The Anthropogenic impacts of Urbanization and Industrialisation on the Water quality, Ecology and Health status of the Palmiet River catchment in Durban, KwaZulu – Natal.

By

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DECLARATION

I, Kushela Naidoo hereby declare that this dissertation and title: The Anthropogenic impacts of Urbanization and Industrialisation on the Water quality, Ecology and Health status of the Palmiet River catchment in Durban, KwaZulu – Natal, is a result of my own investigation and research and that it has not been submitted in part or full for any other degree or to any other institution or university.

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Kushela Naidoo **Date**

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ABSTRACT

Water, a fundamental and irreplaceable resource, is an all-pervasive issue that underpins the social fabric of every society. Rapid population growth and expansion of human activities increases the amount of waste and pollution generated and many local authorities are encountering serious water pollution problems, often concentrated in the lower reaches of catchments and adjacent coastal areas. This problem is predominantly acute in urbanized catchment areas, where waste is concentrated into localized areas, and the authorities are constantly under pressure to provide adequate management and mitigation measures. The Palmiet River system, located in the northern fringe of the city of Durban and draining the highly industrialized Pinetown region in KwaZulu-Natal, South Africa, illustrates a system that has been altered due to human impacts, particularly in its headwaters where the industrial sites are located and, in the lower catchment where a densely populated informal settlement occurs.

A range of chemical and biotic indicators were monitored seasonally and these confirm the influence of the aforementioned human impacts on the quality of the Palmiet River system. Results from the present study were compared with studies conducted over a period of two decades and clearly demonstrate a pattern of increasing pollution loads for the upper and lower parts of the catchment. This study confirms that the Palmiet River is severely degraded in its lower reaches whilst the middle reaches of the catchment where a nature reserve is located is still in a fairly pristine condition. Additionally, the Palmiet River issues discussed in this thesis have direct impacts on the estuarine and adjacent marine ecosystems.

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CHAPTER ONE

INTRODUCTION AND CONTEXTUALISATION OF PROBLEM

1.1 Preamble

Water is all around us - in the oceans, the clouds, the rivers, the plants, and us. Earth is known as the blue planet - the water planet. The first life on earth - plants and animals - developed in water, oceans of water. Water is a source of harmony and healing. Few would argue with the fact that water is the lifeblood of the Earth. Without it there would certainly be no human life. It is the key to sustainable development. Without adequate water supply, food production declines, human health fails, the natural environment suffers and economic development is choked. And yet, all over the world water is being mismanaged, polluted and wasted (Asmal, 2002).

This chapter gives the background of water as a social and environmental concern. It serves as a problem description, explaining the validity of the research being conducted. 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 water course 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 these require vast amounts of money but must be conducted in a socially acceptable and sustainable manner (Howards, 1995).

Until recently, water pollution was viewed primarily as a threat to human health because of the transmission of bacterial and viral waterborne diseases. In less developed countries, and in almost any country in time of war, waterborne diseases remain a major public health threat. We now recognize that water pollution constitutes a much broader threat and continues to pose serious health risks to the public as well as aquatic life (Weiner & Matthews, 2003).

Water pollution as a consequence of human intervention has been in existence as long as humans have been on this planet. The magnitude and subsequent impacts have, in the past two centuries, reached levels unprecedented in history. The generation of large quantities of waste materials most of which are toxic, carcinogenic or mutagenic can, according to Haslam (1990) and Miller (1996) be attributed to rapid industrialization, urbanization and population growth".

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).

1.1.1 Water as a Resource

Water is a finite resource and is probably the most important commodity at the disposal of humans. Contamination of this life-sustaining resource through improper utilization can render it unavailable: being of poor or unacceptable quality (Chan, 1996).

Lack of water management is both an environmental and a social problem, faced in many communities, all over the world. Water is a powerful symbol throughout the world, carrying with it ideas of baptism and new life, cleansing and healing and the promise of growth and prosperity (White Paper on National Water Policy, S.A. 1997).

Water is the most important resource essential for sustaining all life forms. This resource is so vitally important that without it, all human activities would cease and hence all life forms would come to an end. In addition, wholesome water is a basic and an essential ingredient for life. Therefore, everyone should have convenient access to an adequate and reliable source of wholesome drinking water (Mogane, 1997).

The concern of sufficient availability of freshwater is directly interconnecting the destiny of people worldwide. Even if the problem is the most obvious, in countries with a less preferable, dry climate or with poor water service infrastructure, it is an important issue for the whole world. As the fluid of life, water is a resource of considerable complexity with many parallel functions. From the biological perspective, water serves as a habitat for numerous organisms and as a health function for others. The socio-economic function of water relates to the production of food and biomass and acts as a supporting medium for engineering and the development of infrastructure. At the same time, natural freshwater functions in the biosphere, carrying pollutants or other forms of pollution from the previous mentioned activities, to the ecosystems. All these parallel functions make water into a particularly unmanageable resource (Falkemark, 1996).

Only a tiny proportion 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 (Miller, 1996).

The accessible freshwater reserve of the earth is estimated to be 28.8 million km^3 or 2.1 % of the total volume of water. This reserve should be utilized and distributed in a manner that provide all individuals of the world's population of 7 billion people with water, sufficient for living. The distribution and utilization of this vital resource should be executed sustainably so that future generations as well as the environment are not impacted negatively". Even if the amount of freshwater seems fairly sufficient to provide the world's population with water, there are several regions in the world that face water scarcity. As a consequence, these regions have to use the available resources in an unsustainable and environmentally harmful manner (Falkemark, 1996).

Increasing concern is being expressed on the rate of degradation of this important resource which, to a large extent, is due to the advent of industrialization and urbanization. The major causes for this concern is that the progress towards urbanization is often made without due regard to the consequences. Furthermore, the effect of man's social and industrial activities can be seen in the extent to which river quality changes as a river flows from its source to the sea. Water which is returned to the river as affluent is rarely the same quality and is normally contaminated with some form of pollution (Keller and Wilson, 1992).

In the last decade of the 20th century, there was a shift in the rural/urban balance with an increasing proportion of the world's population living in urban areas. In 2001, 47% of the world's population was urban dwellers. In areas where the accelerated urbanisation is combined with a low level of water services such as water supply and sanitation, the risk of suffering from water-related diseases, is high. The total amount of people in the world that is underserved with water is 1.2 billion and for sanitation, the figure is 2.4 billion people (World Health Organisation, 2001).

Considering the largest cities on each continent, the inhabitants in African cities live in the poorest conditions with regards to water service provision. More than a third of the population in the cities is under serviced with water and half the population has access to either no sanitation at all or only to a simple pit latrine. One reason for this remarkable difference in access to water services between Africa and the other continents could be that nearly 27% of all people in African cities live in informal settlements, often under poor circumstances. Due to its nature of lack of formal land tenure, the informal settlements often lack basic water services (World Health Organisation, 2001).

1.1.2 Water in South Africa

South Africa is a semi-arid country, with annual rainfall below the world average, and high evaporation rates. Seasonal rainfall often occurs as high-intensity storms of short duration; the resulting runoff washes silt, and organic and inorganic material accumulated in the catchment, into water bodies. There are marked climatic gradients across the country and these have resulted in a wide variety of different types of aquatic ecosystems with biotas adapted to different water quality regimes and flow patterns (South African Water Quality Guidelines for Fresh water and Marine Coastal Water, 2001).

We do not have a lot of water in South Africa. Our rain is irregular and untrustworthy - one year we have floods, the next few years we may have droughts. We do not have many big rivers compared to other countries. An important measurement of the water status of a country is what proportion of the available freshwater is already being used. Even though Namibia and Botswana are generally considered to be more arid countries compared to South Africa, we are already using in the region of 60% of our available water resources, while they are using less than 10%. How we manage the water will determine our quality of life, the strength of our economy, and our ability to create jobs. If we continue with present practices, there will not be enough water to go around (Asmal, 2002).

In addition, South Africa is experiencing phenomenal urbanization, much of which is in the form of informal settlements. These constitute overcrowded shacks with no running water and sanitation facilities resulting in the production of many third world type catchments such as Khayelitsha urban catchment in the Southern Western Cape (Sanker, 1996).

The current unsustainable practice will impact severely on availability of water for the future. The International Water Management Institute (IWMI) has projected that in the year 2025, South Africa, like the Northern African countries, will face natural water scarcity due to the climatic conditions. Also, when the economy is growing the demand for water is increasing, causing demographic water scarcity. It is recognised, by the South

African government that water scarcity will become a major problem of the future. In close relation to demographic water scarcity, exists the poor provision of other water services as sewage disposal and sanitation, together forming water service scarcity (Department of Environmental Affairs and Tourism, 2000).

The demographic water service scarcity is caused by rapid urbanization, which at the same time is considered to be one of South Africa's greatest environmental problems. The cities are growing and more and more people are moving from the rural areas to the bigger cities such as Durban, Cape Town and Johannesburg. Big townships such as Alexandra in Johannesburg and Cato Manor in Durban are created in the peri-urban areas. The townships consist of formal as well as informal communities. A major problem in these low-income, urban areas is the provision of basic services, which both contribute to the downward poverty spiral and to environmental degradation (Department of Environmental Affairs and Tourism, 2000).

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 government's 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 the resource (Green paper on Population Policy, 1995).

The way that we use our water at the moment is far from ideal: we are not getting the social, economic or environmental benefits from our water use that we could, or should be getting, indeed, that we need to get.

1.2 Contextualization of the Problem

The continuing increase in global population is increasing the demand for fresh water. One important factor affecting freshwater availability is associated with socio-economic development, and another factor is the general lack of sanitation and waste treatment facilities in densely populated areas of developing countries. A principal cause of water scarcity is water quality degradation, which can critically reduce the amount of fresh water available for potable, agricultural, and industrial use, particularly in semi-arid and arid regions. Thus, the quantity of available freshwater is closely linked to the quality of the water, which may limit its use (Peters and Meybeck, 2000).

The major water quality issues resulting in degradation include water-borne pathogens and noxious and toxic pollutants. Despite efforts of United Nations organizations, international banks, and some national governments over the past several decades, human health is still at substantial risk due to water quality problems in many areas of the world (World Resources Institute, 1996). In 1990, 1.2 billion people, or 20 % of the world population, did not have access to a safe supply of water, and about 50 % of the world population had inadequate sanitation services (United Nations Commission for Sustainable Development, 1997). The continued and rapid degradation of water resources may result in hydrocide for future populations (Lundqvist, 1998).

Hydro-geological and biophysical environments are directly affected by changes in land use and socio-economic processes, which are largely controlled by human activities and resource management. A land management decision is a water resource decision, a fundamental concept for addressing and implementing integrated land and water resources management (Falkenmark *et al.*, 1999).

Land alteration and associated changes in vegetation have not only changed the water balance, but typically have altered processes that control water quality. One of the most important issues for effective resource management is the recognition of cyclical and cascading effects of human activities on the water quality and quantity along hydrologic pathways, particularly in a watershed context. Hydrologic pathways are routes along which water moves from the time it is received as precipitation (e.g., rain and snow) until it is delivered to the most downstream point in a watershed, the drainage area defined by the downstream point to which flow converges. The degradation of water quality in upstream parts of a watershed can have negative effects on downstream users, and because there generally is a continuum of users throughout a watershed, the degradation effects cascade through the watershed (Peters and Meybeck, 2000).

The effects of watershed changes on water quality are real and frequently of serious consequence. Such changes may be of great variety, ranging from construction of impoundments to urban development and industrial expansion. Urbanization usually has a detrimental effect on water quality and the aquatic environment which necessitates a policy of adequate treatment, conservation and water quality management (Moore, 1969).

South Africa's rivers are representative of its most vital fresh water resource and are also the most easily contaminated systems. An understanding of the effects of pollution and of control measures that are available is of considerable importance to the management of water resources. One of the major sources of water pollution in KwaZulu-Natal is large discharge of partially treated raw sewage and industrial waste effluent into river systems. Urbanization, legislation, globalization and land reform have opened doors to Un-coordinated development. This development, in the form of informal settlements, located proximal to river courses have led to serious contamination of the water courses. There is a serious impact to the natural environment in South Africa, as a result of water pollution, despite government policies and legislation. This could be attributed to lack of capacity of government to enforce such policies. Thus, the probability that commercial and industrial companies may not be complying with these standards, does exist.

It is assumed that rapid urbanization and industrialization have affected the water quality of the Palmiet River over the past two decades. Industrial development in Pinetown, in the upper part of the catchment increased considerably during this period, thereby implying potential deterioration in the water quality of the catchment. Also, an informal community located on the shallow banks of the Palmiet River, close to the Palmiet Bridge is known to use the river for domestic as well as sanitational purposes. The location of the Palmiet Informal Community (PIC) makes it vulnerable to flooding even during minor flood events of the Palmiet River. There is a serious danger to life and property as a consequence.

1.3 Aims, Objectives and Hypothesis of Study

1.3.1 Aim of Study

The aim of the study is to quantify changes in the water quality of the Palmiet River over the past two decades as a consequence of the rapid urbanization and industrialization in the Durban-Pinetown region.

1.3.2 Objectives

The objectives of the study are:

- To quantify the present day water quality of the Palmiet River as well as the elements that affects this quality;
- To determine the changes that has occurred in the water quality of the Palmiet River over the past two decades.
- To assess the role that pollution from the industrialization of Pinetown has played in influencing these changes;
- To identify the impacts that residential (including formal and informal) settlements have on the water quality of the Palmiet River and, in turn, how this water quality affects their quality of life. Also, to assess the vulnerability that this residential settlements have to flooding hazards;
- To determine how increased human occupation and utilization of the catchment has influenced morphological changes and degradation to the riverine environment;
- To develop explanations for the cause(s) of the improvements (or deterioration) of water quality of the Palmiet River.

1.3.3 Hypothesis of Study

The increase in urbanization and industrialization over the past twenty years has impacted negatively on the water quality of the Palmiet River.

1.4 Chapter sequence

This study comprises of five chapters. Chapter two, the literature review, forms an extensive part of this report and provides a conceptual framework by discussing the approaches to the study and a detailed review of literature concerning water quality. Chapter three focuses on providing an in-depth description of the study area as well as a description and analysis of the techniques and methodologies employed during the study. Chapter four addresses the issue of data analysis and evaluation while chapter five, the final chapter, provides a detailed discussion of results, recommendations and an overall conclusion of the study.

1.5 Conclusion

All life on earth depends on water, from microbes to plants to the larger land and marine animals including humans. Water is important to individuals, society, and natural ecosystems, for life cannot exist without a dependable supply of water of suitable quality. The quality of water can be negatively influenced by natural phenomena, but the common reason for impaired water quality is contamination caused by human activities. Pollution of the hydrosphere by anthropogenic activities is of great concern to society (Boyd, 2000).

The demand for water is increasing exponentially and, depending on 'worst-case' or 'best-case' scenarios, it is estimated that much of South Africa will experience the equivalent or permanent drought somewhere between 2020 and 2040. Water rationing is likely to become a fact of life. Water conservation measures must be implemented across all facets of life as a matter of urgency (Yeld, 1993).

CHAPTER TWO

WATER QUALITY: A THEORETICAL REVIEW

2.1 Introduction

Clean, plentiful water is infinitely precious for without this resource we could not survive. Yet humans use waterways as a dumping ground for waste, loading billions of tonnes of chemicals, metals, and organic pollutants into rivers, lakes, and oceans every year. Even today, individuals continue to ignore the vital importance of water, and so continue to over utilize it (Stauffer, 1998).

Rivers are important to humans because they supply fresh drinking water, serve as a habitat for aquatic organisms, provide transportation routes, and are the source for irrigation water and hydroelectric power. Humans have used rivers since the beginning of civilization. Other important aspects of rivers are the ecological characteristics of river channels and floodplains. However, the various processes controlling river water quality may be in a delicate balance and that a slight modification to the catchment could generate significant changes in water quality (Boyd, 2000).

Humans must use water for many purposes, and water quality deteriorates as a result. The demand for water is increasing because of the rapid increase in the human population (Boyd, 2000). Water pollution stems from a myriad of sources and causes. Humans have a long history of introducing pollutants into aquatic environments, and have had only partial success at repairing the destruction already inflicted, and curbing the activities that result in environmental degradation. Non-point source pollution continues to be a serious threat to receiving waters, as does the continued release of sewage and industrial effluents into rivers and streams (Weiner and Matthews, 2003).

The process that contributes to water quality can best be understood if examined in the context of a catchment ecosystem. Recognition of a catchment as an inter-related system is particularly instructive as it contains many of the factors that are relevant to the control and management of water quality. Humans modify water quality not only directly through discharges but also indirectly through such activities as adjusting flow regimes and impounding and abstracting. Clearly, man is a major biotic influence but, it is also important to realize that his activities in a catchment modify a system which is already dynamic and varying (Gower, 1980).

2.2 The Importance of Water

Fresh water is arguably the most important of all resources. It is integral to all environmental and societal processes and a critical component of ecological cycles. For centuries, water has been harnessed to provide drinking water, sewage systems and to irrigate cultivated lands. As the twentieth century drew to a close, it was evident that efforts to harness water have been inadequate and misdirected (Clarke, 1993).

Water is important physiologically. It plays an essential role in temperature control of organisms. It is a solvent for minerals, organic nutrients, and metabolic wastes. Water is important ecologically as it is the medium in which many organisms inhabit. The distribution of vegetation is controlled undeniably by the availability of water as can be seen when well-watered regions are compared to arid regions. Water shapes the earth's surface through dissolution, erosion, and deposition and, besides its requirement in maintaining bodily functions, humans utilize water for domestic needs, including sanitation, bathing, washing clothing, food preparation. Water is a key ingredient of industry for power generation through the use of flowing waters to turn turbines, steam generation, cooling, and processing – used as ingredient, solvent, or reagent (Boyd, 2000).

2.3 Importance of Rivers

Rivers are of immense importance geologically, biologically, historically and culturally. Although they contain only about 0.0001% of the total amount of water in the world at any given time, rivers are vital carriers of water and nutrients to areas all around the earth. They are critical components of the hydrological cycle, acting as drainage channels for surface water - the world's rivers drain nearly 75% of the earth's land surface. They provide habitat, nourishment and means of transport to countless organisms; their powerful forces create majestic scenery; they provide travel routes for exploration, commerce and recreation; they leave valuable deposits of sediments, such as sand and gravel; they form vast floodplains where many of our cities are built; and their power provides much of the electrical energy we use in our everyday lives. Rivers are central to many of the environmental issues that concern society, and they are studied by a wide range of specialists including hydrologists, engineers, ecologists and geomorphologists (Huffman, 1991).

Rivers in general embody many values. For example, rivers symbolize connections, since they touch everyone, and everybody in principle lives downstream. Rivers also symbolize human health, since fresh water from rivers is essential to our communities and ourselves. Another value embodied by habitat, is protecting freshwater ecosystems for fish and wildlife. Rivers are also major destinations for recreation by communities. Fishermen fish in rivers, and other recreative activities such as boating, wildlife-watchers, sports and other leisure activities also take place along rivers (Department of Water Affairs and Forestry, 2001).

What we fail to see sometimes is that throughout a river's course, human activities have a significant impact on rivers. For example, pollution is increasingly becoming a major problem, where the economy and traditions are affected by polluted water.

2.3.1 Environmental Problems of Rivers

Rivers are indeed facing a number of environmental problems. This is despite the fact that more than half of potable water comes from rivers. This is so bad that in some cases, rivers, lakes and estuaries are unsuitable for such basic uses as fishing and swimming.

Communities living along rivers are most affected by these negative trends. Pollution of drinking water and rivers and lakes are two top environmental concerns. Communities realize that protecting and conserving rivers - the major source of drinking water - is critical for their future survival, but don't know how to take action. Many communities don't know how their everyday actions create water pollution, even though most are willing to change simple behaviours once they are informed (Dallas and Day, 1993).

Many river-side communities still believe industrial output is the main source of pollution in our rivers. But the experts know the story is more complex. One of the most overlooked causes is non-point sources of pollution. This is the leading cause of water pollution in rivers today, and is expected to increase. The main sources of non-point pollution are from farm fields and lawns, roads and parking lots, storms and flooding, etc. (Tripathi and Pandey, 1995).

2.4 Water Quality

Water quality is a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose. Although scientific measurements are used to define a water's quality, it's not a simple thing to say that "this water is good," or "this water is bad." After all, water that is perfectly good to wash a car may not be good enough to serve as drinking water for human consumption. When the average person asks about water quality, they probably want to know if the water is good enough to use at home, to play in, to serve in a restaurant, etc., or if the qualities of our natural waters are suitable for aquatic plants and animals (Asmal, 2002).

Presently the frequency of situations where water has been rendered unsuitable for normal use has increased significantly. Bacteria and micro-organisms have contaminated drinking-water supplies, sometimes causing severe illness to townfolk; chemical pollutants have been detected in streams, endangering plant and animal life; sewage spills have occurred, forcing people to pre-treat their drinking water; pesticides and other chemicals have seeped into the ground and have harmed the water in aquifers; and, runoff containing pollutants from roads and parking lots have affected the water quality of urban streams (Boyd, 2000).

Water quality has become a very big issue today, partly because of the tremendous growth of the nation's population and urban expansion and development. Rural areas can also contribute to water quality problems. Medium- to large-scale agricultural operations can generate in animal feed, purchased fertilizer, and manure, more nitrogen and phosphorus than can be used by crops or animals. These excess nutrients have the potential to degrade water quality if incorporated into runoff from farms into streams and lakes. All this growth puts great stress on the natural water resources, and, if we are not diligent, the quality of our waters will decline significantly (Helmer, 1989).

2.4.1 Decline in Water Quality: A Natural Process

The quality of surface water or groundwater at any point in a watershed reflects the combined effect of many physical, chemical, and biological processes that affect water as it moves along hydrologic pathways over, under, and through the land. The chemical composition of water varies depending on the nature of the solids, liquids, and gases that are either generated internally or with which the water interacts. Furthermore, the chemical composition depends on the type of interaction. At the mostly pristine part of the hydrologic cycle, precipitation quality is derived from interactions with gases, aerosols, and particles in the atmosphere. Evaporation purifies water as vapor but concentrates the chemical content of the water from which it evaporated. Condensation begins the process of imparting chemical quality to atmospheric moisture by inclusion of chemical substances through the dissolution of condensation nuclei. The complexity of the water-material interaction increases as precipitation falls on the land (Lundqvist, 1998).

The physical characteristics and mineralogical composition of soil and bedrock, topography, and biology substantially affect water quality. Most freshwater is a mixture of water derived from several hydrologic pathways. For example, stream water may be composed of varying mixtures of shallow and deep groundwater, precipitation, snowmelt, through-fall, overland flow, interflow, or through flow in the soil. Furthermore, the stream water composition may change in *situ* due to biological reactions or due to the interactions with the streambed and adjacent riparian zone. Living organisms, particularly micro-organisms such as phytoplankton and bacteria, affect water quality genesis through several mechanisms. For example, the biota can use and release nutrients and other elements that are commonly specific to particular plants and geographic regions or generate other products, including gases (Hem, 1985).

Natural water quality varies markedly and is affected by the geology, biology, and hydroclimatic characteristics of an area. Even under natural conditions, water may be toxic or otherwise unfit for human consumption. The occurrence of high and toxic metal concentrations is not uncommon and can be attributed to weathering of naturally occurring ore deposits. Although generally non-toxic, the solute concentrations of "pure" bottled spring water can vary by several orders of magnitude worldwide. However, the concept of pollution is relative, in that it reflects a change from some reference value to a value that causes problems for human use. A worldwide reference value is difficult to establish because of insufficient monitoring prior to changes in water quality due to human activities. Furthermore, there is no universal reference of natural water quality because of the high variability in the chemical quality of natural waters (Meybeck, 1996).

Natural water quality variations occur over a wide range of time scales. Long-term changes in water quality can occur over geologic time due to factors such as soil evolution, glaciation, mountain building, and mass wasting (downslope gravitational movement of soil and rock). Intermediate changes can occur due to successional changes in vegetation, forest fires, floods, and droughts. Seasonal and shorter-term variations in stream and river water quality are partly explained by variations in the mixture of contributing waters (water partitioning), each of which has different compositions due to transit time and contact with materials and the growth cycle of vegetation. Rapid changes in water quality can occur over relatively short spatial distances (Meybeck, 1996).

2.4.2 Human Impacts on Water Quality and Quantity

Human influences have had a direct effect on the hydrologic cycle by altering the land in ways that change its physical, chemical, and biological characteristics (Lundqvist, 1998; Hem, 1985). Physical alterations such as urbanization, transportation, farming (irrigation), deforestation and forestation, land drainage, channelization and damming, and mining alter hydrologic pathways and may change the water quality characteristics by modifying the materials with which the water interacts. For example, the impervious surfaces created by urbanization produce overland flow and high amounts of runoff even at moderate rainfall intensities (Arnold and Gibbons, 1996). In addition, these human activities alter water quality not only by changing hydrologic pathways, but by the addition of substances and wastes to the landscape.

The chemical alteration associated with human activity is, in part, related to the physical alteration, but occurs mainly through the addition of wastes (gases, liquids, and solids) and other substances to the land. These additions include waste disposal on the land or in water ways and the application of substances to control the environment, such as fertilizers for crop production, herbicides for weed control, and pesticides for disease control.

Human requirements for water also directly affect hydrologic pathways by providing water of a specified quality for different activities to sustain human existence (e.g., agriculture, potable supplies, power generation, power plant cooling, and industry). The quality of water from urban areas is complex due to the myriad of sources and pathways (Driver and Troutman, 1989). In these areas, not only are there multiple sources of individual substances, but the natural hydrologic pathways are replaced with artificial drainage channels, wet and dry storage basins, sewers, and water distribution systems, all of which affect the spatial and temporal quantity and quality of urban runoff. The management of the delivery of untreated waste (point source) directly to surface water has received considerable attention in developed countries, and recently, more emphasis has been placed on controlling diffuse sources (Line *et al.*, 1999).

Human activity is now one of the most important factors affecting hydrology and water quality. Humans use large amounts of resources to sustain various standards of living, although measures of sustainability are highly variable depending on how sustainability is defined (Moldan *et al.*, 1997). Nevertheless, the land must be altered to produce these resources. Irrigated agriculture alone is responsible for about 75 percent of the total water withdrawn from "surface water and groundwater sources," and more than 90 percent of this water is consumed and delivered to the atmosphere by evaporation (United Nations Commission for Sustainable Development, 1997).

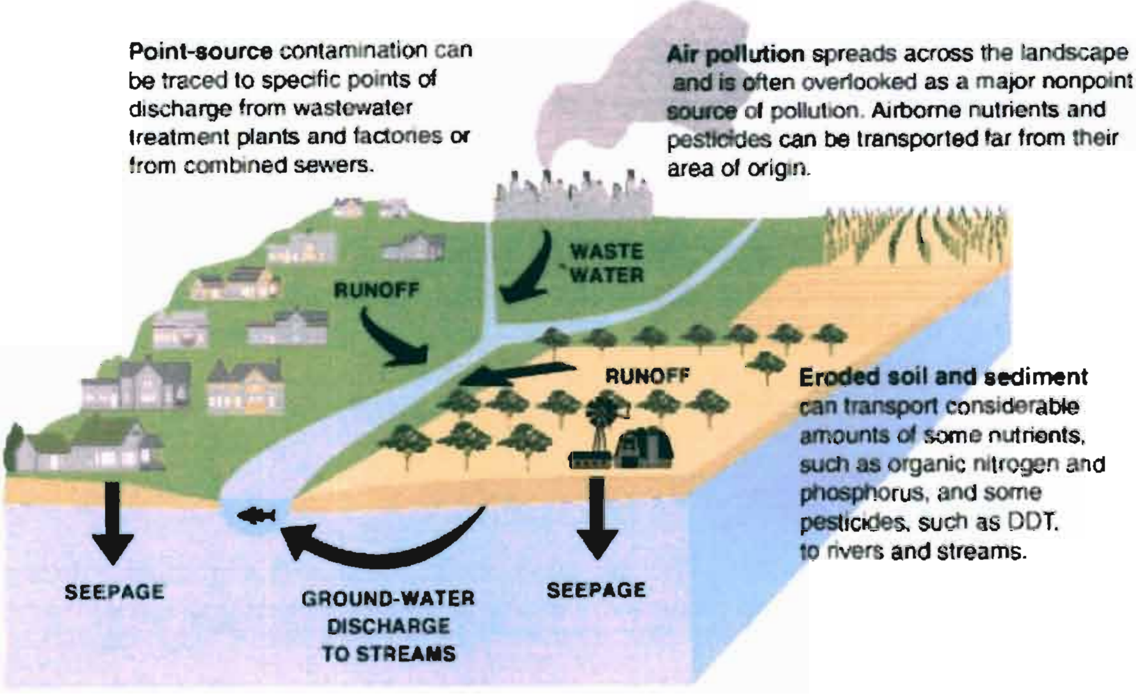


Figure 2.1 Various anthropogenic sources of pollution that impact on surface and subsurface waters.
(http://ga.water.usgs.gov...).

2.4.3 Water Quality in an Ecological Reserve Assessment

Methods for quantifying environmental water quality still focus on only magnitude (concentration) and, frequency and duration are only taken into account *via* flow-concentration modeling (Malan and Day, 2002; Malan and Day, 2003; Malan *et al.*, 2003). The task of the flow component of an Ecological Reserve Assessment is to provide both quantified and descriptive information about the pattern and reliability of environmental flows, with information on frequency, magnitude and duration, so that an entire modified flow regime can be provided (King *et al.*, 2000).

During an Ecological Reserve Assessment, the Ecological Reserve for water quality is provided as class boundary-value concentrations for each variable From the many possible water quality variables, the initial suite to be considered in South Africa includes: inorganic salts (sodium chloride, sodium sulphate, magnesium chloride, magnesium sulphate, calcium chloride, calcium sulphate); nutrients (phosphate and total inorganic nitrogen); physical variables (turbidity, pH, oxygen, and temperature); and those toxic substances (herbicides, pesticides and industrial compounds) listed in the *South African Water Quality for Aquatic Ecosystems* (DWAF, 2001).

2.5 Complex Systems

Aquatic ecosystems include numerous species, habitats and processes, all of which are interlinked and interdependent, and which require protection if healthy ecosystem structure and functioning are to be maintained. As a consequence of the complex and interlinked nature of aquatic ecosystems, the effects of changes in water quality on specific components of ecosystems are often indirect. A simple example of such indirect effects might be that a certain species of fish might disappear as a result of a change in water quality, not because the fish species itself cannot tolerate the change in water quality, but because the organisms that are its primary food source might be eliminated by that particular change in water quality (South African Water Quality Guidelines for Aquatic Ecosystems, 1996).

The wide variation in mineral content and silt load can be attributed to the influence of types of rocks and soil over which the river flows. The Orange River, for example, naturally carried a heavy silt load before man increased it through agricultural malpractices. Ironically, the name of the "Orange", first coined by Colonel Robert Gordon in 1779, was chosen in honour of the then Prince of Orange rather than because of the orange colour resulting from the river's striking silt load. Many of the waters of the southern and south-western Cape are also very different from most of that elsewhere, for they are exceptionally acid. The reasons for their acidity are not entirely understood, but the entire area overlies old, nutrient-poor, well-leached rocks. The natural fynbos vegetation is highly adapted to these nutrient-poor conditions and contains unusually large quantities of plant chemicals known as humic substances. These are very dark in colour, very acidic and decompose very slowly, producing the so-called "black waters" typical of the region. Many of the aquatic species of these streams are highly adapted to these unusual conditions and seem to occur nowhere else. By studying the aquatic life, a river biologist can tell whether a river is functioning normally or whether unnatural physical or chemical changes are taking place (Hughes, 2001).

Pollution is a catchword commonly used by the general public, and is certainly the most obvious problem associated with rivers. The term covers all manner of evils and refers to any substance that adversely affects the natural environment. Even naturally occurring mineral ions can be pollutants in certain circumstances. Common pollutants include industrial and domestic wastes (sewage, toxic metals, oils, washing, spillages, acids, alkalis, solvents and so on), litter, particulate waste, agricultural fertilizers, hot water and herbicides and pesticides. Pollutants entering rivers from "point sources" may be discharged legally under controlled or semi-controlled conditions, while others are discharged deliberately and illegally and yet others are discharged accidentally. Diffuse (or non-point) pollution occurs when pollutants enter the river, either from the atmosphere or in water draining the land anywhere in the catchment, and thus is extremely difficult to identify and control (Line *et al.*, 1999).

Farmers enrich their lands with fertilizers (nutrients) in order to increase crop yields. A large proportion of these nutrients is either washed off the soil into the rivers or leaches through the soil into the groundwater and hence into a river. On reaching the river these nutrients are as effective in increasing plant production in the water as they are on land. When present in excess, they stimulate the unbridled development of algal blooms, floating pest plants or expanding stands of rooted plants, any of which may reach pest proportions. The sight of a river with water that looks like pea-soup or one clogged from bank to bank with aquatic plants, often alien, is a familiar one throughout the country (Roux, 2004).

Sewage is rich in both organic matter and nutrients. The activities of the micro-organisms of decay cause deoxygenating of the water, resulting in the death of many normal riverine species. Sewage farms (or water treatment plants, as they are now more elegantly termed) take advantage of the propensity of micro-organisms to break down organic materials and even to turn some nitrogenous compounds into atmospheric nitrogen that will be removed from the system. Thus far, however, the technology for the removal of other major nutrient, phosphorus, is still in its infancy, so that the effluent from a well-run, up-to-date sewage works is usually very low in organic nitrogen but invariably high in phosphates, leading to the possibility of eutrophication of the receiving stream. When sewage is treated inadequately, before it reaches a river, the decay process will take place within the river itself. Fortunately, polluted water below a sewage outfall will become increasingly clean as it moves downstream, due to the activities of the aquatic plants and animals. Zones of increasing recovery occur along the river and this is reflected in the change in communities of plants and animals further and further away from the source of pollution. Such cleansing processes are impossible where toxic substances and pesticides change the physical and chemical nature of the water, killing those organisms that are hardy enough to withstand gross organic pollution and thus initiate the cleaning process (Jooste and Rossouw, 2002).

Solid wastes, such as soil particles from erosion, mining effluents such as coal dust, and iron oxides, agricultural washings and building debris also play a role in polluting rivers. Their effects may be devastating. Silt smothers animals and their eggs, blocks gills, deprives riverine animals of a firm substratum to cling to, and blankets their food. If the silt is continuously present in the water, the fauna will be numerically improved, but will resemble in character that of a lower river, as described above; if siltation occurs as an isolated incident, it will break the cycle of aquatic communities by killing the animals and their eggs, and then washed on its way, leaving no other trace of its presence. The affected stretch of river may nonetheless be barren for months or even a year until recruitments from other areas is successful. Litter in the form, is not damaging although in large quantities it can physically choke small streams (Jooste and Rossouw, 2002).

It is often possible to abstract and treat water of poor quality before it is used off stream, but in the case of aquatic ecosystems it is seldom possible to mitigate the effects of poor water quality to the same degree. Hence, for the purpose of protecting and maintaining aquatic ecosystems, prevention, rather than mitigation, of the effects of poor water quality has to be given even greater emphasis than would be the case for other water uses.

For this reason, the criteria for aquatic ecosystems provide different levels of protection. This is in contrast to the criteria for other water uses, which show the effects of changes in water quality for a particular water use sector (DWAF, 1996).

2.6 Water Pollution

One of the most important properties of water is its ability to dissolve chemical substances and transport them between different points in the environment. These dissolved chemical substances in the aquatic environment can, at times be beneficial but in most instances are very detrimental (Ellis, 1988).

A pollutant can have a wide range of definitions depending upon the terms of reference used. Ellis (1988) quotes various definitions including that of Dr Arthur Key who says: "A river is polluted when the water in it is altered in composition or condition, directly or indirectly as a result of the activities of man, so that it becomes less suitable for any or all of the users which it would be suitable for in its natural state."

Ellis (1988) claims more succinctly that: "There is no such thing as pollution. It is merely a problem of having valuable chemicals in the wrong place at the wrong time." Wisdom (1956) quotes the legal definition of pollution as: "The addition of something to water which changes its natural qualities so that the riparian owner does not get the natural water to the stream transmitted to him."

Pollution in general is derived from humans and their activities and can be classified under three main categories with a fourth for other miscellaneous forms. These are:
Industrial – These include products either used or produced in industries namely:
Engineering: hydrocarbons and trichlorinated solvents used in degreasing;
Insulation installer: Formaldehyde;
Printing: inks, dyes, bleaching agents;
Electroplaters: heavy metal and arsenic salts;
Woolen mills: dyes, bleaching agents, and pesticides;
Glass manufacturers: heavy metal and arsenic salts.

Agricultural – pesticides and fertilizers stored in barns or outbuildings which if spilled into a water course where drinking water is abstracted, could cause serious damage. The leakage of fodder with its high liquor content creates an extremely high biological oxygen demand on the water course and may reduce the available oxygen level that is necessary for the survival of the fish population.

Sewage Related – a diverse mixture of waste produced mainly by human activity. The mixture will contain human effluent; industrial effluent; run-off from roads; domestic waste water and a myriad of other minor sources. The mixture contains not only biodegradable materials but also insoluble substances, toxic and non-toxic materials as well as ineffective and non-infective agents.

Other Than the Above – these include the fire-fighting activities and services which are normally called in to deal with chemical spillages during a road accident. Methods of disposal of spilled materials include covering up with an absorbent material then sweeping up and flushing down the nearest drain with large amounts of water.

In addition, natural pollution that is arising without the assistance of man and which creates an added demand for oxygen can arise from the presence in water bodies of dead animals, decaying vegetation either from river plants or from vegetation falling into the water and, animal wastes.

Natural pollution may increase the particulate content of the water, increase the acidity, add coloured material or give the water an unacceptable flavour. It may also reduce the oxygen content of the water to such an extent that the loss of aquatic life may occur (Iwugo, 1995).

During the 1950s and 1960s, the major sources of pollution, within UK rivers were those of organic pollution arising from sewage, detergents and other foam producing agents and heavy metal salts. Point-source pollution, from sewage and effluent outfalls were major problems between 1960 and 1970. Regrettably, in the 1990s and presently, the problem with these sources still exist despite attempts by legislators and an unprecedented amount of public and media pressure (Tchobanglous and Schroeder, 1985).

Pollution incidents arising in a water course usually derive from one or two types of sources namely Diffuse sources and Point sources.
Diffuse sources are those which continuously add extraneous material into a water course from a widely spread area. The following are examples:

a) Nitrates and pesticides used in agriculture which are washed into the rivers by precipitation run-off;
b) Hydrocarbons and lead contained in the run-off from roads and highways (Keller and Wilson, 1992).

Certain diffuse sources are either very difficult to control or are beyond practicable control when considering pollution prevention. The amount of nitrate or phosphate contained in the run-off from an agricultural field is such an example. The main reasons for this are the limiting factors which govern modern farming practice and over which the farmer has little or no control. For maximum benefit from the fertilizer or pesticide treatment has to be done when the condition of the sand and weather are appropriate – factors which are beyond the control of the farmer (Keller and Wilson, 1992).

Unfortunately, not all of the controllable sources are subject to legislation or are able to be controlled by legislation. When the source is detected, it is seldom economical or practical to contain it. Disturbance of a site and clean-up operations can take several years to accomplish, in which time a large proportion of the pollutant may have been released into the aquatic environment (Keller and Wilson, 1992).
Point – source pollution, as opposed to diffuse pollution can be defined as a pollutant entering the environment from a fixed source and generally over a very limited period of time. Examples include the accidental releases of chemicals from industrial sites; leakage of silage liquor and yard washings from agricultural premises; discharge effluent outside

the consent limits from sewage treatment works; industrial effluents; storm overflow from sewage works; illegal tipping of industrial and other wastes; run-off from fire-fighting activities; transportation accidents; agricultural and industrial treatment systems failures; release of sheep dip material after use and the discharge of excess pesticides from farms (Tripathi and Pandey, 1995).

Industries are of great concern and industrialization contributing to water pollution has reached an alarming situation. Less than 5% of the industries have provided adequate measures for the treatment of effluents. Factory wastes include:

a) Oil: in forming a thin, widely dispersed film on the surface, it reduces the intake of oxygen by the water;
b) Detergents: they reduce the oxygen absorption capacity of fresh water;
c) Suspended particles and Poisonous chemicals: (such as sulphides and sulphites) acting as reducing substances, these lower the oxygen concentration in the water (Tripathi and Pandey, 1995).

Polluted and unpotable water due to poor environmental sanitation has been the major cause of diseases such as diarrhea, dysentery, typhoid fever, intestinal heleminths, jaundice, cholera, etc. Sources of water pollution are countless and the most detrimental and of great concern are those induced by human activities. Even today, open defaecation in the fields and along the drains and water resources are common in India (Tripathi and Pandey, 1995). Whilst pollution of river water is not a modern-day phenomenon, it is evident that the nature and quantity of pollutants has changed dramatically for the worst.

2.6.1 Water-Borne Diseases

Water-borne diseases are "dirty-water" disease – 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 *et al.*, 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 and some 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 and contaminate freshwater sources. 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).

Diarrohea, 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 diarroheal 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 fertilise 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.*, 1998). 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).

The seepage of toxic pollutants into ground and surface water reservoirs used for drinking and household use causes health problems in industrialized regions 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 with heavy metals, a practice that helps explain high infant mortality rate and endemic diarrhoeal and intestinal diseases (Edwards *et al.*, 1997).

2.7 Solid Waste

Solid waste is defined as waste that cannot be disposed of as a liquid by a sewage system (Cummningham and Saigo, 1990). Solid waste pollution includes such items as household refuse, semi-solids, liquids (in containers) and gases (in solid container) that result from various activities. The solid waste stream includes the services in place to remove household refuse or street litter. This could be house to house collection, or skip systems or in some places where no services exist. A waste stream can be seen as a visual passage of waste that arise from industrial, commercial and domestic activities (Cunningham and Saigo, 1990).

According to Armitage *et al*., (1998), a simple classification of solid waste is as follows: **Plastics** (Shopping bags, wrappings, containers, *etc*); **Paper** (Wrappers, newspaper, cardboard, cigarette boxes, bus tickets, *etc*); **Metals** (Foil, cans, number plates, vehicle engine parts, *etc*); **Vegetation** (Branches, rotten fruit and vegetables, uprooted trees); **Animals** (carcasses); **Construction materials** (Planks, broken bricks, lumps of concrete, *etc*) and **miscellaneous** (old clothing, shoes, tires, *etc*).

2.7.1 Solid waste pollution

When solid waste is dumped into rivers or streams it can alter aquatic habitats and harm native plants and animals. The high nutrient content in organic wastes can deplete dissolved oxygen in water bodies, denying oxygen to fish and other aquatic life forms. Solids can cause sedimentation and change stream flow and bottom habitats. Siting dumps or landfills in sensitive ecosystems may destroy or significantly damage these valuable natural resources and the services they provide. As a country becomes more developed and thus more commercialised, the solid waste problem becomes increasingly evident. Solid waste is a more apparent phenomenon in the much more developed countries, where the technology exists and certain industries, namely the plastic industries, facilitates the production of material that is often discarded by the consumers. However, in most of these countries allowances are made to reduce this problem where possible, i.e. brown paper bags are often used instead of plastic shopping bags due to its biodegradability; beverages are supplied in returnable glass bottles, instead of disposable plastic sachets or cans and more often than not, food is bought fresh rather than pre-packed. There is ultimately less waste to dispose of in these developed countries due to the nature of their economy (Botkin and Keller, 1995).

2.7.2 Solid waste in South Africa

Pollution from densely populated informal settlements is perhaps one of South Africa's most important but also most complex pollution problems. South Africans generate approximately 40 million tones of solid waste per annum. A large amount of this is packaging material mostly found in urban areas. In South Africa, the first and third world interface lies within the borders of the same country. The duality of the two sectors resulted in a complex situation with regard to the problem of solid waste, as the patrolling of it has not developed sufficiently to cope with the demands of both these interfaces simultaneously. Furthermore, nearly all the solid waste that is found in the country's water ways are said to be derived from urban areas, although these urban areas comprise of only 5.6% of the total land area of the Republic. This generation of solid waste is an inevitable consequence of the modern day urban living conditions of South Africans (Labat & Hayes, 1991).

The immense quantities of solid waste, impacts heavily on humans and the natural environment, the extent and the nature of the impact is pending on a number of factors. That includes the quantity of waste being generated, the composition of the waste; collection services and the methods of disposal. Armitage *et al.*, (1998), suggest that the most common sources of litter in South Africa are the anti-social behaviour of individuals in dropping litter on footpaths, throwing out of their vehicles and illegal dumping of household waste, the imposition of unwanted packaging on unwilling consumers, the failure of street-sweepers to rid the pavements and public areas of litter and inadequate disposal of facilities.

2.7.3 Water Pollution and Solid Waste

Water pollution is a substance or an effect which adversely alters the environment by changing the growth rate of species, interferes with the food chain, is toxic or interferes with health, comfort and amenities or property value of people (Van Loon, 2000). More simply put, pollution of rivers occurs when too much of a harmful or undesired substance enters a water body, exceeding the natural ability of the said water body to remove the undesired material (Botkin and Keller, 1995).

The quality of the water shows that urban, rural, agricultural and industrial areas all contribute to water pollution in some way, and also determines its uses (Botkin and Keller, 1995). In addition, certain air-borne pollutants are deposited into the rivers. Water pollution elements are numerous in number, and can be categorically divided.

2.7.4 Main Categories of Water Pollution

Category	Example of source	Impacts
Dead organic matter	Urban garbage, Sewage run-off	Reduces Biochemical Oxygen Demand (BOD)
Pathogens	Human and animal excreta	Causes Cholera and cryptosporadiosis
Inorganic chemicals	Acids and metals	Acid disposal and mining contribute to water pollution
Sediment	Soil run-off	Reduces water quality

Table 2.1 Categories of Water Pollution (combined list from Botkin & Keller, 1995 and Cunningham & Saigo, 1990)

With reference to the table, we see that solid waste, as defined by Cunningham and Saigo (1990) as well as Armitage *et al.*, (1998), is not categorized as an explicitly separate contaminant of water. It may be dumped in the river itself, along the riverbanks or may be deposited into the river *via* the storm water system. Once actually in the drainage system, the solid waste will, in turn, lead to the degradation of the water body. Of all the pollutants solid waste is most aesthetically unappealing.

2.8 The Physical, Chemical 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, phosphorus, etc. content of sample water; and, finally, the *biological* characteristic of water include the total coliforms, *E.coli* content, *etc.*

2.8.1 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.

2.8.1.1 pH

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:
$pH= -\log_{10}[H^+]$, where $[H^+]$ is the hydrogen ion activity. The pH of pure water (that is, water containing no solutes) at a temperature of 24°C is 7.0, the number of H^+ and OH^- ions are equal and the water is therefore electrochemically neutral. As the concentration of hydrogen ions $[H^+]$ increases, pH value decreases and the solution becomes more acid. As $[H^+]$ decreases, pH value increases and the solution becomes more basic (South African Water Quality Guidelines for Aquatic Ecosystems, 1996).

2.8.1.2 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).

2.8.1.3 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.

2.8.1.4 Temperature

Temperature may be defined as the condition of the 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. The rise in water temperature contributes to the degradation of water quality and negatively impacts fish populations. It can also lead to the death of many other organisms in the water ecosystem. High temperatures are also linked to rampant algae growth, causing fish kills in rivers and lakes. (Duffus, 1980).

Natural thermal characteristics of running waters are dependant on hydrological, climatological and structural features of the region and catchment's area. 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 of 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 include topographic features and vegetation cover. Channel form, water volume, depth and turbidity; affect the amount of solar radiation reaching and heating water, and thus its thermal regime (Reid and Wood, 1976).

2.8.1.5 Total Dissolved Solids (TDS)

The total dissolved solids (TDS) is a measure of the amount of various inorganic salts dissolved in water. The TDS concentration is directly proportional to the electrical conductivity (EC) of water. Since EC is much easier to measure than TDS, it is routinely used as an estimate of the TDS concentration. Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence of ions in water such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge. Most organic compounds dissolved in water do not dissociate into ions, consequently they do not affect the EC. Virtually all natural waters contain varying concentrations of TDS as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material and the TDS of natural waters is therefore often dependent on the characteristics of the geological formations the water was, or is, in contact with.

Typically, the concentration of the TDS in rainwater is low, generally less than 1 mg TDS/L; water in contact with granite, siliceous sand and well-leached soils is generally low, less than 30 mg TDS/L; water in contact with Precambrian shield areas is generally below 65 mg TDS/L; and water in contact with Palaeozoic and Mesozoic sedimentary rock formations is generally in the range of 195 - 1 100 mg TDS/L. TDS are likely to accumulate in water moving downstream because salts are continuously being added through natural and man-made processes while very little of it is removed by precipitation or natural processes. Domestic and industrial effluent discharges and surface runoff from urban, industrial and cultivated areas are examples of the types of return flows that may contribute to increased TDS concentrations (DWAF, 1996).

2.8.1.6 Total Suspended solids (TSS)

The total suspended solids (TSS) concentration is a measure of the amount of material suspended in water. This definition includes a wide range of sizes of material, from colloids (0.1 Fm) through to large organic and inorganic particulates. The concentration of suspended solids increases with the discharge of sediment washed into rivers due to rainfall and resuspension of deposited sediment. As flow decreases the suspended solids settle out, the rate of this is dependent on particle size and the hydrodynamics of the water body. Correlation of turbidity with the concentration of suspended solids (mass/unit volume) is difficult because the size, shape and refractive index of particulates affect the light scattering properties of the suspension. The relationship between turbidity and suspended solids may however, be determined on a site-specific basis. A turbidity meter, calibrated with consideration of the site-specific characteristics, may then potentially be used to monitor suspended solids.

Increases in total suspended solids may also result from anthropogenic sources, including: discharge of domestic sewage, discharge of industrial effluents (such as the pulp/paper mill, 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).

2.8.1.7 Ammonia

Ammonia (NH^3), where the nitrogen atom is in the III oxidation state, can readily take up an additional (hydrogen ion) to form the ammonium ion (NH^3+). In solution ammonia occurs positive in equilibrium with the ammonium ion and the position of equilibrium is governed by pH and temperature. Ammonia is not toxic to man at the concentrations likely to be found in drinking water but does exert other effects. For example, elevated concentrations of ammonia can compromise the disinfection of water and give rise to nitrite formation in distribution systems, which may result in taste and odour problems. At high pH, ammonia exits predominantly as a gas in solution, and can be released to the atmosphere from water. At low and neutral pH, ammonia is found predominantly as the ammonium ion. Surface waters which are not contaminated with organic wastes, generally have a low ammonia-nitrogen concentration, typically less than 0.2 mg/L. Concentrations exceeding 10 mg/L are found in raw untreated sewage; ammonia concentrations tend to be elevated in waters where organic decomposition under anaerobic conditions takes place. Ammonia is found in runoff from agricultural lands, where ammonium salts have been used for fertilizers (McKee and Wolf, 1963).

2.8.1.8 Calcium

Calcium is an alkaline earth metal and exists as the doubly positively-charged ion, Ca (II). Calcium occurs naturally in varying concentrations in most waters and, together with magnesium, is one of the main components of water hardness. Occurrence Mineral deposits of calcium are common, usually as calcium carbonate, phosphate or sulphate. Calcium bicarbonate, chloride and nitrate are very soluble in water, calcium sulphate is moderately soluble and calcium carbonate and phosphate are insoluble. Typically, the concentration of calcium in: fresh water is 15 mg/L; and in sea water is approximately 400 mg/L (Day and King, 1995).

2.8.1.9 Chloride

Chloride is the anion of the element chlorine. Chlorine does not occur in nature, but is found only as chloride. The chlorides of sodium, potassium, calcium and magnesium are all highly soluble in water. Chloride is of concern in domestic water supplies because elevated concentrations impart a salty taste to water and accelerate the corrosion rate of metals. High concentrations of chloride can also be detrimental to chloride-sensitive garden plants. Chloride is a common constituent in water, is highly soluble, and once in solution tends to accumulate. Typically, concentrations of chloride in fresh water range from a few to several hundred mg/L. In sea water the concentration is approximately 19 800 mg/L. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes. Chloride can only be removed from water by energy-intensive processes or ion exchange (Raju, 1995).

2.8.1.10 Fluoride

Fluoride is the most electronegative member of the halogens. It has a strong affinity for positive ions and readily forms complexes with many metals. In its elemental form, fluorine is a greenish-yellow gas which readily dissolves in water to form hydrofluoric acid. Fluorine is highly reactive and will attack most materials, including glass. Apart from the alkali metal fluorides, most fluorides are insoluble in water. Many soluble complexes are formed with silicates and the transition metals. Common fluoride minerals are fluor-spar (CaF) and fluor-apatite, a calcium fluoro- phosphate. Others of importance include various fluoro-silicates and mixed fluoride salts, such as cryolite (Na AlF). Typically the concentration of fluoride in unpolluted surface water is approximately 0.1 mg/L; ground water, is commonly up to 3 mg/L, but as a consequence of leaching from fluoride containing minerals to ground water supplies, a range of 3 - 12 mg/L may be found; sea water is approximately 1.4 mg/L (South African Water Quality Guidelines for Aquatic Ecosystems, 1996).

2.8.1.11 Magnesium

Magnesium is an alkaline earth metal which reacts with oxygen and water to form magnesium oxide and magnesium hydroxide, respectively. Magnesium is a common constituent of water and occurs as a doubly positively-charged magnesium (II) ion. The solubility of magnesium in water is governed by the carbonate/bicarbonate equilibrium and hence, the pH. Magnesium, together with calcium, is responsible for the hardness of water. Magnesium in water can make a significant contribution to the total dietary intake.

Magnesium is also a basic, essential element for plants (the central metallic ion in chlorophyll) and most other living organisms, since it is a component of important enzyme co-factors. The solubility of magnesium in water is governed by the pH. Magnesium hydroxide is relatively soluble at pH 7, but gradually becomes less soluble as the pH increases. Magnesium bicarbonate, chloride, nitrate and sulphate are very soluble in water, whereas magnesium carbonate, silicate and the phosphate are insoluble. Typically, the concentration of magnesium in fresh water is between 4 - 10 mg/L; and sea water is approximately 1 300 mg/L (South African Water Quality Guidelines for Aquatic Ecosystems, 1996).

2.8.1.12 Nitrate and Nitrite

Nitrate is the end product of the oxidation of ammonia or nitrite. Nitrate (NO_3) and nitrite (NO_3) are the oxyanions of nitrogen in which nitrogen is found in the +V and +III oxidation states, respectively. Nitrates and nitrites occur together in the environment and inter-conversion readily occurs. Under oxidising conditions nitrite is converted to nitrate, which is the most stable *positive* oxidation state of nitrogen and far more common in the aquatic environment than nitrite. Nitrates are ubiquitous in soils and in the aquatic environment, particularly in association with the breakdown of organic matter and eutrophic conditions.

Concentrations of nitrate in water are typically less than 5 mg/L of nitrate-nitrogen (or, alternatively, 22 mg/L nitrate). A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement.

Treated sewage wastes also contain elevated concentrations of nitrate. Nitrate tends to increase in shallow ground water sources in association with agricultural and urban runoff, especially in densely populated areas. Nitrate together with phosphates stimulate plant growth. In aquatic systems elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms. Algal blooms may subsequently cause problems associated with malodours and tastes in water and the possible occurrence of toxicity (DWAF, 1996).

2.8.1.13 Sodium

Sodium is an alkali metal which reacts with water to form highly soluble, positively-charged sodium ions. It is an essential dietary element important for the electrolyte balance and the maintenance of many essential physiological functions. Sodium is present in all food to varying degrees. Sodium is ubiquitous in the environment and usually occurs as sodium chloride, but sometimes as sodium sulphate, bicarbonate or even nitrate. Sodium is found as solid sodium chloride (rock salt) in areas where geological deposits occur. The levels of sodium in surface waters are generally low in areas of high rainfall and high in arid areas with low mean annual precipitation. Sodium is highly soluble in water and does not precipitate when water evaporates, unless saturation occurs. Hence, water in arid areas often contains elevated concentrations of sodium. High concentrations also occur in sea water, at approximately 11 g/L (Hellawell, 1986).

2.8.1.14 Sulphate

Sulphate is the oxy-anion of sulphur in the +VI oxidation state and forms salts with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium. Potassium, sodium, magnesium and ammonium sulphates are highly soluble, whereas calcium sulphate is partially soluble and barium and lead sulphates are insoluble. Consumption of excessive amounts of sulphate in drinking water typically results in diarrhoea. Sulphate imparts a bitter or salty taste to water, and is associated with varying degrees of unpalatability.

Sulphate is a common constituent of water and arises from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals. Since most sulphates are soluble in water, and calcium sulphate relatively soluble, sulphates when added to water tend to accumulate to progressively increasing concentrations. Typically, the concentration of sulphate in surface water is 5 mg/L, although concentrations of several 100 mg/L may occur where dissolution of sulphate minerals or discharge of sulphate rich effluents from acid mine drainage takes place; and sea water is just over 900 mg/L (DWAF, 1996).

2.8.1.15 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 on 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)

2.8.1.16 Biological Oxygen Demand (BOD)

The rate of oxygen consumption is commonly referred to as BOD. BOD is not a specific pollutant, but rather a measure of the amount of oxygen required by bacteria and other microbes engaged in stabilizing decomposable organic matter over a specified time period. The BOD determination is an empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewaters, effluents, and polluted waters. The test has its widest application in measuring waste loadings to treatment plants and in evaluating the BOD-removal efficiency of such treatment systems.

The test is a measure of the molecular oxygen utilized during a specific incubation period for the biochemical degradation of organic material such as sulphides and ferrous ion. It may also measure the amount of oxygen used to oxidize the reduced forms of nitrogen unless an inhibitor prevents such oxidation.

The BOD test is often used to estimate the impacts of effluents that contain appreciable amounts of biodegradable organics such as is found in food processing plants, pulp mills, and wastewater treatment facilities. A high oxygen demand indicates the potential for developing dissolved oxygen sag as the microbial oxidize the organic matter in the effluent. A very low oxygen demand indicates either clean water or the presence of a toxic or non-biodegradable pollutant (Boyd, 2000; Pelczar *et al.*, 1993; Weiner and Matthews, 2003; White, 1987).

2.8.1.17 Chemical Oxygen Demand (COD)

One problem with the BOD test is that it takes five days to run, represented as the BOD_5. If the organic compounds were oxidized chemically instead of biologically, the test could be shortened considerably. Such oxidation can be accomplished utilizing the COD test. The COD is as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidizing agent – an excess of potassium dichromate ($K_2Cr_2O_7$) added to water (H_2O) acidified with sulphuric acid (H_2SO_4). For samples from a specific source, COD can be related empirically to BOD, organic carbon, or organic matter. The test is useful for monitoring and control after correlation has been established (Boyd, 2000; Weiner and Matthews, 2003; White 1987)

Because nearly all organics are oxidized in the COD test, while only some are decomposed in the BOD test, COD results are usually higher than BOD results. For example, in wood pulping waste, compounds like cellulose readily undergo chemical oxidation (high COD), but decompose very slowly biologically (low BOD).
A low BOD or COD is not an indication that no pollutants are present in the sample. Anaerobic pathogens such as *Shigella spp* and *Salmonella spp* may be present. The presence of inorganic chemicals and\metal ions also yields a low BOD\COD value.

2.8.2 The Biological Characteristics of Water

The biological characteristics of water, related primarily to the resident aquatic population of micro-organism impact directly on water quality. The most important impact is the transmission of disease by pathogenic organisms in water. Other important water quality impacts include the development of tastes and odours in surface waters, groundwaters, the corrosion of heat transfer surfaces in cooling systems and water supply and wastewater management facilities (Gray, 1994).

2.8.2.1 *Escherichia coli (E.coli)*

The coliform bacteria as a group are characterized as gram-negative non-spore-forming facultative rod-shaped bacteria that ferment lactose with production of acid and gas within 48 hours at 35°C. Coliform bacteria, especially the faecal coliforms, are neutral, normal inhabitants of the intestinal tract of warm-blooded animals including man. Coliforms co-exist in faecal matter with pathogens such as bacteria, viruses, and protozoa. Coliforms are highly concentrated in wastewater and generally sparse or absent from other habitats. As a consequence of this correlation between wastewater and coliforms, the presence of coliform bacteria in water is considered an indication of pollution\contamination. *E.coli* is a member of the group of coliform bacteria (Pelczar *et al,*, 1993).

E.coli most closely satisfies the requirements of an ideal pollution indicator and is the organism of choice in the United States. Other bacteria, such as *Streptococcus faecalis* and *Clostridium perfringens*, have been suggested and used as pollution indicators; both are normal inhabitants of the intestinal tract of humans and animals (Curds *et al.*, 1990; Pelczar *et al.*, 1993). E.coli can also easily be distinguished from other members of the coliform group e.g. the absence of urease and the presence of β–glucuronidase (Maier *et al.*, 2000).

2.8.2.2 Total coliforms (TC)

Total coliforms bacteria include the faecal coliforms and a wide variety of other species. They are usually associated with faecal material, but some species thrive on certain types of vegetation, in soils, and in some industrial processes. Species of *Escherichia, Klebsiella, Enterobacter,* and *Citrobacter* are important members of the total coliform group (Curds *et al.*, 1990).

The total coliform group has served as the main indicator of water pollution for many years; however, many of the organisms in this group are not limited to faecal sources. Thus, to restrict the enumeration to coliforms more clearly of faecal origin, the feacal coliforms are utilized (Maier *et al.*, 2000).

Faecal coliforms are a subgroup of the total coliform group. They are thermo-tolerant and are thus capable of existing at elevated or warm-blooded temperatures. The most abundant species in the faecal coliform group are *Klebsiella spp* and *E.coli.*

2.9 Legislation and Policy

'Society, as it strives to achieve ever increasing standards of living, has an insatiable demand for clean water, both for its own consumption and enjoyment in the environment. Too often, creation of a higher standard of living carries with it an environmental 'price' and, at the same time, spread it equally among all water users, society passes laws to manage water quality. The exact form and nature of these laws has evolved over the years' (Loftis *et al.*, 1990).

South Africa is emerging from a period of unsustainable and inequitable development. One outcome of this period was environmental degradation, which imposes significant negative economic and social impacts. Key to effecting a transformation to development which is economically, environmentally, and socially sustainable is to redefine the current and future management of pollution and waste in South Africa (DEAT, 2000). Pertinent to effective management of pollution and waste, are the promulgation of legislation and policy by Government and the enforcement of said legislation and policy by the authorities, such as DEAT and DWAF, who have been vested with the said responsibility.

2.9.1 Role of Legislation

Throughout history, rules and regulations were numerous, and ineffective in the long term, if not in the short. In democratic societies, like South Africa, the political process is how decisions are made as to whether actual or potential changes in the environment are of significant concern to adopt policy measures (eg. laws and regulations) to prevent, alter, or reverse these changes. Some notion of the damages or risks that will be avoided by taking action is one essential element of the decision-making process. Ultimately, a range of factors influences community and national decisions about environmental policies. Such factors include the influences of culture, social values, and economics (Rubin, 2001).

Rubin (2001) goes on to say that because of these factors, priorities and preferences for environmental protection often vary between communities and nations. For example, a poor nation struggling to provide its citizens with basic necessities like water, electricity, and sanitation is unlikely to be concerned about environmental protection as would a wealthier nation. Environmental policies are also based on the concept of equity such as the idea that all citizens have the right to breathe clean air, and have access to potable water. In other cases, the principles of ethics are of substantial importance, as with the protection of endangered species. Because of the inherent economic implications within policy development, private as well as public interest almost always influences it.

At all stages in the policy development process, one important approach is to adopt policies whose benefits clearly outweigh the cost of measures taken. Usually, an economic cost-benefit analysis is employed to evaluate the merits of proposed policies. However, placing a monetary value on expected environmental and health benefits can be especially problematic and controversial. Numerous laws and regulations, which relate to the management, prevention, and remediation of pollution and waste, are currently promulgated in South Africa. These include:

2.9.2 The Water Act, Act 54 of 1956

The responsibility of preventing the causes of water pollution and related water quality problems is vested with The Department of Water Affairs and Forestry (DWAF). Legislation has deemed it possible that no waste water from industry or domestic, can be discharged or untreated into natural water bodies such as rivers, streams, and lakes.

In terms of the Water Act, Act 54 of 1956 the following regulations are to be adhered to:

- No person or persons may discharge sewage or effluent into a watercourse if it does not comply with certain quality requirements as set out in the General Standards (DWAF limits), or to conditions as per a permit by the controlling state department.
- An industry may by agreement discharge effluent of lower quality into the sewers of a local authority that then undertakes to treat this effluent, in conjunction with their domestic sewage, to a quality that complies with water quality requirements as set out in the General Standards.
- Discharge of untreated sewage is not permitted into the sea. Under certain conditions as set out, permission may be obtained to discharge partially treated effluents to the sea via outfall pipes.

2.9.3 The National Environmental Management Act, Act 107 of 1998

- 'where as many inhabitants of South Africa live in an environment that is harmful to their health and well-being;
- Everyone has the right to an environment that is not harmful to his or her health or well-being;
- Everyone has the right to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures…

In terms of the NEMA, Act 107 of 1998, the following National Environmental Management Principles are critical to curbing waste and pollution:

- Pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimized and remedied;

- That waste is avoided, or where it cannot be altogether avoided, minimize and reused or recycled where possible and otherwise disposed of in a responsible manner;

- That negative impacts to the environment and on people's environmental rights be anticipated and prevented, and where they cannot altogether be prevented, are minimized and remedied.

2.9.4 Legislation related to Water Services

Since the 1990's, the South African water legislation has moved through an extensive revision from being nearly unchanged for over 30 years. South Africa's water law came out of a history of conquest and expansion. The colonial lawmakers tried to use the rules of the colonising countries of Europe that had good, extensive water resources and applied them in the dry and variable climate of southern Africa. The consequence was legislation with little or no correlation with the conditions of the country it was meant for (White Paper on National Water Policy, 1997).

From a historical perspective, the legal framework for water management of South Africa also took several traditional socio-political aspects into consideration. The Water Act from 1956 regulated the water allocation until the National Water Act in 1998 came into force. Although the 1956 version was regularly amended to take into account industrial changes and the rapid urbanisation of South Africa, it still protected the private water ownership. As a consequence, it did not take into account the basic water needs of the poor population, especially of the Black, Indian and Coloured (White Paper on Water Supply and Sanitation Policy, 1994).

2.9.5 The Program of Free Basic Water Supply

DWAF, with due consideration for the poor and from within the context of the new equalized legal framework, initiated an investigation into the possibility of providing water free of charge to the poor. In February 2001, the Minister of Water Affairs and Forestry, announced that the government had made a decision to provide a basic supply of 6000 litres of water per month, to every household, free of charge. This decision is a part of the government's integrated rural development strategy and urban renewal programme (DWAF, 2001).

The amount of 6000 litres per month was based upon of the World Health Organisation's (WHO) standard of 25 litres of water per day as the basic amount of water a person needs. The household was then estimated to have eight members (DWAF, 2001). The National Water Act No. 36 of 1998 states that pricing strategies may differentiate on an equitable basis in respect of different geographic areas, on the basis of socio-economic aspects within the area in question. This statement might have been one of the underlying legal incentives for developing the free basic water programme.

The legal implications of the Free Basic Water Programme that now has been incorporated in the Water Service Act (108 of 1997) may have several impacts on the water service provision for low-income households. Households that only have access to inadequate water services such as standpipes or are unable to pay for the water consumed.

The Water Service Act (108 of 1997):
The definition of the minimum standard of basic water supply:

- The provision of appropriate education in respect to effective water use;
- A minimum quantity of potable water of 25 litres per person per day or 6 kilolitres per household per month at a minimum flow not less than 10 litres per minute within 200 metres of a household; and
- Water should be provided with effectiveness such that no consumer is without a supply for more than seven full days, any year.

A water service institution must ensure that the water interruption does not last longer that 24 hours and that the consumer has access to alternative water services comprising at least 10 litres of potable water per person per day and sanitation services sufficient to protect health (South African Government, 2001).
The Free Basic Water Programme was implemented on the 1 July 2001. The responsibility of implementing the programme of providing water to the poor, free of charge, was that of local governments. Durban Metropolitan Unicity Council (DMUC) was one of the first municipalities in South Africa to start implementing the free basic water programme in low-income communities within its jurisdiction (DWAF, 2001).

2.10 Conclusion

Water is an essential element in the maintenance of all life forms, and most living organisms can survive for only short periods without it. This has resulted in the development of direct relationships between the abundance of water, population density, and the quality of life. In addition to being in abundance, water must have specific characteristics; water quality being defined in terms of these characteristics. Throughout history, the most important of these characteristics has been the concentration of dissolved salts because of the intrinsic relationship between salinity and land productivity. As population density increased, health-related characteristics such as the presence of pathogenic organisms also became important. (Zuane, 1990).

Water quality deterioration has become a serious issue in many nations. Unless measures are implemented to conserve the quality and quantity of water, the planet faces a bleak future.

The usefulness of water declines as its quality deteriorates; high quality water is in greater demand and is of increased value than lower quality water. As humans begin to exert control over the quality of water, it is found that waters vary in character such as colour, taste, and temperature, with these characteristics influencing the suitability of water for differing requirements. It is now apparent that there is an ever-increasing risk to river systems from irregular pollution incidents with the same causes of pollution recurring with unfailing repetition, with man often finding it difficult to learn from his mistakes (Zuane, 1990).

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 Introduction

Scientific research begins with the realization that current knowledge is insufficient to handle certain problems, and no questions can be asked, nor answered, beyond some knowledge base. Part of the background knowledge is ordinary and in part scientific. As research progresses, it corrects and even rejects parts of ordinary knowledge, thereby enriching the latter with the results of science. Part of today's science is yesterday's result of research. Research begins where ordinary experience and thought fail to solve problems, or even pose them (Bunge, 1967)

A clear statement of the research methodology and study area should be an integral part of an investigation. A detailed description of the study area is important to the reader and future researchers. It informs the reader of the location where the study was carried out, what type if study has taken place and the choice of that particular area for the investigation. In addition, maps serve as important tools to geographically locate such an area. This allows the reader and future researchers to understand the geographic location of the study area.

A scientific, valid and recognized method of investigating has to be implemented while a detailed description of the method implemented to execute the investigating is essential mainly for the reader to understand how the data was collected, analysed and presented.

3.2 The Study Area

The Palmiet River and its catchment form the area of study for this project (Fig 3.3). The catchment is located within the Durban Metropolitan Area (Fig 3.2). The Palmiet River rises in the Kloof escarpment, flows through the Pinetown-New Germany industrial area, a source of potential river pollution, and thereafter is the key drainage feature of the Palmiet Nature Reserve (PNR). It enters the Mngeni River as a tributary in Springfield.

Three small, short tributary streams within the PNR enter the river; the Umthini on the western boundary from the south and the Nsimba and Mvuzi from the north. The Palmiet River is 26 km long with only 6 km passing through the reserve. The rest is bordered by factories and built up areas. Its source is the Kloof escarpment and it then flows through the residential and industrialised areas of Pinetown and New Germany onto the residential suburbs of Westville and Clare Estate. It enters the Mngeni River at Springfield Park a distance of 24 km.

Ever increasing hardened surfaces including roads, pavements and shopping centre parking lots simply drain into the Palmiet. The result is one very sensitive "stormwater drain" with frequent flooding and scouring of the river banks.

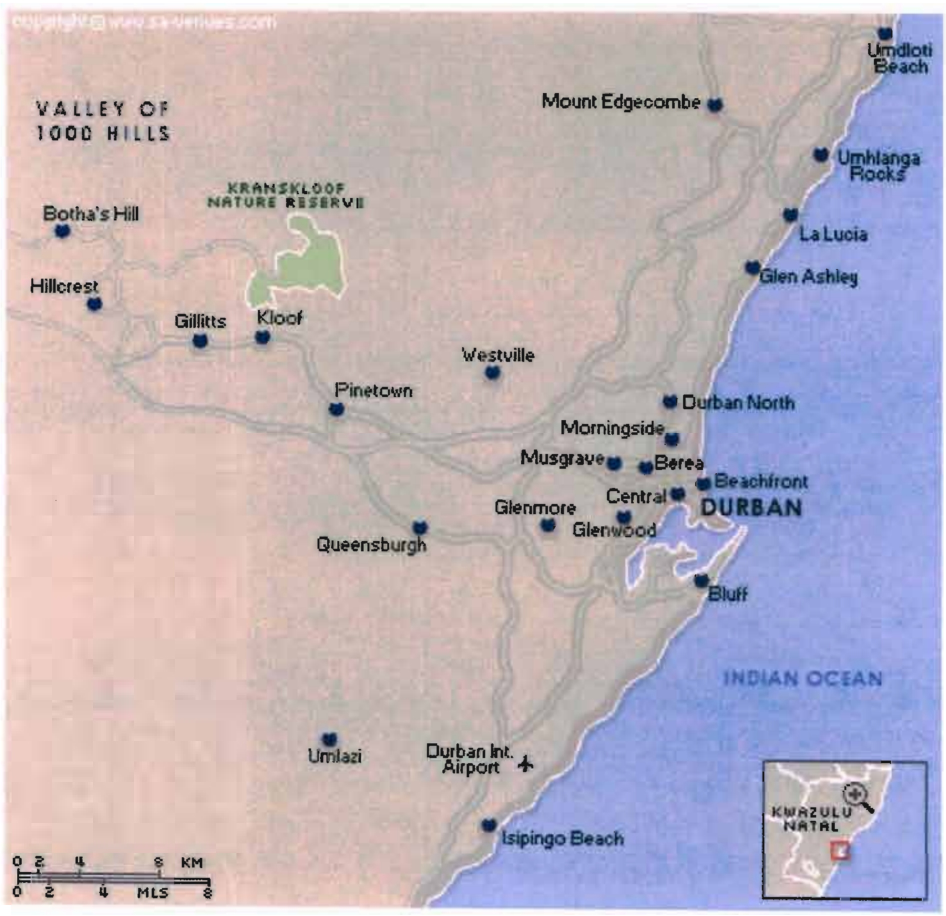


Figure 3.1 The Durban Metro Area

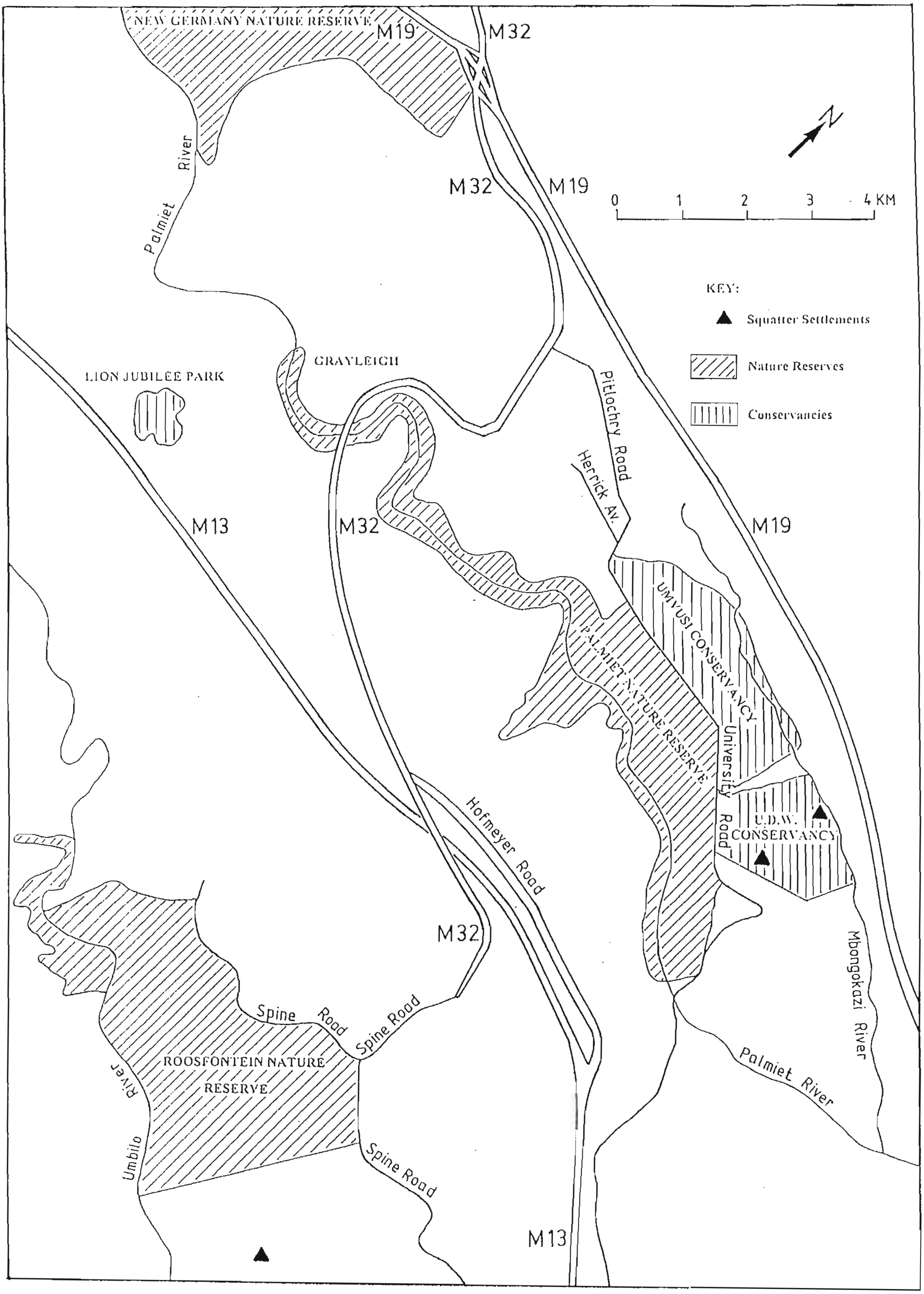
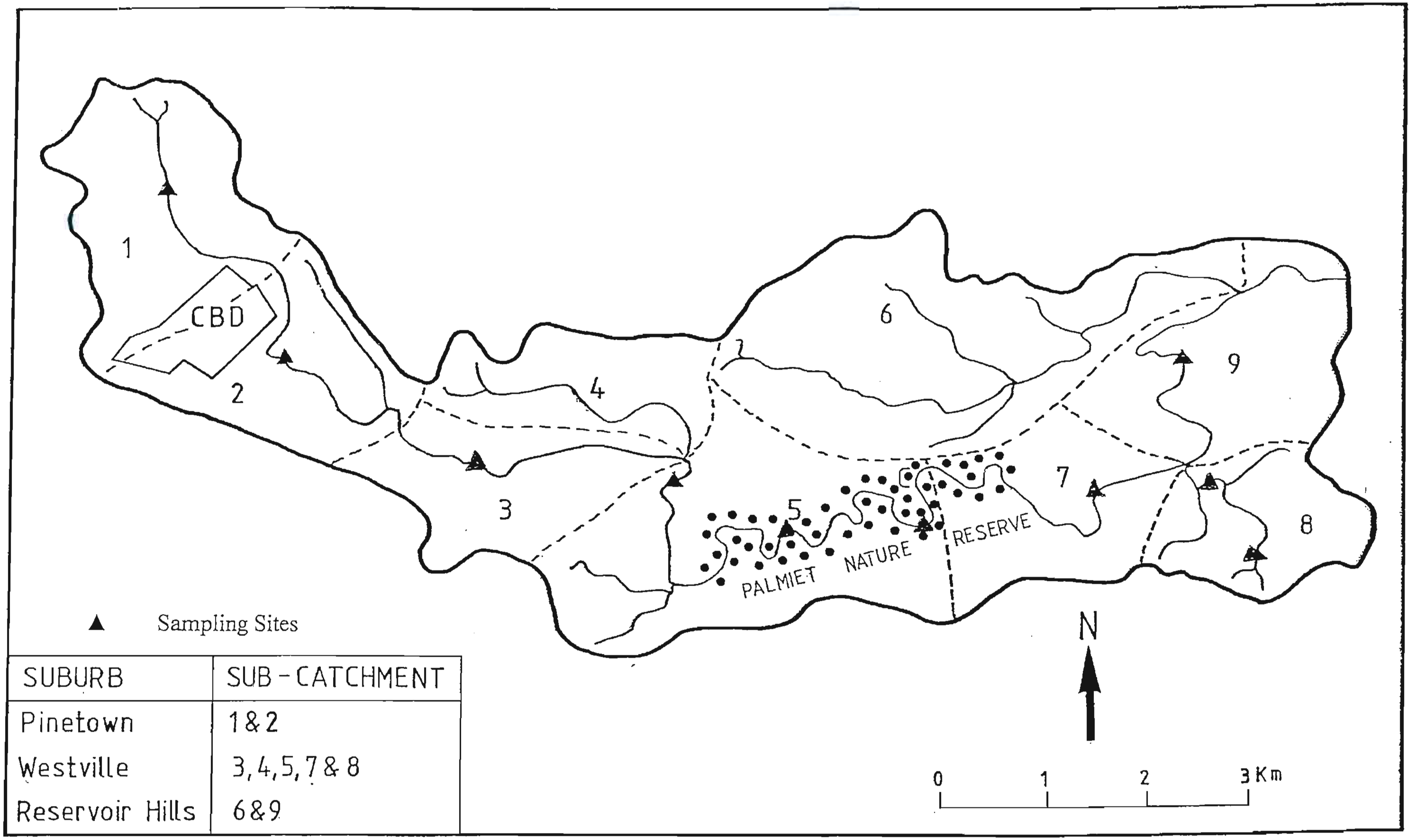


Figure 3.2 Location of The Palmiet River along Major Roads within the DMA.



SUBURB	SUB - CATCHMENT
Pinetown	1&2
Westville	3,4,5,7&8
Reservoir Hills	6&9

Figure 3.3 The Palmiet River Catchment, sub-catchments and Sampling Sites

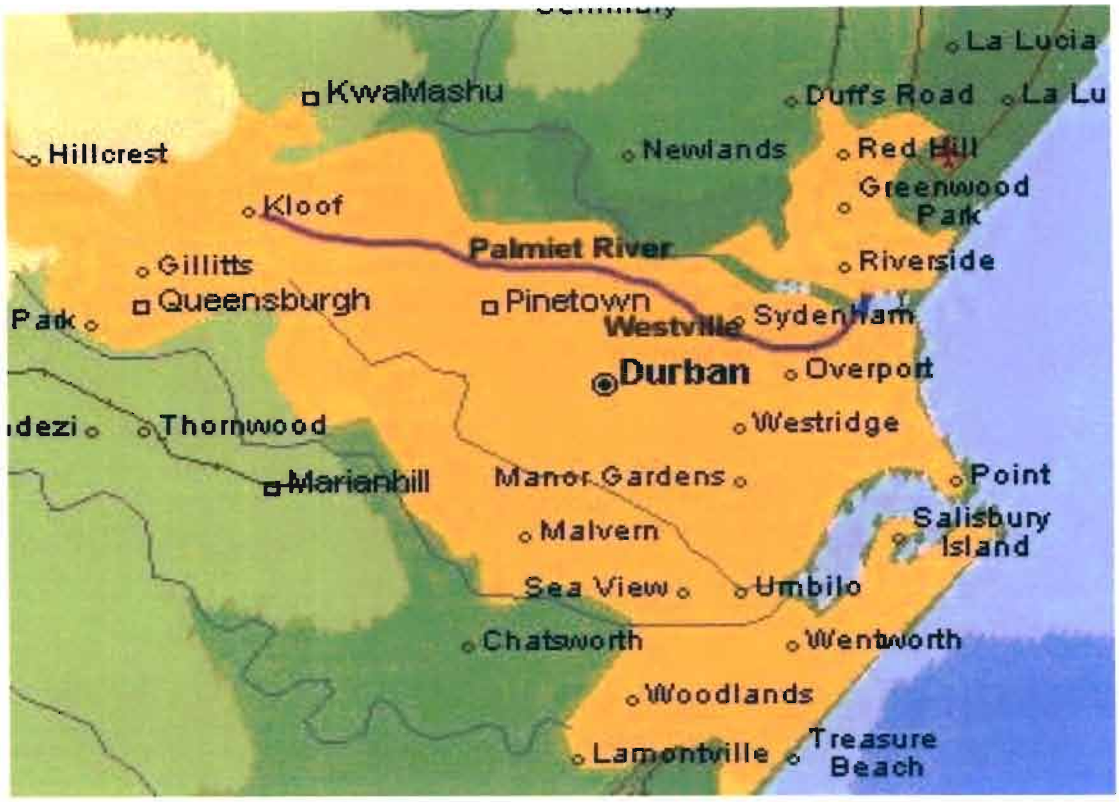


Figure 3.4 The Palmiet River (in purple) and it's location within the DMA (orange) and important suburbs.

3.3 The Palmiet Nature Reserve

The Palmiet Nature Reserve (PNR) is a community managed municipal Nature Reserve. The reserve and river named after the riverine plant *Prionium serratum* (Palmiet). It is located 11 km from central Durban in Westville, a suburb of the Ethekwini Municipality, in the Palmiet River valley, from which it takes its name. It extends some 4.8 km along the Palmiet River, while the UDW Conservancy follows the river for another 1.8 km. The PNR is 0.9 km at its widest point, across the Faurea woodland spur to the opposite southern slope. It is therefore somewhat elongated in shape, following the meandering Palmiet river (Read, 2003).

3.3.1 Topography

The PNR occupies a steep valley with rugged krantzes, which enhances it as a spectacular scenic destination. It has an undulating, steep topography. The highest altitude in the PNR is 240 meters which is the boundary on summit of the Out span Cliff, while the altitude of the south-western end of North Cliff is 228 m, the Faurea entrance is 214 meters and the gate in the Dissotis wetland is 212 meters. The Palmiet River is 172 meters where it enters the PNR in the west and 87 meters where it exits it at the eastern boundary, this being the lowest point in the PNR. The account in Dunlevey (1999) states that a massive 120 meter drop in sea level, approximately 20 000 years ago, created a sudden increase in gradient which caused the rivers to cut down into the existing channels, resulting in the incised meanders of the present day Palmiet River valley, where a relatively small river occupies a deep and highly sinuous gorge.

3.3.2 Drainage and hydrological regime

As the Palmiet River catchment is largely urbanised with impervious hard surfaces that increase run-off, the hydrological regime is typical of an urban river hydrograph. The 4.5 m flood of February 1999, when 305 mm of rain was recorded in the PNR in 14 hours, caused much damage to the Reserve. This and a second heavy flood in December of the same year, resulted in the flood plain of the river being increased to about three times its former width (Read, 2003).

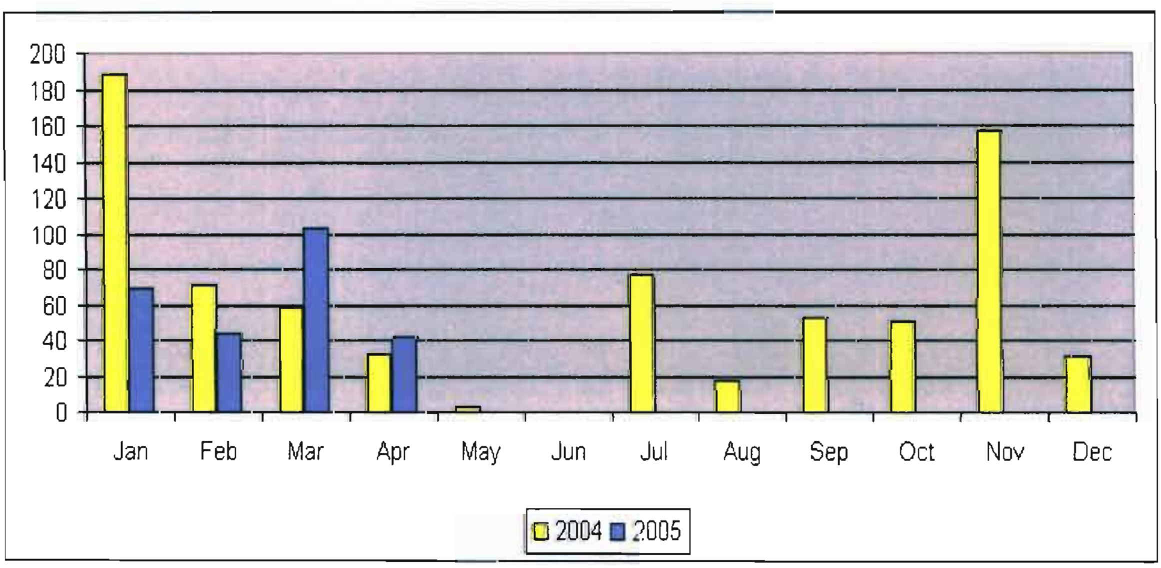


Figure 3.5 Rainfall Figures for the Palmiet Reserve (mm) 30 April 2005 (Read, 2005).

3.3.3 Geology

Dunlevey (1999) identifies the sandstones of the Natal Group, formed about 600 million years ago, as the main rock in the PNR. Within these sedimentary deposits are coarser pebbles, including quartz, jasper and chert, which can be found, as a result of the weathering of the sandstones, along the river bed. To the east, are the molten glacial tillite deposits of the Dwyka Group from the ice age of about 350 million years ago. With the break up of Gondwanaland some 200 million years ago, magma, trapped within fractures, solidified to form dolerite, which has subsequently been exposed by erosion. A doleritic dyke is now visible in the Palmiet River bed near the Nsimba Stream and dolerite rocks can be found washed downstream of this outcrop.

Figure 3.6 An outcrop of sandstone in the PNR

3.3.4 Soils

The bulk of the soils of the PNR are derived from the sandstones of the Natal Group. They are prone to erosion when disturbed, hence the need to ensure that hiking paths do not cause a problem in this regard. Cole (1961) describes them broadly as grey-like podsolic soils of the eastern coastal belt, where high temperatures promote rapid decomposition of organic matter and which are generally leached on account of heavy thunderstorms. According to Emery (pers. com., 2000), the soils down to about 0,15 m are moist, light brown, firm silty medium sand and this is repeated to a depth of 1 m with the addition of pinkish brown weathered sandstone fragments.

3.3.5 Vegetation

Vegetation in the PNR, as per the Acocks (1975) classification, falls within the Coastal Tropical Forest of KZN. However, this represents a broad picture which is not relevant considering the present vegetation communities, which have been highly modified by human intervention. Cottrell (1978) identifies four main plant communities, namely, (1) lithophytic and cliff-top communities; (2) grass with bush clumps, to which must be added the Faurea saligna woodland on the Grass Ridge spur; (3) scrub and (4) forest. The numerous cliffs in the PNR provide a home for many interesting lithophytic species, ranging from lichens and mosses to trees which survive in soil pockets created from weathering rock processes and the accumulation of organic material. Although not a rare species elsewhere, the *Faurea saligna* woodland stands are unique in the Ethekwini area, the only other known occurrence being in New Germany Nature Reserve. The grass communities are probably relics of what were undoubtedly more widespread distributions in the past. By far the best and largest forest is that on the southern campus slopes of the UKZN (Westville) Conservancy. The former gallery forests that overhung most parts of the Palmiet River have disappeared in the 1999 floods, but trees still thrive along the edge of the widened flood plain.

3.3.6 Bird, mammal, reptile and other life

The abundant bird life, with over 150 species and the list of over 170 trees, make the Nature Reserve a desirable destination for wildlife enthusiasts. However, as mammals have not been introduced into the PNR, these are seldom seen by visitors. Vervet monkeys are the most numerous of the mammals, but these are also not often visible, as they disappear during the day in search of more easily secured food in residential areas. Snakes, although seldom seen, are plentiful, both in numbers and species variety, while the monitor lizard is perhaps the most visible reptile (Cortell, 2003).

3.4 RESEARCH METHODOLOGY

Research Methodology is a continuing process; a continuum that is ever changing and ever developing. A detailed description of the research methodology informs the reader exactly how the researcher handled the data (Leedy, 1993).

3.4.1 Measurement of Water Quality

In most nations of the world, attempts are made to maintain the quality of natural waters within limits suitable for aquatic life. Water quality standards have been recommended for natural waters, and effluents must meet certain criteria to prevent pollution and other adverse effects on fauna and flora (Boyd, 2000)

Quantitative measurements of pollutants are obviously necessary before water pollution can be controlled. Measurements of these pollutants is, however fraught with difficulties. Sometimes specific materials responsible for the pollution are not known. Moreover, the polluting agents may be present in very low concentrations, and extremely accurate detection methods are required (Weiner and Matthews, 2003)

3.4.2 Water Quality Parameters

Since water is a good solvent there is an almost endless list of materials which could be present in a particular sample. When assessing water quality it is therefore often convenient to use what are termed '"blanket parameters" which measure the presence of a group of contaminants or indicate a particular property. The relevance of various water quality parameters depends upon the nature of the water or wastewater and its actual or potential use. There are three basic types of characteristics which are of importance. These include:

3.4.2.1 Physical Characteristics

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

3.4.2.2 Chemical Characteristics

Alkalinity, hardness, organic content, nutrients, dissolved oxygen, inhibitory and toxic compounds comprise the category of chemical characteristics (Gray, 1994).

3.4.2.3 Biological Characteristics

Natural waters normally form a balanced ecosystem containing microorganisms such as bacteria, protozoa and algae. Microorganisms provide food foe fish and other higher life forms. Wastewaters can contain large numbers of microorganisms, particularly bacteria and are potentially hazardous because of the connection with water-related diseases. Although on occasion individual species may be identified, it is common for blanket determinations of biological populations (Tchobanoglous and Schroeder, 1985).

3.4.3 Sampling

A collection of individuals forming party of a population is called a sample of that population, while the process incorporated in selecting the sample is termed sampling. The success or failure of an induction is very much dependant on the nature of the sampling process. For some tests, the measurements need to be conducted at the site as the process of obtaining the sample may change the measurement. For example, in measuring the dissolved oxygen in a stream, the measurement should either be conducted at the site or the sample must be exposed to the atmosphere (Weiner & Matthews, 2003)

Sampling is a very important stage in the assessment of water quality because of the sample is unrepresentative; the analytical results will be useless (Hounslow, 1995). Representative samples need to be obtained since the data from the analysis of the samples will ultimately serve as a foundation for pollution control and implementation of measures. Suitable sampling locations need therefore be determined. The collection of a representative sample from a source can be achieved by a simple grab sample.

A sample collected at a particular time and locality is representative only of the composition of the source at that time and locality. However, when a source is known to be relatively constant in composition or over considerable distances in all directions, then the sample may be said to represent a larger volume. Under said circumstances, the source may be represented adequately by grab samples. In addition, when a source is known to vary with time, grab samples collected at suitable intervals and analysed separately, can document the extent, frequency, and duration of these variations. Grab samples are also appropriate if the purpose of sampling is to monitor whether or not water quality are variable, then a composite sampling technique should be available (Bitton, 1994).

Most tests can be carried out on a water sample extracted from a stream. The process, by which the sample is obtained, may greatly influence the result. There are three basic types of samples: grab samples, composite samples, and flow-weighted composite samples (Raju, 1995):
The grab sample, as the name implies, measures water quality at only one point. Grab samples accurately represent the water quality at the time of sampling, but provides no indication as to the quality before or after sampling. The frequency of grab sampling is dependant on the magnitude of fluctuation in the quality of the source.

A composite sample is obtained by mixing together a series of grab samples collected at the same sampling point at different times. Grab samples do not provide the average quality over a given period of the source. In certain cases, though, e.g. the determination of the efficiency of a wastewater treatment plant, the average quality is what is required.

The flow-weighted composite is obtained by taking each sample such that the volume of the sample is proportional to the water flow at that time. This is especially useful when the daily loadings to wastewater treatment plants are calculated.

Whatever the technique or method employed, the analysis can only be as accurate as the sample; often the sampling methods are appreciably sloppier than the analytical analysis (Weiner & Matthews, 2003).

3.4.3.1 Sampling Locations

Effluent sampling locations should be representative of the material discharged to the receiving waters. In-stream sampling provides useful results and should include sampling sites downstream, upstream, and the point of effluent discharge. Samples should be collected at times indicative of the various possible conditions. These include high flow, low flow, wet flow, wet weather, dry weather, morning, afternoon and evening (Curds *et al.*, 1990).

3.4.4. Questionnaire survey method

A questionnaire is a set of printed questions used by a surveyor for obtaining statistically useful or personal information from an individual or family. In the questionnaire method, an individual questionnaire form is filled out by each person or family being interviewed and the results are later tabulated and analyzed. Questionnaires are most commonly used in needs assessments to help determine the individual needs and priorities of the victims. In such assessments, questionnaires may be used in several ways: for interviewing officials knowledgeable about needs, or for direct interviews with households and families. Questionnaires may be used for interviewing a total target population, but sample surveys are more commonly used (Brehob, 2001).

The main advantage of questionnaires is that detailed information about needs can be obtained and the tabulated results can provide much needed statistical information about families and their condition. Not only can this give a good analysis of the impact of a disaster at the individual and family level, but if the survey covers a significant part of the population to be served by the relief agency, the questionnaires can also be used as the initial record for individual casework.

The disadvantage is that surveys using questionnaires are slow. If a large percentage (sample) of the target population is to be interviewed, the number of interviewers required to conduct the survey can be quite large (and therefore more costly in terms of time and resources). Some disaster managers also question the validity of questionnaires as an emergency assessment technique because they feel that all needs are relative depending on the time that the survey is taken. Interviews of relief officials are also often criticized because they rely on people's opinions and are only as good as the persons chosen to be interviewed. If the survey is being conducted by expatriates, the process generally depends upon interpreters or use by national staff. Language difficulties and the objectivity of the interviewers regarding the victim population may tend to make the results less than reliable (Pearlman, 1998).

In summary, questionnaires appear to be a useful method for obtaining specific information for programming and planning purposes in certain sectors, but not a good tool for collecting situation information in the immediate aftermath of the disaster.

3.4.5. Analytical Analysis

Analysis is absolutely necessary in the design of a water treatment facility as well as to monitor its operation and evaluating the quality of the treated water at the point of the plant discharge outlet and in the natural environment. The relentless progress of analytical techniques makes it possible to improve our knowledge of the constituents of the various types of water and their effects. Quality standards are increasingly rigorous, treatments are increasingly sophisticated, and monitoring needs to be increasingly more precise and reliable (Degrèmont, 1991)

Many water pollutants are measured in terms of milligrams of the substance, per litre of water (mg/L). Pollutant concentrations may also be expressed as parts per million (ppm), a weight/weight parameter. If water is the only liquid involved, ppm and mg/L are equivalent, as one litre of water weighs one thousand grams. For many aquatic pollutants, ppm and mg/L is equal, however, because some wastes might have specific gravity differing from that of water, mg/L is preferred (Weiner & Matthews, 2003).

Analytical procedures must be carefully carried out so as to obtain accurate results. There are four main types of analyses commonly employed in the examination of water and wastewater. These include colorimetric, gravimetric, volumetric, and potentiometric analysis. For detection and enumeration of microorganisms, including bacteria, viruses, and algae specialized microbiological analyses are employed. A wide variety of methods are available to measure the concentration of pollutants in streams (Tchobanoglous & Schroeder, 1985)

3.4.5.1 Potentiometric Analysis

Many water quality parameters (Revelle & McGarity, 1997) can be measured by the utilization of electronic probes. These include the measurement of dissolved oxygen, electrical conductivity (which relates to salinity), ammonium and nitrate ion concentration, and turbidity. The intensity of acidity or basicity, expressed as pH of a solution, has also been measured for many years using a glass electrode that is sensitive to hydronium ions in solution. Coupling these probes to a computer enables on-site following of the evolution of the water quality with time (Degrèmont, 1991).

3.4.5.2 Colorimetric Analysis

'Colorimetric analysis was originally defined as a technique of matching visually the colour of a solution containing the constituent to be determined, against the colour of standard solutions containing known quantities of the constituent' (Belcher & Nutten, 1960) 'The variation of the colour of a system with change in concentration of some component forms the basis of colorimetric analysis' (Vogel, 1961).

Colorimetry is based on 'coloured reactions' in which the intensity of the coloured disks, plates or strips serving as gauges (Degrèmont, 1991). These techniques are exploited for field use and for the continuous monitoring of some wastewater constituents. Colorimetry is inaccurate in the presence of suspended matter as the particles absorb light providing an erroneous indication of concentration (Tebbutt, 1990).

3.4.5.3 Gravimetric Analysis

Gravimetric procedures are fundamental to all branches of chemical analysis. The importance cannot be over-emphasised, notwithstanding many of the classical methods of analysis being surpassed by more rapid operations and technologies, in modern analysis (Belcher & Nutten, 1960)

The principle of gravimetry is based on measuring a mass that is equal or directly proportional to the element being sought. The solids being weighed is obtained from a known volume of sample after evaporation, filtration, or precipitation. An example of the application is in the measuring of the suspended solids (SS) after solid-liquid separation; the sulphate (SO_4^{2-}) ions can be determined by barium sulphate ($BaSO_4$) precipitation. These methods are limited by the accuracy of these scales (Degrèmont, 1991; Tebutt, 1990).

3.4.5.4 Microbiological Analysis

Microbiological contamination is measured utilizing either membrane filtration or multitude fermentation tests that provide an indication of the number of faecal coliforms organisms present in a measured volume of sample, typically 100mL (Revelle & McGarity, 1997).

3.4.5.5 Volumetric Analysis

Volumetric analysis allows for the rapid and convenient determination of water quality; a procedure whereby an analysis is made by means of reactions that are instantaneous and complete, and occur in known proportions between substances in solutions. Where the reaction is carried out as a titration, the term titrimetric analysis is used. The final calculation is based on volume measurements. Volumetric analysis may be employed in the field if desired. Numerous parameters are determined by volumetry, including alkalinity, total hardness and chlorides (Degrèmont, 1991; Tebbutt, 1990).

Titrations utilize certain substances called 'indicators'. These indicators function to indicate when the stoichiometric or equivalence point of the reaction has been attained. The indicator confers a coloured reaction with the reagent on constituent, such that an excess of either may be detected (Belcher & Nutten, 1960).

3.4.5.6 Electrodes

For many years, pH, which expresses the intensity of acidity or alkalinity of a solution, has been measured using a glass electrode which is sensitive to hydrogen ions in solutions. More recently, many other electrodes have become available to measure specific ions such as ammonium, nitrate, chloride, calcium and sodium. Dissolved oxygen is also easily measured by means of a special electrode which is suited for field use (Gray, 1994).

3.4.6 Research Techniques Employed in Study

The methodologies adopted for the investigation included sample collection, questionnaire survey and analytical analysis at an independent laboratory. The data obtained from the laboratory analysis is subsequently analysed, statistically.

3.4.6.1 Collecting of Water Samples

For the investigation, the researcher needed to ensure a high degree of accuracy. This was achieved through the visitation of the river and aquatic systems, prior to sample collection to ascertain sampling locations. The sampling locations would help ensure a good sampling strategy. 10 water sampling points were selected to cover the main channel and its tributaries. These sampling points included the most polluted and populated areas of the river. Of the 10 sampling points, 5 were located upstream and 5 were located downstream of the river channel. This enabled the researcher to perform a significant difference test to compare results.

Sterile 500ml glass sampling bottles were used for all collections, as every sample would be subjected to microbiological examination, and thus the requirement to avoid contamination. The sample bottles were submerged into the stream to a depth of approximately 30 cm, the same at every location, the required volume (100% of volume of sample bottle) attained and the bottles sealed and stored on ice. The sample bottles were filled to volume negating oxidation or chemical reactions in the samples attributed to the presence of atmospheric oxygen.

Each sample bottle was accurately labelled to indicate the GPS position at which sample was taken, sample number, time taken and depth of sample. Each sample position was fixed using a GPS. Water samples were taken on a seasonal basis. The sampling surveys were thus conducted during May 2004 (Autumn), August 2004 (Winter), November 2004 (Spring), February 2005 (Summer). On subsequent surveys, samples were taken as close as possible to the original GPS fixed positions. On completion of sample collection, all samples were transported to the Water and Wastewater Research Laboratory at the Durban Institute of Technology (DIT) for analytical analysis. It was of utmost importance to transport the samples immediately to the laboratory, as secondary (chemical) changes in the samples may produce erroneous results.

3.4.6.2 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 the 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 Water and Wastewater Research Laboratory at the Durban Institute of Technology (DIT) 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
- Nitrates
- Ammonia

- Chemical Oxygen Demand (COD)
- Biological Oxygen Demand (BOD)
- Total Coliform Count
- Chloride
- Sodium
- Calcium
- Magnesium
- Fluoride
- Sulphate
- Phosphate
- Total Dissolved Solids
- Conductivity
- *E.coli (Escherichia coli)*

At the laboratory the Inductively Coupled Plasma (ICP) was used to measure heavy metal concentrations. An ICP typically includes the following components:

- ICP torch
- High frequency generator
- Transfer optic and spectrometer
- Computer interface

Inductively Coupled Plasma is an analytical technique for the detection of trace metals in environmental samples. The primary goal of ICP is to get elements to emit characteristics wavelength specific light which can be measured. An ICP procedure is frequently used, as it is more reliable and much more cost effective then most procedures.

3.4.6.3 Questionnaire survey

Interviews via a structured questionnaire were conducted with 50 households of the informal community adjacent to the Palmiet River. A questionnaire survey was administered, on a face-to-face basis. Respondents were assured of the confidential nature of the responses. Each interview lasted approximately 45 minutes. Questionnaires comprised of both closed and open-ended questions as detailed responses were desired by the researcher. As a result, the interviews had to be recorded. None of the respondents were uncomfortable with this. One questionnaire was used, however, some questions applied only to a specific sector of the sample and these are indicated on the questionnaire. The general response of those interviewed was good – respondents were interested in the research and were eager to assist.

Data was analysed using Microsoft Excel. In analysing the data, verbatim responses from the respondents was used. Some details of the respondents were used to contextualise the responses without compromising the anonymity of the respondents. Opinions may vary as to the accuracy and appropriateness of the criticisms and compliments.

The questionnaire addressed the following aspects:

- Socio-economic/ demographic characteristics of respondents;
- Household's perceptions regarding the Palmiet River and water quality in general;
- Current household's uses or activities that impact directly or indirectly on the river;
- Aspects of flooding; and
- Attitudes towards polluting agents as well as suggestions regarding the sustainable management of the Palmiet River.

A copy of the questionnaire that was administered is given in the appendix.

3.4.6.4 Statistical Analysis

Statistics enable the researcher to interpret numerical data in a scientific setting. It provides procedures for analyzing, collecting, interpreting, presenting, and summarizing empirical data. Simply, it is a method of dealing with data (Roberts, 1996).

The categories of statistical techniques include:

- **Descriptive statistics:** techniques for displaying, interpreting, and summarizing sets of data; taking the form of graphs and tables.

- **Inferential statistics:** techniques that enable the researcher to make statements about a population based on data from a sample, performed within strictly defined limits; including hypothesis testing, probability, and sample distribution.

- **Significance:** techniques that allow the researcher to decide whether an observed trend or relationship is significant or merely a result of chance.

Drawing comparisons between data relies upon hypothesis testing which is very closely linked to estimation.

Student's t-Test

The student's T-test was employed in this study. The student's t-Test, one of the most powerful parametric tests, establishes whether there is a difference between the means of two samples, and if so, at what level of significance. For the purpose of this study, the Student's t-Test was incorporated to determine whether there was a difference between the summer results obtained in this study, to that recorded in Malan and De Villiers study, conducted two decades ago, was significant or not. The result obtained in the t-Test allows the researcher to draw comparisons of water quality from that taken two decades ago to present.

South African Water Quality Guidelines

The South African Water Quality Guidelines for Fresh Water (Second Edition, 1996) was used in this research to examine aspects of water quality and to describe water quality – related problems or issues. This approach allowed for:

- Description of water quality-related problems or issues, typically experienced in South Africa, and which affect the protection of aquatic ecosystems; and
- Ascertaing the key water quality constituents in South Africa which are associated with these problems or issues.

Secondary data was accessed via desktop research, the world wide web and based upon previous research findings on the Palmiet River. The collection of material will be obtained by searching for books, articles and journals or other appropriate literature.

3.4.6.5 Time Series

A time-series of land use changes in the study area was undertaken. Alder & Roessler (1964; cited in Hammond & McCullagh, 1974), define a time series as, "successive observations of the same phenomenon over a period of time". According to Anderson, *et al.*, (1976), one of the prime prerequisites for better use of land is information on existing land use patterns and changes in land use through time in order to determine better land use policies, to project transport and utility demand, future development pressure points and areas and to formulate effective regional plans.

Aerial photography (1:10 000), was obtained in digital version for the period 2003 (Department of Agriculture: Natural Resources Section) and 1983 (CSIR – Durban). These dates cover a span of 20 years, with a 10 year interval.

3.4.6.6 Data Accuracy

Most analysis of land use data are predicted upon the belief that the data are correct, or at worst, sufficiently correct for conclusions drawn to stand (Rhind & Hudson, 1980). The land use data used in this research is believed to be correct and without any biases.

3.5 Conclusion

Water quality characteristics of aquatic environments are a result of a multitude of physical, chemical and biological interactions. The water bodies are in a constant dynamic state of change with respect to their geological age and geochemical characteristics. This is demonstrated by continuous accumulation, circulation, and transformation of energy and matter through the medium of biota and their activities. This dynamic balance is upset by human activities resulting in pollution, which manifests itself as a fish kill, offensive odour and taste (De, 1994).

It has thus become significantly imperative that man institutes a policy of measurement and monitoring and control of all activities and subsequently, of all pollutants. A wide variety of methods are available for the measuring of pollutants in waters and wastewaters. Conventional analytical chemistry techniques include titrations and colorimetry, the use of electronic probes, and examinations of microbiological contamination.

Sample collection forms an important function as a component of the research process. The sample, upon analysis, will provide information to the researcher, including other interested and affected parties, as to the extent of pollution (if this has been confirmed) of the watercourse of which the sample was collected. The authorities can then initiate the necessary proceedings in evaluating and assessing the causative agents and subsequently embark upon an appropriate course of action to mitigate the problem and effectively administer suit against the parties responsible.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

One of the most challenging and rewarding tasks in research comes after the samples and data have been collected, statistically analysed, and interpreted. Statistics provide the basic tools for summarizing data, and measuring the degree of association between variables and subgroups (Hounslow, 1995). When utilizing data, it is important to appreciate the degree of accuracy and variations in measurements. It is important not to afford a greater degree of accuracy to measurements than is warranted by the data (Tebbutt, 1990).

Tables are the key vehicles for conveying data to the reader, a table may be considered a complete entity, and should thus be able to exist separately within the report. A well-constructed table should be self-explanatory and be characterized by its simplicity and unity. Well-drawn figures can greatly enhance the effectiveness of the display and interpretation of results. Graphs are often produced from the analysed data. A graph can provide much more information than any set of data, providing a visual representation of trends and relationships (Williams, 2001).

This chapter presents the results obtained upon analysis of the samples. Statistical analysis – The Student's t-Test – aims to determine whether a significant relationship exists between the data sets, thus enabling the researcher to formulate a statistical interpretation of the data results. This chapter will also present a comprehensive, analytical discussion of the results and analysis obtained in the water testing as well as the questionnaire survey.

4.2 Water quality data analysis

Water quality data may be interpreted on the basis of both individual analysis and sets of analysis from one sampling site or different sampling sites in an area being examined (Hounslow, 1995). Data obtained from analysis of water samples undertaken at the Water and Wastewater Research Laboratory at the Durban Institute of Technology (DIT) for the ten samples collected during each of the four seasons will be examined in this chapter. The variables for which the laboratory analysis were undertaken included pH, Nitrates and Nitrites, Ammonia, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Coliform Count, Chloride, Sodium, Calcium, Magnesium, Fluoride, Phosphate, Total Dissolved Solids, Conductivity and *E.coli (Escherichia coli).*

A comparative analysis using the student's T-test will be carried out. The results obtained from this research will be compared to those recorded in the Malan and De Villiers study undertaken in 1985. This would allow the researcher to note and explain the differences in the water quality of the Palmiet River catchment over the past two decades. Malan & De Villiers water quality study in 1985 was conducted over two seasons namely summer and winter and focused primarily on anion and cation concentrations. However for the purpose of this study, the researcher felt that a step further should be taken and therefore samples were carried out over the four seasons namely spring, summer, autumn and winter and also looked at the biological characteristics of water such as total coliforms and *E.coli* content. The results for each variable were compared against South African Freshwater standards (DWAF, 1996) where possible.

4.2.1 pH Concentration

SEASON	SAMPLE SITE									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	7.1	6.7	6.8	7.2	7.5	6.8	7.2	7.6	7.4	7.4	**7.2**
SUMMER	7.2	7.1	7.8	7.9	7.5	8.0	8.0	7.9	7.8	7.2	**7.6**
AUTUMN	7.0	7.1	7.2	7.5	7.6	7.9	7.6	7.2	7.6	7.2	**7.4**
WINTER	6.9	7.0	7.1	7.2	7.2	7.5	7.4	7.5	7.1	6.9	**7.2**

Table 4.1 pH concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	7.4	7.6	7.2	7.2	6.8	7.2	7.4	7.2	7.0	**7.2**
WINTER	7.6	7.6	7.1	7.3	7.0	7.4	7.3	7.4	7.2	**7.3**

Table 4.2 pH concentrations from Malan & De Villiers study

pH is determined largely by the concentration of hydrogen ions and alkalinity by the concentrations hydroxyl, bicarbonate and carbonate ions in water. The pH values from Table 4.1 and 4.2 are relatively similar except for summer in Table 4.1. This depicts that there has not been a significant difference in pH concentrations of the river over the last two decades. However from Table 4.1 it appears that the average pH concentration is the highest for summer, with a significant increase from sample sites 3-9. This increase in alkalinity can be related to increase in microbial activity during summer as water temperature raises and a number of organisms experience rapid growth and expansion of population. During summer, Site 6 and 7 recorded the highest levels; this increase may more likely be derived from increased eutrophication. The DWAF standard for pH for freshwater bodies ranges from 5.5 – 9.5. On average the pH of the Palmiet River for spring, summer, autumn and winter are 7.2, 7.6, 7.4 and 7.2 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 of the river in terms of its pH status.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two pH sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.950$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.950 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is accepted

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is no significant difference between the mean summer pH concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.2 Ammonia Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	2	3	4	5	6	7	8	9	10	AV
SPRING	1.0	0.9	2.1	1.8	0.3	0.3	0.4	0.8	1.2	1.2	**1.0**
SUMMER	1.2	0.8	1.8	2.2	0.7	0.6	1.4	1.8	2.1	1.2	**1.38**
AUTUMN	0.6	0.5	0.5	1.8	0.3	0.3	0.8	1.2	0.8	1.8	**0.86**
WINTER	0.6	0.8	1.6	2.2	0.4	0.1	0.6	0.6	1.6	1.6	**1.01**

Table 4.3 Ammonia concentrations for each of the four seasons

SEASON	SAMPLE SITE									
	1	2	3	4	5	6	7	8	9	AV
SUMMER	0.06	0.33	0.57	0.22	0.07	0.21	0.06	0.06	0.05	**0.27**
WINTER	0.07	0.07	0.50	0.04	0.04	0.05	0.07	0.05	0.04	**0.10**

Table 4.4 Ammonia concentrations from Malan & De Villiers study

Ammonia concentrations from Table 4.3 are higher when compared with those recorded in Table 4.4. The levels of ammonia are fairly high during summer with site 4 recording the highest levels in all seasons, associating with it the fact that ammonia is a common pollutant generally associated with sewage and industrial effluents; since this is the point located near the informal settlement and experiences immense pollution. The high level of ammonia at this Site can also be attributed to the fact that this is the point in the river where the informal dwellers wash their clothes using detergents and thus increasing the ammonia concentrations in this area. From Table 4.3, ammonia levels are also high at Site 10; this can be associated with the industrial effluents emanating from the Pinetown industrial reaches of the catchment. The DWAF limit for ammonia is <7mg/L, thereby implying that the laboratory values are much lower than the DWAF standards. This means accordingly, that the concentrations are acceptable and should not pose a detrimental effect on the water quality of the river. From the both tables there has not been any difference in ammonia concentrations observed over the past two decades.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two ammonia sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 3.291$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$3.291 > 2.110$

$t_{calc} > t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer ammonia concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.3 Chloride Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	59	67	80	71	83	75	79	60	62	54	**69**
SUMMER	52	66	103	85	88	62	78	69	72	76	**75**
AUTUMN	39	42	68	65	62	74	63	128	36	62	**64**
WINTER	40	33	50	49	54	60	89	61	60	81	**58**

Table 4.5 Chloride concentrations for each of the four seasons

SEASON	SAMPLE SITE									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	49	56	45	42	43	37	35	37	42	**43**
WINTER	45	51	45	30	41	24	29	30	38	**37**

Table 4.6 Chloride concentrations from Malan & De Villiers study

Table 4.5 shows that summer has the highest concentration of chloride whereas winter has the lowest concentration. In summer, Sample Site 3 and in winter Site 8 have the highest concentrations of chloride. Generally, chloride is not known to have toxic effects on biota other than to increase TDS. The DWAF limit for chloride is from 100 – 200mg/L. Therefore the average concentrations found in the river are within the DWAF general limits. The concentrations of chloride therefore should pose no detrimental effect on the rivers, water quality. It is also quite evident from the both tables that there has been a significant increase in chloride concentrations over the past two decades. This can be attributed to increased urbanization and industrialization of the catchment.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two chloride sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.145$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.145 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer chloride concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.4 Sodium Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	42	56	66	52	63	47	64	39	42	35	**51**
SUMMER	50	48	65	58	60	68	72	54	42	52	**57**
AUTUMN	32	33	45	44	38	42	37	50	84	52	**46**
WINTER	36	62	43	40	41	45	59	45	49	43	**46**

Table 4.7 Sodium concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	41	51	37	33	29	28	37	32	29	**35**
WINTER	40	47	36	28	31	25	32	28	28	**33**

Table 4.8 Sodium concentrations from Malan & De Villiers study

Sodium is an alkali earth metal which reacts with water to form highly soluble, positively- charged sodium ions. From Table 4.7, summer has the highest average sodium concentration with spring closely following. Autumn and winter have the same average concentrations. The variation was also strongly linked to seasonal variation and higher values were observed during the rainy season. From Table 4.8 it can be deducted that there has been a significant increase in sodium concentrations in the Palmiet River catchment over the past two decades. This increase can again be attributed to increased urbanization and industrialization along the catchment.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two sodium sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sample sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.170$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.170 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer sodium concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.5 Calcium Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	24	23	16	20	25	24	23	41	32	27	**26**
SUMMER	24	25	20	16	22	33	16	36	41	38	**27**
AUTUMN	15	15	21	24	22	21	20	37	24	25	**23**
WINTER	20	16	25	23	24	33	41	32	22	27	**26**

Table 4.9 Calcium concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	18	17	16	17	10	17	28	18	12	**17**
WINTER	16	16	16	14	11	15	16	14	12	**14**

Table 4.10 Calcium concentrations from Malan & De Villiers study

Table 4.9 shows that on average summer has the highest concentration of calcium whilst autumn has the lowest concentration. The concentrations of calcium are extremely low in the Palmiet River as compared with that of DWAF limits which is from 150 – 300mg/L. Since calcium is one of the major elements for living organisms, these waters which are low in calcium would be unable to support many life forms, such as molluscs and crustaceans. Table 4.9 shows that the average calcium concentration remains constant during spring and winter. With reference to the both tables, calcium has however increased in the river over the past two decades.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two calcium sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.101$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.101 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer calcium concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.6 Magnesium Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	9.8	16	11	19	9.6	7.7	19	20	13	17	**14.2**
SUMMER	6.5	12	11	15	8.1	8.5	13	18	10	21	**12.3**
AUTUMN	7.3	7.0	11	10	7.6	7.3	7.3	12	11	18	**9.9**
WINTER	9.5	7.7	11	10	8.8	13	19	11	11	16	**11.7**

Table 4.11 Magnesium concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	9.6	14.6	8.0	6.7	6.6	6.2	7.7	6.7	6.8	**8.1**
WINTER	9.2	11.3	8.1	5.3	7.4	5.0	5.8	6.4	6.1	**7.2**

Table 4.12 Magnesium concentrations from Malan & De Villiers study

Magnesium is a basic, essential element for plants (the central metallic ion in chlorophyll) and most other living organisms, since it is a component of important enzyme eco-factors. Therefore it does not pose a threat to the river system, unless it exceeds acceptable concentration levels of between 4 - 10 mg/l for fresh water. However from Table 4.11 it is quite evident that these levels exceed the acceptable concentration levels with spring recording the highest magnesium average concentration and more notably sample Site 10 which is located in the industrial vicinity having the highest site concentrations. This can be attributed to the increased industrial activity in the Pinetown area over the past two decades which is why magnesium concentrations in Table 4.11 are significantly higher than those recorded in Table 4.12.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two magnesium sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.167$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.167 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer magnesium concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.7 Fluoride Concentration (mg/L)

SEASON	SAMPLE SITE

	1	2	3	4	5	6	7	8	9	10	AV
SPRING	0.14	0.11	0.15	0.14	0.16	0.08	0.11	0.12	0.18	0.17	**0.14**
SUMMER	0.24	0.21	0.26	0.26	0.18	0.24	0.22	0.22	0.26	0.21	**0.23**
AUTUMN	0.14	0.22	0.26	0.20	0.20	0.26	0.26	0.28	0.26	0.10	**0.22**
WINTER	0	0	0	0	0	0	0	0	0	0	**0**

Table 4.13 Fluoride concentrations for each of the four seasons

SEASON	**SAMPLE SITE**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	0.13	0.12	0.31	0.18	0.07	0.12	0.16	0.19	0.2	**0.17**
WINTER	0.17	0.15	0.29	0.15	0.09	0.12	0.17	0.16	0.20	**0.17**

Table 4.14 Fluoride concentrations from Malan & De Villiers study

Table 4.13 shows that on average summer has the highest concentration of fluoride whilst winter has the lowest concentration. Table 4.13 shows that the average fluoride concentration remains constant during summer and autumn. With reference to the both tables, fluoride has increased in the river over the past two decades. All seasons in both tables have an average fluoride concentration which is lower than the <1mg/L which occur in many aquatic ecosystems. The concentrations of fluoride pose no detrimental effects on the water quality of the Palmiet River.

Student's T-Test:

Null hypothesis (H_0): There is no significant difference between the summer means of the two fluoride sample sets.
Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 12.684$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$12.684 > 2.110$

$t_{calc} > t_{crit}$ therefore H_0 is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer fluoride concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.8 Sulphate Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	22	19	25	38	19	17	35	40	25	33	**27**
SUMMER	25	20	23	28	25	21	40	28	31	31	**29**
AUTUMN	18	18	21	25	13	13	19	16	12	20	**18**
WINTER	19	15	26	25	25	26	38	27	23	50	**27**

Table 4.15 Sulphate concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	32	35	29	24	20	29	57	30	23	**31**
WINTER	22	29	33	15	16	15	30	17	14	**21**

Table 4.16 Sulphate concentrations from Malan & De Villiers study

Table 4.15 shows the sulphate concentration at the different sampling points for the four seasons. In average, summer has the highest sulphate concentration and autumn has the lowest. Spring and autumn's concentrations are the same and very close to that of summer. However summer concentrations from Table 4.16 are the highest of all the seasons. This high sulphate concentration was attributed by Malan & De Villiers to spillage by at least two industrial concerns. The one used sulphuric acid to manufacture detergents, and the other to neutralize alkaline effluent. Sample Site 10 in Table 4.15 has very high sulphur concentrations; this is a result of industrial activity in the upper catchment. The high sulphate concentrations in the Palmiet River are 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 ecosystem.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two sulphate sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = - 0.014$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$-0.014 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer sulphate concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.9 Phosphate Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	2.8	3.1	3.2	3.8	4.6	4.0	4.9	5.5	3.4	4.8	**4.0**
SUMMER	3.5	3.8	7.5	6.4	4.2	3.8	4.6	6.2	5.2	5.6	**5.1**
AUTUMN	2.6	3.8	6.0	4.2	3.2	2.8	3.2	3.2	4.1	4.4	**3.8**
WINTER	2.0	3.9	5.6	7.0	7.9	1.7	2.6	2.8	3.4	4.0	**4.1**

Table 4.17 Phosphate concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	0.14	0.02	0.03	0.04	0.02	0.05	0.63	0.08	0.02	**0.11**
WINTER	0.01	0.05	0.01	0.03	0.02	0.28	0.05	0.05	0.02	**0.06**

Table 4.18 Phosphate concentrations from Malan & De Villiers study

Phosphorous is an essential nutrient required by aquatic plants to grow. However in large quantities, it can cause a major water pollution problem. From Table 4.17 it can be deduced that on average summer has the highest concentration and spring has the lowest. The highest concentration of phosphate is experienced in summer at Sample Site 3. The cause of this high concentration is the informal settlement is located at this site. Here, human waste, excrement and laundry detergent are deposited directly into the river thus leading to major degradation of the water quality. The high eurtophication levels have also resulted in excessive algal proliferation in the river, in this vicinity. Thus the average phosphate concentrations are well above the DWAF general limits of 1.0mg/L. Two decades ago – no informal settlements existed at this site. This explains the low phosphate concentrations recorded by Malan & De Villiers (summer 0.11 and winter 0.06 mg/L); levels that were well below the DWAF general limit of 1.0 mg/L for phosphorus.

Therefore it can be deducted that the increase in phosphate concentrations over the past two decades was largely due to urbanization.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two phosphate sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 3.068$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$3.068 > 2.110$

$t_{calc} > t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer phosphate concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.10 Nitrate Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	5.5	6.1	7.8	8.6	4.8	5.3	5.6	6.2	5.7	6.1	**6.2**
SUMMER	6.4	6.0	8.2	8.4	6.6	5.8	7.0	7.4	5.6	6.1	**6.8**
AUTUMN	5.9	5.8	7.3	7.7	6.2	5.4	5.7	6.2	6.5	5.9	**6.3**
WINTER	6.3	6.4	7.5	7.4	7.0	4.9	5.4	6.1	5.8	6.5	**6.3**

Table 4.19 Nitrate concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**AV**
SUMMER	0.6	0.1	0.8	0.8	1.4	0.6	0.4	1.0	1.1	**0.8**
WINTER	0.6	1.7	0.8	0.8	1.5	1.2	1.1	0.3	1.4	**1.0**

Table 4.20 Nitrate concentrations from Malan & De Villiers study

The presence of nitrate is mainly due to the presence of sewage contamination. From Table 4.19, summer has the highest nitrate concentration with exceptionally high levels at Sites 3 and 4 which is located in the midst of the informal settlement. The average nitrate concentrations for spring, autumn and winter are relatively the similar. Faecal contamination is higher downstream of the community than upstream of the community. The cause for such high levels of nitrate is surface runoff from the surrounding catchment area, the discharge of effluent into the stream containing human and animal excrement, and organic industrial wastes are the major sources of nitrogen which enters the aquatic system. Although the nitrate concentrations are much higher than that recorded 2 decades ago, it is still within the DWAF general limit of 6 – 10mg/L.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two nitrate sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 5.976$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$5.976 > 2.110$

$t_{calc} > t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer nitrate concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.11 TDS Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	2	3	4	5	6	7	8	9	10	AV
SPRING	5200	3800	4800	3800	5400	3600	6400	5200	6200	5800	**5020**
SUMMER	6200	5600	5200	4200	7200	4600	5600	5600	6000	4400	**5460**
AUTUMN	3600	4600	5600	2800	3000	3400	4000	5200	5200	2800	**4020**
WINTER	2400	2800	4200	1800	3000	2600	5200	3400	5800	1400	**3260**

Table 4.21 TDS concentrations for each of the four seasons

SEASON	SAMPLE SITE								
	1	2	3	4	5	6	7	8	9	AV
SUMMER	217	268	198	180	146	175	251	182	155	**197**
WINTER	199	228	196	148	152	138	188	154	149	**173**

Table 4.22 TDS concentrations from Malan & De Villiers study

TDS represents the total quantity of dissolved material, organic and inorganic, ionized and un-ionized, in a water sample. With reference to Table 4.21, on average, summer has the highest TDS concentration, followed by spring, autumn and then winter. However the TDS concentrations recorded in Table 4.21 are extremely higher than those recorded two decades ago. This is due to anthropogenic activities such as industrial effluents, rapid urbanization, pollution and over utilization of the catchment. There were seasonal changes associated with the TDS variation and the general tendency was high values during the rainy season. TDS levels from Table 4.22 are well within the DWAF general limit of 200mg/L, but those recorded in Table 4.21 far exceed this limit.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two TDS sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.007$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.007 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer TDS concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.12 Conductivity (mS/m)

SEASON	SAMPLE SITE										
	1	2	3	4	5	6	7	8	9	10	AV
SPRING	30	32	41	32	29	33	35	44	38	40	**35**
SUMMER	41	44	52	39	56	41	55	52	52	48	**48**
AUTUMN	52	41	60	37	37	40	38	59	36	32	**43**
WINTER	28	29	32	26	29	28	37	42	37	28	**32**

Table 4.23 Conductivity for each of the four seasons

SEASON	SAMPLE SITE								
	1	2	3	4	5	6	7	8	9	AV
SUMMER	38	44	35	33	28	32	41	32	30	**35**
WINTER	37	42	37	28	29	26	32	29	28	**32**

Table 4.24 Conductivity from Malan & De Villiers study

Conductivity in water quality terminology is 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. From Table 4.23, summer has the highest average conductivity with winter having the lowest; autumn has the second highest with Sample Site 3 having the highest level this is because the informal settlement is located here with raw sewage emanating from it. The large quantities of raw sewage therefore lead to high values of conductivity while at the same time being a contaminant in the water supply of the nearby informal community, with the potential for disease being ever present. The conductivity levels varied with the seasons and were generally high during the wet season. Average conductivity concentrations of spring and winter are the same for that of summer and winter levels respectively, taken two decades ago.

Student's T-Test:

Null hypothesis (H_o): There is no significant difference between the summer means of the two conductivity sample sets.

Alternative hypothesis (H_1): There is a significant difference between the summer means of the two conductivity sets.

Rejection level: $\alpha = 0.05$ df = 17 $t_{calc} = 0.215$

Therefore, with 17 degrees of freedom and at a 0.05 significance level: $t_{crit} = 2.110$

$0.215 < 2.110$

$t_{calc} < t_{crit}$ therefore H_o is rejected

On the basis of the t test it is therefore safe to assume at a 0.05 significance level that there is a significant difference between the mean summer conductivity concentrations recorded two decades ago by Malan & De Villiers to that recorded for the purpose of this study.

4.2.13 COD Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	78	82	76	86	84	87	77	94	88	97	**85**
SUMMER	85	85	88	92	105	93	84	93	87	111	**92**
AUTUMN	66	75	70	78	82	91	76	77	82	88	**79**
WINTER	67	71	65	82	86	74	63	77	85	72	**74**

Table 4.25 COD concentrations for each of the four seasons

The chemical oxygen demand is the amount of oxygen necessary to oxidize carbon completely to carbon dioxide. By examining the above table it can be seen that the COD values are highest for summer, followed by spring, then autumn and finally winter. This pattern can be attributed to temperature. The DWAF standard for COD is 75mg/L. Winter is the only season whose average concentration is within this limit. The COD concentration for spring, summer and autumn are higher than the DWAF limit, this is due to various industrial activities along the Palmiet River. Sample Site 10 is seen to have the highest COD concentration especially in summer, this can be attributed to increased industrialization in the Pinetown area. 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 riverine functioning are significant in the Palmiet River catchment. No comparison is available to that taken two decades ago as this variable was not analysed by Malan & De Villiers.

4.2.14 BOD Concentration (mg/L)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	40	46	40	49	46	50	42	56	51	59	**48**
SUMMER	48	52	44	56	58	52	48	62	60	62	**54**
AUTUMN	36	44	42	42	52	48	38	55	49	52	**46**
WINTER	36	40	36	43	44	40	35	41	45	39	**40**

Table 4.26 BOD concentrations for each of the four seasons

BOD is not a specific pollutant, but rather a measure of the amount of oxygen required by bacteria and other microbes engaged in stabilizing decomposable organic matter over a specified time period. A high oxygen demand indicates the potential for developing a dissolved oxygen sag as the microbial oxidize the organic matter in the effluent. A very low oxygen demand indicates either clean water or the presence of a toxic or non-biodegradable pollutant. From the above table it can be noted that summer has the highest average BOD concentration with winter having the lowest. It is also evident that Sample Sites 1 – 5 have lower concentrations compared to those recorded in Sites 6 -10. This could be due to the informal settlement being located in this vicinity and contribute to the large amounts of non-biodegradable pollution of the lower catchment. No comparison is available to that taken two decades ago as this variable was not analysed by Malan & De Villiers.

4.2.15 Total *E.coli* ($x10^6$ cfu)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	5.2	5.5	7.9	7.4	2.3	1.7	4.3	4.1	4.4	4.8	**4.8**
SUMMER	5.8	5.5	8.2	8.5	2.6	2.4	4.5	4.2	4.8	6.2	**5.3**
AUTUMN	4.8	5.1	7.2	6.8	1.8	1.2	3.1	3.6	3.2	4.5	**4.1**
WINTER	4.3	4.5	6.4	6.9	2.2	1.5	3.5	4.1	3.7	4.2	**4.1**

Table 4.27 Total *E.coli* concentrations for each of the four seasons

Coliforms are highly concentrated in wastewater and generally sparse or absent from other habitats. Because of this correlation between wastewater and coliforms, the presence of coliform bacteria in water is considered an indication of pollution\contamination. The above table clearly depicts that summer has the highest average *E.coli* concentration with autumn and winter having the lowest. It is also quite evident that the highest concentrations were recorded in summer at Sample Sites 3 & 4. This is largely due to the washing of clothes, bathing and sanitational activities of the informal settlement located here. The DWAF general limit for *E.coli* is 0 cfu/100ml. The average concentrations of *E.coli* found in the Palmiet River catchment are extremely high which increases the possibility of water-borne diseases. It is also interesting to note that *E.coli* is present in every sample site and during every season, although its presence is comparatively low at Sites 5 and 6 which are within the Palmiet Nature Reserve. This could be due to the natural rehabilitation effect of the nature reserve as well as conservation measures imposed in this area.

4.2.16 Total Coliform Count (x10^6 cfu)

SEASON	SAMPLE SITE										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**AV**
SPRING	5.8	6.4	8.2	8.7	3.8	4.1	4.1	7.1	6.4	7.4	**6.2**
SUMMER	6.6	6.9	8.8	9.1	4.1	4.2	4.4	7.4	6.9	7.2	**6.6**
AUTUMN	5.4	5.8	7.2	8.2	3.2	4.2	4.2	6.2	5.3	6.8	**5.7**
WINTER	5.6	6.2	7.1	8.2	3.6	3.5	4.2	5.8	4.8	6.6	**5.6**

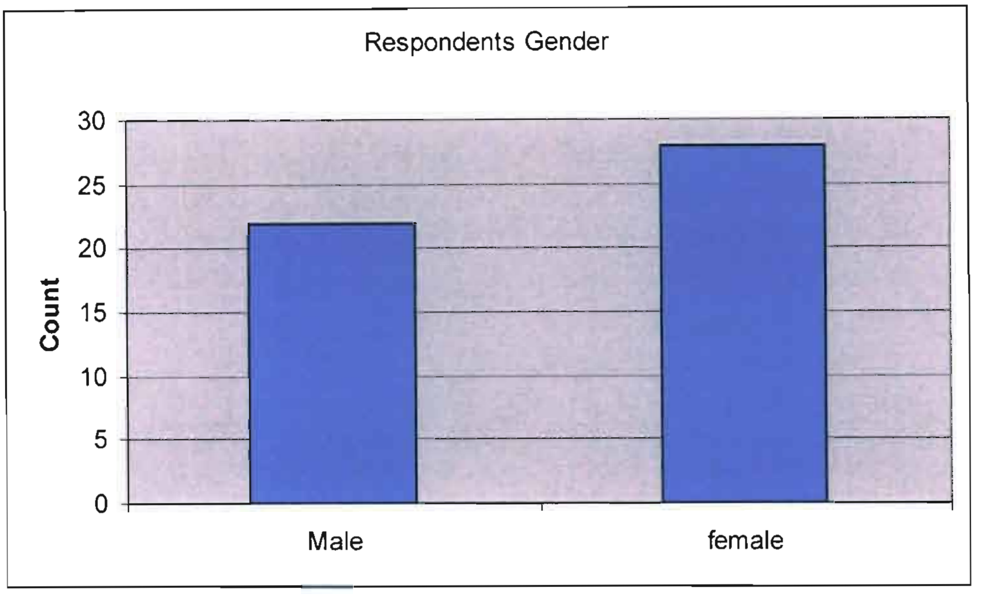
Table 4.28 Total coliform count for each of the four seasons

Total coliforms bacteria include the faecal coliforms and a wide variety of other species. They are usually associated with faecal material. A low coliform count indicates a low number of pathogenic bacteria in the water while a high coliform count indicates the presence of a high number of disease causing bacteria. Therefore from the above table, it can be deducted that the Palmiet River has a high coliform count and thereby has a high number of disease causing bacteria especially near the informal settlement. Similar to the average *E.coli* concentrations of the river, the average total coliform count is highest in summer and lowest in winter. Also the sample site pattern of increases and decreases in total coliform count mirrors that of *E.coli* concentrations.

4.3 Questionnaire survey analysis

Interviews via a structured questionnaire (Appendix 1) were conducted with 50 households of the informal community adjacent to the Palmiet River. The questionnaire survey analysis provides findings from the research in order to meet the research objectives. The results obtained from the fieldwork are in direct relation to the questions asked. These results are discussed further after each table and graph.

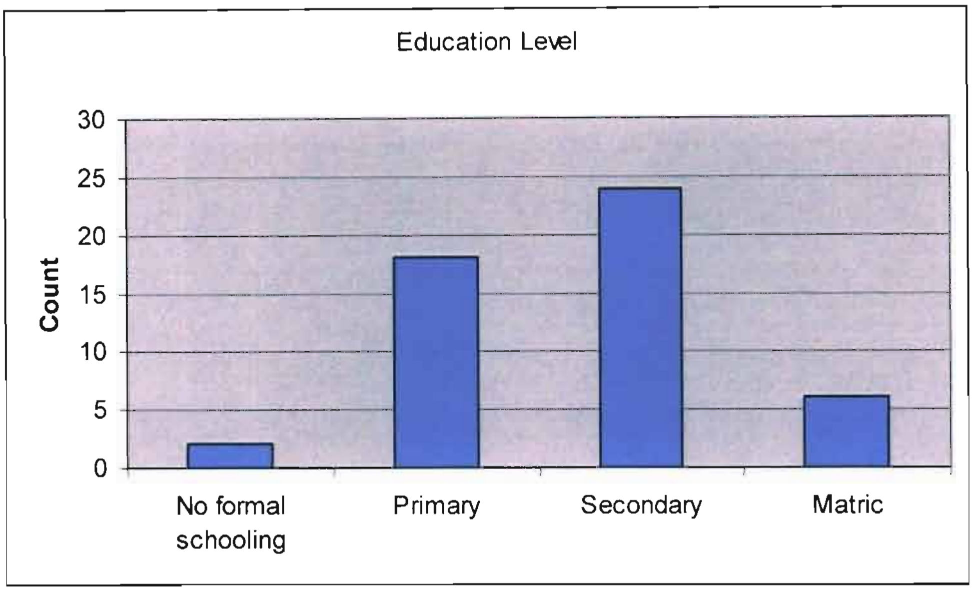
Figure 4.1 Respondents Gender



	Respondents Gender	
	Count	Percentage
Male	22	44
Female	28	56
Total	50	100

There was almost an even split in the gender of the respondents interviewed. However the reason for the female count being slightly higher was because the men were at work at the time of the interviews. It was noticed that when a male and female were present at home, the male felt he should answer the questions. This was due to the fact that the men saw themselves as the dominant figure in the household and thus the decision makers of the household. Therefore they felt the need to answer the researcher's questions.

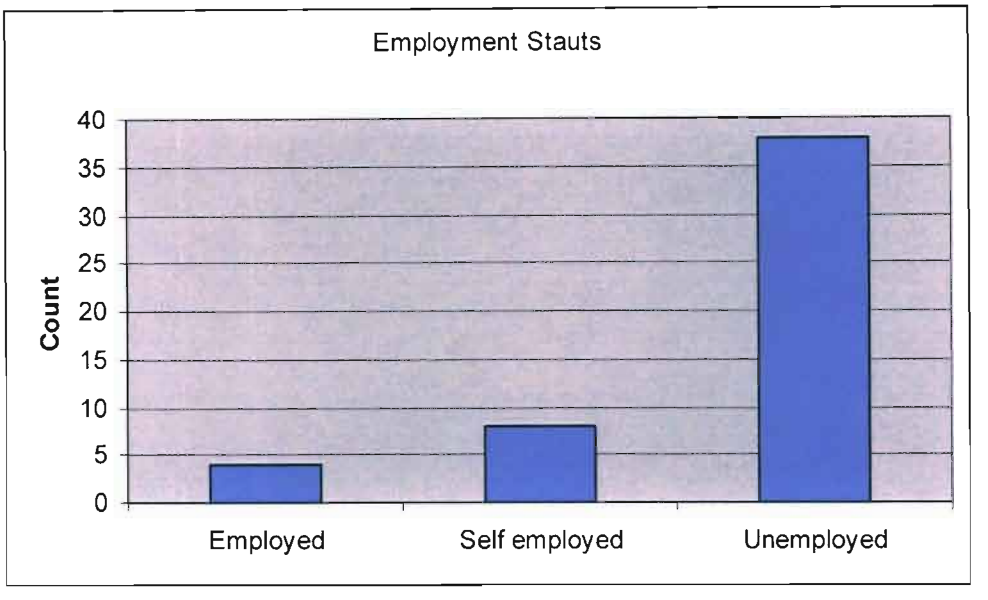
Figure 4.2 Respondents level of education



	Education level	
	Count	Percentage
No formal schooling	2	4
Primary	18	36
Secondary	24	48
Matric	6	12
Total	50	100

The respondents interviewed are very literate with 48% of them having a secondary education and 36% having a primary education; this can be attributed to the fact that education is well encouraged in the community. Two people had no formal schooling, this was because they could not afford to go to school and they started working from a young age, thus they had no time for school. This portrays the plight of many individuals from disadvantaged backgrounds. However it was admirable to see that six respondents were university students. This shows that these residents recognize that a good education is a stepping stone to success and want to live a better life by acquiring good jobs.

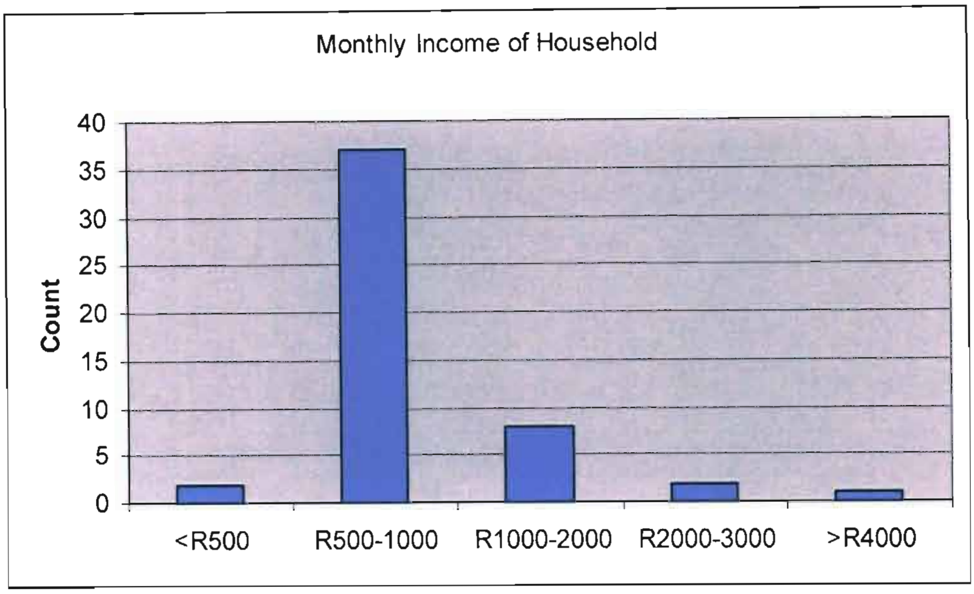
Figure 4.3 Respondents employment status



	Employment status	
	Count	Percentage
Employed	4	8
Self employed	8	16
Unemployed	38	76
Total	50	100

From the above table; unemployment is rife in this informal settlement with 76% of the respondents being unemployed. The minute number of respondents (8%), that are employed are mainly in the informal sector. The small percentage (16%), that makes up the self employed are engaged in: selling sweets & chocolates outside schools, operating a car wash, operating a tuck shop and tavern. One individual even runs a garden service; cleaning people's gardens and cutting grass to earn some money.

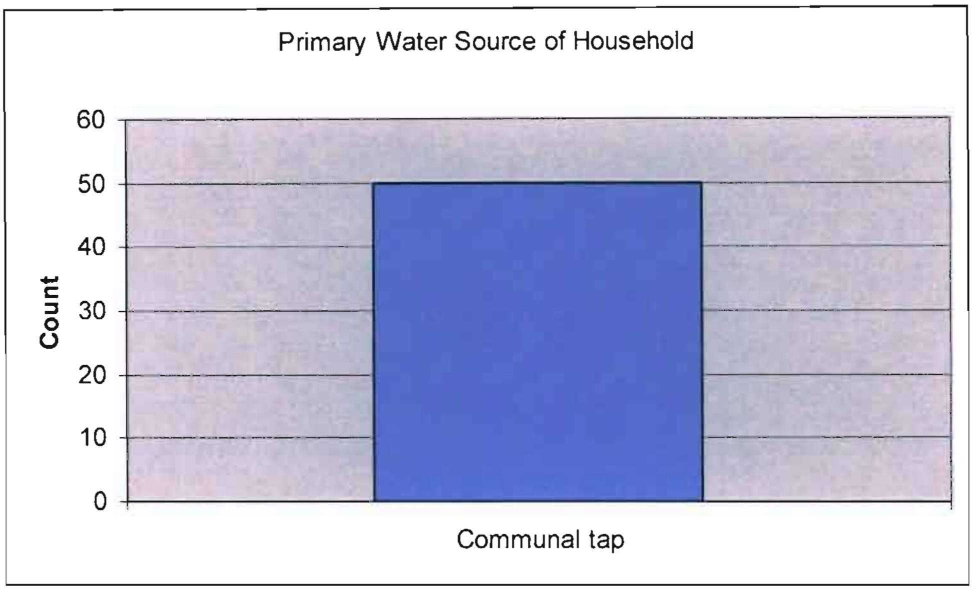
Figure 4.4 Monthly income of household



	Monthly income	
	Count	Percentage
<R500	2	4
R500-1000	37	74
R1000-2000	8	16
R2000-3000	2	4
>R4000	1	2
Total	50	100

It is interesting to note that even though there are a large percentage of unemployed people in the community, every household has some form of income with 74% of the households earning between 500-1000 rand a month. This could indicate that they answered to being unemployed in the hope of the researcher finding them a better job where in actual fact they are engaged in some form of income generating activity. 20% of the respondent's households earn between 1000-3000 rand a month. This correlates with the count of the employed and self employed. The person who runs a garden service is the one who earns over 4000 rand a month. In summary, this informal settlement has a better economic status compared to most informal communities.

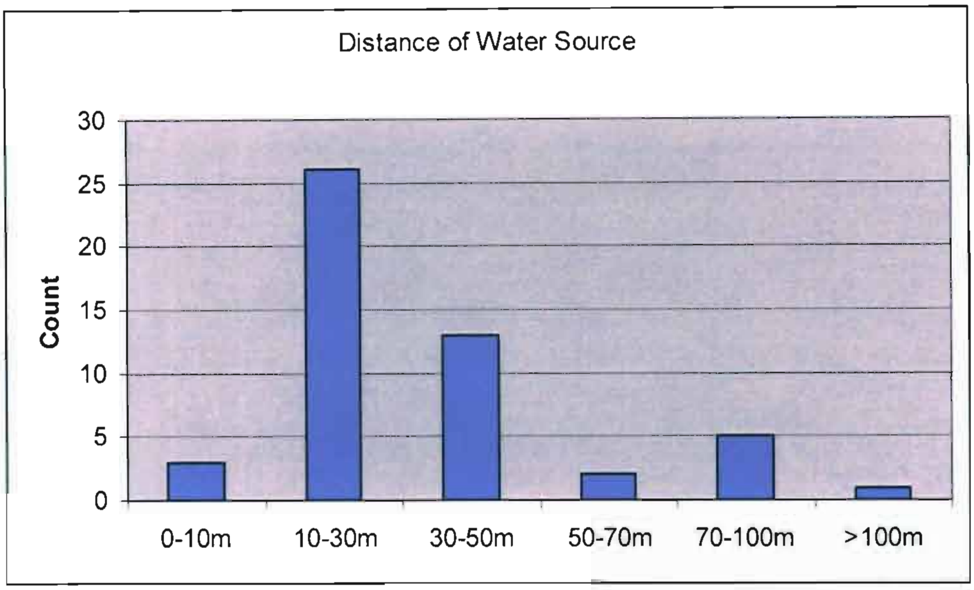
Figure 4.5 Primary water source of household



	Primary water source	
	Count	Percentage
Communal tap	50	100
Total	50	100

It was unanimous with 100% of the respondents indicating that a communal tap was the primary water source used by the household. This tap satisfied most of their water needs.

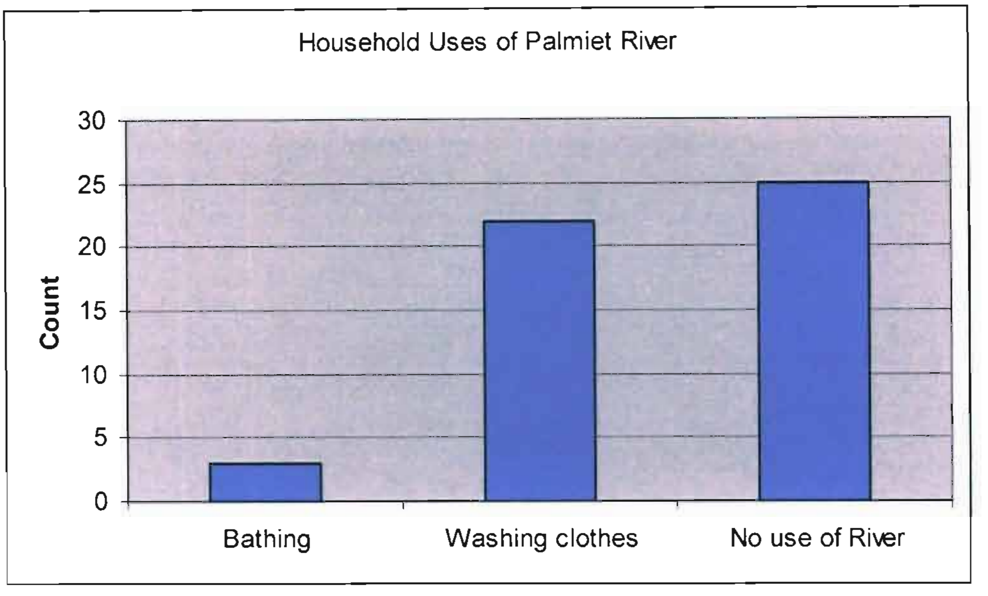
Figure 4.6 Distance of water source from household



	Distance of water source	
	Count	Percentage
0-10m	3	6
10-30m	26	52
30-50m	13	26
50-70m	2	4
70-100m	5	10
>100m	1	2
Total	50	100

58% of the respondent's indicated that the water source was within 30 meters of their household. 16% had the communal tap located further than 50 meters from their household. This is relatively close considering the large distances some people walk to fetch water for the household; also there were no complaints from the respondents regarding the location of the tap.

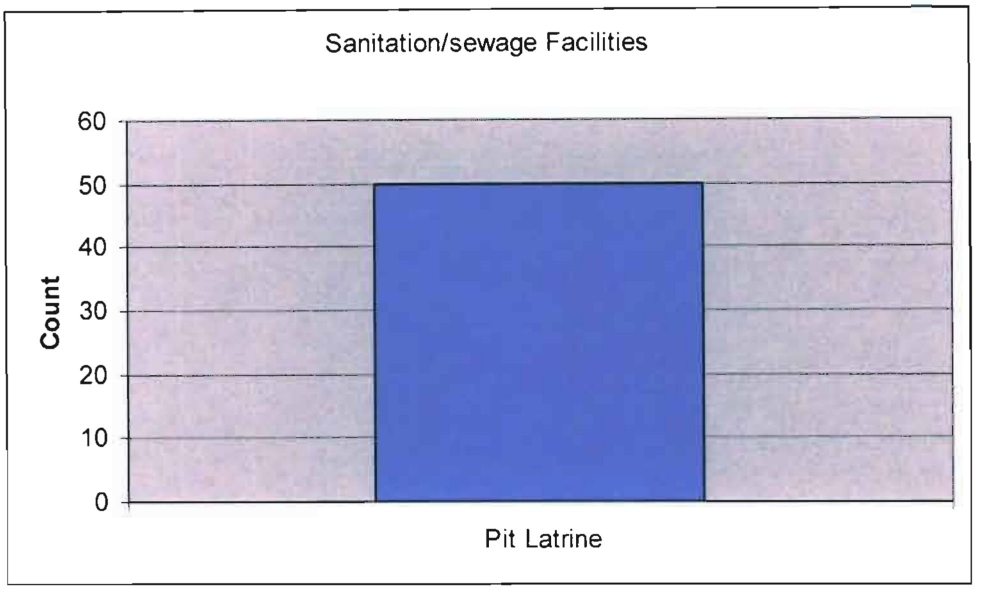
Figure 4.7 Household uses of the Palmiet River



	Household uses of palmiet river	
	Count	Percentage
Bathing	3	6
Washing Clothes	22	44
No use of river	25	50
Total	50	100

50 % of the respondents indicated that they had no use of the river; where as 44% used the river for washing their clothes and other utensils. Only 6% indicated that they utilized the river for bathing purposes, however the researcher felt that many respondents felt embarrassed to divulge that they too used the river for bathing. On site observations also confirmed the researcher's perceptions. Detergents such as washing powder and soaps were utilized when washing clothes and bathing. It was also observed that a large number of children use the river for recreational purposes such as swimming and fishing.

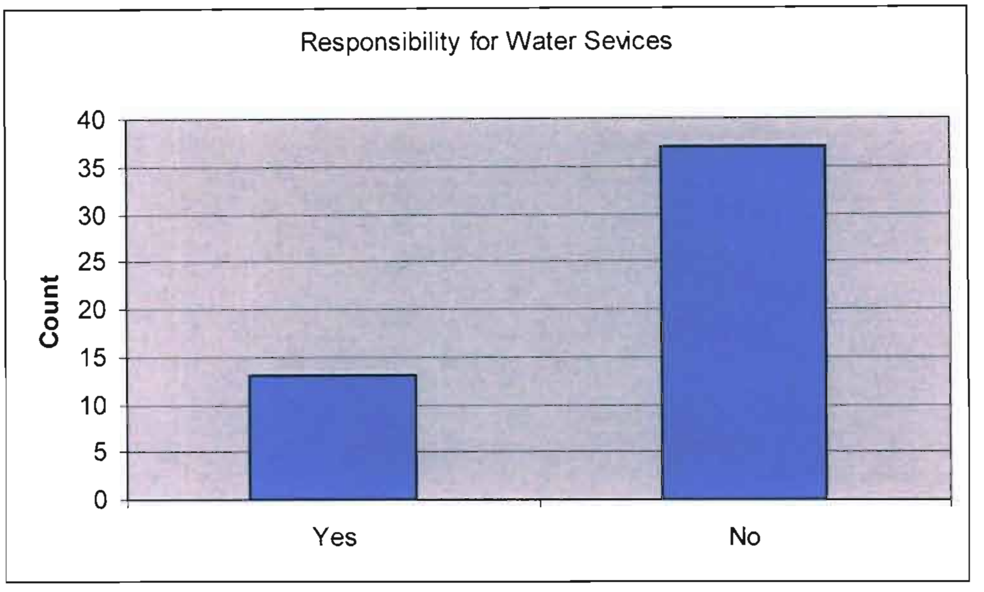
Figure 4.8 Sanitation/sewage disposal facilities used by household



	Sanitation/sewage facilities	
	Count	Percentage
Pit Latrine	50	100
Total	50	100

This informal settlement has no sewage disposal system and sanitation in the form of a pit-latrine which is most often shared with other households. There are no facilities to discharge waste water; the residents therefore discharge the water from cooking, washing and cleaning by throwing it out the front door, which is very unhygienic since children play around the dwelling. This community does not have any form of proper sanitation and are sometimes forced to use the river for sanitational purposes. The pit latrine is a hole dug in the ground covered by a piece of board or wood. Once the pit is full, it is filled with soil and another one is dug next to the first one. There is consequently a high risk of pollutants leaching into the river system and contributing to the high level of eutrophication.

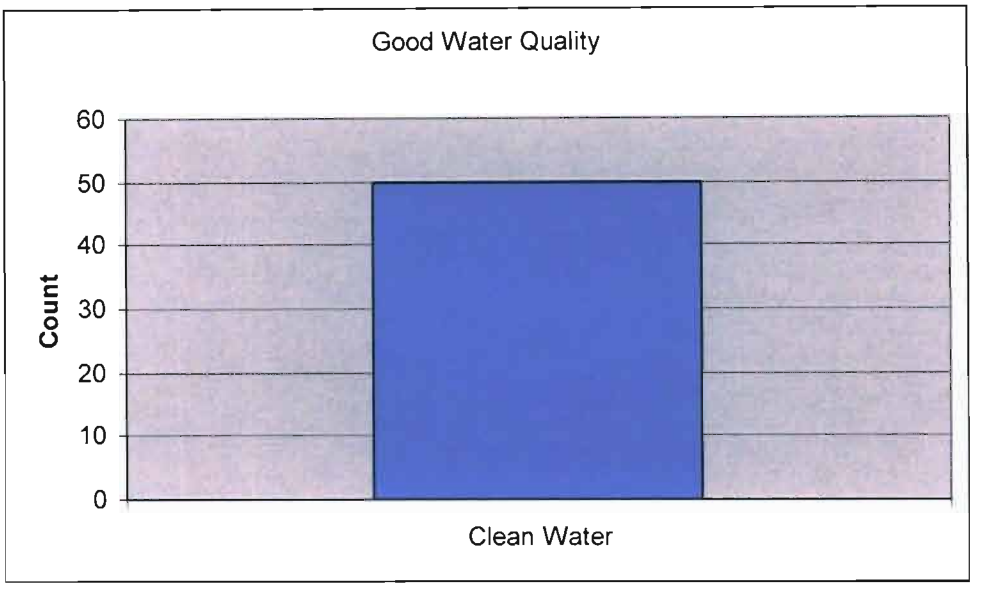
Figure 4.9 Responsibility for water services in the community



	Responsibility for water services	
	Count	Percentage
Yes	13	26
No	37	74
Total	50	100

It is quite clear from the above table that majority of the respondents (74%) have no idea who is responsible for water services in the area. 26% are aware that Durban Metro Water is responsible for water services in the area, although they feel that Durban Metro Water does not service them adequately. Respondents complain that Durban Metro Water takes to long to attend to water cut-offs and other water complaints and in some cases they don't even bother.

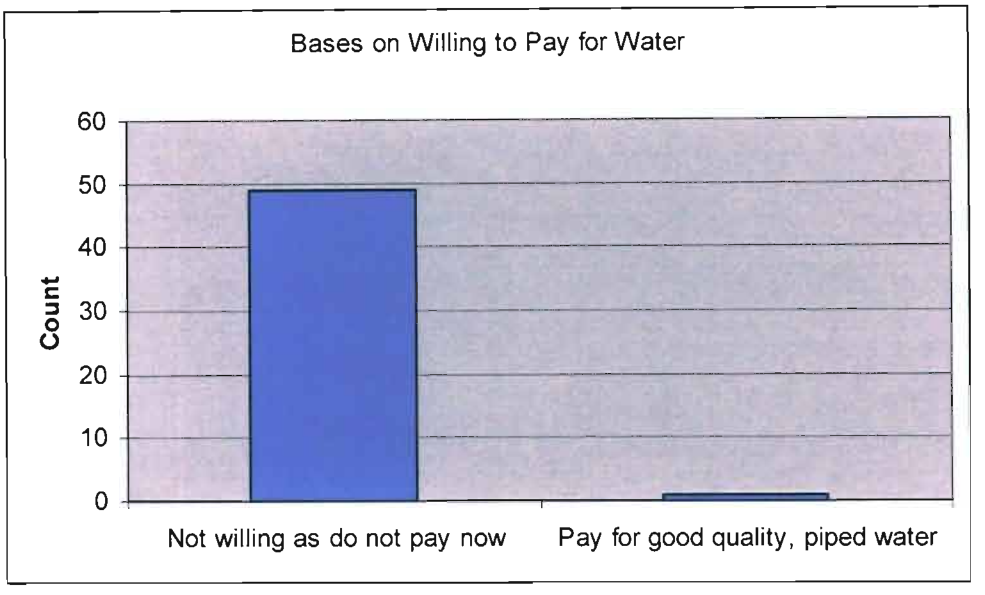
Figure 4.10 What is good water quality?



	Good water quality	
	Count	Percentage
Clean Water	50	100
Total	50	100

From the above table it is evident that the respondents have a good idea of what good water quality is. Clean water was the only reply from respondents on good water quality. Respondents unanimously agreed that clean, clear, open-tap, drinking water is good water quality. Although some felt that most of the time they received clean water, there were times when they got water that was murky and smelt of chlorine. Respondents also felt that piped water contributed to good water quality and if the water was of good quality they would not get sick.

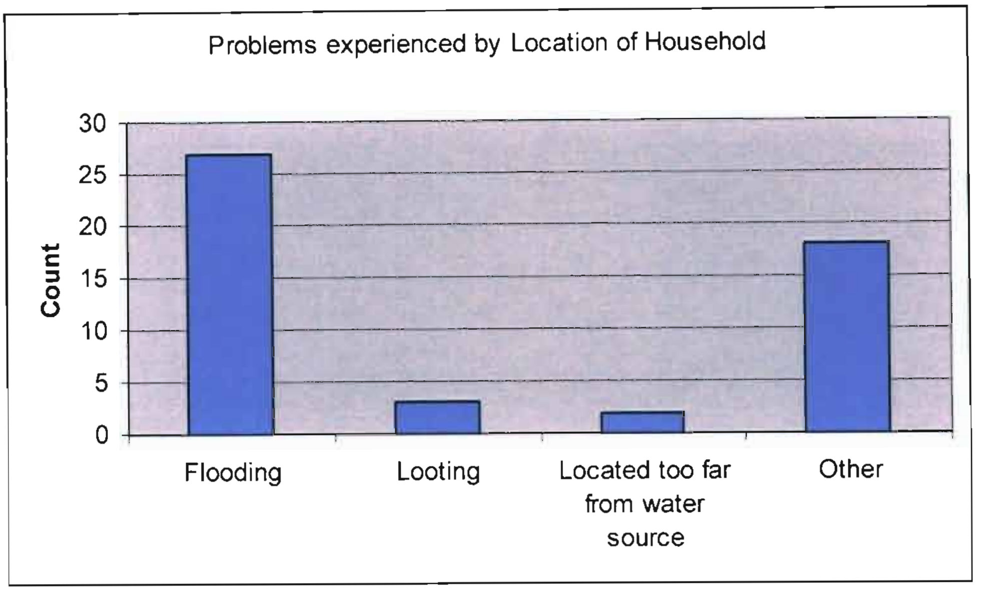
Figure 4.11 Basis on willing to pay for water



	Bases on willing to pay for water	
	Count	Percentage
Not willing as do not pay now	49	98
Pay for good quality, piped water	1	2
Total	50	100

From the above table it is quite evident that the community is not willing to pay for water as they do not pay now, with 98% of the respondents stating this. They were very adamant on this as they feel that it is their constitutional right to free, clean water and that their community leader instilled this into them. It was also commendable to see that one person was willing to pay for good quality, piped water inside his house.

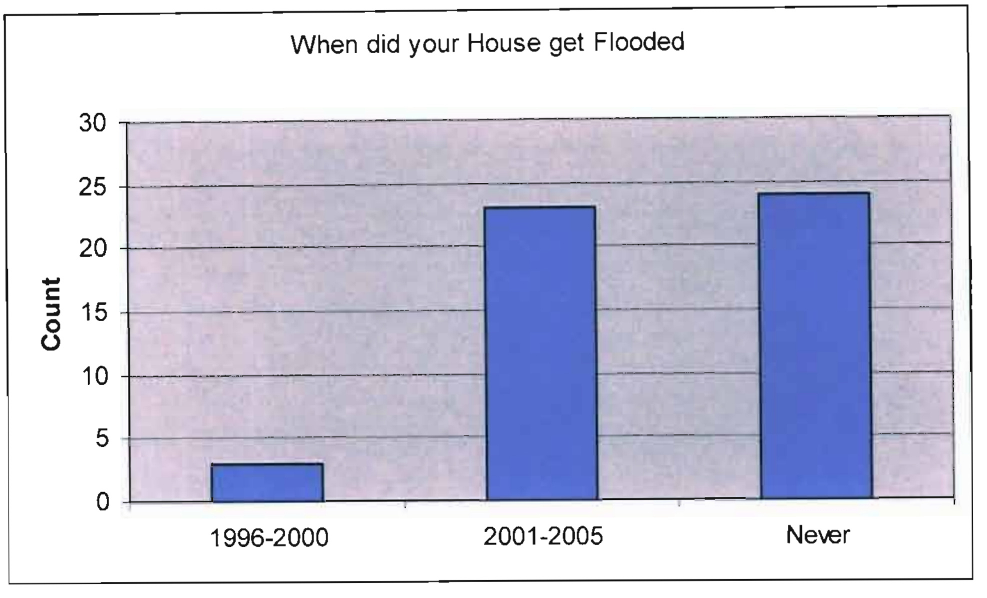
Figure 4.12 Problems experienced by location of household



	Problems experienced by location of household	
	Count	Percentage
Flooding	27	54
Looting	3	6
Located too far from water source	2	4
Other	18	36
Total	50	100

Fifty four percent of the respondents indicated that flooding was a problem experienced by the location of their household. Six percent indicated that they were prone to looting as they did not have any fence or proper locks on their doors. Four percent indicated distance from water source as being a problem. The thirty six percent who made up the other category experienced problems of being located to close to the road and highway and the noise emanating from cars made it difficult for them to sleep at night. Insufficient lighting within the community was another problem experienced due to location.

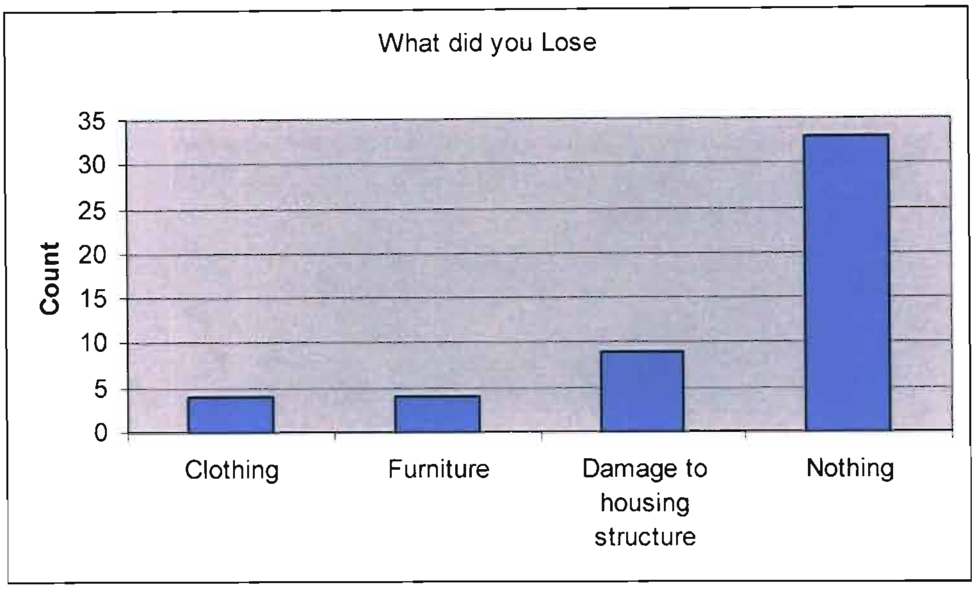
Figure 4.13 Time of household experiencing flooding conditions



	When did your house get flooded	
	Count	Percentage
1996-2000	3	6
2001-2005	23	46
Never	24	48
Total	50	100

Six percent of the respondents indicated that their household experienced flooding conditions during 1996-2000. These were houses located on the lowest lying area, close to the river and were prone to flooding conditions during moderate rains. However forty six percent indicated that they experienced flooding conditions during 2001-2005. These houses were not too badly located, but due to heavy, continuous rains experienced the full wrath of the floods. Forty eight percent of the respondents indicated that they had never experienced flooding conditions. This was due to the houses being located close to the road and had contingency flood measures in place.

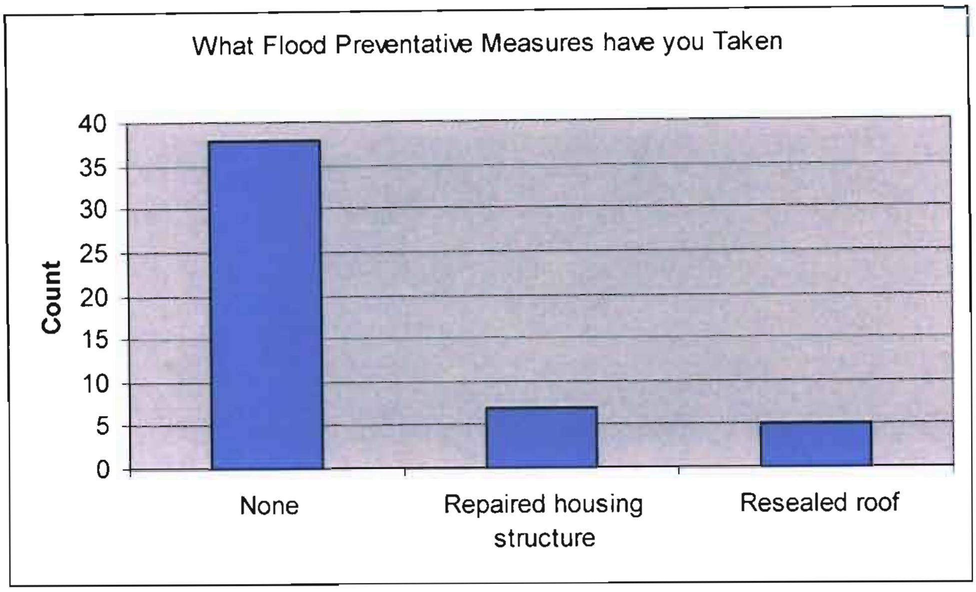
Figure 4.14 Impacts of the flooding conditions



	What did you lose	
	Count	Percentage
Clothing	4	8
Furniture	4	8
Damage to housing structure	9	18
Nothing	33	66
Total	50	100

Of those respondents that did experience flooding conditions, 8% indicated that they lost some form of clothing, 8% experienced damage to furniture and 18% incurred damage to the housing structure many of which were roof related problems. As expected those that never lost anything did not experience any flooding conditions.

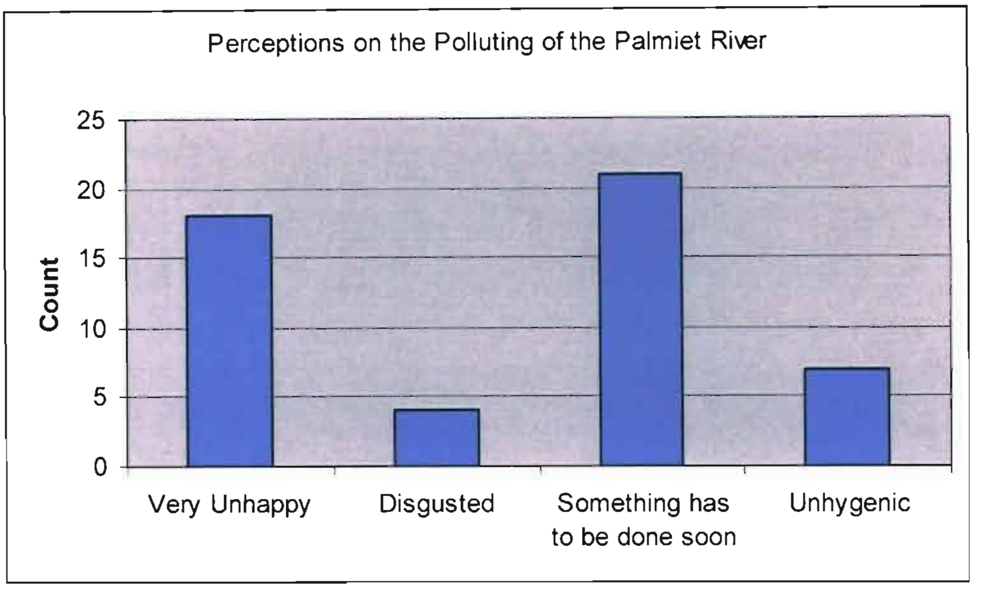
Figure 4.15 Flood preventative measures that were taken



	What flood preventative measures have you taken	
	Count	Percentage
None	38	76
Repaired housing structure	7	14
Resealed roof	5	10
Total	50	100

Seventy six percent of the respondents did not take any flood preventative measures which makes them prone to future floods. However fourteen percent indicated that they had repaired the housing structure by raising their front door entrance and putting a piece of rubber underneath the door to prevent water from seeping in. Some added more plastic and waterproofing material to the housing structure. Ten percent of respondents had resealed their roofs and made it steadier by placing heavy metals and tyres on top of it.

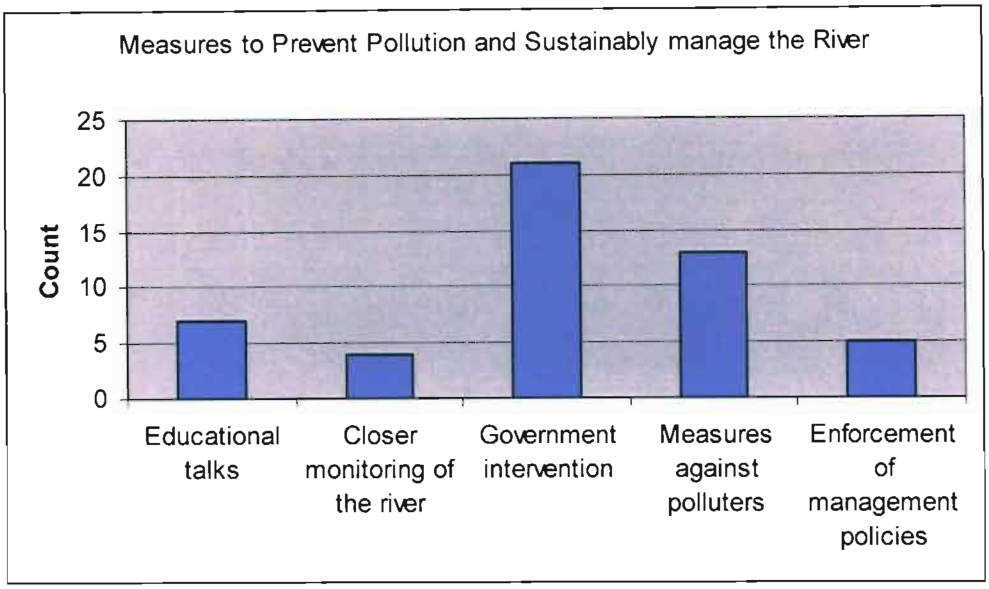
Figure 4.16 Perceptions on the polluting of the palmiet river



	Perceptions on the polluting of the Palmiet River	
	Count	Percentage
Very Unhappy	18	36
Disgusted	4	8
Something has to be done soon	21	42
Unhygenic	7	14
Total	50	100

The community interviewed is aware of the polluting of the Palmiet River with thirty six percent very unhappy about the situation. Eight percent are disgusted and fourteen percent know that this polluting is unhygienic. Forty two percent of the respondents feel that something has to be done about this pollution because it is affecting their quality of life, as some of them are dependant on this river. They are also frustrated with their living conditions and quality of life, thus a sense of helplessness is plaguing the community.

Figure 4.17 Measures to prevent pollution and sustainably manage the river



	Measures to prevent pollution & sustainably manage the river	
	Count	Percentage
Educational talks to households on pollution and conservation	7	14
Closer monitoring of the river	4	8
Government intervention	21	42
Stricter measures against polluters	13	26
Stricter enforcement of management policies	5	10
Total	50	100

From the above table it is quite evident that the respondents know what measures are required to sustainably manage the river with government intervention being the most accepted measure. Respondents also feel that very little is being done to deter polluters with 26% calling for stricter measures against polluters. 14% also felt that people need to be better educated on alternative practices and conservation methods.

4.4 On-site Observation Analysis

On-site observations formed an integral part of this research as it allowed the researcher to experience first hand the various processes and activities that influence the water quality, health status and ecology of the Palmiet River catchment. The images depicted below encapsulate the on-site observations followed by an analysis of these images.

Plate 4.1 The Palmiet Nature Reseve area

The Palmiet Nature Reserve is located within the Westville residential area. The Nature Reserve area seems to be untouched and preserved in its natural state. The middle reaches or 6km of the river which pass through the Palmiet Nature Reserve are still in a fairly pristine condition. The quality of the water found within the nature reserve is more or less equivalent to samples taken before the nature reserve. The river vegetation within nature reserve serves as a natural filter of any woody debris or effluent.

Plate 4.2 Lower regions of the Palmiet River

Site visits and reviews of aerial photographs have revealed that the land used in the lower regions of the Palmiet River has turned into a residential dumping zone.

Plate 4.3 illegal residential waste dumping along the banks of the river

Rapid urbanization along the middle reaches of the Palmiet River has lead to an increase in storm water. Additionally, a high concentration level of squatters along the lower reaches of the river has led to complete neglect of this area. Dumping of waste and inappropriate development is leading to increasing degradation of the ecological and amenity value of the Palmiet.

Plate 4.4 Pollution of the river affecting its natural flow

It is quite evident, in the photographs and through frequent visits to the site, that solid waste on the banks influences the pollutants within the river, and thus increases the level of nitrogen within the water content.

Plate 4.5 Massive dumping of solid waste on the banks

As viewed in this picture, the slope of the bank promotes the cascading, of sediments and solid waste into the river; this causes the stream channel to become narrower in width hindering the natural flow. At this site the rivers width measured approximately 1½ m.

Plate 4.6 Algal proliferation in the river

Analysis of chemical concentrations of water samples taken at this site indicates that there are high levels of nitrogen. The cause for such high levels of nitrogen is surface runoff from the surrounding catchment area, the discharge of effluent into the stream containing human and animal excrement, and organic industrial wastes are the major sources of nitrogen which enters aquatic systems. Algal proliferation is also high due to eutrophic conditions of the river waters.

Plate 4.7 Constriction of the river channel

This picture shows an excess of in-stream vegetation which is caused by high eutrophication levels at this site

Plate 4.8 Use of the river for washing clothes

Results from the water samples within the informal settlement in Clare Estate indicate that there are high levels of *Faecal Coli* forms and nitrogen. The reason for high levels of *Faecal Coli* forms is because locals in the informal settlement dispose of their raw sewage on the banks of the Palmiet River. People living within the informal settlements wash their clothing in the river which quantifies the high level *Faecal Coli* forms.

Plate 4.9 Illegal dumping of tyres in the catchment

This picture depicts illegal dumping and burning of tires on the river bank

Plate 4.10 Pollution by industries

It is common practice to blame the informal settlements of polluting the rivers along which they border. But it is the large companies who are the main culprits in the poisoning and destruction of our rivers. This picture depicts an industrial tanker dumping large amounts of waste into the river. This can be attributed to the lack of monitoring of the river as well as relatively light measures against polluters.

4.5 Conclusion

Modern society too often views water as a convenient vehicle for disposing of waste and the results are becoming increasingly apparent. Analysis of fresh water supplies frequently reveals disturbing levels of pollution including human waste, heavy metals and synthetic chemicals to the detriment of human heath and the health of the entire ecosystems. Even today, humans continue to ignore the vital importance of water while consuming more and more. Not only is the level of water in the global well getting low, the water is also polluted, sometimes to the point where it is no longer drinkable (Stauffer, 1998).

This chapter focused on the analysis of data obtained from the water analysis of the samples collected and analysed at the Water and Wastewater Research Laboratory at the Durban Institute of Technology (DIT). Analysis of the questionnaire survey also made up the primary data of this research. Analysis and on-site observations thus concluded that the upper waters of the Palmiet River catchment are taking strain due to the increased urbanization & industrialization emanating from the Pinetown area. The middle reaches or 6km of the river which pass through the Palmiet Nature Reserve are still in a fairly pristine condition. However, the lower reaches of the catchment is in a deplorable state that needs much rehabilitation. The following and last chapter will provide the final conclusions from the findings of the analysis together with recommendations as a possible means of actions to the problems associated with water quality.

CHAPTER FIVE
CONCLUSIONS & RECOMMENDATIONS

5.1 Introduction

"The fragmented and uncoordinated way pollution and waste is currently being dealt with, as well as the insufficient resources to implement and monitor existing legislation, contributes largely to the unacceptably high levels of pollution and waste in South Africa" (Moosa, 2000).

The quality of water is of vital concern to humans as water quality is directly linked with human welfare. Presently, the menace of water-borne diseases and epidemics still looms on the horizon of many developing countries. In all such cases, polluted water is the culprit. The major sources of water pollution include domestic waste from urban and rural areas, and industrial wastes discharged into natural waters (De, 1994).

Where there is water there is life. Where the quality is poor and scarce, life has to struggle. There is an increasing awareness of the need to conserve the environment, and in recent times considerable emphasis has been placed on pollution of natural watercourses. Water resources are becoming increasingly contaminated with pollutants derived from ever expanding urbanization and industrialization (Tebutt, 1983).

5.2 State of Palmiet River

The river area that was investigated can be divided into five land use categories:

- The high income housing areas
- The CBD, industrial area.
- The middle income housing area
- The nature reserve area &
- The informal settlement area

It was concluded that the Pinetown industrial area is known to be the largest in KwaZulu Natal. For years industries in Pinetown have been dumping of their affluent waste into the Palmiet River. This lead to increasing levels in the waters physical, chemical and biological content which has given rise to a number of problems concerning the water quality and the state of the ecosystems found within the Palmiet River catchment area. The Pinetown area of the Palmiet River has been studied by De Villiers & Malan (1985) quite comprehensively. Their research indicated that the Pinetown industrial vicinity has a high concentration of SO_4 due to spillage by at least two industrial concerns. The one uses sulphuric acid to manufacture detergents, and the other to neutralize alkaline effluent. De Villers & Malan, 1985, further state that one of the main potential pollution sources was at the head waters, in Pinetown, where the local authorities ensured that the capability of the catchment was to absorb resiliently pressure to which it could be subjected, and not exceeded. They also recommended a fair amount of mitigation and conservational methods, to maintain the discharge of effluents into the river.

However, results of this study indicate that the upper reaches of the Palmiet River is in fairly good condition in the sense of ecology management. Westville residential area has a number of storm water drainage pipes that lead into the Palmiet River. This adds to the problem of pollution, whereby any form of litter or residential waste tends to be swept into the river system. This causes the river to be polluted or hinders the natural flow of the river.

The issue of solid waste pollution is associated with human habitation, and is rapidly increasing with population density and the level of development. The Palmiet River is a fragile little river that has been used as a collection point for storm water for an ever-growing residential area. At present it flows into the Pinetown area, down into and through the residential areas of Westville and Clare Estate before joining the Mngeni River. Site visits and reviews of aerial photographs show that the lower region of the Palmiet River has turned into a residential dumping zone. The amount of solid waste found in the river channel itself causes the river morphology to change, creating stagnate pools of waste.

Rapid urbanization along the middle reaches of the Palmiet River has lead to an increase in storm water. The presence of large numbers of squatters along the lower reaches of the river has led to complete neglect of this area. The Clare Estate area is also having a devastating effect on the river system. The population 'growth spurt' has led to a further degradation of the system. Illegaldumping is destroying the natural vegetation found in and around the river as well as its stream-flow. In this study the sites examined in the residential areas displayed a gross misuse of the river. With the exception of a small nature reserve and relics of sub-tropical forest here and there, the catchment is fully urbanized. Housing consists of detached dwellings, on plots approximately $2000m^2$, with established gardens. This area has previously been categorized as high income-group housing with middle income- group housing on plots of $1000m^2$.

The informal settlement area found in the lower reaches of Palmiet has the highest concentration of waste along the entire river path. People living within this area of the catchment are dependent on the river water for recreational as well as sanitational purposes. The river helps sustain their livelihood, by providing them with water for bathing, washing, cooking, and a sewage disposal site. Due to a lack of cleaning services in the area; people tend to dispose of the waste anywhere that is appropriate for them. Solid waste containing tires, building rubble, tin sheets, etc, are to be found scattered along the banks. High concentrations of in-stream vegetation also pose a threat, as the waste materials get caught in the vegetation (water reeds) which causes a blockage in the rivers path. This also made it quite difficult to identify waste within the stream. The informal community has located their homes in a very dangerous area along the river; in case of flood conditions, most of the settlements would be destroyed.

Results from the water samples within the informal settlement in Clare Estate indicate that there are high levels of *Faecal Coli* forms and nitrogen. The reason for high levels of *Faecal Coli* forms is due the informal community using the river for sanitational purposes as well as for washing their clothes. Further downstream is the Clare Estate crematorium, where human ashes in clay pots are placed within the stream, which forms obstacles that trap waste floating in the river. This causes stream-flow to be slower and more or less stagnate.

For all the measured variables there were seasonal changes whereby higher values were recorded during the wet season than the dry season. This occurred because during the rainy season the grasslands will be wet and therefore the amount of sewage effluent that infiltrates into the ground will be low resulting in higher volumes flowing to the nearby river. The increased nutrient concentration is also due to increased runoff from the river catchment area which brings into the tributary a variety of substances.

5.3 Recommendations

It has become obvious that our rivers are experiencing degradation due to urbanization and industrialization at an alarming rate. This has played a major role in the deterioration of the water quality of the Palmiet River catchment. As a result, the following recommendations can be made:

- The problem is complex, and therefore the solution is also complex and multi-faceted. Communities living along rivers need to be the key targets for action to mitigate problems related to river pollution;

- Prevention, as the saying goes, is nine-tenths of the cure. This is simplistic, but true. Preventing water pollution is much easier, cheaper, and more effective than trying to undo the damage it does. The more we minimize pollution, the less we have to clean up. Unfortunately, this has not been the traditional approach (Stauffer, 1998);

- Pollution prevention is one of the most effective means of protecting society and the environment. Pollution prevention promotes sustainable development, as well as eliminates costly and unnecessary and unwanted waste. Adverse effects associated with the risks to human health and well-being can be greatly reduced by eliminating the cause as opposed to treating the effects imposed by pollution and waste;

- Programmes need to be developed that help the communities take action to improve the condition of rivers. This can be done using an aggressive public awareness and education campaign to show how everything we do on a daily continual basis, negatively impacts our rivers;

- Partnerships are the key in order to bring together a range of stakeholders who bring different resources and skills to the partnership in order to solve multi-faceted problems. Community-based action therefore needs active partnerships with local stakeholders such as local governments, universities and research institutions, private sector companies and NGOs. Each stakeholder will bring an important resource to promote the activities that will lead to a healthy river;

- Developing alternate sanitation systems since sanitation affects the quality of life and the quality of the water sources. Consideration must therefore be given to on-site sanitation, especially water borne sanitation since it has been shown that in developing countries where water borne sanitation had been used, there has been substantial improvements in health and environmental quality;

- In South Africa we have well developed and structured legislation and policy, but sadly, ineffective monitoring and enforcement. There must be continued and consistent monitoring and collection of data relating to operations and process performance, water pollution risks, and waste generation (eg. sludge). This is crucial for the implementation and management of pollution and waste minimization policies and strategies. The abatement of pollution, minimization of waste, and immediate and effective remediation of any pollution of the environment may be achieved through effective monitoring and control;

- The authorities that have been vested with the responsibility must ensure compliance with respect to legislation and policies. Compliance in respect of permits granted by the issuing authorities must be enforced. Companies and organizations who fail to comply with permit and other government regulations and protocols must be liable for environmental damage and must pay the remediation costs, both to the environment and to human health, including the costs of preventative measures to reduce or prevent further pollution and environmental damage – *Polluter Pays Principle;*

- The water hyacinth in the Palmiet River needs to be removed which would promote healthy conditions within the river. It would make the river aesthetically pleasing and promote greater recreational activities in the river ultimately promoting social upliftment in the Clare Estate area while the residents of the informal community can involve themselves with the cleaning up of the river;

- There is talk of "water crisis", but at the same time talk of tremendous opportunity, because water, and the need to share it, can also become a learning ground for building community at all levels, from local to international. We in South Africa agree with this need to attack the problem in an integrated way and on all fronts and, in particular, with the new emphasis on the local level and the need for a devolved management of water resources;

- Lastly, it must be recognised that only local government can achieve true integrated development, through integration of different functions including water and sanitation development together with hygiene education towards achieving improved community health, domestic water supply together with agricultural water supply to achieve economic development and water and land management to achieve a holistic resource protection.

5.4 Conclusion

Humans do not yet sufficiently comprehend the many chemical and biochemical consequences of environmental pollution, evidenced by the significant number of anthropogenic impairments to natural ecosystems (Falkemark, 1996).

Water equals life. Without water there would be no life. This is where the problem establishes itself. Humans are ultimately using too much water. The planet receives approximately the same volume of precipitation each year, but the world's population is growing continuously. As the world's population grows, there is increased pressure on water reserves and more water is used.

Human activities in the landscape result in alterations of hydrologic pathways by physically altering the land, by changing the vegetation, and by artificially routing water to where humans want it. In addition, human activities have affected water quality by adding substances (gas, liquid, and solid). Human requirements for sustainability, cultural characteristics of the population, socio-economic situations, and the biophysical and climatic settings of an area determine the level of interaction, and consequently, the rate of water degradation. Human activities on all spatial scales affect water quantity and quality. Furthermore, the results of these human activities affect users downstream; at some point, everyone lives downstream, and everyone experiences the consequences of human effects on the hydrologic cycle.

Water quality control combined with water resource protection is of fundamental importance in South Africa, as rapid population growth is placing increased demands on the countries diminishing water resources. Droughts have exacerbated the adverse effects of increased water pollution from industrial and domestic sources, with the reuse of polluted water being the only means of balancing supply and demand. Pollution poses one of the most serious threats to water quality (Peters and Meybeck, 2000).

APPENDIX A

SURVEY QUESTIONNAIRE

A. Community Details

1. Name:______________________
2. Location:______________________

B. Respondents Background

1. Gender

Male	Female

2. Marital Status

Married	Single	Divorced	Widowed	Other

3. Age

<20	20-39	40-49	50-59	60-69	70+

4. Number of members in the household

Females	Males	Total

5. Education level

No formal schooling	
Primary	
Secondary	
Matric	
Post-matric (tertiary)	

6. How long have you been living in the area? (No of years)

<5	6-10	11-15	16-20	>20

7. Employment status

Employed	Self employed	Unemployed	Other

8. Monthly income of household

<R500	R500-R1000	R1000-R2000	R2000-R3000	R3000-R4000	>R4000

C. Water Issues

1. What is the primary water source used by your household?

Source	
Communal Tap	
Piped – Yard Tap	
Borehole	
Rainwater	
River	
Tanker	
Dipping Tank	
Roof Tank	
Other	

2. How far is this water source located from your household?

0 – 10m	
10 – 30m	
30 – 50m	
50 – 70m	
70 – 100m	
>100m	

3. Is the water source/s identified above, adequate in terms of supply or volume and quality to meet your needs throughout the year?

Response	Volume/Supply	Quality
Yes		
No		
Sometimes		

4. What are some of the water source problems experienced by your household?

Supply or volume of water is low	
Bad smell	
Bad colour	
Bad taste	
Rubbish in water	
People use water as a toilet	
People bathing in water source	
People washing clothes in water source	
Located too far away	
Other	

5. What are the common sanitation/sewage disposal facilities used by your household?

Response	
Pit latrine	
Flushing toilet	
River	
Portable Toilets	
Other	

6. Do you know who has the responsibility for water services in your community?

Yes	No

7. What is good water quality?

Clean water	
Piped water	
Clear water with no odour	
Water that u can drink without getting sick	
Other	

8. What are the most common illnesses in this community related to water?

Stomach aches	
Cholera	
Malaria	
Headaches	
Vomiting	
diahorrea	

9. What are the bases upon which you would be willing to pay for water?

Not willing to pay for water, as I do not pay now	
Already paying for water by bill	
Will continue to pay for water, as long as I get good quality tap water	
For as long as they can afford to	

10. How does the water and sanitation services your community can access, influence your surroundings/environment?

No where to throw waste water – dispose of it outside the front door.	
Air has a stale, damp smell	
Area outside household very dirty and unhygienic	
Undisposed waste attracts flies and causes diseases	
Broken and leaking pipes cause muddy conditions	
Unscheduled cut off's in the water supply, prevents flushing of toilet which can sometimes cause problems.	

11. What are your household uses of the Palmiet River?

Drinking	
Cooking	
Bathing	
Washing Clothes	
Irrigating vegetable gardens	
No use of river	

12. What are some of the problems experienced by the location of your household?

Flooding	
Looting	
Located too far from water source	
Soil erosion	
Other	

13. When did your household experience flooding conditions and what did you loose in the floods?

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____

____

14. What have you done to prevent your household from future flooding hazards?

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15. How do you feel about the polluting of the Palmiet River?

____

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____

16. What do you think should be done to prevent pollution of the river as well as to sustain ably manage the Palmiet River?

Educational talks to households on pollution and conservation	
Closer monitoring of the river	
Government intervention	
Stricter measures against polluters	
Stricter enforcement of management policies	

17. Do you have any other issues or concerns that you would like to raise in regard to water quality of the Palmiet River?

____

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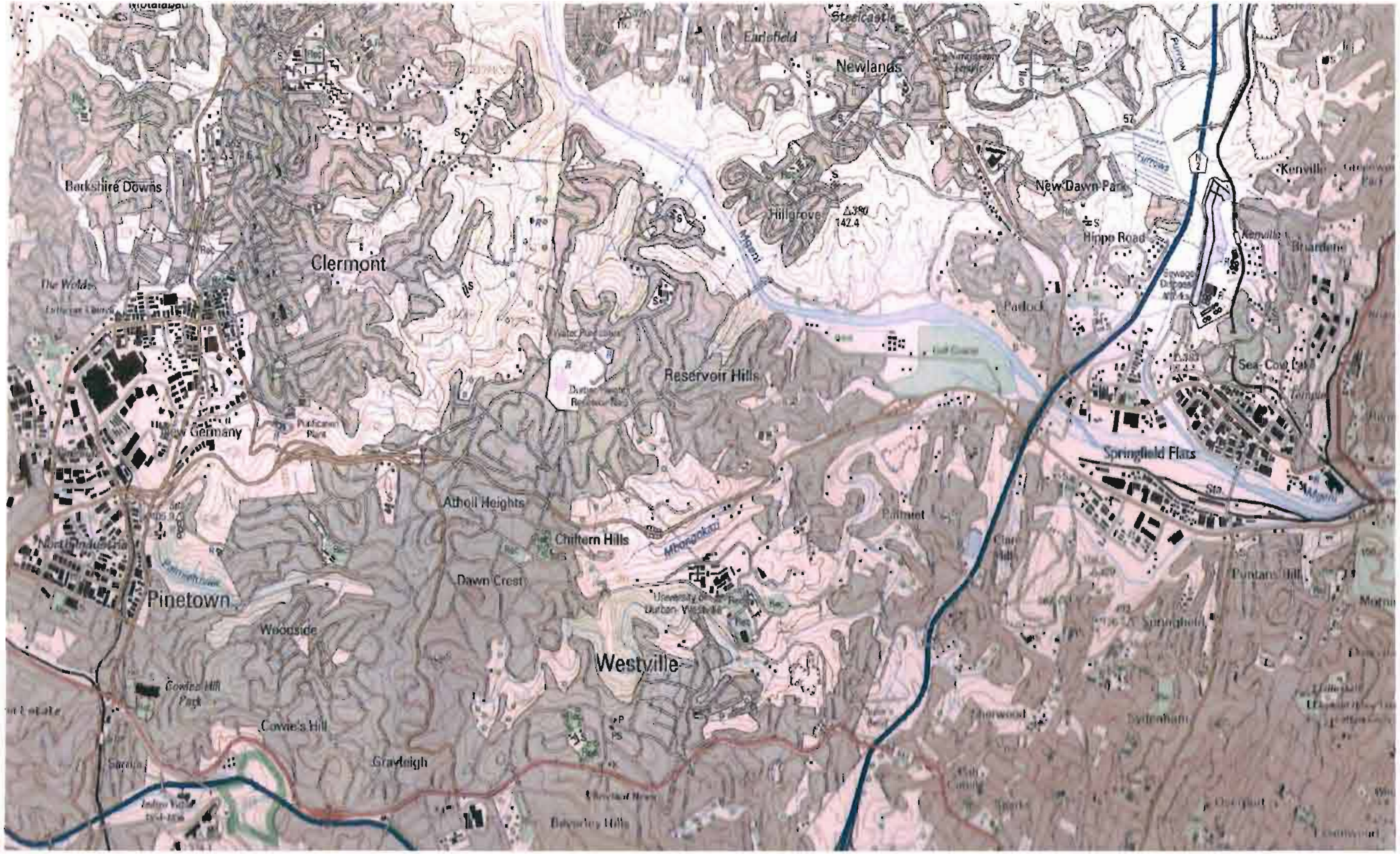
APPENDIX`B



Newlands
Earlsfield
Berkshire Downs
Clermont
Hillgrove
New Dawn Park
Kenville
Hippo Road
Reservoir Hills
New Germany
Springfield Flats
Atholl Heights
Chiltern Hills
Dawn Crest
Pinetown
Woodside
Westville
Cowie's Hill
Sea Cow Lake
Puntans Hill
Sydenham
Padlock
Palmiet
Graylegh
Beverley Hills
Mgeni
Mbongokazi

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