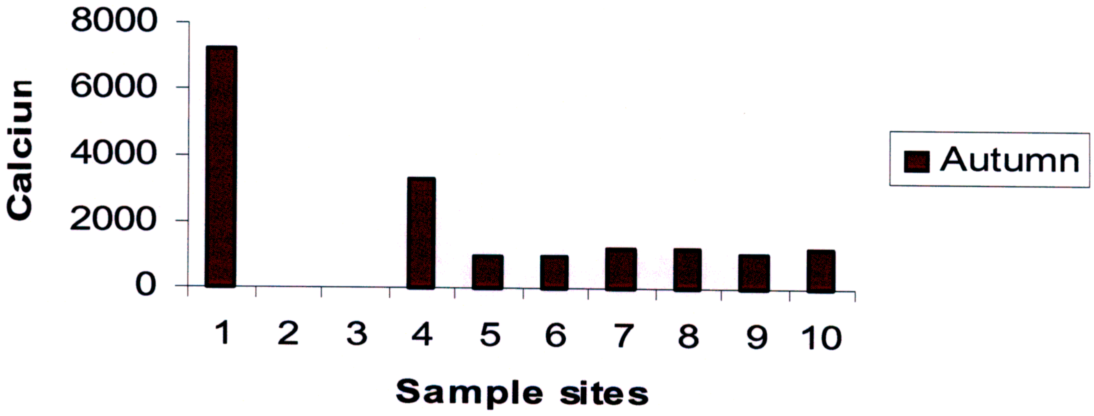


FIGURE 5-5B CALCIUM VALUES FOR AUTUMN AT THE DIFFERENT SAMPLE SITES

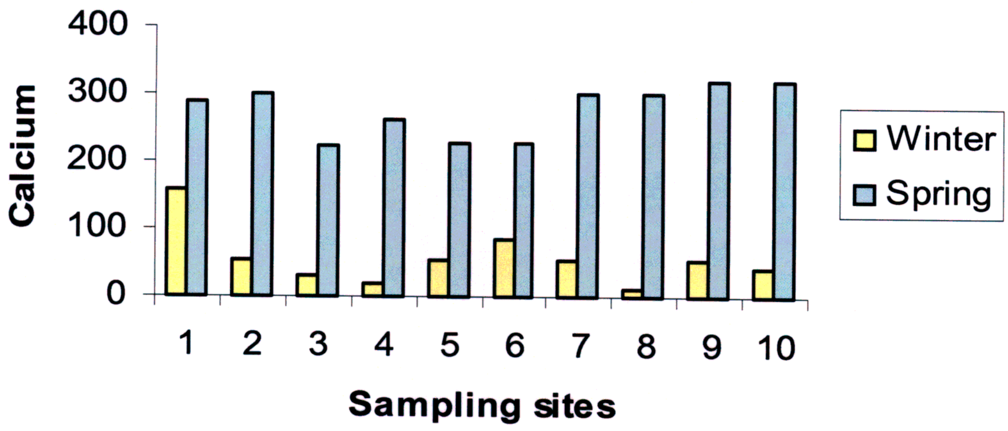


FIGURE 5-5C CALCIUM VALUES FOR WINTER AND SPRING AT THE DIFFERENT SAMPLE SITES

From Figure 5-5A and Figure 5-5B it can be seen that summer has the highest calcium concentration at sites 7, 8 and 10 and autumn has the lowest concentration at sites 2 and 3.

From Figure 5-5C, it can be seen that winter has the lowest concentration of calcium. The spring calcium concentrations are much higher than that of winter.

Calcium in the water mirrors that of sulphate, except that the spring recovery is much more sun-duel.

5.2.6 Chloride Concentration

TABLE 5-6: Chloride concentration for each of the four seasons (mg/l)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	35	53	106.22	85	87.5	162.5	175	188.75	112.5	12	**101.75**
AUTUMN	65	68	42	39	36	40	42	38	52	55	**48**
WINTER	22	15	18	21	32	32	28	27	20	15	**23**
SPRING	146.5	155	132.50	189	141.5	136.5	138.5	135.60	139.9	145.5	**146**

The above table shows that spring has the highest concentration of chloride whereas winter has the lowest concentration. Summer also has a fairly high concentration of chloride.

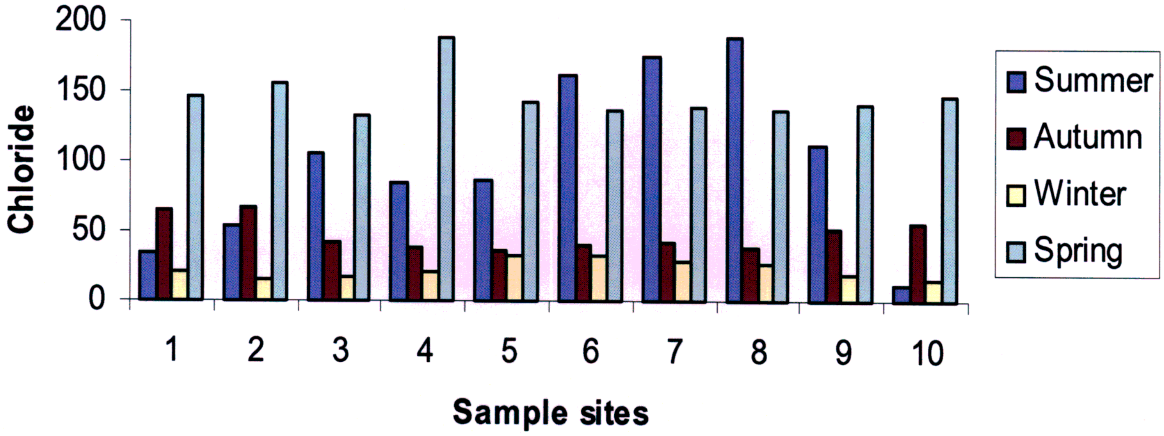


FIGURE 5-6 CHLORIDE VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES

From the above graph, the highest concentrations belong to summer and spring. The lower chloride concentrations are the winter and autumn. The concentration is highest at sites 6, 7 and 8 for summer with the highest concentration in spring at site 4.

5.2.7 Nitrate/Nitrite Concentration

TABLE 5-7: Nitrate/Nitrite concentration for each of the four seasons (mg/lN)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	-	-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	**0.1**
AUTUMN	2.9	3.2	0.77	0.55	0.67	0.69	0.75	0.77	0.77	1.2	**1.3**
WINTER	2.2	2.7	2.1	0.56	0.52	0.66	0.8	0.8	0.7	1.1	**1.2**
SPRING	2.1	0.93	2.0	0.64	0.79	1.1	1.5	1.5	1.3	1.5	**1.3**

The above table for nitrate/nitrite concentration indicates that in summer the concentrations remained more or less the same with there being no nitrate/nitrite present at sampling points 1, 2 and 10. The concentrations for autumn are high at points 1, 2 and 10 and are remain below 1mg/lN for the rest of the sampling sites.

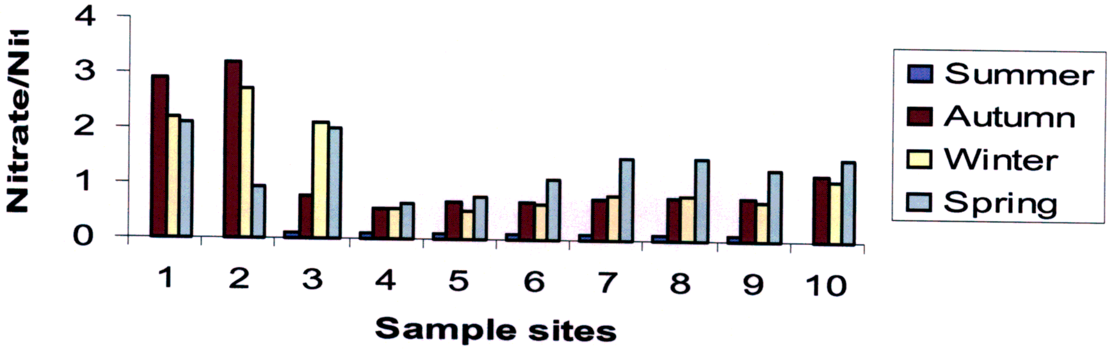


FIGURE 5-7 **ILLUSTRATION OF NITRATE/NITRITE VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES**

From the above graph it can be seen that autumn experienced the highest concentration of nitrate/nitrite at sampling sites 1 and 2, and summer the lowest. Winter and spring concentrations remain in-between.

5.2.8 Phosphate Concentration

TABLE 5-8: Phosphate concentration for each of the four seasons (mg/l P)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	0.42	0.58	<0.10	<0.10	1.0	0.45	0.3	0.21	0.28	0.71	**0.4**
AUTUMN	0.44	0.20	0.25	0.08	0.04	0.04	0.05	0.05	0.05	0.04	**0.1**
WINTER	0.35	0.2	0.33	0.1	0.1	0.05	0.04	0.05	0.05	0.5	**0.2**
SPRING	0.24	0.17	0.41	0.25	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**0.2**

From the above table it can be deducted that on average summer has the highest concentration of phosphate with autumn having the lowest concentration. The averages for winter and spring are the same.

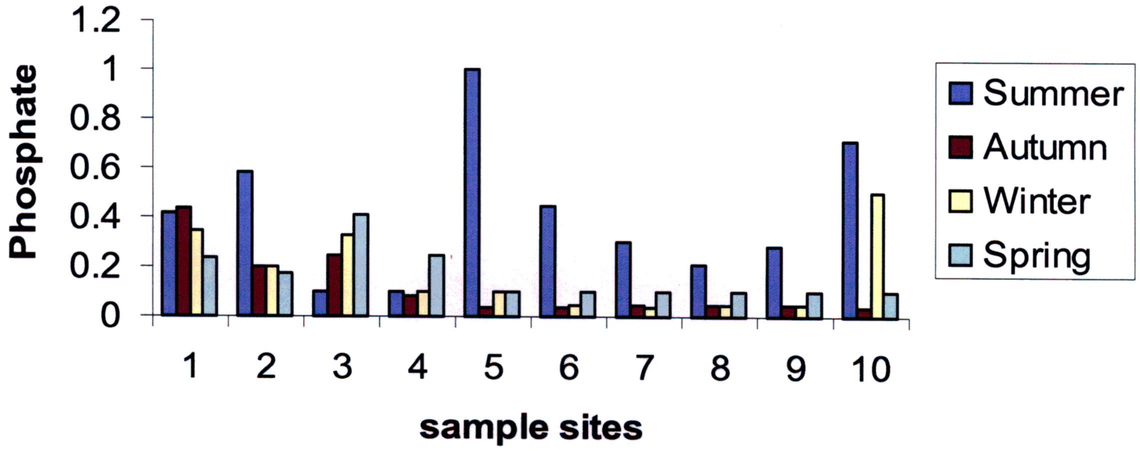


FIGURE 5-8 **PHOSPHATE VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES**

From Figure 5-8 the highest concentration of phosphate is experienced in summer at sample site 5 with the lowest concentration of phosphate being experienced in autumn at sample sites 5 and 10.

The concentrations for winter and spring remain fairly low with the highest concentration for winter being at sample site 10 and the highest concentration for spring being at sample site 3.

5.2.9 TDS Concentration

TABLE 5-9: TDS concentration for each of the four seasons (mS m^{-1})

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	77	78	75	66	66	72	81	74	80	73	**74**
AUTUMN	24	45	27	34	24	25	32	26	32	27	**30**
WINTER	93	55	80	72	98	92	99	96	98	99	**88**
SPRING	28	29	24	30	30	32	35	30	34	31	**30**

From the above table it can be seen that on average winter has the highest percentage of TDS followed by summer. The averages for autumn and spring are the same.

The highest percentage for TDS is experienced by winter at sample sites 7 and 10. The percentages remain fairly high from sample sites 5 to 10. The lowest percentage for TDS is experienced in autumn and spring. These two seasons have the lowest percentages for TDS.

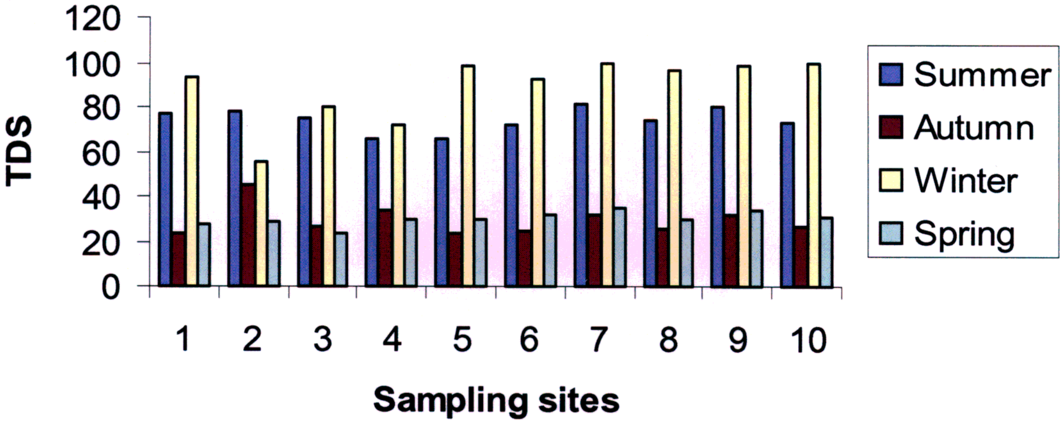


FIGURE 5-9 **TDS VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES**

The above graph clearly shows that winter and summer has the highest percentage for TDS, and autumn and spring has the lowest percentages.

5.2.10 E.coli Concentration

TABLE 5-10: E.coli concentration for each of the four seasons (cfu/100ml)

	SAMPLE SITE										
SEASON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SUMMER	1000	900	2500	1000	1000	500	1000	500	1000	900	**940**
AUTUMN	500	250	250	850	500	250	900	500	850	800	**565**
WINTER	1000	250	750	1200	500	400	2200	2500	1000	1000	**1080**
SPRING	1800	250	850	1200	500	400	1400	2050	500	500	**945**

The above table clearly shows that on average winter has the highest concentration of E.coli and autumn has the lowest concentration. Summer and spring has only a small concentration difference on average.

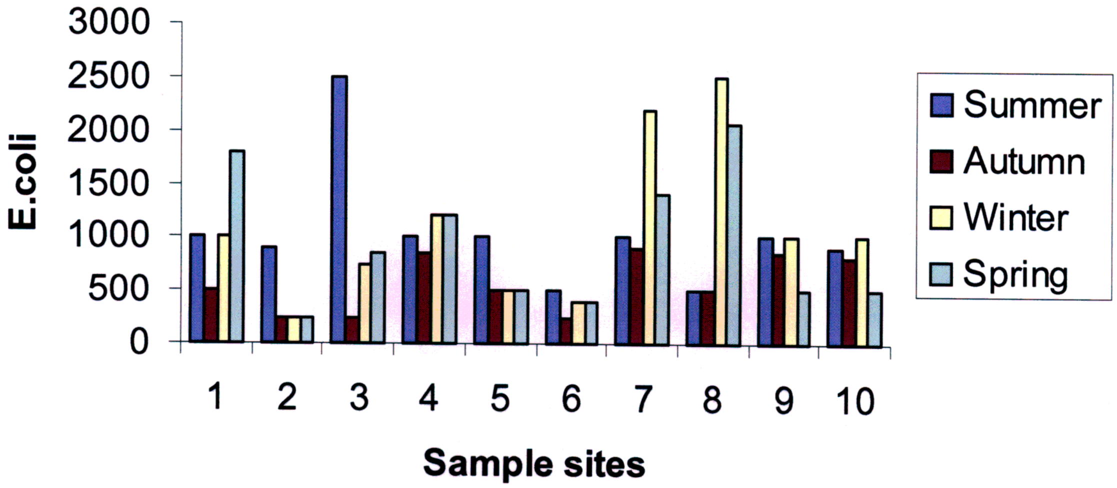


FIGURE 5-10 E.COLI VALUES FOR EACH OF THE FOUR SEASONS AT THE DIFFERENT SAMPLE SITES

From the above graph it can be seen that the highest concentration of E.coli is experienced in summer at sample site 3 and in winter at sample site 8. The autumn concentrations remain fairly low with it s highest concentration being at sample site 7 and its lowest at sample sites 2, 3 and 6. The E.coli concentrations for spring are highest at sample sites 1 and 8 with its lowest concentration being at sample site 2.

CHAPTER 6

DISCUSSION, RECOMMENDATIONS AND CONCLUSION

6.1 INTRODUCTION

Aquatic ecosystems are particularly vulnerable to pollution. Rivers are confined, uni-directional systems that act as “drains” for the landscape, while lakes and estuaries are usually “sinks”, accumulating materials brought in by wind, water and humans from their surroundings. Activities anywhere in its catchment are reflected in a river and its associated ecosystems and alterations or perturbations, even in the upper reaches, may have an effect down its entire length. Estuaries, being places where sediments and water tend to accumulate, are even more exposed to build-up of pollutants both in their waters and in their sediments (Allan, Erickson and Fay, 1997).

The longitudinal and temporal effects of pollutants in a river depend on the extent to which its biota can degrade and so remove the particular pollutants entering it. At the same time, the extent to which the biota can purify water in a river depends on the quantity and type of pollutants entering it. No organism can break down chemical elements like heavy metals, for instance (although they can break down and so remove most organic substances); nor can they function adequately in the presence of toxins. The effectiveness of the purification process is also influenced by the degree to which a pollutant is diluted by rainfall or river flow. Thus concentrated pollutants may inhibit or even destroy the ability of a river or estuary to cleanse its own waters (Boulton and Brock, 1999).

The main impact on the natural coastal environment is the loss of ecosystem integrity. This can be attributed to many factors; e.g. deterioration in marine water quality as a result of pollution, resource shrinkage due to over-exploitation of target organisms for food and bait, habitat elimination and fragmentation and reduced freshwater inflow into estuaries. This loss of ecosystem integrity also gives rise to impacts on the human environment which is compounded by population growth and largely uncontrolled expansion of the built environment within the coastal zone (Attwood *et al.*, 1997).

Overexploitation of resources and human activities which result in threats to biodiversity, disruption of ecosystem processes and habitat loss and fragmentation are mainly a consequence of human population growth, which is manifested by urban encroachment into the coastal zone.

Plate 6.1 – Degradation of the coastal environment along the Californian coast – the result of hinterland mismanagement together with dumping along the coast.

Source: **www.ngo.grida**

6.2 DISCUSSION

6.2.1 ANTHROPOGENIC IMPACTS IN THE MNGENI CATCHMENT

The general physiographic characteristics of the Mngeni catchment have been described earlier. The Mngeni catchment is of vital importance to the major economic powerhouse of KwaZulu-Natal. The Mngeni Catchment provides the water source for both the Greater Durban and Pietermaritzburg Metropolitan areas in KwaZulu-Natal. Some 1.5 million people live in the area upstream of Inanda Dam, while a further 3 million are supplied by transfers of water captured in the Mngeni catchment to areas downstream (up and until the estuary) of Inanda Dam in the Durban Functional Region (Figure 6.1)

The population in Greater Durban area has been projected to expand between 9 and 12 million by the year 2025, with major population concentrations in and adjacent to the Mngeni catchment (WRC, 1997).

In addition, the Mngeni system has various industrial and residential areas both within and around Durban. Most of the activities located along the lower catchment are predominantly industrial activities. The middle to upper catchment sustains much of the farming and other related activities (Figure 6.2). Apart from these and the large urban centres and towns, the entire catchment contains rural settlements – some of which are dispersed whilst others are densely populated. Thus, the entire catchment is in some way or the other impacted upon by man. The major pollutants deriving from natural catchment processes are therefore compounded by anthropogenic contributions together with anthropogenic mismanagement of portions of the catchment. For instance, during summer months, frequent convective thunderstorms result in the transport of suspended solids, pathogens and phosphorous from the sub-catchments into receiving channels, with the consequence that domestic, agricultural, industrial, ecological

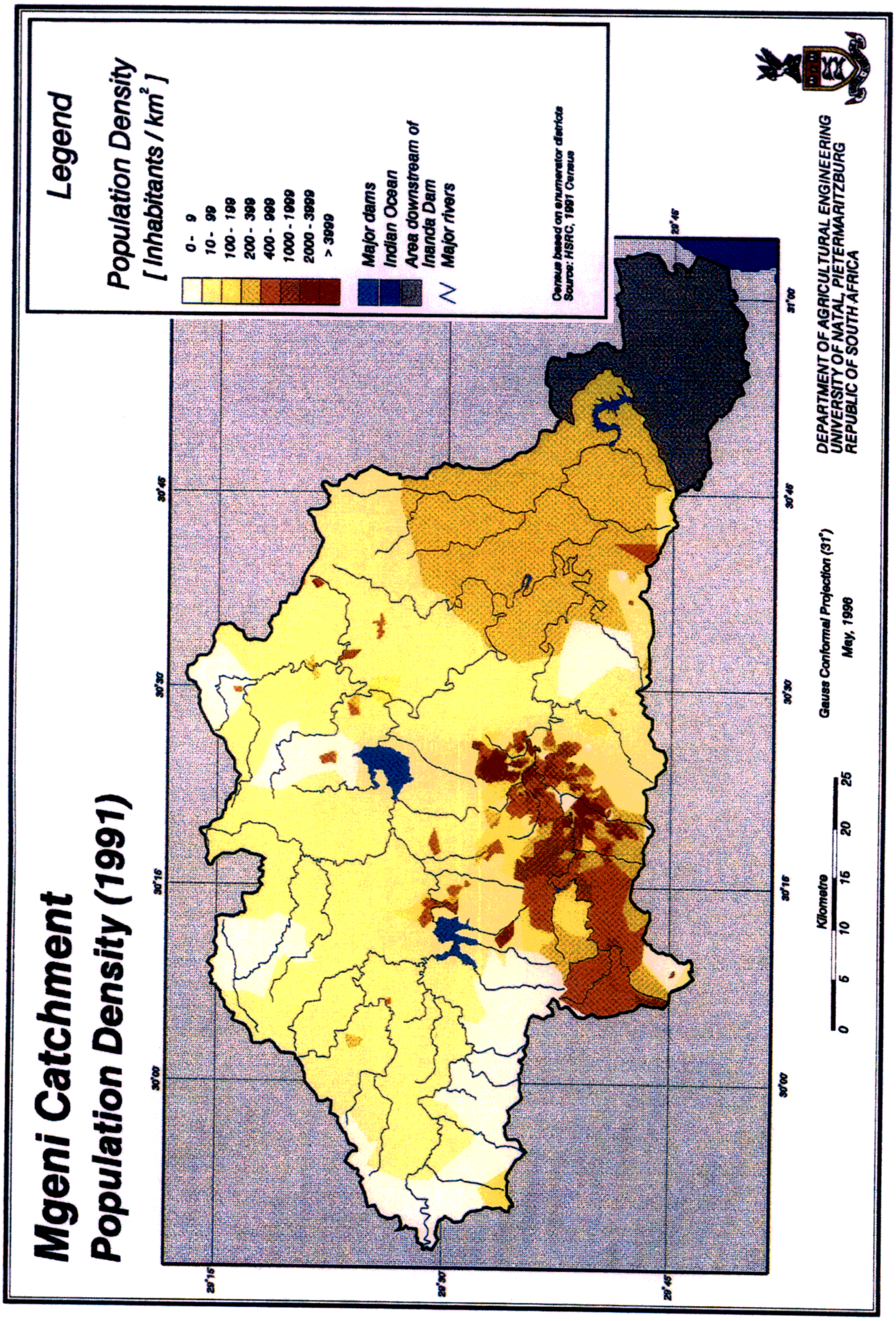


Figure 6.1: The Mngeni Catchment Population Density (1991).

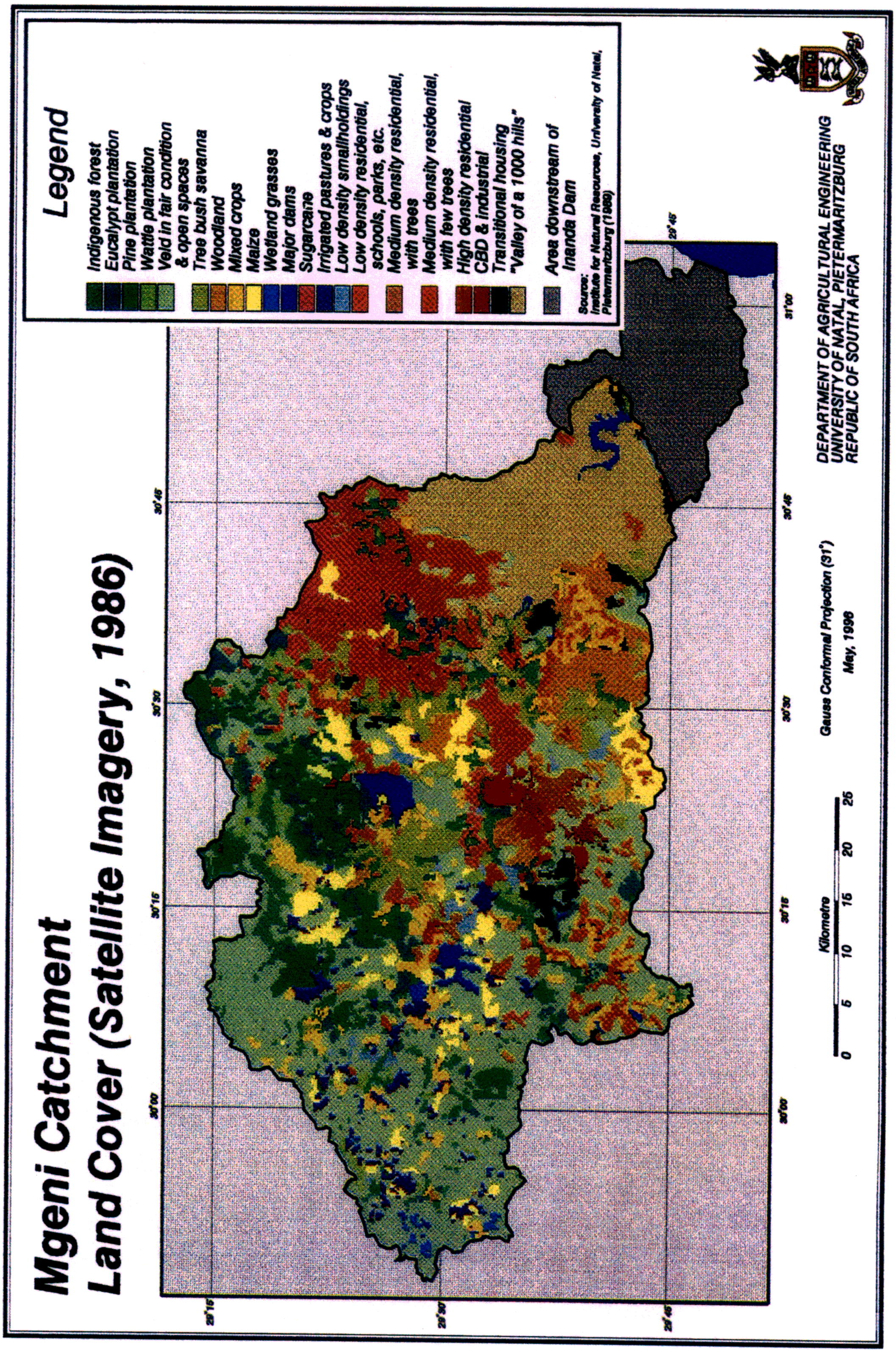


Figure 6.2: Mngeni Catchment Landcover (1986).

and recreational user groups are affected. Eventually, the estuarine environment, being the repository of all that emanates from the catchment is in danger of grave degradation (WRC, 1997).

6.2.2 THE IMPACTS OF CURRENT LAND USES IN THE CATCHMENT

A review of literature on land uses in the catchment as well as aerial photography and site visits to parts of the catchment revealed that there are significant impacts deriving from anthropogenic use of the catchment. Much of these impacts have been documented by several reports published by the WRC and only the major aspects are considered here.

In a major study conducted by the WRC (1997), the catchment was dividedto137sub-catchments and studied in detail to assess the impact of land use upon the system functioning of the Mngeni. These land use impacts were compared with pristine conditions as determined by vegetation cover existing prior to human occupation of the catchment using Acock's Veld Types Map and projecting these veld type cover over the entire catchment (Map of pristine land cover can be found in WRC, report no. TT87/97).

The hydrological impact of land-use upon streamflows is striking in that some sub-catchments demonstrated a virtual doubling on streamflows (due to the increase in impermeable surfaces) to catchments where streamflows decreased by 60%. The highest reductions of streamflow are found in those sub-catchments which are under extreme agricultural use. In particular, sub-catchments with a high proportion of commercial forest or sugarcane plantations display high reductions in water yield of up to 60%. Sub-catchments that are highly urbanized or demonstrate a high population density show an increase in water yield, as in the Pietermaritzburg area and in the Valley of a Thousand Hills immediately upstream of the Inanda Dam. This is a consequence of widespread replacement of pristine vegetal cover with unyielding surfaces or highly compacted soil with large proportions of bare ground in many former KwaZulu-Natal homeland areas (WRC, 1997).

According to Rooseboom *et al* (1992), the mean annual sediment yield for the sub-catchments ranged from 2 to 629 $t.km^{-2}$. The Valley of a Thousand Hills carries the most sediment yield followed by the sub-catchment in the Edendale area where large proportions of informal settlements are situated. The sub-catchment in the higher region of the Mqeku Management sub-catchment has a medium soil loss potential, comprising the full range of very low to very high soil loss potentials, resulting in a mean annual soil loss potential of 2 030 $t.km^{-2}$. The mean annual sediment yield was simulated to be 195 $t.km^{-2}$, which is in the medium to low range compared with the rest of the Mngeni Catchment. Comparatively, the sub-catchment comprising the Inanda Dam was estimated to have a low annual soil loss potential of 641 $t.km^{-2}$, but shows a mean annual sediment yield of 287 $t.km^{-2}$ (WRC, 1997).

Figure 6.3 reflects the main sources of E.coli in the catchment. Mean E.coli concentrations in the sub-catchments range from 30 to 18 200 $counts.100ml^{-1}$. The areas where E.coli concentrations are highest are associated with informal settlements, in particular alongside the Msunduzi River in its lower reaches and central parts the Valley of a Thousand Hills. It is also apparent that high E.coli concentrations are not always related with areas of high sediment yield. This is due to large populations in informal communities in particular areas as well as the relatively high stocking rates (WRC, 1997).
It is of concern that extremely high values of this pathogen are to be found in the vicinity of the Pietermaritzburg metropole and surrounding areas of the Midmar Dam. This is due not only to the high concentration of informal settlements in this area but also due to stock farming in the midlands.

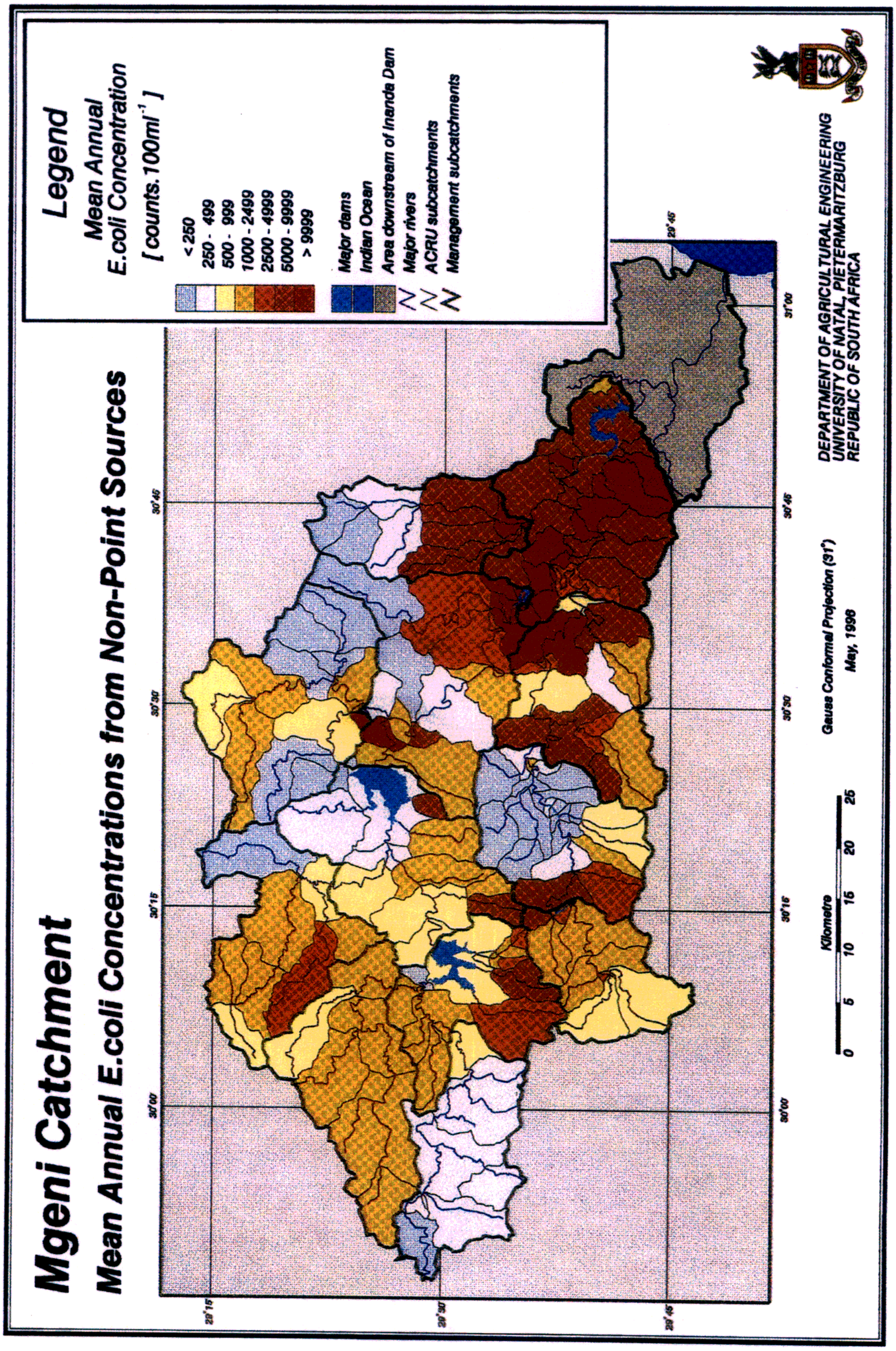


Figure 6.3: The mean *E.coli* concentration in the Mngeni Catchment.

6.2.3 PHYSIOGRAPHIC CHANGES TO THE ESTUARINE ENVIRONMENT

During the course of this study several morphological changes occurred in the estuarine environment and these played a role in the overall dynamics of the system.

Due to prolonged low rainfall from February 2003, water levels in the estuary declined quite significantly. Flood dominance of the tide and wave overwash processes allowed for increased shoaling of the inlet (mouth). As the mouth inlet began to close, venturi effects became more pronounced and allowed for the accumulation of considerable volumes of marine sand in the estuary embayment and the building up of a significantly large flood tidal delta (Figure 6.4). The mouth inlet gradually became more restricted and eventually closed completely on 20 July 2003, creating lagoonal conditions within the estuary. Catchment derived water began to dam up in the estuary embayment and most sedimentary morphological features (flood tidal deltas, subaerial deposits/islands, back-barrier environments and beach deposits) were submerged (Figure 6.5). The National Conservation Service (NCS) decided to artificially breach open the mouth as water was backing up into Beachwood Creek and flooding the mangroves.

Upon breaching, much of the accumulated head of water in the estuary ebbed out to sea but strong flood currents and wave action caused mouth closure overnight and the NCS had to set about re-opening the mouth the very next day (Plate 6.2)

Fortunately rainfall within the Mngeni catchment allowed for stronger fluvial flows and the re-opened mouth stabilized. This open connection to the sea has been maintained throughout winter and spring of 2004. It is not anticipated that the mouth will close during the summer of 2004 as recent heavy summer rains in the catchment has resulted in fairly consistent and strong fluvial flows.

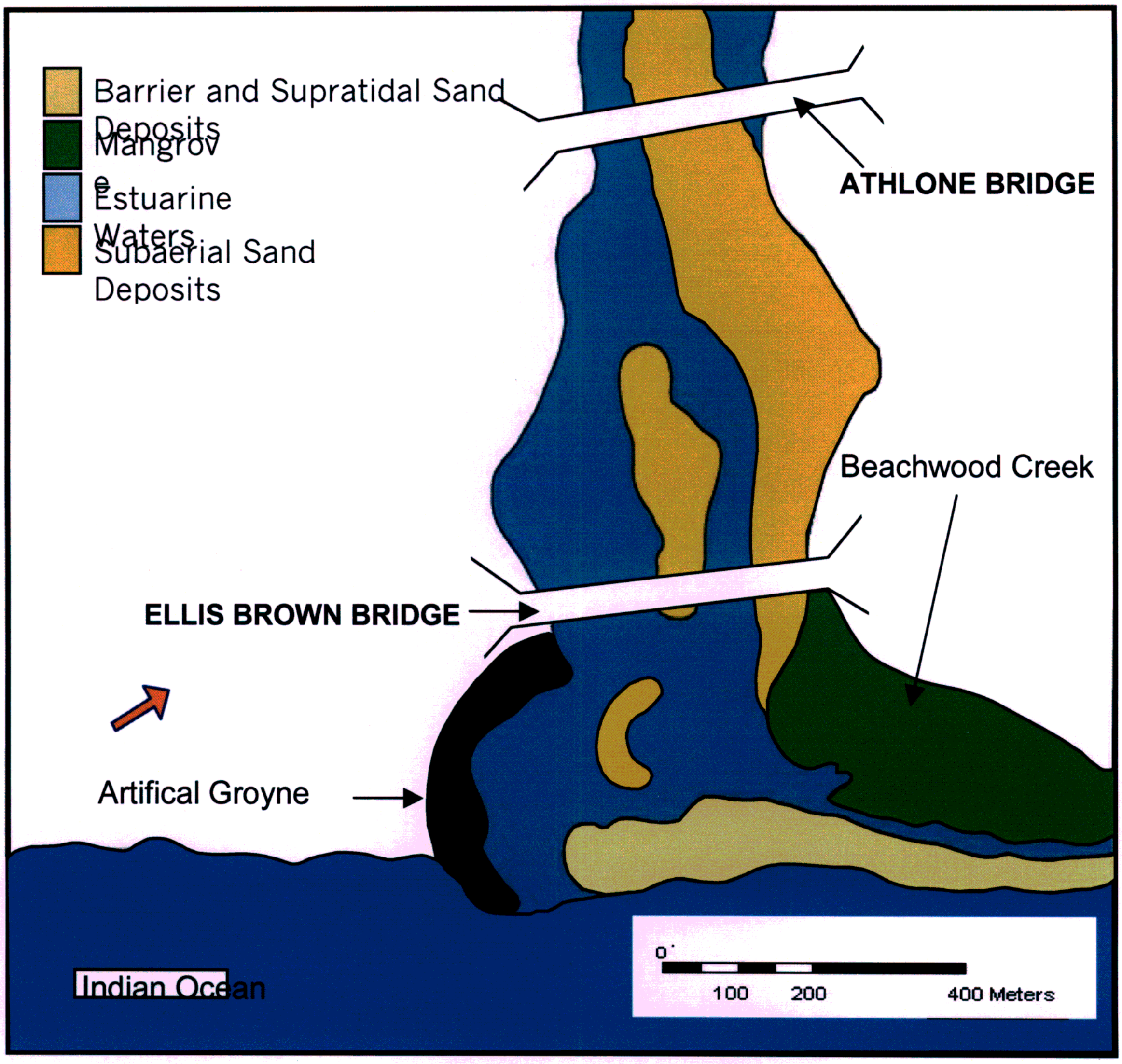


Figure 6.4: Building of a flood tidal delta in the Mngeni Estuary embayment.

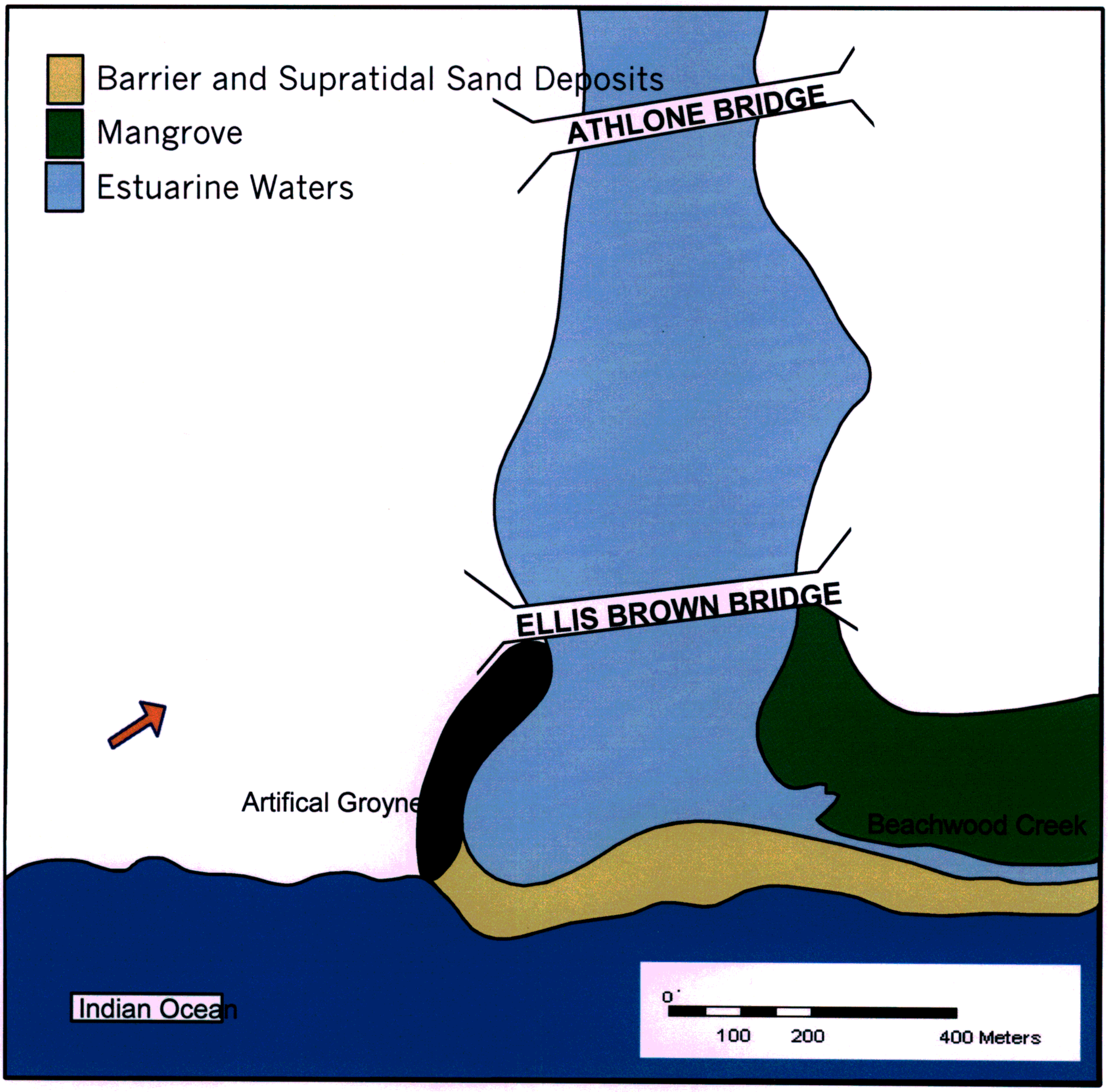


Figure 6.5: The Mngeni Estuary submerged.

However, during the period that the mouth was partially and then wholly closed (approximately three months), lagoonal conditions prevailed, and a thick veneer of fine muds was deposited throughout the estuary, including the mangrove swamp area. Such mud deposits cause considerable problems for estuarine biota and forced human intervention in the system.

Plate 6.2: Artificial breaching of the Mngeni mouth.

Plate 6.3: The incoming tide upon breaching.

6.2.4 POLLUTANTS IN THE ESTUARY

Results obtained in the research (presented in Chapter 5) were compared to the DWAF general limits for aquatic ecosystems:

TABLE 6.1: General Standards for Water Quality: Target Water Quality Range (TWQR)

PARAMETER	GENERAL LIMIT	UNIT
pH	5.5 – 9.5	-
COD	75	mg/L
Ammonia	≤7	mg/L N
Sulphate	200 - 400	mg/L
Calcium	150 - 300	mg/kg
Chloride	100 - 200	mg/L
Nitrate/Nitrite	6.0 – 10.0	mg/L N
Phosphate	1.0	mg/L P
E.coli	0	cfu/100mL
TDS	500	mS m^{-1}

***Source:* DWAF, 1996.**

6.2.5 THE IMPACTOF PHYSIO-CHEMICAL PARAMETERS ON THE MNGENI ESTUARY SYSTEM

Microbiota rather than macrobiota was used as indicators, as logistics and financial constraints refrained the researcher from the latter.

6.2.5.1 pH

pH is determined largely by the concentration of hydrogen ions and alkalinity by the concentrations of hydroxyl, bicarbonate and carbonate ions in water. The

relative proportions of major ions and, consequently, the pH of natural waters is derived from geological and atmospheric sources.
Under natural conditions, most fresh water systems are well buffered and generally neutral with pH ranging from 6 to 8. However, certain vegetation types (e.g. fynbos, mangroves) produce organic acids (humic and fulvic acids) and other polyphenol-rich compounds that leach into the aquatic systems and increase local acidity. On the other hand, extreme rates of photosynthesis commonly cause increases of pH in water bodies. Such high photosynthetic rates may be naturally induced or may occur as a result of eutrophication. High rates of consumption of CO_2 during photosynthesis may drive the carbon dioxide / bicarbonate / carbonate equilibrium far towards carbonate and hence to high pH values (Gardner, 1988; Gale, 1992). Human induced acidification of rivers is normally the result of industrial effluents, mine drainage and acid precipitation. Alkaline pollution is less common but may result from certain industrial effluents and anthropogenic eutrophication.

In the Mngeni Estuary, the pH concentrations were all below 7 at sample site 1 which is near the marsh and back barrier deposits. This could be due to the decomposition of the excessive pollution (garbage) found under the Ellis Brown Bridge which is located close to this sampling site (Refer to Plate 3.14). The consistent low pH value (high acidity) recorded here may also be related to the fact that sample site 1 is located near the mangroves and is impacted upon by organic acids leaching from the mangrove vegetation (Gale, 1992).

On average the winter and spring seasons have higher pH concentrations (alkaline waters). As seen in Figure 3, with the mouth closed, there was flooding in the estuary. In standing waters the rates of photosynthesis increases, whether natural or as a result of eutrophication causing high pH values (as noted above). In the case of the Mngeni estuary, the cause of the increased pH may more likely derive from increased eutrophication as the observed increase in pH occurred in winter. The DWAF standard for pH for freshwater bodies ranges from 5.5 – 9.5. On average the pH of the Mngeni estuary for summer, autumn, winter and spring are 7.2, 7.2, 7.3 and 7.4 respectively. This indicates that these pH values are within the DWAF limits which show that although some eutrophication of the system has occurred, there are no detrimental effects on the water quality or estuarine ecosystems.

Essentially, changing pH values results in a change in the concentration of both H+ and OH^- ions. This in turn affects the rate and type of ion exchange across body surfaces, particularly gills. Thus the direct effect of a change in pH is an alteration in the water, ionic and osmotic balance of individual whole organisms (Wood and Rogano, 1986). Freshwater organisms generally have well developed abilities to maintain ionic and osmotic balance within rather narrow limits. For this reason, It is thought that direct effects of alterations in pH are not normally the most important in determining the detrimental consequences of relatively small changes in pH on freshwater organisms (Sutcliffe, 1983). There is no doubt that the need to increase the rate of osmotic and ionic regulation places physiological stress on organisms by increasing energy requirements. This can in turn have sub-lethal effects such as slow growth and reduced fecundity (Berrill *et al.*, 1991).

pH also determines the chemical varieties of water, and thus the availability and toxicity, of metals in water. For instance, in metals such as aluminium, when the pH falls below neutral, they form available and highly toxic ions. The metals most likely to have environmental effects as a result of lowered pH are silver, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc (Campbell and Tessier, 1987). From the table and graph of results of pH (Chapter 5), the pH values are no lower than 6.8 and does not currently constitute a major threat in this regard. However, constant monitoring of this variable is essential.

6.2.5.2 COD

Biological processes regulate the dissolved oxygen concentration in water through oxygen production and demand. The biochemical oxygen demand (BOD) and the chemical oxygen demand (COD) are time honoured procedures utilized in the evaluation of water quality (Boyd, 2000).

The COD is considered mainly the representation of pollution level of domestic and industrial wastewater, or contamination level of surface, ground, and potable water. This is determined in terms of total oxygen demand created by biodegradable as well as non-biodegradable substances, because it involves oxidation of organic matter with strong oxidizing chemicals. As a result, COD values are greater than BOD and may be much greater when significant amounts of biologically resistant organic matter is present.

The DWAF standard for COD is 75 mg/l. From Table 5-2, it can be seen that only spring (with COD = 64 mg/l) has a value within the DWAF limits. On average the COD values for summer, autumn and winter are 4970 mg/l, 3206 mg/l and 207 mg/l respectively.

The reason for spring having a lower COD values is due to the tidal flushing experienced when the estuary mouth was breached open. Due to this flushing, much of the pollutants were washed into sea.

The winter COD value exceeded the DWAF limits and is due to the estuary mouth being closed during this period. Due to the stagnant water in the estuary and the water being washed down from the catchment, the concentration of the various pollutants or chemicals increased, thus causing a greater COD value.

The COD concentration for summer and autumn is phenomenally high. This is due to the various industrial activities along the Mngeni catchment. The different types of industries located in the lower catchment that contribute to these high COD concentrations fall in various categories: chemical, dairy, oil refineries, poultry and meat processing, pulp and paper manufacture, textile and the sugar industry. In addition, the Northern Wastewater Treatment Plant at Sea Cow Lake is located at the head of the estuary and discharges treated effluents directly into the Mngeni *via* a small tributary. For the purposes of the surveys conducted in this study however, the measured concentrations of 45 mg/l immediately downstream of the treatment plant are well within the DWAF limit of 75 mg/l. Listed below are the concentrations of COD released into Mngeni catchment waters:

TABLE 6.2: COD concentrations from various industries released into the Mngeni system

INDUSTRY	COD RANGE DISCHARGED
Chemical Industry	270 mg/l
Dairy Industry	Up to 2 000 mg/l
Oil Refineries	Up to 75 000 mg/l
Poultry Industry	689 – 6780 mg/l
Pulp and Paper Manufacture	200 – 17 000 mg/l
Red Meat Industry	2 380 – 8 942 mg/l
Sugar Industry	Up to 20 000 mg/l
Textile Industry	2 760 – 29 110 mg/l

***Source:* WRC, 2004.**

It is clearly evident from the above that the extremely high COD assessed for the estuary derive from industrial sources in the catchment. There is a definite seasonal trend from summer highs to winter and spring lows which may be related to the production trends of some of the industries listed above. This anthropogenic influence on COD must be superimposed on an underlying natural chemical oxygen demand which would be difficult to quantify. What is particularly important though is that anthropogenic influences in terms of limiting available oxygen for natural estuarine functioning are significant in the Mngeni estuary.

6.2.5.3 Ammonia

Ammonia is a common pollutant generally associated with sewage and industrial effluents. Ammonia is present in air, soil and water, and in large amounts in decomposing organic matter (Williams *et al.,* 1986). Ammonia is a common pollutant that contributes to eutrophication. Commercial fertilizers contain highly soluble ammonia and ammonium salts. Following application of fertilizer, if the concentration of such compounds exceeds the immediate requirements of the plant, transport *via* the atmosphere or irrigation waters can carry these nitrogen compounds into aquatic systems (DWAF, 1996).

The possible sources of ammonia found in the Mngeni Estuary could be from:

- Fish farm effluent;
- Sewage discharge;
- Discharge from industries that use ammonia or ammonium salts in their cleaning operations;
- Manufacture of explosives and use of explosives in mining and construction; and
- Atmospheric decomposition of ammonia from distillation and combustion of coal, and the biological degradation of manure.

***Source:* WRC, 2004.**

The DWAF limit for ammonia is ≤7 mg/l N. From Table 5-3, the average ammonia values for summer is 1.5 mg/l N and the ammonia concentrations autumn, winter and spring were 0.5 mg/l N.

It is thus clear that the laboratory values are much lower than DWAF standards, indicating that the concentrations are acceptable for aquatic ecosystems. This shows that the ammonia concentrations recorded do not have detrimental effects on the water quality of the Mngeni Estuary or on the aquatic ecosystems. It is interesting to note however, that the seasonal variation in concentrations for the other variables occur with the same consistency in the case of ammonia.

6.2.5.4 Sulphate

Sulphur in water occurs largely as the sulphate ion. In living systems, sulphur is an essential component of proteins and is thus an essential element. In most natural waters, sulphate ions tend to occur in lower concentrations. Sulphates themselves are not toxic. In excess, however, the form sulphuric acid, which is a strong acid which reduces the pH value and can have devastating effects on aquatic ecosystems (WRC, 2004).

The concentrations for sulphate for each of the four seasons are extremely high as compared with the DWAF general standards. The general limit for sulphate is from 200 – 400 mg/l and results show average concentrations of 1 659.5 mg/l, 1 229 mg/l, 933 mg/l and 1 678 mg/l for summer, autumn, winter and spring respectively. The results indicate that the concentration of sulphate in the Mngeni Estuary are far in excess of DWAF limits.

The high sulphate levels in the Mngeni Estuary is indicative of the fact that this system is not well buffered as a consequence of the anthropogenic impact of pollutants from the catchment, and these high concentrations can be potentially detrimental to the aquatic ecosystems.

Sulphates in excess, form sulphuric acid which is a strong acid that can have devastating effects on aquatic ecosystems. This is particularly problematic in water seeping from mines, where sulphate levels can be extremely high.

6.2.5.5 Calcium

Calcium is one of the major elements for living organisms. As well as being found as a structural material in, for example, bones, teeth, mollusc shells and crustacean (e.g. crab) exoskeletons, it is vital for muscle contraction, nervous activity, energy metabolism and a great variety of other biochemical interactions. Waters low in calcium may be unable to support molluscs and crustaceans, both of which require calcium for the construction of shells and exoskeletons (Beadle, 1981).

The concentrations for calcium are high in the Mngeni Estuary as compared with that of DWAF limits. The concentration general limit for calcium is from 150 – 300 mg/l. Only winter and spring meet the DWAF required concentrations for calcium with average concentrations of 57 mg/l and 277 mg/l respectively.

However, the summer and autumn concentrations are 5 313 mg/l and 1 722 mg/l respectively. The sources of the excess calcium during summer and autumn are unknown. Whilst anthropogenic sources are not ruled out, these high concentrations may well be related to natural (temperature, pH) and biotic factors.

6.2.5.6 Chloride

Chloride is a major anion in sea water and in many inland waters. Chloride ions are essential components of living systems, being involved in the ionic, osmotic and water balance of body fluids (Dallas and Day, 2004). Generally, chloride is not known to have toxic effects on biota other than to increase TDS.

The most probable sources of high chloride in the Mngeni Estuary are:

- The textile industry (bleaching);
- The pulp and paper industry (bleaching, slimicide);

- Sewage treatment; and
- Swimming pools.

***Source:* DWAF, 1996.**

The general DWAF limit for chloride is from 100 – 200 mg/l. The average concentrations of chloride found in the Mngeni Estuary are within the DWAF general limits. The concentrations for summer, autumn, winter and spring are 101.75 mg/l, 48 mg/l, 23 mg/l and 146 mg/l respectively.

The concentrations of chloride show that there are no detrimental effects on the quality of the estuarine waters and there will be no effect on the aquatic ecosystems as well.

6.2.5.7 Nitrate/Nitrite

Nitrates are end products of the aerobic stabilization of organic nitrogen and may enter water via fertilizers, agricultural runoff, etc. Nitrates are seldom abundant in natural surface waters (normally < 0.1mg/l N), because photosynthetic action is constantly converting them to organic nitrogen in plant cells. They are, however, found in high concentrations in ground water. Nitrates are not normally toxic but high concentrations can become toxic (Porter, 1975).

Nitrite is a naturally occurring anion in fresh and saline waters. Human activities that increase nitrite concentrations in aquatic environments include industrial production of metals, dyes and celluloid, sewage effluents and certain types of aquaculture (Lewis and Morris, 1986).

The concentrations of nitrate/nitrite in the Mngeni Estuary are within the DWAF general limits. The DWAF general limit for nitrate/nitrite is from 6 – 10 mg/l N. The average concentration of nitrate/nitrite for summer, autumn, winter and spring are 0.1 mg/l N, 1.3 mg/l N, 1.2 mg/l N and 1.3 mg/l N respectively.

As with chloride, the lower nitrate/nitrite concentrations in the Mngeni Estuary should have no detrimental effects on the estuarine water quality and thus the aquatic ecosystem.

6.2.5.8 Phosphate

Phosphate can occur in numerous organic and inorganic forms, and may be present in waters as dissolved and particulate species. Elemental phosphorous does not occur in the natural environment. Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates are found in natural waters. Phosphate gives an estimate of phosphorous immediately available for biological consumption indicating the potential growth of algae and aquatic macrophytes (DWAF, 1996).

The average phosphate concentrations in the Mngeni Estuary are well within the DWAF general limits of 1.0 mg/l for phosphate. The average measured concentrations of phosphate for summer; autumn, winter and spring were 0.4 mg/l P, 0.1 mg/l P, 0.2 mg/l P and 0.2 mg/l P respectively and these low concentrations are not expected to impact negatively on the estuarine ecosystems and their functioning.

The increased occurrence of return flows intensified agricultural practices and the presently uncoordinated growth of large informal settlements which are associated with the population explosion and influxes into the region are anticipated to lead to severe deterioration of the water quality of streams, rivers, estuaries and dams. During summer months, recurrent convective thunderstorms result in the transport of suspended solids, pathogens and phosphorous from the sub-catchments (Figure 3) into receiving channels, with the consequence that domestic, agricultural, industrial, ecological and recreational user groups are affected (Kienzle *et al.*, 1997).

6.2.5.9 *E.coli* (*Escherichia coli)*

The majority of diseases carried by water are of an enteric nature and it is therefore necessary to screen water for possible faecal contamination. The search for indicator organisms such as faecal coliforms and *E.coli* instead of for pathogens themselves is universally accepted for the monitoring of microbial pollution of water supplies. *E.coli* originates primarily in the mammalian intestine. It is excreted in enormous numbers and fresh faeces may contain from 5 million to five hundred million *E.coli* counts per gram, the average amount being about eighty two grams daily per person (Steel, 1979).

The bacterial contamination of water bodies may be caused by human waste discharged or entering a river as untreated sewage. The presence of *E.coli* in water bodies is used as an indicator of faecal pollution (Davies and Day, 1998). Therefore, it is most likely that numerous of South African rivers, both urban and rural, are severely polluted by faecal pathogens, especially where informal settlements accommodates poverty-stricken communities with no sanitation and insufficient water supplies. When water supplies are contaminated by *E.coil* and untreated, the bacterium may change its nature, causing health problems such as diarrhoea and gastroenteritis (Davies and Day, 1998).

The DWAF general limit for *E.coli* is 0 cfu/100ml. The average concentrations of E.coli found in the Mngeni Estuary are extremely high. The average concentrations for summer, autumn, winter and spring are 940 cfu/100ml, 565 cfu/100ml, 1 080 cfu/100ml and 945 cfu/100ml respectively.

Several sources of faecal pollution may occur within the catchment and estuarine area. These include contamination from:

- pit system latrines/toilets used in the vicinity of the Inanda Dam;
- from rural settlements in the catchment;
- squatter settlements;

- vagrants living along the estuarine banks and under the bridges; and
- from the Northern Wastewater Treatment plant.

Measurements taken above and below the wastewater treatment plant has however, cleared the plant of discharging effluents with high organic content into the estuary. It is therefore important to investigate the other sources of pollutants thoroughly – particularly in light of the recent outbreak of water-borne diseases in KwaZulu-Natal (KZN) - most notably cholera.

6.2.5.10 TDS

TDS represents the total quantity of dissolved material, organic and inorganic, ionized and un- ionized, in a water sample. Natural TDS in rivers and estuaries are determined by geological and atmospheric conditions. Anthropogenic activities such as industrial effluents, irrigation and water re-use lead to increases in TDS (Day and King, 1995).

Anthropogenic influences have severely increased the TDS concentrations of inland waters throughout the world, particularly in arid regions (for example, California: Caufield 1985; Australia: Schofield and Ruprecht 1989; Hart *et al* 1991; South Africa: du Plessis and van Veelen 1991), (Dallas and Day, 2004). Besides discharging saline industrial effluents into rivers or lakes, the increasing TDS levels (also known as salinization or mineralization) may be caused by irrigation and large quantities of sewage effluent into inland waters.

The DWAF general limit for TDS is 500 mS m^{-1}. The average concentrations for summer, autumn, winter and spring are 74 mS m^{-1}, 30 mS m^{-1}, 88 mS m^{-1} and 30 mS m^{-1} which are well within the DWAF limits.

Thus it can be seen that since the TDS concentrations are within the DWAF general limits, there would be no detrimental effects on the estuarine waters or its ecosystems.

The Mngeni River has undergone extensive modification, with riparian vegetation and the watercourse significantly altered to accommodate human habitation and development activities. The area is highly urbanized; with a population in excess of 1.3 million. Rising in the hills above Durban are a few smaller rivers, *viz.* the Mhlatuzana River and the Mbilo River, which drain large areas of the urban and industrial development sectors. Water entering the sea, however, is of poor quality, a result of the large volumes of urban pollutants (Metro Water, 2002).

6.3 RECOMMENDATIONS

Improvement in the quality of coastal and marine ecosystems depends largely on the effective implementation of policy and legislation. Stabilization of population growth and migration are also required to ensure sustainable development.

A reduction in ribbon coastal developments (urban encroachment) and more sustainable use of the marine and coastal resources is conceivably possible, although this is only likely to be successful if management strategies and policies are effectively implemented through institutional capacity. However, South Africa's intermediary economic (as well as socio-political) state which emphasizes development and economic growth might, in the short term, act against environmental sustainability and a reduction in marine and coastal pollution (www.ngo.grida).

The coastal zone is estimated to contribute R168 billion to the South African economy. Since there are in the region of 260 functional estuaries on our coast, and they are favoured sites for urban development, commercial activity and recreation, it is easily appreciated that estuaries are very important in coastal economies. Assets of such value demand our attention and commitment to the application of best management practices.

Estuaries are common property: they belong to all of us. Those who benefit from estuaries, in whatever way, are accountable for how their actions affect the estuary and its use by others. This cannot happen if users do not have access to the information necessary for enlightened actions.

The six most important foundations for estuary management include:

- The value of estuaries;
- Structure and functioning;
- Influence of human activities;
- Becoming involved in management;
- Assessing the state of an estuary; and
- Policy and legislation.

Source: **www.cerm.co.za**

It has become obvious that our estuaries are experiencing degradation at an unprecedented rate. This is mainly due to various activities within and around the estuary and has played a major role in the deterioration of the water quality in the Mngeni Estuary. As a result, the following recommendations can be made:

- Management of water releases from Inanda Dam to maintain the services provided by the river and estuary.
- Management and minimization of industrial and domestic pollution.
- Control of rampant aquatic weed, in particular water hyacinth.
- Restoration of riparian vegetation especially by elimination of invasive alien plants (e.g. triffid weed).
- Solid waste disposal, especially in the informal areas, is a priority. Litter of the rivers and Durban Bay is a widespread aesthetic and health problem.

- The NCS should implement programs that educate people on estuaries and their functions.
- Involving the public in “clean-up” programs.
- Action should be taken once research has been conducted ensuring sustainability of our resources.
- Pollution entering the catchment needs to be quantified and this should provide good control to restrict excessive pollution loads entering the Mngeni River and thus the estuary.

Recommendations for the way forward include the effective and efficient implementation of both general environmental management legislation and the coastal management policy. The formation of effective (not merely representative) coastal management forums is essential. These forums must be structured around well resourced institutional structures with clear mandates to ensure the sustainable development of the country's coastal and marine resources (EPA, 2004).

6.4 CONCLUSION

Estuaries are places where freshwater rivers and streams flow into the ocean, mixing with the seawater. A wide variety of birds, fish, and other wildlife make estuaries their home. People also live, fish, swim, and enjoy nature in estuaries and the lands surrounding them.

Modern society too often views water as a convenient vehicle for disposing of waste and the results are becoming increasingly evident. Analysis of fresh water supplies frequently reveals disconcerting levels of pollution including human waste, heavy metals and synthetic chemicals to the detriment of human health and the health of entire ecosystems (Gangoo, 2003).

The degree to which the sustainability of marine and coastal resources can be achieved is directly influenced by the threats to the integrity of the ecosystems and specific resources such as fish stocks and estuaries. Incidents of point- and non-point sources of pollution on the marine and coastal ecosystems together with unsustainable coastal developments (as a consequence of increasing population numbers) as well as over-exploitation of the resource base needs to be addressed.

Increased consideration of environmental issues such as ecosystem integrity and coastal sensitivity in planning procedures for urban development are essential to ensure that marine and coastal systems and their resources are utilized and managed in a sustainable manner. Longer term issues such as global warming and sea level rise also need to be considered and the continuous sea level monitoring initiatives should be maintained.

The development and implementation of principles of Integrated Environmental Management must be continued. The legislation of EIA for activities which may have a substantial detrimental effect on the environment (s.21 of Environmental Conservation Act, No 73 of 1989) needs to be rigorously enforced.

It is important that the Coastal Management Policy for South Africa should be formally adopted. Progress made thus far with this initiative is particularly encouraging as is the development of a coastal management forum for the KwaZulu- Natal coast which is being carried out for the provincial Department of Local Government and Housing (EPA, 2004).

It can therefore be said that from the study undertaken on the Mngeni Estuary, the estuary is experiencing degradation resulting in the deterioration of environmental health. Pollution from anthropogenic sources therefore poses one of the more serious threats to the water quality of this estuary. In addition, there is an escalating public interest in water as a resource and a rising understanding of the need to protect water quality. However, without proper management, water as a vulnerable resource may become over-exploited and over-utilized brought about by man's need for modern living at the expense of the environment.

Urbanization, domestic and industrial pollution are the activities that have the greatest impact on water quality, river flow, and thus our estuaries. This study of water quality and environmental health is therefore of huge value for the quality of water dictated by an outline of interactions rather than by factors in seclusion. It is further hoped that this investigation will prove to be of benefit to researchers, the public as well as policy makers in devising policies regarding issues of environmental health of estuaries and water universally. Therefore from a holistic environmental point of view within a framework of an integrated catchment management plan, it may be concluded that there is a negative impact on the environmental and health status of the Mngeni Estuary.

The comparatively high temperatures and seasonal rainfall over a great deal of South Africa mean that fresh water is a limited resource. Permanent bodies of standing fresh water are practically non-existent, leaving rivers as the only exploitable sources of fresh surface water. Although maps show various rivers in South Africa, many of these rivers are small, or flow only during the wet season, or both. Furthermore, the increase in human populations has resulted in extreme pressure on South Africa's rivers, both as sources of water in terms of pollution, and yet water is of no use to humans or for the maintenance of natural riverine ecosystems if its quality is poor. Thus water is limited resource and both availability and quality need to be managed carefully (WRC, 2004).

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GLOSSARY

abiotic	not related to living things
acclimation	the process whereby an organism become accustomed to artificially imposed conditions
acid precipitation	rain, mist, snow and dust acidified by pollution with oxides of nitrogen and/or sulphur
acid rain	see *acid precipitation*
acidification	here considered as an increase in the acidity of water and soil as a result of human activities
acute effect	in toxicology, the effect of a toxin during a short period of exposure
adsorption	the physical adherence to the surface of a molecule or particle
aerobic	using oxygen
agrochemicals	chemicals, such as pesticides and fertilizers, used in agriculture
algae	non-vascular plant-like organism (seaweeds, pond scum, many kinds of phytoplankton, etc)
alkalinity	the sum of anions of weak acids, plus hydroxyl, carbonate and bicarbonate ions, in a sample of water
ambient	surrounding (for example, ambient temperature s temperature of the surrounding air or water)
anaerobic	not using oxygen
animal	nay heterotrophic, motile organism (includes worms, sponges, birds, reptiles, humans, etc.)
anions	negatively charged ions
antagonist	one acting against the other (in toxicology, a substance that reduces the toxic effect of another)
antecedent	preceding
antibiotic	an anti-bacterial agent

anthropogenic	caused by human activity
aquifer	a subterranean accumulation of water
autotrophic	'self-feeding': using the sun's energy or chemical energy to fix carbon
bacteria	minute prokaryote organisms with no nucleus; some, but not all, bacteria are pathogenic
basalt	a rock type of volcanic origin
benthic	living on the bottom
bilharzias	schistosomiasis: a human parasitic disease caused by a fluke whose intermediate host is a freshwater snail
bioaccumulation	the accumulation of substances within a living organism
bioassessment	assessment, usually of environmental condition, using living organisms
bioavailability	the extent to which a particular constituent is available to living organisms
biocides	substances that kill living organisms (usually substances created by humans for this purpose)
biodegradable	able to be broken down by living organisms, often bacteria
biodiversity	the diversity of living things at the level of genetics, of whole organisms, and of ecosystems
biological indicator	living things that indicate the quality of environmental conditions
biological community	all the interacting members of the biota of a given area

biological oxygen demand	the amount of oxygen consumed by the biota in a sample of water (usually measured over 5 days at 20ºC)
biomass	the mass (weight) of biological material
biomonitoring	using living organisms to monitor aspects of their environment
biota	the totality of the living organisms of a region or a system
biotic	relating to living things
blackwater systems	aquatic systems in which the water is stained with humic, fulvic and/or other polyphenolic acids
BOD	see *biological oxygen demand*
buffering capacity	the resistance to change in pH as a result of the presence in water of a weak acid and its salts

canopy	the leafy parts of trees meeting overhead
carcinogenic	causing cancer
catchment	the entire land area from which a river or reservoir is fed (= drainage basin, = watershed)
cations	positively charged ions
chemical oxygen demand	the amount of oxygen consumed by the abiotic fraction of a water sample
chronic effect	in toxicology, the effect of a toxin over a long period of exposure
COD	see *chemical oxygen demand*
coliform (bacteria)	bacteria related to *Escherichia coli*, which is found in human faeces
community	biologically, the interacting species living together in a particular area
conductivity	the ability of water to conduct an electrical current; since this depends on the number of ions in solution,

	also a measure of the total quantity of salts dissolved in a sample of water
CPOM	coarse particulate organic matter (organic fragments >1 mm in diameter)
Crustacea	the shrimp-like arthropods: crabs, prawns, etc.
decomposer	an organism that feeds on, or lives off, organic material, dead plants and animals
decomposition	the decay and breakdown of organic material, including the dead remains of plants and animals
density	(biological) a measure of the number of organisms per unit area
depauperate	poor, reduced
diatom	any group of unicellular or colonial algae with siliceous "shells" or frustules
dystrophic	with insufficient nutrients
ecology	the study of interrelations between organisms and their environment
ecosystem 'health'	an estimate of the extent of ecosystem integrity
ecosystem	interacting organisms plus their environment
ecosystem functioning	the combined effect of the processes, such as photosynthesis, respiration and nutrient cycling, that make an ecosystem a functional whole
effluent	that which flows out (usually wastewater)
electron transfer	the final process of respiration during which energy and CO_2 are released
empirical	resting on trial or experience
epilimnion	the upper, warmer, layer of a thermally stratified water body (contrast *hypolimnion)*
eutrophic	"well nourished": with an excess of plant nutrients

eutrophication	the process, usually anthropogenic, whereby nutrients accumulate in a body of water
excreta	biological waste products: usually urine and faeces
facultative	optional
faecal	referring to faeces: solid excreted matter
fauna	the animals of an area or region
fecundity	fruitfulness, fertility
floodplain	low-gradient land onto which a river regularly overflows its banks
food chain	a series of organisms connected by the fact that each forms the food for the next
fossil fuel	coal and oil, laid down millions of years ago
FPOM	fine particulate organic matter: organic fragments <1 mm in diameter
fulvic acid	one of the components of the 'humic fraction' of refactory organic compounds
genotoxic	causing genetic defects
geomorphology	the gross structure of landform
gradient	the degree of slope
groundwater	water collected under the ground
habitat	the normal abode of a living organism, defined by the set of physical, chemical and biological features
hardness	of water, the combined concentration of calcium and magnesium
hazardous	according to the US Environmental Protection Agency, of toxic substances, the slightest exposure to which affects human health

headwaters	the upper reaches of a river, usually torrential with steep gradients and a rocky bed
heavy metal	any metal with an atomic mass greater than that of calcium (that is, 40.08)
heterogeneous	not uniform
heterotrophic	of organisms (fungi and animals), those using organic compounds as sources of carbon
“humic” substances	large, complex, polyphenol-rich organic compounds derived as leachates from decomposing vegetation
hydrology	the study of water resources
hydrophobic	repelling water
hygroscopic	absorbing water
hypertrophic	excessively eutrophic
hypolimnion	the lower, cooler, layer of a thermally stratified water body
hypoxia	lack of oxygen
igneous	of rocks, those of volcanic origin
infiltration	percolation (in this volume, percolation of water into the ground)
inorganic	of chemical substances, those not containing carbon of biotic origin
interstitial	occurring between small spaces
inundation	flooding
ion	an electrically charged particle
ionize	to cause to become electrically charged
lentic	of waters, not flowing
limnology	originally the study of lakes; now the study of the physical, chemical and biological properties of inland waters

lithosphere	the rocky crust of the Earth
lotic	of waters, flowing
lower reaches	the downstream part of a river
major ions	those ions (calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride and sulphate) that usually form the bulk of the total dissolved solids in inland waters
maritime	pertaining to the sea
mesotrophic	with moderate levels of nutrients
metal	an element that is a good conductor of electricity
mineralization	i) the release of inorganic ions from oxidized organic material ii) the increasing saltiness of soils and rivers (=salinization)
natural environment	with regard to rivers, aquatic ecosystems and those ecosystems dependent on them
nephelometry	the measurement of turbidity
nitrogen fixation	the process of converting gaseous N_2 to soluble forms (NO_2, NO_3) by bacteria
non-point	diffuse
NTU	nephelometric turbidity unit: used for measuring turbidity
nutrient	in aquatic biology an element whose scarcity can limit plant growth (for example, compounds of nitrogen, phosphorous)
oligotrophic	low in nutrients
organic	of chemical substances, containing carbon
organism	a living thing

orthophosphate	a form of soluble inorganic phosphate
pan	a broad, shallow, sediment-filled basin that receives water in the rainy season
pathogen	a disease-producing organism
pathological	relating to disease
perturbation	disturbance
pH	the negative $\log_{10}$ of the hydrogen ion activity: a measure of acidity ($pH<7$) or alkalinity ($pH>7$)
pollutant	a substance that contaminates
pollution	defilement: unfavourable alteration of our surroundings, normally as a result of human actions; the presence of any foreign substance(s) that impair the usefulness of water
polyphenols	large, complex, acidic organic molecules, characterized by a high proportion of phenol groups and often imparting a dark colour to water
precipitation	rainfall
pristine	unaffected by human activities
receiving water	a water body receiving an effluent
riparian	related to river bank
salinity	“saltiness”: the mass of dissolved inorganic solids in a kilogram of water (usually sea water0
sandstone	type of sedimentary rock
sediments	the soft sands, silts and mud on the bottoms of rivers and lakes
shale	type of sedimentary rock
siltation	becoming silted up
spate	small flood

stratification	in limnology, the separation of the water in a lake into epilimnion and hypolimnion
suspensoids	particles suspended in the water column
TDS	see *total dissolved solids*
thermocline	in a stratified lake, the interface between epilimnion and hypolimnion
total dissolved solids	the total mass of material dissolved in a sample of water
toxicant	a poisonous substance
toxicity	toxic quality, the poisonous-ness of a substance
turbidity	an expression of the optical property of water that causes light to be scattered and absorbed (murkiness)
water quality	the value or usefulness of water, determined by the combined effects of its physical attributes and its chemical constituents, and varying from user to user
water quality standard	a rule authoritatively establishing, for regulatory purposes, the limit of some unnatural alteration in water quality that is permitted or accepted as being compatible with some particular intended use or uses of water
weir	a low dam
wetland	an ecosystem where the nature of the soils and of the biota is dominated by water