YUNIBESITI YA BOKONE-BOPHIRIMA
NORTH WEST UNIVERSITY
NOORDWES UNIVERSITEIT

Effects of Wetlands on Water Quality and Invertebrate Biodiversity in the Klip River and Natalspruit in Gauteng, South Africa

By

KAAJIAL DURGAPERSAD

DISSERTATION

submitted in part fulfilment of the requirements of the degree

MAGISTER SCIENTAE

in

ENVIRONMENTAL SCIENCE

in the

FACULTY OF NATURAL SCIENCES

at the

NORTH-WEST UNIVERSITY

SUPERVISOR: DR ANDRÉ VOSLOO

(Potchefstroom University)

ACKNOWLEDGEMENTS

It is with great appreciation and recognition that I wish to thank the following persons for the tremendous efforts and contributions that they made to the completion of this study:

- *Dr André Vosloo, my supervisor, for his help, guidance and enthusiasm in this study.*

- *Marc de Fontaine, for his time, effort and insightful contributions on the review of this study.*

- *All my family, work colleagues and friends, especially Heidi Oosthuizen for their help and support.*

- *And, to my husband, Danesh for his love, support and understanding.*

ABSTRACT

The Klip River catchment is one of the most heavily impacted river systems in South Africa and is subjected to various types of pollution. The catchment furthermore serves all five recognised user groups identified by DWAF (domestic, agricultural, recreation, industrial and the natural environment). Increasing rates of urbanisation, industrialisation and population growth have aggravated the significance of water pollution as a threat to the wetland resources in the Klip River catchment. A wide range of physical, chemical and biological variables has been evaluated at the inflow and outflow points of the Klip River and Natalspruit wetlands to determine the effects of the wetlands on the incoming water.

The Klip River wetland is impacted upon by mining and industries before the inflow points; three wastewater treatment works during the course of the wetland and informal settlements. Analyses of the wetlands show a significant improvement in conductivity, dissolved oxygen, manganese and sulphate concentrations. A deterioration was found in the suspended solids, chloride, sodium, nitrate and phosphate and chemical oxygen demand concentrations. Microbiological analyses showed that there is 93% removal of faecal coliforms from the wetlands at the output site. There was an increase in the SASS4 score from the inflow to outflow points for both the summer and winter months analysed showing a change from a considerably impaired condition to a moderately impaired condition.

The Natalspruit wetland is impacted upon by mining just before the inflow point, industries, three wastewater treatment works during the course of the wetlands and informal settlements. Readings taken at the outflow point of the wetlands show a significant improvement in conductivity, pH, chloride, iron, manganese, sodium, and sulphate concentrations. A deterioration was found in the fluoride, nitrate and phosphate concentrations. Microbiological analyses show that there is 99% removal of faecal coliforms from the wetlands at the output site. There was a slight increase in the SASS4 score from the inflow to outflow points for both the summer and winter months analysed showing that it is in a considerably impaired condition.

Load analyses of the Natalspruit wetland showed improvements for all the physical, chemical and microbiological analyses carried out. Very little work is done on the Klip River wetlands, and any information with regards to their benefit in being in a catchment especially one as degraded as the Klip River catchment, will result in their importance to all South Africans to be highlighted. Mines, industries and wastewater treatment works, can use wetlands as an added measure to purify water before discharging into rivers.

In comparison, the Natalspruit wetland is functioning more efficiently than the Klip River wetland. Some reasons for this will be discussed.

OPSOMMING

Die Klip Rivier opvangsgebied is een van die mees grootse geaffekteerde rivier sisteme in Suid-Afrika en kan toegeskryf word aan verskeie tipes van besoedeling. Die opvangsgebied dek verder ook al vyf bekende verbruikersgroepe (huishoudelik, landbou, rekreasie, industrieë en die natuurlike omgewing) ge-identififiseer deur DWAF. Toename in die tempo van verstedeliking, industrialisasie en populasie groei het die betekenis van water besoedeling in die Klip Rivier opvangsgebied vleiland hulpbronne as 'n bedreiging vererger. 'n Wye reeks fisiese, chemiese en biologiese veranderlikes is by die invloei en uitvloei punte van die Klip Rivier en Natalspruit vleilande geëvalueer, om die effekte van die vleilande op die inkomende water te bepaal.

Impakte op die Klip Rivier vleiland sluit in mynbou, industrieë, drie rioolwerke deur die verloop van die vleiland en nedersettings. Analises op die vleiland het 'n aansienlike verbetering in die konduktiwiteit, opgeloste suurstof, mangaan en sulfaat konsentrasies getoon. 'n Afname in gesuspendeerde materiale, chloriede, natrium, nitrate, fosfate en COD konsentrasies is gevind. Mikrobiologiese analises toon 'n 93% fekale coliforme verwydering wat by die opbrengsarea van die vleiland voorkom. 'n Toename in die SASS4 telling vanaf die invloei tot by die uitvloei punte vir beide somer en winter maande toon verandering vanaf 'n aansienlike verswakte kondisie tot 'n matige verswakte kondisie.

Die Natalspruit vleiland word geaffekteer deur mynbou net voor die invloei punt, industrieë, drie rioolwerke deur die verloop van die vleiland en nedersettings. Monsters geneem by die uitvloei punt van die vleiland toon 'n aansienlike verlaging in die konduktiwiteit, pH, chloriede, yster, mangaan, natrium en sulfaat konsentrasies. 'n Afname in fluoriede, nitraat en fosfaat konsentrasies kom voor. Mikrobiologiese analises toon 'n 99% verwydering van fekale coliforme vanaf die vleiland by die opbrengsarea. Die effense toename in die SASS4 telling vanaf die invloei tot by die uitvloei punte vir beide somer en winter maande, dui op 'n aansienlike verswakte kondisie.

Lading analises van die Natalspruit vleiland toon verbeterings vir al die fisiese, chemiese en mikrobiologiese analises. Min werk is gedoen omtrent die Klip Rivier vleilande, enige inligting wat tot hulle voordeel kan dien veral in 'n opvangsgebied so gedegradeer soos die Klip Rivier opvangsgebeid, sal hul belangrikheid vir alle Suid-Afrikaners beklemtoon. Mynbou, industrieë en rioolwerke kan vleilande gebruik as 'n "ekstra maatstaf" vir die suiwering van water, voordat dit vrygestel word in die riviere.

In vergelyking, funksioneer die Natalspruit vleiland meer effektief as die vleilande van die Klip Rivier. Redes vir laasgenoemde sal in meer diepte bespreek word.

CONTENT

Page

Page

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

APPENDICES

Page

Chapter 1

Introduction

1.1 KLIP RIVER CATCHMENT

The Klip River catchment (Figure 1.1) is one of the most heavily impacted river systems in South Africa and is subjected to a wide variety of pollution types. Water in the southern parts of Greater Johannesburg drains to the Vaal Barrage and the Atlantic Ocean via the Klip River (DWAF, 1999). The catchment furthermore serves all five recognised user groups identified by DWAF (domestic, agricultural, recreation, industrial and the natural environment). Water is a scarce and critical resource for the whole Greater Johannesburg. The Upper Klip River in the south is located in an area of urban development and past mining activity, and is subject to intense pressure from human activities. In addition to water scarcity, a large percentage of drinking water is lost due to degradation of the water supply infrastructure, water wastage and leakages. The main concerns from an environmental perspective are the impacts of the increasing demands on water resources, and the impact of pollution on downstream impoundment and on users of this water source. The downstream communities, which are exposed to raw sewage and polluted streams and rivers, face serious health hazards.

The Klip River and its tributary the Rietspruit have their upper catchment boundaries situated in the southern portion of the greater Johannesburg metropolitan area. This boundary covers a distance of some 60 km from Roodepoort in the west through Benoni in the east. In the upper section of the catchment, small headwater streams drain the parallel ridges and link with the main streams that have eroded through the ridges to flow southwards towards the Vaal River. There are two main streams draining the central and western parts of the catchment. These are the main tributary, the Klip River, and a smaller stream known as the Klipspruit. In the east, the Elsburgspruit joins the Natalspruit in the upper reached of the catchment. The Natalspruit runs parallel to the Rietspruit. These three main rivers form the Rietspruit sub-catchment. The Rietspruit confluences with the Klip River approximately 30 km above the confluence of the Klip River with the Vaal River.

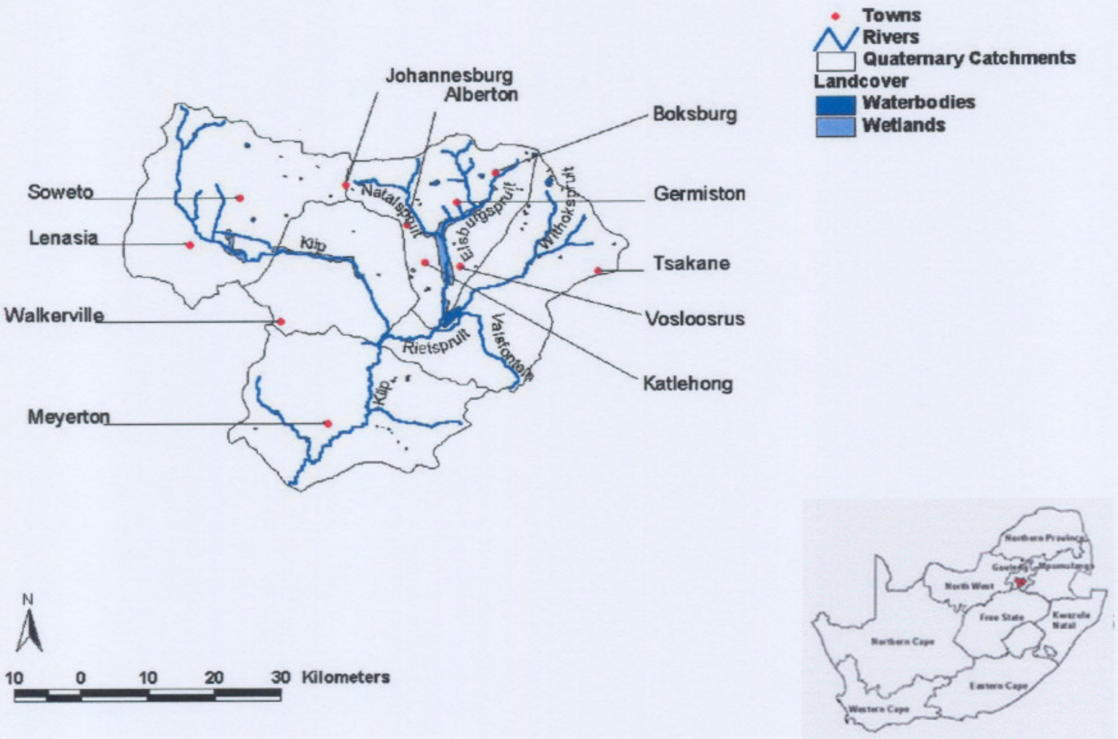

Figure 1.1 Rivers and Wetlands in the Klip River catchment.

1.1.1 Topography

The topography along the northern boundary of the catchment consists of a number of parallel hills elongated in a west-to-east direction to form a terrain known as scarp and vale (Scott 1995). These hills with their associated streams and waterfalls provide the features, which have given the area its name of "Witwatersrand" (white water ridge). The Upper Klip sub-catchment is bounded on the north by the Witwatersrand ridge with altitudes of up to 1800 m. A number of slimes dams and mine dumps from current and old mine workings in the northern areas have altered the natural topography of the area. The Rietspruit sub-catchment, which lies between the Witwatersrand ridge in the northwest and the Suikerbosrand ridge in the southeast, is gently undulating and lacks any predominant topographical features other than mine dumps and slimes dams in the northern areas. The Klip River catchment spans an altitude range from 1800 m above sea level to 1425 m at its confluence with the Vaal Barrage. The first 40 km of the river has a relatively steep gradient, but thereafter there is a flattening of the gradient, particularly after the confluence between the Klip River and the Rietspruit.

1.1.2 Geology and Soils

The geology of this catchment is complex with rocks of the Witwatersrand Group creating the reefs that have provided the basis of the South African gold mining industry. Ten gold-bearing reefs have been mined along the ridge with Main Reef, Reef Leader and the South Reef being the most exploited because of their high gold content. The surface geology indicates that the upper reaches of the catchment comprise porous, unconsolidated and consolidated strata while a large area of "water sensitive" dolomite and limestone lies within the middle reaches of the catchment.

Soils of the catchment are all moderate to deep with those in the upper reaches being sandy loam and those of the lower catchment being clayey loam, possibly a reflection of past erosion. The natural vegetation of the western portion of the catchment is predominantly "false grassveld" whereas towards the east the catchment contains "pure grassveld".

1.1.3 Groundwater

Little readily available information on the groundwater status of the Klip River catchment exists. All main river courses flow through wetlands with phreatophyte vegetation, indicating a shallow groundwater table. The Klip River compartment consists of numerous small sub-compartments where areas with similar groundwater tables are grouped. Most of these sub-compartments seem to be hydraulically linked to the Klip River. Scott (1995) reports that the groundwater record indicates historical evidence for a shallow water table in the upper parts of the catchment with the presence of wetland areas. These wetland areas existed in a trough-like depression along the mining activity within the Jeppestown sub-group. Florida Lake is apparently a dammed remnant of the swamps in the area. The presence of yellow residual soils in the area is evidence of a lowering of the water table and a subsequent loss of the wetlands. Further down the catchment there is an interesting association with the dolomitic and limestone area. Of particular note is an apparent linkage of the Klip River system with an important dolomitic compartment, the Zuurbekom groundwater compartment, that provides water supplies to Rand Water. It is reported that there is contamination of the compartment by point and non-point sources within the Klip River (Rand Water, 1998). The upper wetland areas in the Klip River are close to this compartment.

1.1.4 Wetlands in the Klip River catchment

In the Klip River system it is apparent that there are currently (or have been historically) several types of natural wetlands, notably (a) sponges in the headwater area, (b) reedbed marshes along the middle reaches of the river system and, (c) pans in the mining and urban area (Figure 1.1). In addition there are several small man-made reservoir systems that can be classified as wetlands. It is also apparent that development activities have both created as well as destroyed wetland areas. Furthermore, it is not clear which of the wetland systems are natural, which have been created as a result of development activities, or which have been man-made. Both the Klip River and the Rietspruit catchments have numerous small wetlands in the headwaters, but more importantly, have substantially larger areas in their middle reaches. The Klip River has four stretches of wetland ranging from 5 km to 20 km in length (and at points almost 1 km wide). The Rietspruit has one large wetland area whereas the Natalspruit has two, all of which are at least 5-10km in length. Most of the wetland areas appear to be dominated by the emergent reed, *Phragmites spp.* (Rand Water, 1998). The dominant vegetation of the wetlands in the upper Klip catchments is *Phragmites communis* and *Typha capensis.* (Kotze, 2002)

1.1.5 Catchment Management

Catchment management plays an important role in the health of wetlands as the wetlands are strongly influenced by the catchments, from which they receive water, dissolved and suspended material, introduce microbiological organisms and cause change in the types of other aquatic organisms. This makes wetlands vulnerable to improper catchment management practices. Run-off contaminated by fertilisers and biocides can drastically increase the nutrient levels of recipient wetlands, disrupting their ecosystem processes (Gopal, 2003). Poorly conserved croplands result in unnatural rates of soil loss that can have a negative impact on aquatic ecosystems (Russell, 1998). Dams and water abstraction reduce the amount of water available to support wetland and river systems, and alter the properties of water flow downstream (Davies and Day, 1998). Poorly placed and designed roads and tracks can increase fluvial sediment loads, smothering aquatic biota and modifying wetland and stream geometry, as well as creating an influx of heavy metal and other toxicants absorbed onto the sediment particles (Coetzee, 1995). Irrigation return flows can have elevated levels of salts precipitated out by evaporation and collected as the water percolates through the soil. This results in a dramatic increase in the salinity of return flows that can have a serious impact on wetland biota (Coetzee, 1995).

1.2 IMPORTANCE OF WETLANDS IN SOUTH AFRICA

According to the definition in the National Water Act (No 36 of 1998) a wetland is a: "land that is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or land that is periodically covered with shallow water and usually inhabited by hydrophytic vegetation". The definition according to the Ramsar Convention is more specific: "areas of marsh, fen, peatland or water, whether natural, artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Cowan, 1995).

Wetlands are crucial to our national economy and the well being of all South Africans. They perform a crucial role in managing water due to the presence of dense strands of reeds, rushes and other emergent plants. They improve water quality by breaking down, removing, using or retaining nutrients, organic waste and sediment carried to the wetland with runoff from the catchment. They also reduce severity of floods downstream by retaining water and releasing it during drier periods thereby helping to prevent soil erosion. They recharge groundwater, potentially reducing water shortages during dry spells. Wetlands provide food and other products, such as commercial fish and shellfish, for human use. They promote a diverse number and types of animals. Wetlands provide fish and wildlife, including numerous rare and endangered species with food habitat, breeding grounds, and resting areas. Furthermore, wetlands increase opportunities for recreation e.g. bird watching, waterfowl hunting, photography and outdoor education.

Unfortunately wetlands also have negative characteristics such as: providing habitats for human diseases (e.g. malaria and bilharzias); contributing to loss of water through high evapotranspiration rates; interfering with access to water; and in some cases can be aesthetically unpleasant. Most residents consider wetlands a haven for vagrants and criminals.

Human impacts on wetlands are many and varied. They include:

- Alteration of wetlands for urban development, including housing, transportation, industry and recreation
- Alteration of wetlands for agricultural purposes, which include drainage of wetlands for the production of crops and planted pastures;
- Alteration of wetlands for forestry – often non-indigenous timbers are produced and alien plant growth is promoted
- Overharvesting – harvesting of any of the renewable resources of wetlands above their carrying capacity, will ultimately lead to a collapse of the stock e.g. overfishing and excessive removal of vegetation
- Burning of wetlands - wetlands are burnt by farmers and local communities for a variety of reasons; including wildlife management, enhancing stock grazing value, reducing fire risk and assisting in alien plant control (Kotze and Breen 1994)
- Pollution – effluent from agricultural and industrial lands, plus runoff from rural and urban communities may cause pollution of wetland systems
- And alteration of flow regime - many river systems have had their flow regimes altered due to excessive abstractions of additions of water.

The cumulative effect threatens the value of remaining wetlands and impacts the entire catchment - residents, plants, animals, water quality and quantity.

An estimated 50% of wetlands are lost in South Africa mostly through unwise development and poor land management. Apart from the land use impacts on wetlands (e.g. drains, agriculture in wetlands, erosion), three of the biggest threats to South Africa's wetlands are:

- lack of wetland management training;
- lack of people working in wetland conservation outside reserves;
- lack of co-operation between non-governmental organisations (NGO), government departments, land owners and the public. (Rennies Wetland Project, 2002)

Preservation and protection is the most economical way to "manage" wetlands. However, this is not an option for the many already altered wetlands. In these areas, restoration is often the best solution. Restoration is the process of returning the wetland system to an approximation of its predisturbed condition. This does not mean returning all altered wetlands to their unaltered state. It simply means replacing the lost values with newly created or "restored" wetlands. In other words, the goal is to restore the value rather than restore a particular site with a self-sustaining system that requires little human "management."

Currently, Working for Water and the Department of Environment Affairs and Tourism have formed a partnership to address wetland rehabilitation. In 2001 R30 million has been allocated towards wetland projects throughout the country. The projects include national priority wetlands, including existing and proposed Ramsar wetlands of international importance. (Working for Water, 2002). Rehabilitation work includes gabion construction, the removal of invasive alien plants, surveying of flood irrigation furrows, construction and placing of grass bale gabions and levelling of drainage furrows.

1.3 AIMS/OBJECTIVES

In order to address the issues posed, i.e. to determine the effects of wetlands on water quality and invertebrate biodiversity, two study areas were chosen in the Klip River catchment to determine whether wetlands have an effect on water quality and invertebrate biodiversity. These two wetlands are the Klip River and Natalspruit wetlands.

The objectives of this study were:

a) To determine if there is a change in water quality due to water flowing through the Klip River wetland.
b) To determine if there is a change in water quality due to water flowing through the Natalspruit wetland.

1.4 WATER QUALITY

Water quality is defined in DWAF (1996) as the term "used to describe the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of the health integrity of aquatic systems."
Samples were therefore analysed monthly for conductivity, dissolved oxygen, pH, temperature, aluminium, chloride, fluoride, iron, manganese, sodium, nitrate, ammonia, sulphate, phosphate, and chemical oxygen demand. Faecal coliforms were analysed only at the output sites.
Physical, chemical and microbiological data were analysed over a two year period, i.e. from 1 October 2000 to 30 September 2002. The summer SASS4 analyses for the two wetlands and the reference site were carried out in February/March 2001. The winter SASS4 and the reference site analyses were carried out in June/August 2001. Rand Water Analytical Services completed all the analyses.

1.5 STUDY AREA

1.5.1 Klip River wetland

Description

The first study area is situated on the Klip River, at Olifantsvlei, Lenasia, Witwatersrand (Figure 1.2), at coordinates 26°20'S – 27°55'E (800 ha). The Klip River, before it enters the wetland is impacted by mining, industries, and informal settlements. Three of Johannesburg Water waste water treatment works (WWTW), namely Olifantsvlei, Goudkoppies and Bushkoppies are found in this sub-catchment.

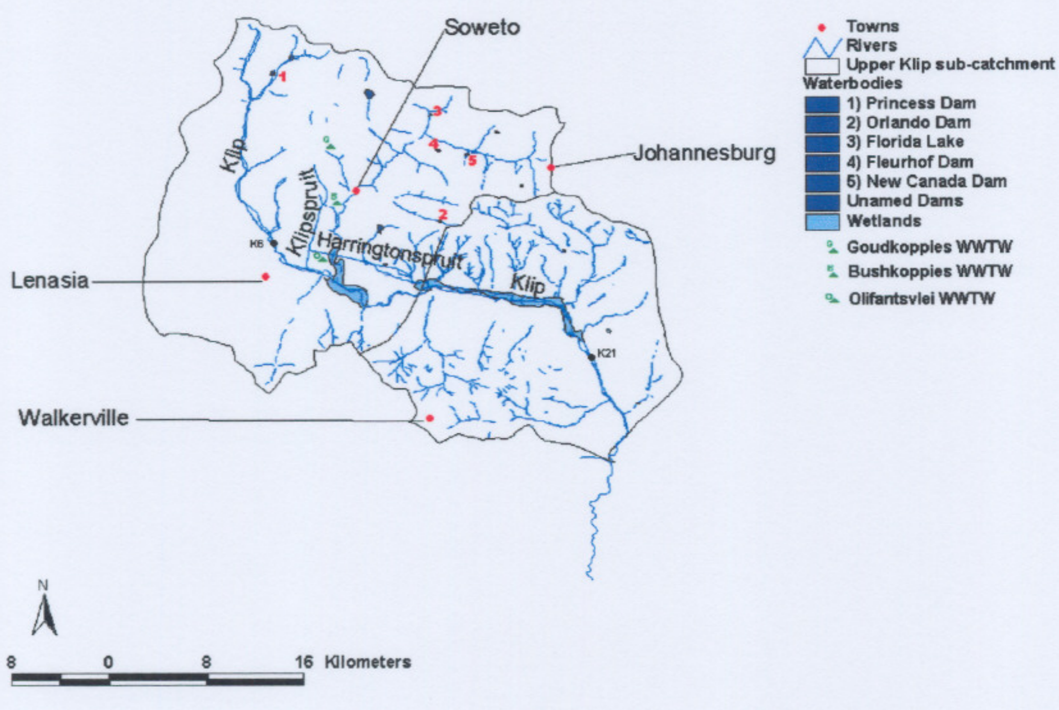

Figure 1.2 Rivers, wetlands, impoundments and sewage works in the Upper Klip catchment (updated from WGS84 GEOGRAPHIC, 2002).

One input and one output site (Figure 1.2) was chosen for each wetland. The input site chosen was at K6 (Klip River at Potchefstroom Road) with coordinates, 26°17.36' S and

27°50.15' E (Figure 1.3). The output site chosen was at K21 (Klip River weir at Zwartkoppies farm) with coordinates 26°24.02' S and 28°04.48' E (Figure 1.4).

Figure 1.3: Klip river Wetland input site - K6 (Klip River at Potchefstroom Road) facing downstream.

Input site K6 is impacted on from the source water areas of the Klip River in eastern Krugersdorp, from western Roodepoort and western Soweto. Past mining activities, urban development and the introduction of squatter camps have severely decreased the quality of the water entering the wetland at K6. Informal settlements in the Soweto and Eikenhof areas are increasing in size and number and are the main source of diffuse pollution in the area. An important point to note is that not all water entering at K6 passes through the wetland. Some water runs parallel to the wetland thus not being impacted on by the wetland. This should be taken into consideration when analysing the data.

The disused East Champ D'or gold mining land in eastern Krugersdorp, south of Main Reef Road, occurs near the source of the Upper Klip. There is currently only one operating gold mine area in the area, which is Durban Roodepoort Deep (DRD). Underground mine water from the neighbouring Rand Leases Mine to the east is currently decanting into DRD (Davidson, 2000). Industrial areas that occur upstream of K6 include parts of the Chamdor industrial area, Factoria and Manufacta.

Downstream of K6, the Klip River is impacted upon by western Johannesburg, Soweto, Lenasia and Eldorado Park. The wetland areas intensify at the foot of the Klipspruit where it joins the Klip River. Further east, the disused mining area of the Consolidated Main Reef Gold Mine, the defunct Robinson Deep Gold Mine and the disused Crown Mines are present. Mine dumps in these areas are being reworked and reclaimed by Central Gold Recovery (Bohlweki, 1999) The Upper Klip sub-catchment has an expanding number of manufacturing and service industries as well as a number of closed industrial sites that still cause pollution. The existing industrial zones in the area are, Industria, Devland, Nancefield, Chrisville, Booysens, Selby, Ophirton, Newtown and Amalgam. Hippo Quarries is also found in the Upper Klip sub-catchment area. A number of agricultural plots occur in the Vlakfontein and Zuurbekom agricultural area. Farming activities in these areas are in the decline.

Three sewage works present are the Johannesburg's southern wastewater treatment works, namely, Olifantsvlei, Goudkoppies and Bushkoppies. There are a number of informal domestic waste sites lining the banks of the Klip River as well as at defunct mining areas. Formal waste sites include the Marie Louise waste disposal site located on the mining land adjacent to Dobsonville Road, the Goudkoppies sludge landfill site at the Goudkoppies wastewater treatment works and the Robinson Deep solid waste site. The Ennerdale landfill site is found in the oustkirts of Lawyley near Lenasia. A now closed solid waste site is located at the head of the Diepkloofspruit near Meredale.

Impoundments or dams are confined mainly to the upper reaches of the catchment and are mostly man-made structures associated with earlier mining activities. These impoundments are predominantly used for recreational purposes. The impoundments within the Upper Klip sub-catchment include: Princess Dam, Orlando Dam, Florida Lake, Fleurhof Dam, New Canada Dam, and a few unnamed dams. (Figure 1.2) The tributaries of the Klip River in the area include: Klipspruit, Fordsburg Canal, Robinson Canal, Russell Stream, Diepkloofspruit, Harringtonspruit, Bloubosspruit and Glenvistaspruit.

In the Upper Klip sub-catchment there are no permitted discharges from mines, although illegal discharging may be occurring. Permitted discharges by DWAF are allowed only from Bushkoppies and Olifantsvlei WWTWs. Goudkoppies WWTWs has a landfill site, as mentioned previously, and discharge their effluent to the Bushkoppies WWTWs.

Figure 1.4: Klip River Wetland output site - K21 (Klip River weir at Zwartkoppies farm) facing upstream.

1.5.2 Natalspruit Wetland

Description

This study area is situated from the lower Elsburgspruit to the Natalspruit River, Witwatersrand (Figure 1.5), with coordinates, 26°25'S – 28°10'E (400 ha). The Natalspruit River, before it enters the wetland, is mostly impacted by mining, e.g. East Rand Proprietary Mine (ERPM). It is also impacted by three of ERWAT's sewage disposal sites: Rondebult, Dekema and Vlakplaats. Dekema and Vlakplaats discharge their effluents close to the output sites.

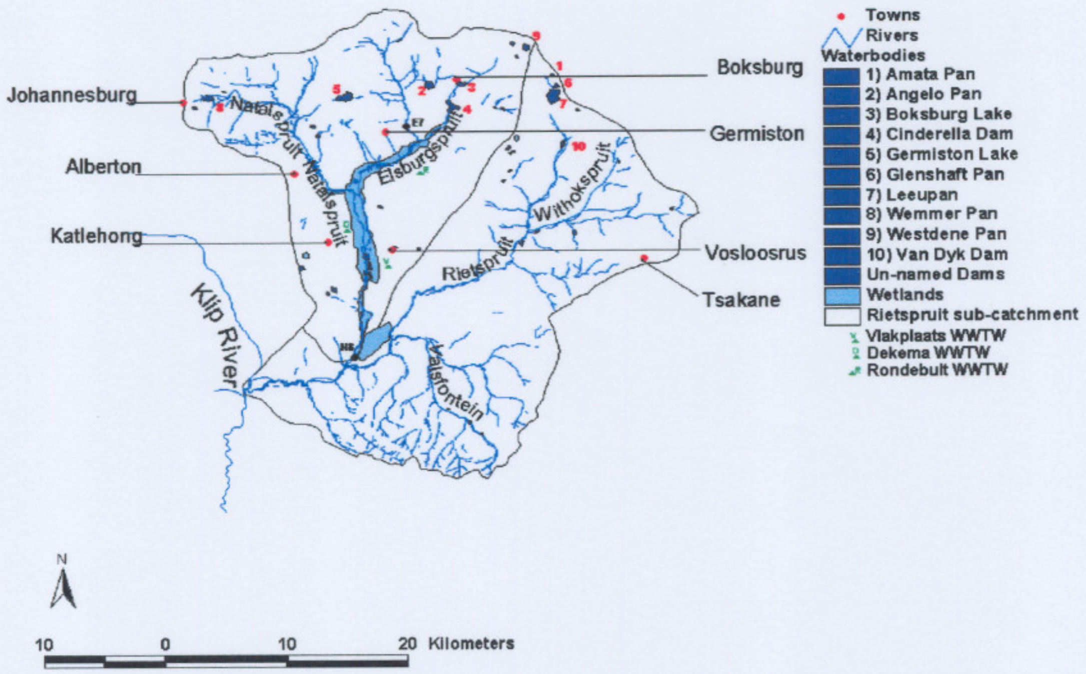

Figure 1.5: Rivers, wetlands, impoundments and sewage works in the Rietspruit catchment (updated from WGS84 GEOGRAPHIC, 2002).

One input and one output site (Figure 1.5) were chosen for each wetland. The input site chosen was at E7 (Elsburgspruit at Elsburg town) with coordinates, 26°15.631' S and 28°12.540' E (Figure 1.6). The output site chosen was at N8 (Natalspruit at Heidelberg road) with coordinates 26°25.564' S and 28°09.881' E (Figure 1.7).

Figure 1.6: Natalspruit Wetland input site E7 (Elsburgspruit at Elsburg town) showing upstream on the left and downstream on the right.

The input site E7 occurs in the headwaters of the Elsburgspruit at Elsburg town downstream of the Elsburg Dam. The headwaters of the Elsburgspruit are found in Germiston and Boksburg. The Elsburgspruit joins the Natalspruit which stretches from Alberton to confluence at the south of Wadeville. The Natalspruit then links up to the Reitspruit. The Rietspruit then confluences with the Klip River approximately 30 km above the confluence with the Vaal River (Figure 1.5). An important point to note with regards to the Natalspruit wetland is that it does not run continuously from the input to the output point. There is a break in the wetlands downstream of the Vlakplaats WWTWs, with a clearly defined stream running through the wetland for a short period (Viljoen *et al*, 1985). This must be taken into consideration when analysing the data.

E7 is impacted mostly by mining i.e. ERPM, which is still in operation. There are two mine effluent discharge points from the ERPM gold mine. Firstly, water from the South West vertical shaft is pumped to a plant where it is reused and some overflow is discharged to the Elsburgspruit. Secondly, overflow water from the Hercules shaft is discharged into Angelo Pan.

E7 is also impacted on from industries in the area. Upstream of E7 is mainly impacted on by the Germiston area. Numerous industrial zones occur downstream of E7. These include City Deep, Benrose, Denver, Heriotdale, Rosherville, Driehoek and Alrode which all drain into the Natalspruit downstream of E7 when the Elsburgspruit joins the Natalspruit. Industrial impacts from Wadeville occur immediately downstream of E7.

Although industrial effluent from Boksburg enters the Blesbokspruit, the stormwater from Boksburg flows into the Rietspruit sub-catchment just downstream of E7, so discharges into the stormwater drains from Boksburg can impact downstream of E7 as well. Large industries in the area include Scaw Metals.

The Rondebult Bird Sanctuary occurs in the Elsburgspruit wetlands. The Natalspruit flows through Alberton, Germiston, Vosloosrus, Kathlehong and Tokoza. These areas have both formal and informal settlements, with informal settlements concentrated at the output point of the wetland (Figure 1.7).

Figure 1.7: Natalspruit Wetland output site N8 (Natalspruit at Heidelberg road) facing upstream.

Numerous small water bodies both natural (vlei areas) and man-made (recreational, farm and mine dams) are scattered across the sub-catchment. The named impoundments in the area are: Amata Pan, Angelo Pan, Boksburg Lake, Cinderella Dam, Germiston Lake, Gelshaft Pan, Leeu Pan, Wemmer Pan, Westdene Pan, Van Dyk Dam and a few unnamed dams (Figure 1.5). The Klippoortjie agricultural lots are located in the upper reaches of the Natalspruit, between the Elsburgspruit and the Rietspruit. Sewage works in the area include ERWAT's Rondebult WWTW, Dekema WWTW and Vlakplaats WWTW. These are the only permitted discharges into the catchment.

1.6 REFERENCES

BOHLWEKI. 1999. Development of a water quality management plan for the Klip river catchment. Phase1: situation Analysis. Bohlweki Environmental (Pty) Ltd, Stewart Scott (Pty) Ltd), Pulles Howard and De Lange Incorporated.

COWAN, G.I. 1995. Wetlands of South Africa. SA Wetlands Conservation Programme series. Department of Environmental Affairs and Tourism. South Africa

COETZEE, M.A. 1995. Water pollution in South Africa: Its impact on wetland biota. In: GI Cowen (Ed), Wetlands of South Africa. Department of Environmental Affairs and Tourism. South Africa.

DAVIES, B. and DAY, J. 1998. Vanishing Waters. University of Cape Town Press, Cape Town, South Africa. 487pp.

DAVIDSON, C. 2000. Catchment diagnostic framework for the Klip River Catchment, Vaal Barrage, October 1998 - September 1999. University of Witwatersrand, Witwatersrand, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). 1999. Development of a Water Quality Management Plan for the Klip River Catchment. Phase 1: Situation Analysis. Draft Final Report. Pretoria, South Africa.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). 1996. South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems. First Edition. Pretoria, South Africa.

GOPAL, B. 2003. Wetlands, agriculture and water resource management: The need for an integrated approach. International Journal of Ecology and Environmental Sciences 29 470-540.

KOTZE, D.C. and BREEN, C.M. 1994. Agricultural land-use impacts on functional values. WRC Report No 501/3/94, Water Research Commission, Pretoria.

KOTZE, P.J. 2002. The Ecological integrity of the Klip River and the Development of a sensitivity weighted fish index of biotic integrity (SIB). Faculty of Natural Sciences. Rand Afrikaans University. Johannesburg. South Africa.

RAND WATER. 1998. The Socio-Economic Value of Wetlands in Highly Industrialised Catchments: Development of a Programme for the Klip River Catchment. Vol. 2 no. 1. 64 pp. Rand Water Head Office, Rietvlei, South Africa.

RENNIES WETLAND PROJECT. 2002. http://psybergate.com/wetfix/

RUSSELL, W. 1998. The cost of farmland degradation. In: Wrussell (Ed), Conservation of Farmland in Kwazulu-Natal. Department of Agriculture and Environmental Affairs, South Africa.

SCOTT, R. 1995. Flooding of Central and East Rand Gold Mines: An investigation into controls over the inflow rate, Water Quality and the Predicted impacts of Flooded Mines. WRC Report No. 486/1/95, Water Research Commission, Pretoria.

VILJOEN, F.C., PHILLIPS, A.L., CHRISTODOULOU, L.S. AND HAYNES, R.E. 1985. An input output study of various constituents in the water after passage through a section of the Natalspruit wetland. Report no. 85/1. Rand Water. Johannesburg. South Africa.

WGS84 GEOGRAPHIC. 2002. Topographical Maps.

WORKING FOR WATER. 2002. http://www.dwaf.gov.za/wfw/Wetlands/

Chapter 2

Selected physical characteristics

2.1 INTRODUCTION

Wetland functions provide a number of societal values. One of the most important is the potential of wetlands in maintaining or improving water quality in downstream areas of the catchment, as they perform a variety of biogeochemical functions, including sediment deposition, nitrogen and phosphorus removal, and transformation of inorganic nutrients to organic forms. Riparian wetlands are generally considered to have the most important water quality role in catchments, due to their strategic location between upland and aquatic ecosystems. Nutrient removal and storage capacity in wetlands is controlled by the interaction of a number of physical, chemical and biological processes in the soil and biota. The net result of these processes determines the potential of a wetland to serve as a filter or sink for nutrients (De Busk, 1999). The monitoring of physical, chemical, and biological characteristics of wetlands is done to assess their functional health and the condition of the surrounding catchment.

The physical characteristics that were analysed in this chapter include: conductivity (mS/m), pH, dissolved oxygen (mg/l), suspended solids (mg/l) and temperature (°C). These characteristics were chosen for the study because they were chosen by members of the Klip River Forum as important variables to assess the Klip River catchment as a whole. These characteristics are assessed according to the Klip River Forum instream Water Quality guidelines (KF). These guidelines are determined by the analysis of background data in the Klip River catchment. It is then further reviewed by the stakeholders (DWAF, municipalities, industries, interested and affected people) at the Klip River Forum who make the final decision of the guideline ranges. The South African Water Quality guidelines, Volume 7: Aquatic Ecosystems (DWAF) is included for reference (Appendix A12). The KF guideline values are placed next to the characteristic below and are coloured according to their ranges. The Ideal range (blue) is found in the left. The Acceptable range (green) is found second and the Tolerable range (yellow) is found third. The Unacceptable range (red) is found in the right. No value is indicated in grey.

2.1.1 Conductivity (mS/m)

<80	80-100	100-150	>150

Conductivity is the ability of a solution to conduct an electric current. In solutions the current is carried by cations and anions. The conductivity reading of a sample will change with temperature. Conductivity measurement is an extremely widespread and useful method, especially for quality control purposes as it provides an estimation of the total number of ions in a solution. Conductivity measurements cover a wide range of solution conductivity from pure water at less than 1 x 10-7 S/cm to values of greater than 1 S/cm for concentrated solutions. Changes in conductance measurements can be an indicator of perturbations (e.g., sediment deposition, nutrient input) to a wetland system. Wastewater, industrial and domestic effluents often contain high amounts of dissolved salts. High salt concentrations in effluents can increase the salinity, which may result in adverse ecological effects on the aquatic biota (Fried, 1991). For this reason, conductivity can serve as a useful indicator of water quality.

2.1.2 pH

6.0 – 9.0		<6.0;>9.0

pH is an abbreviation of "pondus hydrogenii" and expresses the concentration of hydrogen ions. The definition based on hydrogen activity is: $pH = -\log_{10} a_{H+}$

pH represents the intensity of the acid or alkaline condition of a solution. A pH of 7 indicates neutral conditions on a scale of 0 (acidic) to 14 (alkaline). Many of nature's processes are dependant on pH. pH is essential for some enzymatic processes to occur. It is also important for certain living organisms of whose biological fluids function optimally at particular pH ranges. The pH of water in a wetland strongly affects the biogeochemical processes that are essential to the proper functioning of a wetland system. Furthermore, the biota (flora and fauna) associated with a wetland is affected by fluctuations in the chemistry of the system; especially through changes in nutrient form and availability.

The pH is affected by factors such as temperature, the concentration of inorganic and organic ions and biological activity. The pH may also affect the availability and toxicity of constituents such as trace metals, non-metallic ions such as ammonium, and essential elements such as selenium. Industrial activities generally cause acidification rather than alkalinisation of rivers. Acidification is normally the result of three different types of pollution, namely (a) low-pH point-source effluents from industries, such as pulp and paper and tanning and leather industries (b) mine drainage, which is nearly always acid, leading to the pH of receiving streams dropping to below 2 and (c) acid precipitation resulting largely from atmospheric pollution caused by the burning of coal (produces sulphur dioxide) and the exhausts of combustion engines (produces nitrogen oxides). Both sulphur oxides and nitrogen oxides form strong mineral acids when dissolved in water (DWAF, 1996).

2.1.3 Temperature (°C)

No range identified

Temperature regimes control the rates of important biological processes, such as those involving organic matter decomposition, and consequently, accumulation of peat in the wetland. On a large scale, the increasing temperatures globally are likely to result in a warming of water temperatures in lakes and rivers, the greatest effect of which would be at high latitudes where biological productivity would increase and in low-latitude boundaries of cold- and cool-water species ranges and where extinction would be greatest (IPCC, 1996). Rare and endangered plant and animal species with sensitivity to small temperature changes often have no alternative habitat. Besides the warming effect, Talling and Lamoalle (1998) have pointed to the possibility of increased mixing of stratified water bodies due to increased storm activity, which could result in the large-scale die-off of fish species.

Anthropogenic sources which result in changes in water temperature include: discharge of heated industrial effluents; discharge of heated effluents below power stations; heated return flows of irrigation water; removal of riparian vegetation cover, and thereby an increase in the amount of solar radiation reaching the water; inter-basin transfers; and discharge of water from impoundments (DWAF, 1996).

2.1.4 Dissolved Oxygen (mg/l)

	>6	5-6	<5

Dissolved Oxygen (DO) in water is formed when oxygen is added to the water by the process of diffusion or as a by-product of the photosynthetic process in aquatic plants. Both animals and plants need oxygen for the process of respiration. The amount of DO that can be present in water is influenced by the temperature. Colder water can hold more dissolved oxygen than warmer water. The process of decay requires oxygen and some chemicals will bind to the dissolved oxygen. The amount of DO present in the water column and soil substrate strongly regulates the productivity and level of biological activity within a wetland system. Changes such as sedimentation and dense algal blooms tend to lower the level of DO in wetland systems. Low levels of DO usually indicate serious pollution.

The maintenance of adequate DO concentrations is critical for the survival and functioning of the aquatic biota because it is required for the respiration of all aerobic organisms. Therefore, the DO concentration provides a useful measure of the health of an aquatic system. Reduction in the concentration of DO can be caused by several factors: (a) Resuspension of anoxic sediments, as a result of river floods or dredging activities, (b) turnover or release of anoxic bottom water from a deep lake or reservoir, (c) The presence of oxidisable organic matter, either of natural origin (i.e. detritus) or originating in waste discharges, (d) the amount of suspended material in the water affects the saturation concentration of DO, either chemically, through the oxygen scavenging attributes of the suspended particles, or physically through reduction of the volume of water available for solution (DWAF, 1996).

2.1.5 Suspended solids (mg/l)

<20	20-30	30-55	>55

Suspended solids is the measure of the amount of material suspended in water. This includes a wide range of sizes of material, from colloids 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, as in wetlands, suspended solids settle out. Increases in suspended solids may also result from anthropogenic sources, including (a) discharge of domestic waste, (b) discharge of industrial effluents (i.e. pulp/paper mill, chin-clay, and brick and pottery industries), (c) discharge from mining operations and, (d) physical changes from the road, bridge and dam construction (DWAF, 1996).

2.2 MATERIALS AND METHODS

2.2.1 Sample Analyses

Two 1 litre plastic bottles with screw caps were used to collect the water samples for chemical analysis. The sample depth was 15-30 cm below the water surface. The sample bottle was opened and placed with the open neck facing upstream, away from the hand of the sampler. The container was filled entirely before removing it from the water. The screw cap was replaced and tightened so as to avoid trapping air bubbles. Sample bottles were transported in a cooler box to the laboratory. Randwater monitored the input points twice a month, while the output points were monitored every week (Appendices A1 and A2). Conductivity, pH and temperature were determined by the Metrohm autotitrate method. One hundred ml of unfiltered sample was placed in the Metrohm instrument and the results were generated by the instrument and printed. Dissolved Oxygen was determined by manual titration until endpoint was reached.

Suspended solids are determined by the Gravimetric analysis. A 0.45 µm filter paper is weighed and the mass recorded. After 100 ml of sample is passed through the filter paper, it is placed in an oven at 105 °C. The filter paper is weighed again and the difference between the two masses is used to determine the amount of suspended solids present.

2.2.2 Statistical Analyses

The z-test was used to statistically analyse all the data. (Appendix A3). The z-test is a statistical test used in inference. It is used to determine whether two series of measurements come from a distinct distribution. The z-test was used instead of the t-test as a large sample size was used and the means and standard deviation were known. The z-test is calculated as follows:

$$z = \frac{\text{Mean}_{input} - \text{Mean}_{output}}{\sqrt{\frac{SD^2_{input}}{n_{input}} + \frac{SD^2_{output}}{n_{output}}}}$$

Significant differences were noted if the z-value was found to be < -1.96 or $> +1.96$. If the z-value was found to be within this region i.e. $-1.96 <= z <= +1.96$ then no significant differences were noted between the two means.

2.2.3 Seasonal Variation

The input and output points for both the Klip River and Natalspruit wetlands were divided into two sections based on seasons to determine seasonal variation. (Appendices A4 and A5). The input and output site of each wetland was divided into spring and summer, and autumn and winter sections to determine variation. The spring and summer section included months September, October, November, December, January and February. The autumn and winter section included months March, April, May, June, July and August. Two means were determined from these two sections and they were analysed according to the z-test mentioned above.

2.2.4 Percentage Differences

Percentage difference calculations were used to compare the two wetlands, in order to determine which wetland was functioning more efficiently. As actual differences between the Klip River input and output sites, of the wetland, and the Natalspruit input and output sites, of the wetland, could not be compared the differences were expressed as percentages. It was determined as follows between the input and output sites per wetland:
Percentage Difference = (Maximum value – Minimum value)/Maximum value] x 100
Significant differences were noted as per Appendix A3 and incorporated into Table 2.1 to add more value to the data. Variables that showed significance differences, either improvements or deteriorations were noted. Comparisons between the two wetlands, showing either greater improvement or lesser deterioration were also indicated to determine which wetland was functioning more efficiently.

2.3 RESULTS

2.3.1 Klip River Wetland

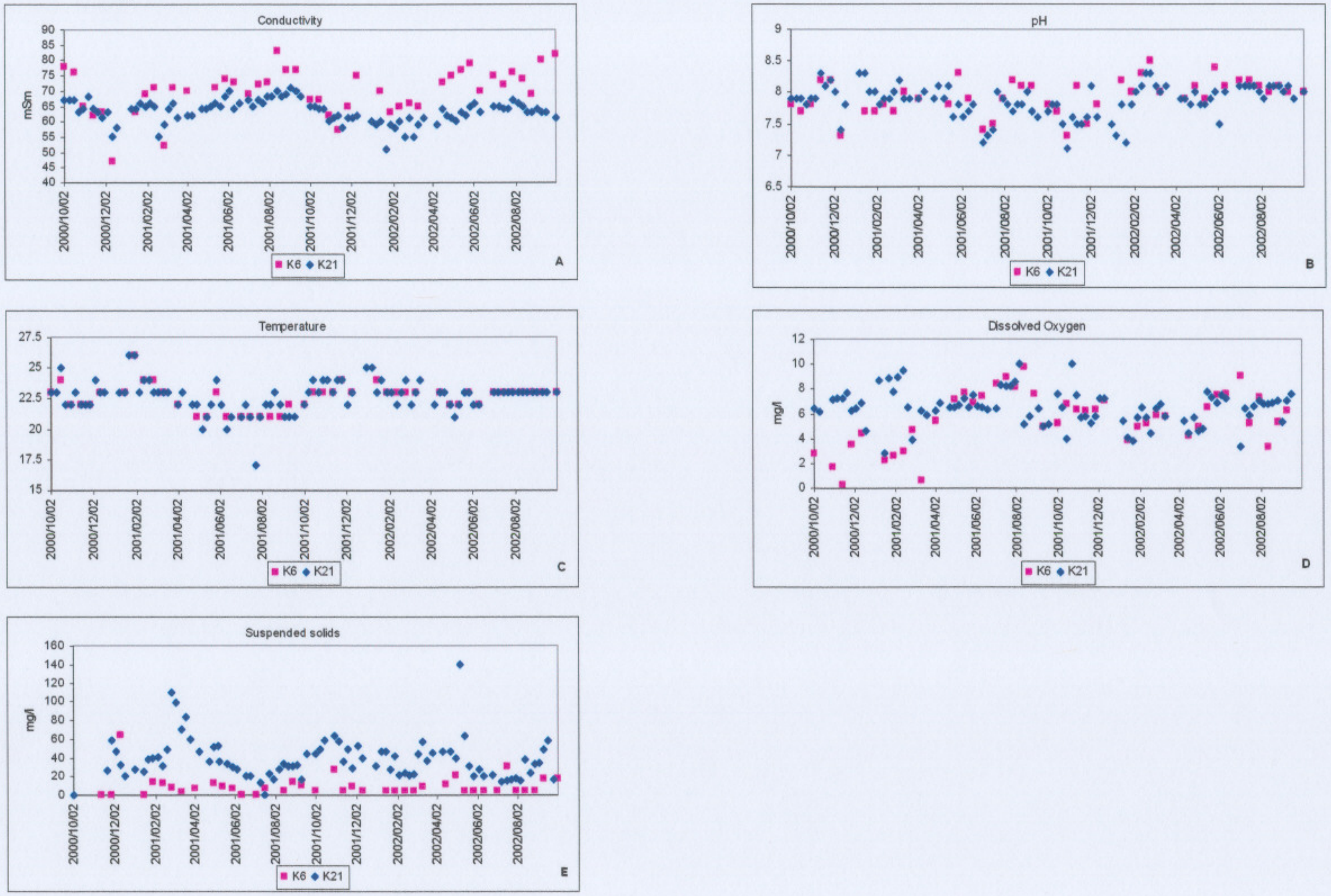

Figure 2.1 Conductivity (A), pH (B), Temperature (C), Dissolved oxygen (D) and Suspended solids (E) for the Klip River Wetland at the input (K6) and output (K21) sites.

2.3.2 Natalspruit Wetland

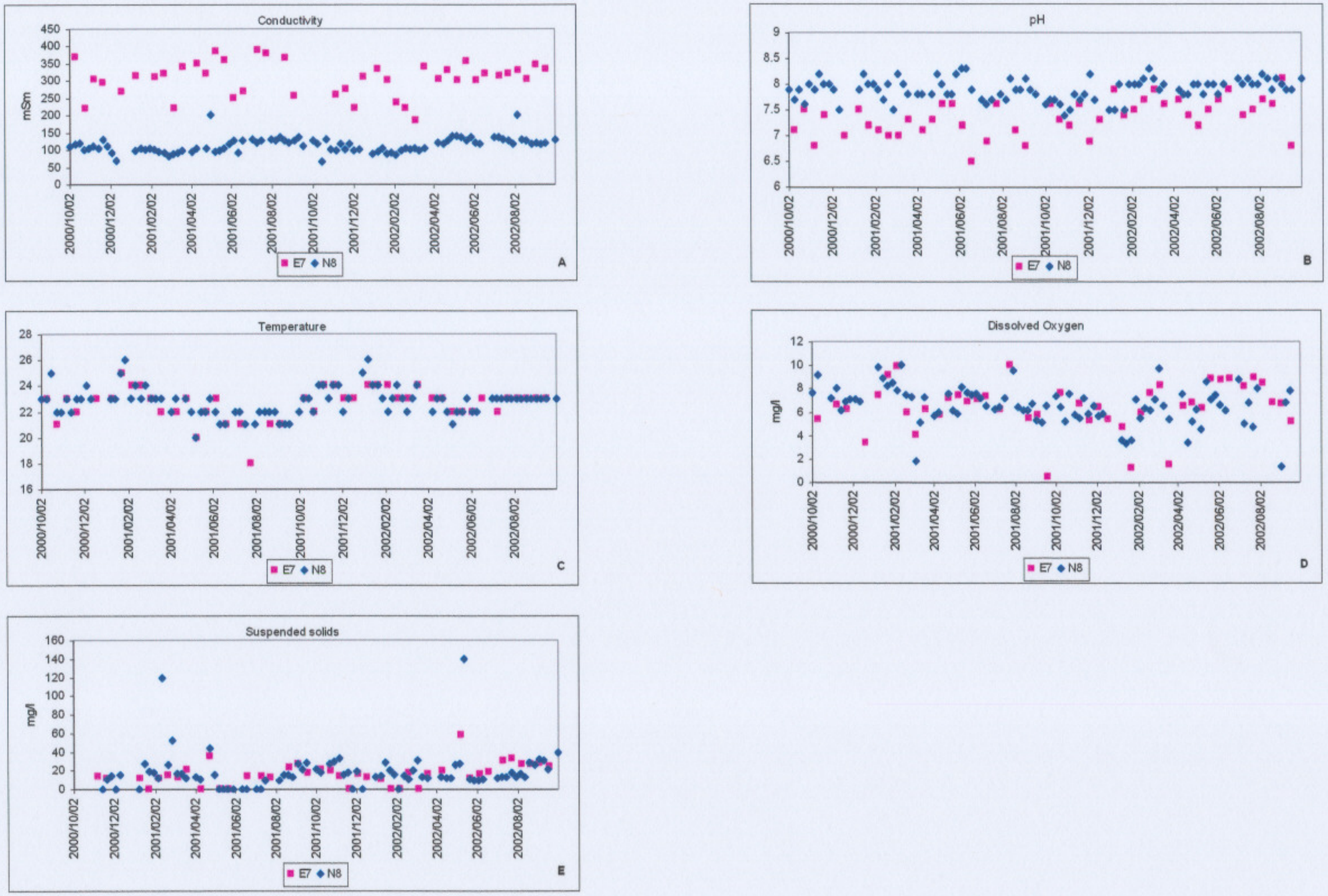

Figure 2.2 Conductivity (A), pH (B), Temperature (C), Dissolved oxygen (D) and Suspended solids (E) for the Natalspruit Wetland at the input (E7) and output (N8) sites

2.3.3 Seasonal Variation

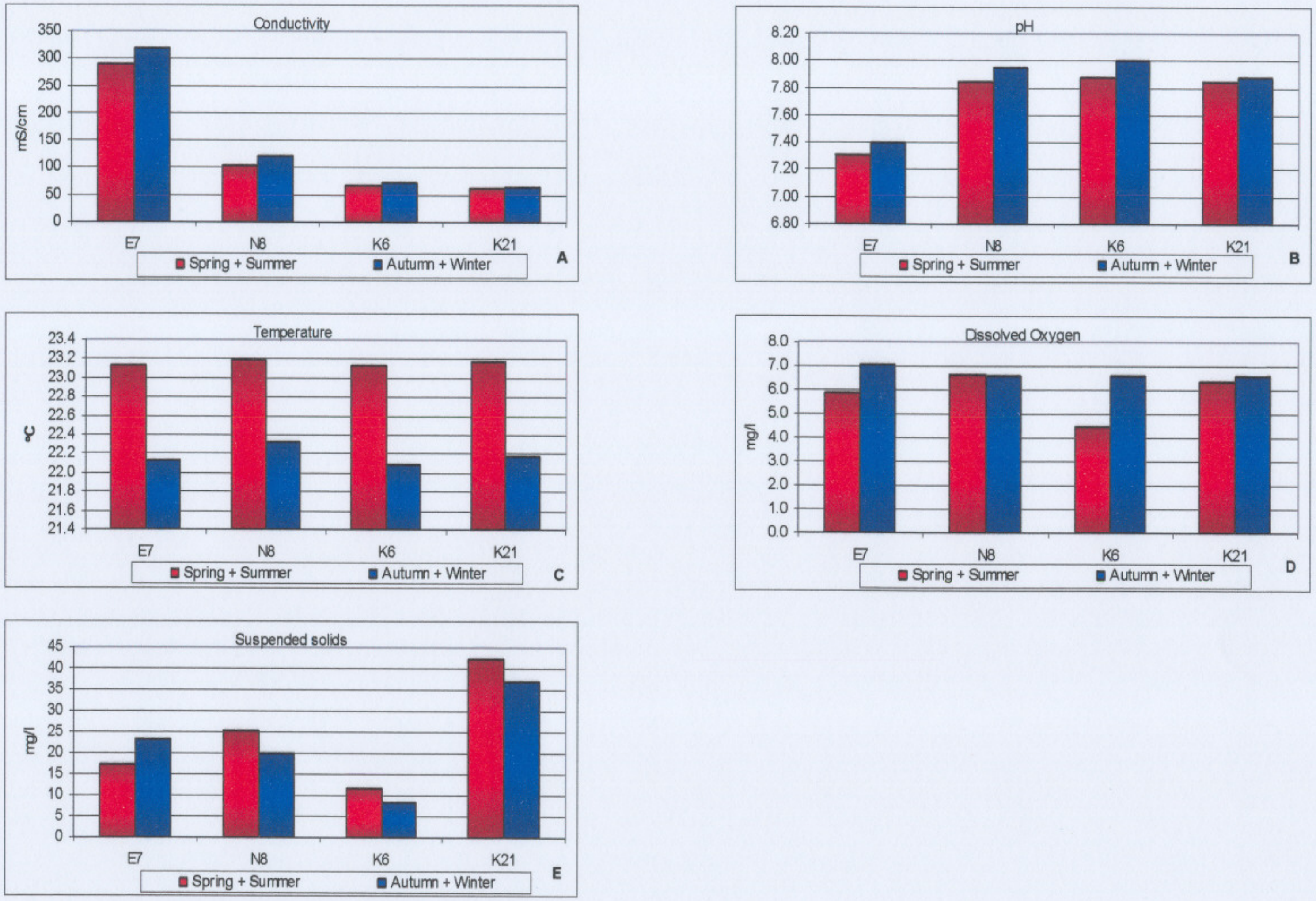

Figure 2.3 Seasonal variation for Conductivity (A), pH (B), Temperature (C), Dissolved oxygen (D) and Suspended solids (E) for the Klip River (input K6 and output K21) and Natalspruit (input E7 and output N8) Wetlands.

2.3.4 Comparison between Klip River and Natalspruit Wetlands

Table 2.1 Percentage differences between input and output means of the Klip River and Natalspruit Wetlands for selected physical characteristics.

Variable	Klip River Wetlands				Natalspruit Wetlands			
	Input	Output	%Diff	I / D	Input	Output	%Diff	I / D
	K6	K21			E7	N8		
Conductivity (mS/m)	70.00	63.34	9.52	I	305.48	112.56	63.15	I
PH	7.94	7.86	0.92		7.36	7.90	6.89	I
Temperature (°C)	22.62	22.68	0.28		22.62	22.77	0.63	
DO (mg/l O_2)	5.55	6.48	14.27	I	6.50	6.60	1.53	
Suspended solids (mg/l)	9.93	39.47	74.84	D	20.52	22.57	9.09	

(grey) No significant difference between the input and output means
I Improvement
D Deterioration
(yellow) Greater improvement / Lesser deterioration

2.4 DISCUSSION

Klip River Wetland

Significant differences ($-1.96<=z<+1.96$) were found between the input and output values for the following physical parameters: conductivity, dissolved oxygen and suspended solids (Appendix A3). There was no significant difference for the pH. Reasons for these differences can be attributed to many factors, which are discussed below.

Conductivity, as shown in Figure 2.1a, indicates that although both the input and output sample points are within the Ideal range of the KF guidelines, there is a significant improvement in the conductivity values of the water exiting the wetlands. As conductivity is an indication of ions entering the river from sewage works, urban runoff, agricultural runoff and mining, the higher conductivity values at the input of the wetlands can be due to the mining runoff north of Soweto; associated industrial areas as mentioned in Chapter 1, including more prominently Nancefield and Devland; as well as sewage and urban runoff from Soweto and its associated informal settlements. The water quality of the Klip River after passing through the wetlands improved significantly.

The DO concentration provides a useful measure of the health of the aquatic systems as adequate DO concentrations are critical for the survival and functioning of the aquatic biota because they are required for the respiration of all aerobic organisms. Therefore, a significant increase in DO in the wetlands is a definite improvement of the water quality. There is an improvement for the DO from the Tolerable range at the input point to an Acceptable range at the output site of the KF guidelines. Reasons for higher DO concentrations can be attributed to many factors. One of which may be the decrease in flow rates once the water enters the wetland, which results in a higher retention time allowing the inflow into the wetland more contact time with the wetland vegetation.

There is a significant increase in suspended solids as the water exits the wetland, as can be seen in Figure 2.1e. This increase in suspended solids is a deterioration in water quality and is due to the WWTW's effluent discharge as well as industrial and quarry effluent. The suspended solids have moved from the Ideal range at the input point to the Tolerable range at the output point. An increase in suspended solids can be attributed to the decrease in flow as the inflow at wetland results in the suspended particles settling in the wetland and not moving downstream as they would have in faster flowing water.

Natalspruit Wetland

Significant differences ($-1.96<=z<+1.96$) were found between the input and output values for the following physical parameters: conductivity and pH (Appendix A3). There was no significant difference for dissolved oxygen and suspended solids. There was an improvement on conductivity from the Unacceptable range in the input point to the Tolerable range of the KF guidelines. High conductivity values at the input point of the wetlands can be due to intensive mining occurring upstream of the input point. Also, the three WWTWs also contribute significantly to the high conductivity values. Significant decrease in conductivity can be due to less ions from industrial and WWTWs effluent being present in the wetland. The decrease in flow rate as the water enters the wetland results in there being a greater contact time between the effluents and the wetland plants and sediments. These reactions result in sediment deposition, nitrogen and phosphorous removal and transformation of inorganic nutrients to organic forms, which result in the removal of ions in the incoming water.

Although the pH values for the Natalspruit is still within the Acceptable range of the Rand Water guidelines, the z test does show that there is a significant difference in the pH over the time period of the study. The minimum pH value at the input point is 6.5 and maximum pH value is 8.1 showing that there is significant variation in the pH values. There is less variation at the output points with the minimum value being 7.4 and the maximum value being 8.3. The high variation at the input point is mainly due to the mining occurring upstream of the input point. Industrial effluents entering the rivers further aggravate the problem. The wetlands have a positive effect on the pH of the water as it neutralises the acidic pH of the water entering the wetland, resulting in a more neutral to alkaline pH for the water exiting the wetland.

Seasonal variation

For the Klip River wetlands in the spring and summer group significant differences (-1.96<=z<+1.96) were found to be between the input and output values for conductivity, dissolved oxygen and suspended solids. (Appendix A4). There was no significant difference for pH. Conductivity and DO showed a significant improvement, while suspended solids showed a significant deterioration in the spring and summer group.
For the autumn and winter group significant differences were found for conductivity and suspended solids. There were no significant differences for dissolved oxygen and pH. Conductivity showed a significant improvement while suspended solids showed a significant deterioration in the autumn and winter group. No seasonal variation was shown for conductivity and suspended solids as they showed no differences in either the hot or cold months. DO was the only variable that showed seasonal variability as it showed improvement in the spring and summer months as opposed to the autumn and winter months.

For the Natalspruit wetlands in the spring and summer group significant differences were found to be between the input and output values for conductivity, pH and suspended solids. (Appendix A5). There was no significant difference for dissolved oxygen. Conductivity and pH showed significant improvement while suspended solids showed a significant deterioration in the spring and summer months.
For the Autumn and Winter group significant differences (-1.96<=z<+1.96) were found for conductivity and pH. There were no significant differences for dissolved oxygen and suspended solids. Conductivity and pH showed significant improvement in the autumn and winter months. Suspended solids was the only variable that showed seasonal variability as it showed significant deterioration in the spring and summer months as opposed to the autumn and winter months.

For both the wetlands, both the input and output points showed an increase in conductivity over the autumn and winter values from spring and summer values (Figure 2.3a). This shows an increase in conductivity concentrations over winter. E7 shows the highest conductivity values, although significant differences were only noted for the Natalspruit wetlands.

Comparison between the Klip River and Natalspruit Wetlands

Although the Klip River wetland shows an improvement in two variables namely, conductivity and DO, with a higher percentage improvement for DO, the Natalspruit wetland shows a higher percentage improvement for both conductivity and pH (Table 2.1). The Klip River wetland also shows a deterioration in suspended solids thus resulting in the Natalspruit wetland being better able at improving the quality of the incoming water than the Klip River wetland. Reasons for the Klip River wetland being not as efficient as the Natalspruit wetland can be due to it being more negatively impacted upon by industries, mines and WWTWs. Also, the Klip River wetland has a diversion canal, so that not all the water entering at the input point passes through the wetlands, some flows through a canal. Thus, the water travelling through the canal is not being positively impacted upon by the wetlands.

2.5 REFERENCES

DE BUSK, W.F. 1999. Functional Role of Wetlands in Watersheds. Soil and Waterscience Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1996. South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems. First Edition. Pretoria, South Africa.

FRIED, J.J. 1991. Nitrates and their control on the EEC aquatic environment. In: Morrison, G., Fatoki, O.S., Persson L. and Ekberg, A. Assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Kieskamma River – pH, electrical conductivity, oxygen-demanding substance (COD) and nutrients. Water environment transport, Chalmers University of Technology, Goteborg, Sweden.

IPCC - INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 1996. Climate Change 1995 - Impacts, Adaptations and mitigation of climate change: scientific technical analysis. Contribution of Working Group II to the second Assessment Report of the IPCC. Cambridge University Press, Cambridge.

TALLING, J. AND LAMOALLE, J. 1998. Ecological dynamics of tropical inland waters. Cambridge University Press, Cambridge, 441 p.

Chapter 3

Selected chemical characteristics

3.1 INTRODUCTION

Wetlands not only regulate the quantity of water flow but also regulate its quality (Baker and Maltby, 1995). A wide array of chemical processes in wetlands interact to provide a natural filtering mechanism in the catchment to maintain or enhance downstream water quality.

The term "biogeochemical" refers to the partitioning and cycling of nutrients and other compounds between the biotic (living) and abiotic (non-living, such as soil minerals and organic matter) components of an ecosystem. Among the important biogeochemical functions and values provided by wetlands are sediment deposition, nitrogen and phosphorus removal and transformation or inorganic nutrients to organic forms. Wetlands are unique in that they are able to remove or sequester nutrients and toxic environmental contaminants. In this way, wetlands provide ideal conditions for settling of particulate matter, i.e. shallow water, low current velocity and the physical filtering action of plant stems and leaves.

The loading of nutrients to surface waters by WWTWs, informal settlements and industries can result in undesirable environmental and economic impacts to aquatic ecosystems. The fate of nutrients in wetlands is controlled by biogeochemical cycling in the soil and water, and by the capacity of the soil and vegetation to assimilate and store N and P (De Busk, 1999). Wetlands can filter or store these nutrients, which would otherwise flow into other groundwater or surface waters. Wetlands can store the nutrients on a short-term basis within wetland plant tissue or on a longer term basis in the substrate. Short-term storage of nutrients by the wetlands is beneficial because it keeps the high nutrient levels in the wetlands thus preventing them from accumulating downstream. Because a large portion of the wetland nutrient export is not immediately bioavailable, nutrient-related impacts in downstream surface waters, such as excessive growth of algae, may be greatly reduced or eliminated. Also, the wetlands can convert nitrogen to its gaseous state (denitrification), thereby removing it from the aquatic environment. Long-term storage of nutrients in the wetland sediments often occurs because of their shallow water, low current velocity and the physical filtering action of the wetland plants. This results in many toxic substances being stored or transformed to a less toxic state within the wetland sediment. However, nutrient-retention efficiency varies widely among wetlands. Much of this variability can be attributed to the environmental factors such as those related to climate, geomorphology and water source.

Wetlands can also function as transformers of nutrients from inorganic to organic forms. The nutrient transformation function of wetlands, coupled with their ability to buffer pulses of nutrients in the watershed by storing and slowly releasing nutrients to downstream waters, provides a significant measure of ecological stability to contiguous aquatic systems (De Busk, 1999).

The chemical characteristics that were analysed included: aluminum, chloride, fluoride, iron, manganese, sodium, nitrate, ammonia, sulphate, phosphate and chemical oxygen demand (COD). All guideline values are expressed as mg/l.

3.1.1 Aluminium (Al) (mg/l)

	<0.3	0.3 - 0.5	>0.5

Aluminium is the third most abundant element in the Earth's crust and constitutes 7.3% by mass. In nature, however, it only exists in very stable combinations with other materials (particularly as silicates and oxides). Aluminium is one of the principal particulates emitted from the combustion of coal, and aluminium fluoride is emitted from aluminium smelters. Industries using aluminium in their processes or in their products include the following: the paper industry, the metal construction industry, and the textile industry. (DWAF, 1996)

3.1.2 Chloride (Cl) (mg/l)

<50	50 - 75	75 - 100	>100

Chloride is found in most natural waters. The chloride ion (Cl^-) in lake water is commonly considered an indicator of human activity. The following contribute to an increase in chloride levels: aridity, return drainage from irrigation, sewage, drainage from oil wells, salt springs, and industrial waste. Increased levels of chloride will heighten the corrosive effects of water; combined with sodium, causes a salty taste. Water with excessive amounts of chloride can be very toxic to most plants (DWAF, 1996).

3.1.3 Fluoride (F) (mg/l)

0.19	0.19 – 0.7	0.7 – 1.0	>1.0

Fluoride occurs either as the F^- ion on its own or in combination with calcium, potassium and phosphates. It is rarely found as the free fluorine gas in nature. It is used in: the manufacture and use of insecticides, disinfecting brewery apparatus, fluxes used in the manufacture of steel, wood preservatives, glass and enamel manufacture, chemical industries and water treatment, where fluoride may be added for dental purposes. Increasing water temperature increases the toxic effects of fluoride, while increasing water hardness reduces toxic effects (DWAF, 1996).

3.1.4 Iron (Fe) (mg/l)

<0.5	0.5 – 1.0	1.0 – 1.5	>1.5

Iron is a metal often found in waters. It is particularly a problem in ground water supplies, where the water is acid and has passed through some iron bearing rock i.e. Sulphide ores, igneous, sedimentary and metamorphic rock. The dissolved iron usually takes the form of ferric sulphate, which at pH values above 3.0 may become hydrolised and form iron hydroxide. It is usually the occurrence of iron hydroxide rather than the iron itself that kills fish.

Iron is also released into the environment by human activities, mainly from the burning of coke and coal, acid mine drainage, mineral processing, sewage, landfill leachates and the corrosion of iron and steel. Various industries that also use iron in their processes, or in their products, include: the chlor alkali industry, the household chemical industry, the fungicide industry and the petro-chemical industry (DWAF, 1996).

3.1.5 Manganese (Mn) (mg/l)

<1	1 – 2	2 – 4	>4

Manganese is a gray-white metal, resembling iron. It is a hard metal and is very brittle, fusible with difficulty, but easily oxidised. Manganese is rather electropositive and combines with some non-metals when heated.

Soil sediments and metamorphic and sedimentary rocks are significant natural sources of manganese. Industrial discharges also account for elevated concentrations of manganese on receiving waters. Various industries use manganese, its alloys and manganese compounds in their processes, or in their products of which include the steel industry (in the manufacture of dry cell batteries), the fertiliser industry (manganese is used as a micro-nutrient fertiliser additive), and the chemical industry) in paints, dyes, glass, ceramics, matches and fireworks) (DWAF, 1996).

3.1.6 Sodium (Na) (mg/l)

<50	50 – 80	80 – 100	>100

An ion found in natural water supplies, and introduced to water in the ion-exchange water-softening process. Sodium compounds are highly soluble. Like the other alkali metals, sodium is a soft, light-weight, silvery white, reactive element that is never found unbound in nature. Sodium floats in water and decomposes water releasing hydrogen and forming hydroxide. Effluents rich in sodium contribute to the salt content in the receiving waters resulting in adverse ecological effects (Morrison *et al*, 2001).

3.1.7 Nitrate (NO_3) (mg/l)

<2	2 – 4	4 – 7	>7

A nitrate is any compound containing the nitrate group (such as a salt or ester of nitric acid) that can exist in the atmosphere or in water and that can have harmful effects on humans and animals at high concentrations. It is the most completely oxidised state of nitrogen found in water. High nitrate levels can occur naturally, but may indicate biological wastes in the water, run-off from heavily fertilised fields or industrial waste effluents. The presence of nitrate in water bodies arises mostly from the use of fertilisers in agriculture and any nitrate not taken up by crops is likely to be dissolved in rainwater and either percolates down into groundwater or runs off into streams (Rand Water, 1998).

3.1.8 Ammonia (NH_3) (mg/l)

<0.5	0.5 – 1.5	1.5 – 4.0	>4.0

Ammonia is a pungent colourless gaseous compound of nitrogen and hydrogen that is very soluble in water and can easily be condensed into a liquid by cold and pressure. Ammonia reacts with NOx to form ammonium nitrate. It is a product of microbiological decay of plant and animal protein. Presence of ammonia in surface waters usually indicates domestic or agricultural pollution, for example, animal waste runoff. The discharge of effluent streams containing animal and human excrement, agricultural fertilisers and organic industrial wastes are the major sources of ammonia which enter the aquatic systems (DWAF, 1996).

3.1.9 Sulphate (SO_4) (mg/l)

<200	200 – 350	350 – 500	>500

Sulphate is essentially a salt of sulphuric acid. Sulphate is a natural forming mineral When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals, or of atmospheric deposition. Point sources include sewage treatment plants and industrial discharges such as tanneries, pulp mills, and textile mills. Runoff from fertilised agricultural lands also contributes sulphates to water bodies (Davidson, 2000)

3.1.10 Phosphate (PO_4) (mg/l)

<0.2	0.2 – 0.5	0.5 – 1.0	>1.0

Phosphate is a salt of phosphoric acid. Phosphate is often a limiting reagent in many environments. Introduction of non-naturally occurring levels of phosphate to those environments causes an ecological disequilibrium, leading to booms in the population of some organisms and subsequent busts in the populations of others deprived of other nutrients or essential elements by the rapid growth and consumption by the booming population. Phosphates enter the water supply from domestic and industrial effluents, atmospheric precipitation, urban runoff, the drainage from agricultural land, in particular from land on which fertilisers have been applied. Phosphates are necessary for biological growth of aquatic plants, but too much phosphate causes excessive growth of aquatic plants and eutrophication of lakes (Rand Water, 1998).

3.1.11 COD (mg/l)

<15	15 – 30	30 – 40	>40

COD is the amount of oxygen consumed to completely oxidise the organic and inorganic compounds in water. Indirectly it measures the amount of organic compounds in water. The determination of the amount of organic pollutants found in surface water (e.g. lakes and rivers), makes COD a useful measure of water quality. The process of measuring COD causes the conversion of all organic matter into carbon dioxide. For this reason, one limitation of COD is that it cannot differentiate between levels of biologically active organic substances and those that are biologically inactive. COD is used to assess sewage or industrial discharges. It is therefore deemed to be an important variable for stream and industrial waste studies and the control of waste treatment plants by Standard Methods (1976).

3.2 MATERIALS AND METHODS

3.2.1 Sample Analyses

3.2.1.1 Inorganic Chemistry

Aluminium, Iron, Manganese and Sodium were determined by the Multi-Element Inductively Coupled Plasma – Atomic emission Spectrometry method.
Fluoride, Chloride and Sulphate were determined by the Ion chromatography method. The Metrohm 761 Compact IC - system A is used for the analysis. Ion chromatography operates in the polarity of an ionic stationary phase and the polarity of anionic mobile phase. In this method, chemical suppression is used, whereby the background conductivity is suppressed both chemically and electronically.

Ammonia concentrations of the water samples were determined using the Flow Injection Analyser (Photometric method) that is based on the reactions that are specific for ammonium ions. The results are expressed in mg l^{-1} N. The principle of the method entails the ammonia being heated with salicylate and hypochlorite in an alkaline phosphate buffer. An emerald green colour is produced which is proportional to the ammonia concentration. The colour is intensified by the addition of sodium nitroprusside. The absorbance of the reaction product is measured at 630 nm and is directly proportional to the original ammonia concentration. Ammonia interferences can occur in three possible ways. Firstly, calcium and magnesium ions may precipitate if present in sufficient concentrations. To prevent this problem, titriplex is added to the sample. Secondly, colour, turbidity and certain organic species may interfere. Turbidity is removed by manual filtration. And thirdly, samples may gain 0.8 mg l^{-1} N as NH_3 per hour from the air. This is prevented by the samples not being allowed to be open for extended periods of time.

Nitrate concentrations are determined by the hydrazine reductions of nitrate using the Flow Injection Analyser. The results are expressed as NO_3 mg l^{-1}. The principle of the method entails the nitrate being reduced to nitrite with hydrazine sulphate. The reduced nitrate is then determined by diazotising with sulphanilamide followed with N-(1-

naphthyl)-ethylenediamine dihydrochloride. The resulting water-soluble dye has a magenta colour that is read at 520nm.

Ortho-phosphate is determined by the soluble reactive Phosphate method using the Flow Injection analyser. The method is based on the reactions that are specific for phosphate ions. The results are expressed in mg/l P. The (PO_4^{3}) orthophosphate ion reacts with ammonium molybdate and antimony potassium nitrate under acidic conditions to form a phospho-molybdic complex. This complex is reduced with ascorbic acid to form a blue complex that absorbs light at 880 nm. The absorbance is proportional to the concentration of orthophosphate in the sample. Orthophosphate forms a blue colour in the test. Polyphosphates and organic phosphorous compounds are not covered. The sulphuric acid in the molybdate reagent does not have enough contact time with polyphosphates to hydrolyse them. Orthophosphate interferences occur in two possible ways. Firstly, silica forms a pale blue complex, which also absorbs at 880 nm. This interference is generally insignificant, as a silica concentration of approximately 30 mg l^{-1} would be required to provide a 0.007 mg l^{-1} P positive error in orthophosphate. Secondly, concentrations of ferric ions greater than 50 mg l^{-1} will cause a negative error due to the precipitation, and subsequent loss, of orthophosphate. Samples high in iron can be pre-treated with sodium bisulphide (or bisulphite – please check) to eliminate this interference. Treatment with bisulphite will also remove the interference due to arsenates.

3.2.1.2 Organic Chemistry

Chemical oxygen demand (COD) was determined by a Filterphotometer – 300D. Two ml of sample is added to a strongly acidic dichromate solution and placed on a Labcon COD heating block for 2 hours at 148±5°C. Silver sulphate is used as a catalyst and mercuric sulphate as a masking agent. The dichromate is partially reduced by the oxidisable material in the sample. The remainder of the dichromate is photometrically determined at 345 nm for low range COD and at 436 nm for high range COD respectively by the Filterphotometer. Randwater monitored the input points twice a month, while the output points were monitored every week.

3.2.2 Statistical Analyses

The z test was used to statistically to analyse the data (Appendix A3), as described in Materials and Methods, Chapter 2.

3.2.3 Seasonal Variation

The data was analysed for seasonal variation as described in Materials and Methods, Chapter 2.

3.2.4 Percentage Differences

The data was analysed for percentage differences as described in Materials and Methods, Chapter 2.

3.3 RESULTS

3.3.1 Klip River Wetland

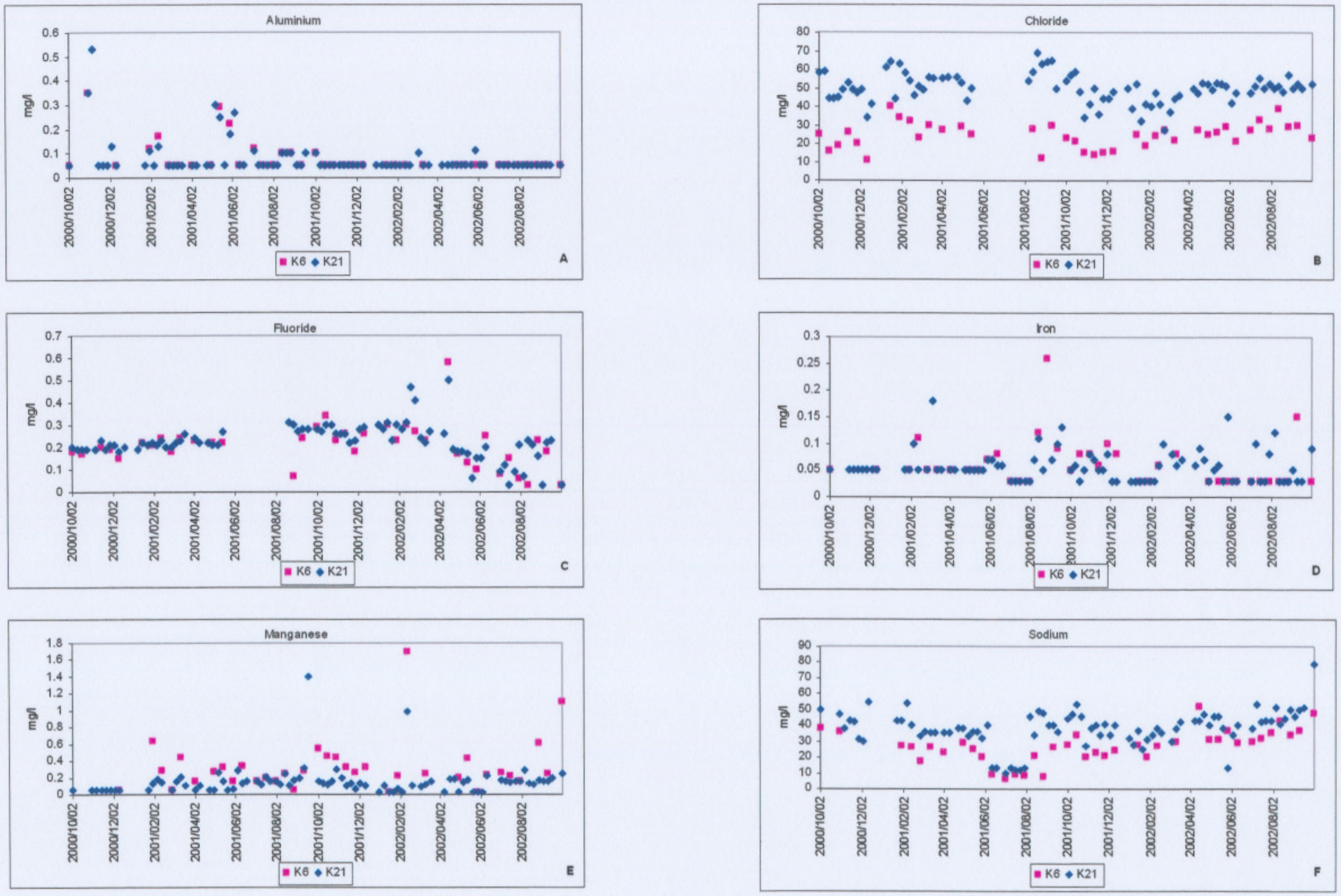

Figure 3.1 Aluminum (A), Chloride (B), Fluoride (C), Iron (D), Manganese (E) and Sodium (F) for the Klip River Wetland at the input (K6) and output (K21) sites.

Klip River Wetland (continued)

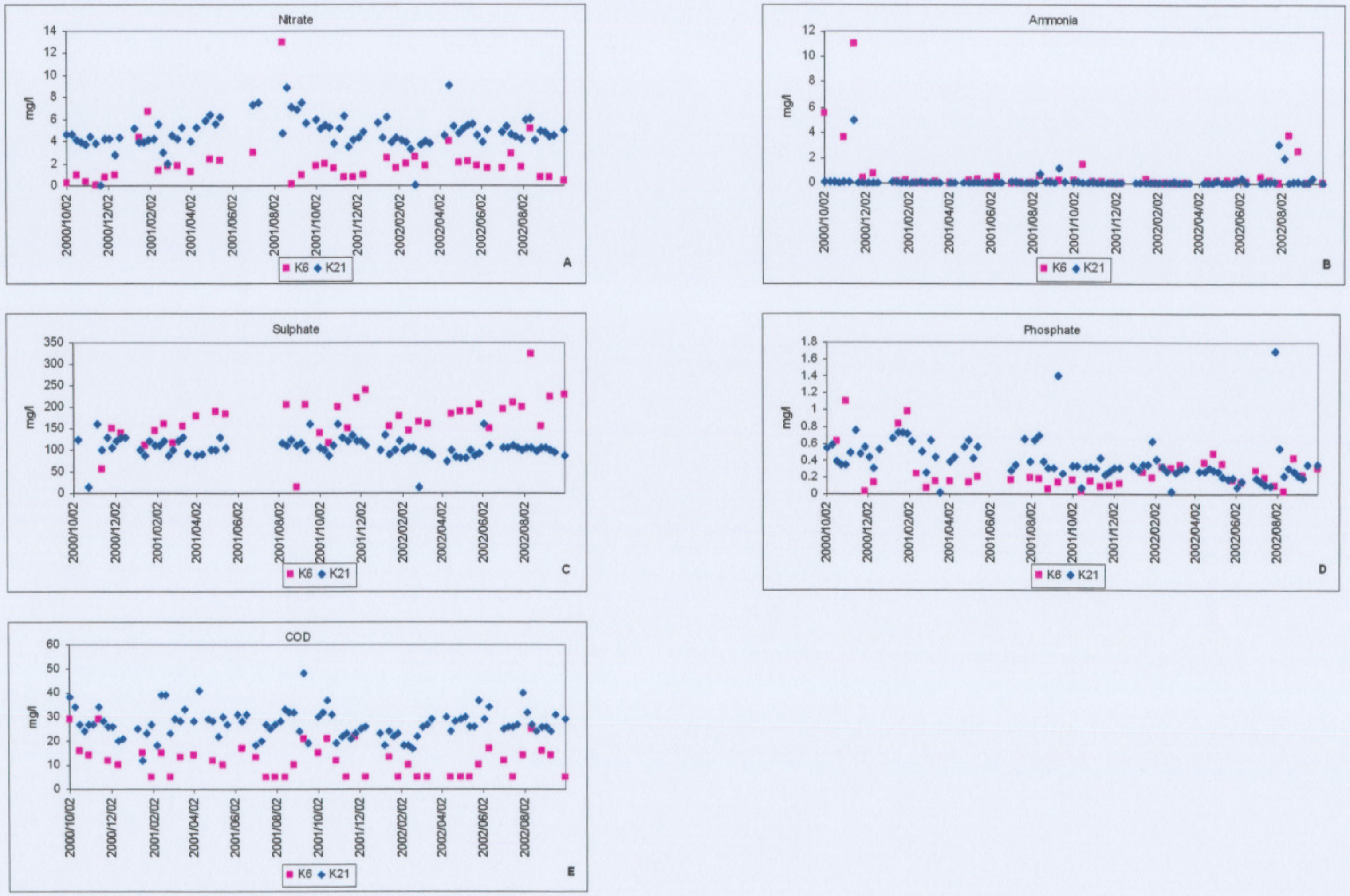

Figure 3.2 Nitrate (A) and Ammonia (B) Sulphate (C), Phosphate (D) and COD (E) for the Klip River Wetland at the input (K6) and output (K21) sites.

3.3.2 Natalspruit Wetland

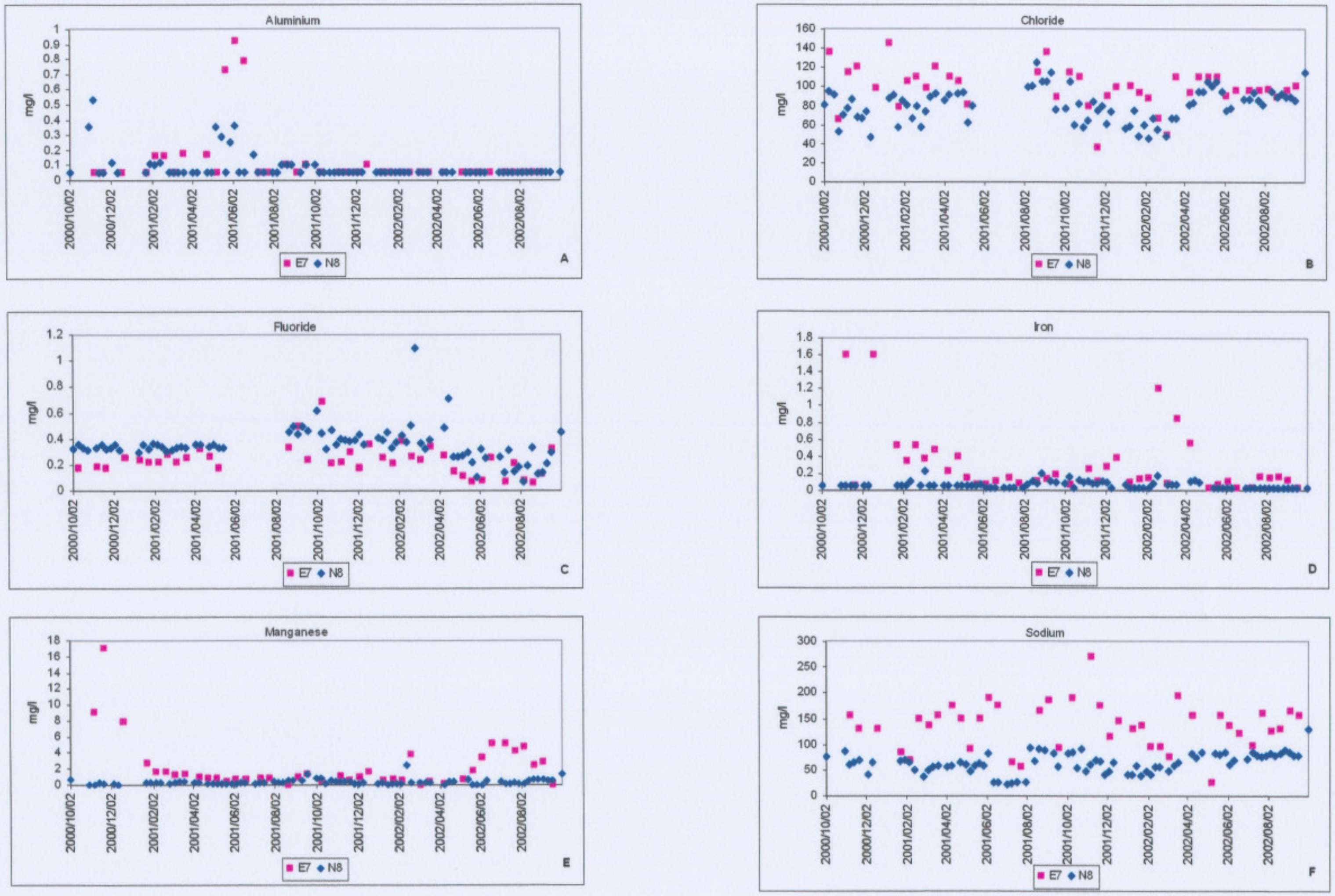

Figure 3.3 Aluminum (A), Chloride (B), Fluoride (C), Iron (D), Manganese (E) and Sodium (F) for the Natalspruit Wetland at the input (E7) and output (N8) sites.

Natalspruit Wetland (continued)

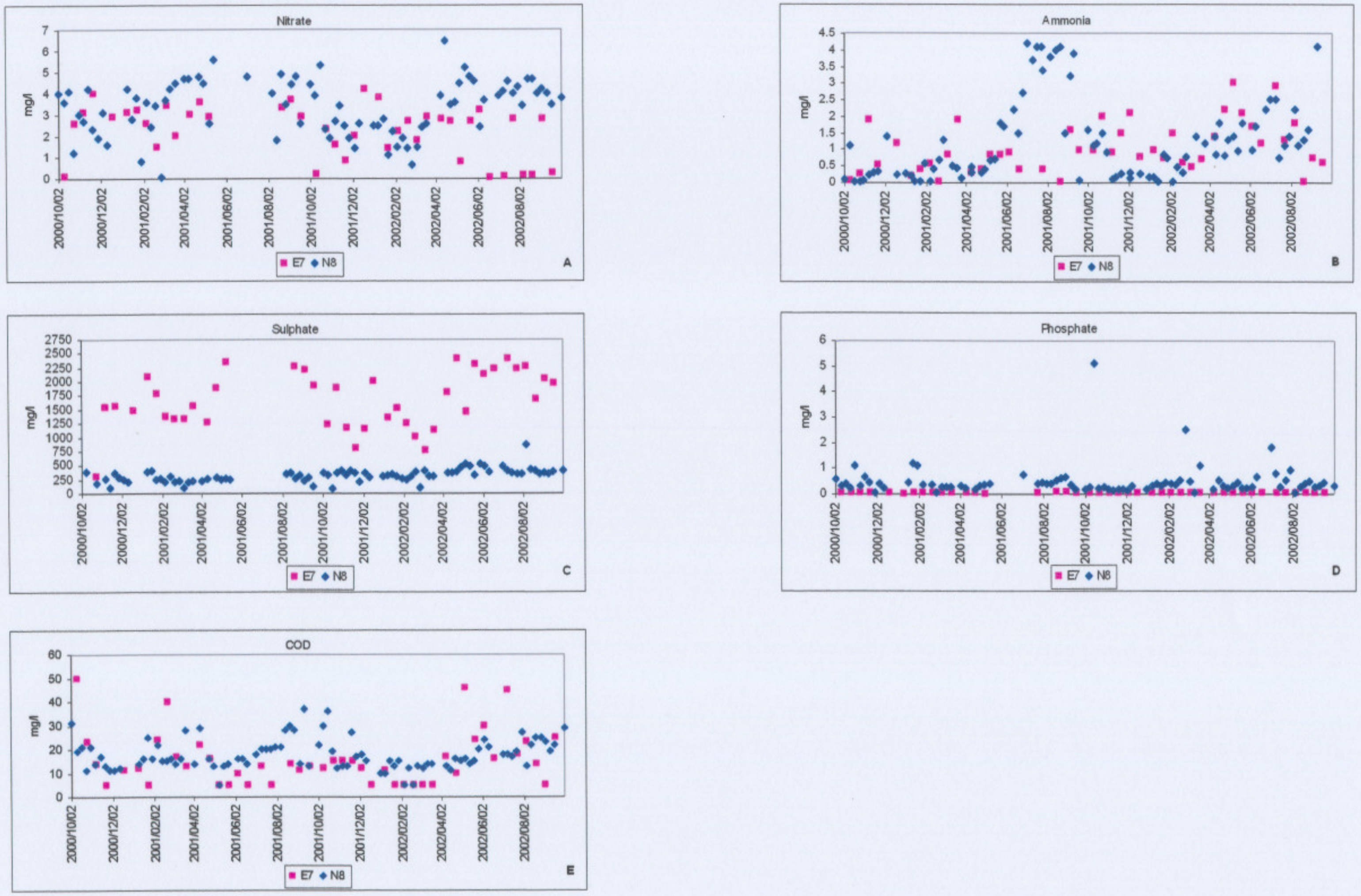

Figure 3.4 Nitrate (A) and Ammonia (B) Sulphate (C), Phosphate (D) and COD (E) for the Natalspruit Wetland at the input (E7) and output (N8) sites.

3.3.3 Seasonal variation

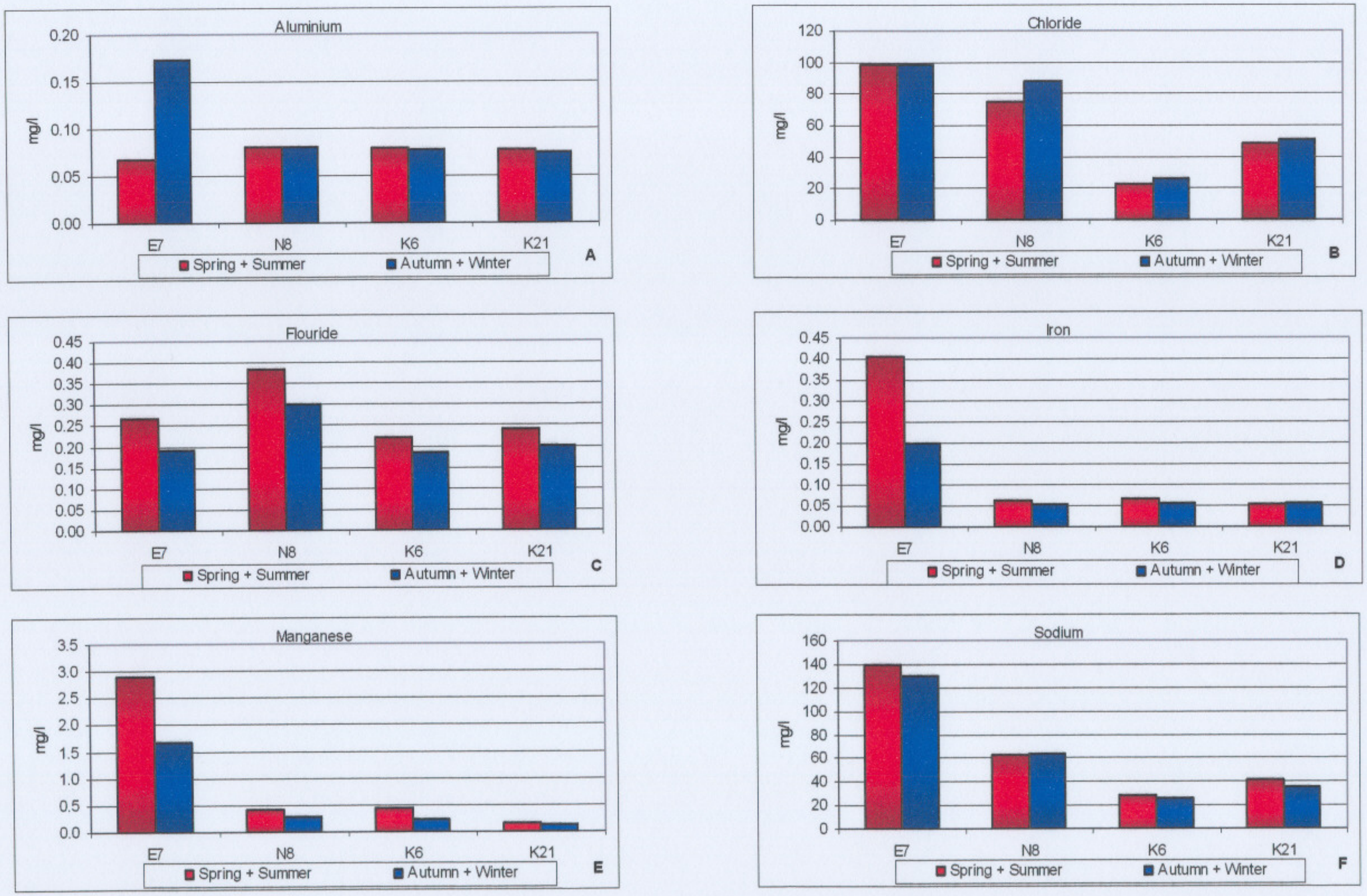

Figure 3.5 Seasonal variation for Aluminium (A), Chloride (B), Fluoride (C), Iron (D), Manganese (E) and Sodium (F) for the Klip River (input K6 and output K21) and Natalspruit (input E7 and output N8) Wetlands.

Seasonal variation (continued)

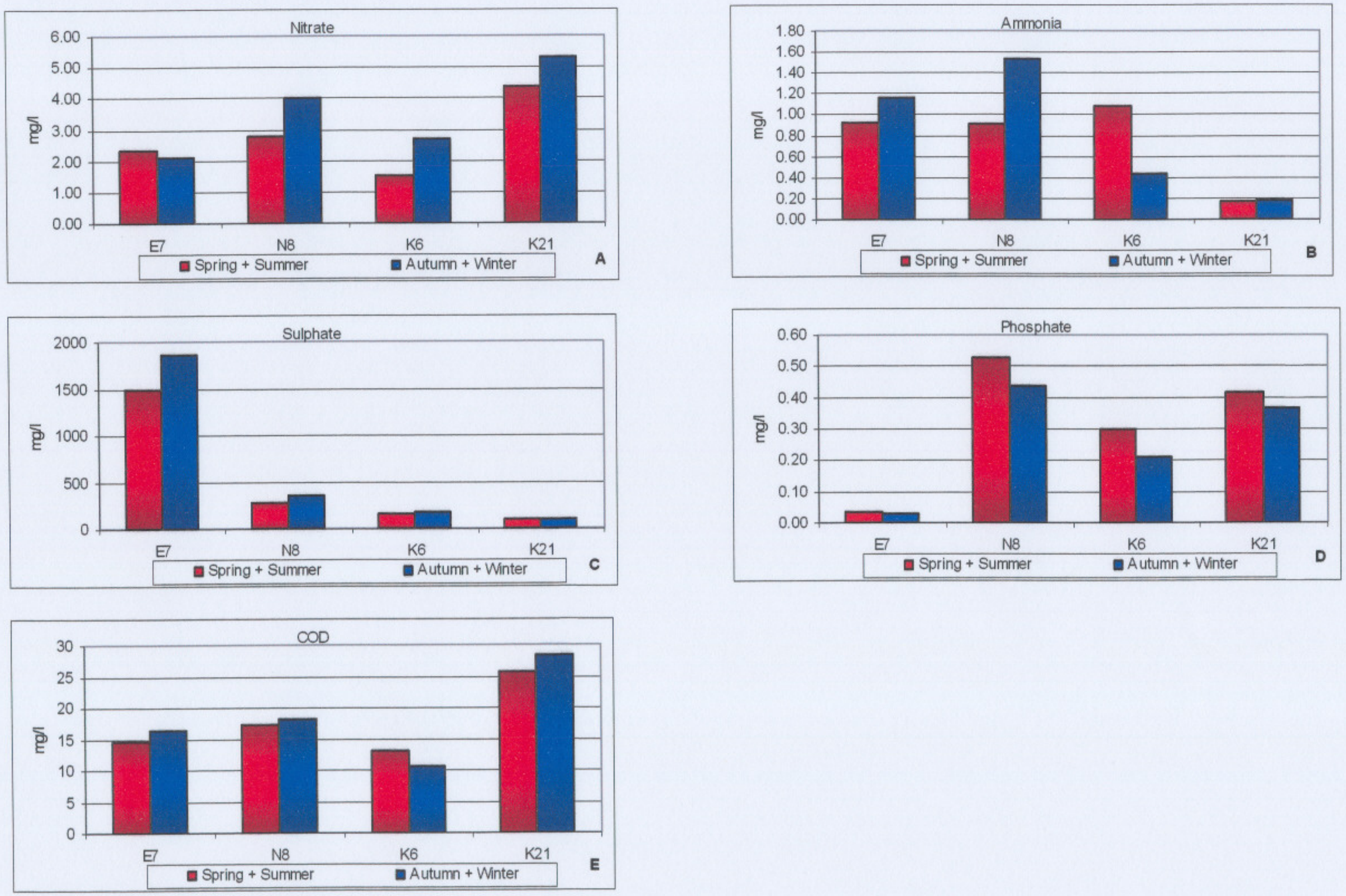

Figure 3.6 Seasonal variation for Nitrate (A), Ammonia (B), Sulphate (C), Phosphate (D), and COD (E) for the Klip River and Natalspruit Wetlands Klip River (input K6 and output K21) and Natalspruit (input E7 and output N8) Wetlands.

3.3.4 Comparison between Klip River and Natalspruit Wetlands

Table 3.1 Percentage differences between input and output means of the Klip River and Natalspruit Wetlands for selected chemical characteristics.

Variables	Klip River Wetlands				Natalspruit Wetlands			
	Input K6	Output K21	%Diff	I / D	Input E7	Output N8	%Diff	I / D
Aluminium (mg/l)	0.08	0.08	2.91		0.12	0.08	34.99	
Chloride (mg/l)	24.63	49.78	50.53	D	98.63	80.46	18.43	I
Fluoride (mg/l)	0.21	0.22	7.97		0.23	0.35	32.85	D
Iron (mg/l)	0.06	0.06	7.64		0.30	0.06	80.00	I
Manganese (mg/l)	0.33	0.15	53.80	I	2.24	0.35	84.22	I
Sodium (mg/l)	26.87	38.00	29.28	D	135.32	63.87	52.80	I
Nitrate (mg/l)	2.06	4.78	56.99	D	2.25	3.34	32.60	D
Ammonia (mg/l)	0.76	0.18	76.49		1.04	1.22	4.69	
Sulphate (mg/l)	171.4	105.91	38.19	I	1660.6	320.37	80.71	I
Phosphate (mg/l)	0.26	0.39	34.30	D	0.03	0.49	93.09	D
COD (mg/l)	11.95	27.12	55.92	D	15.57	17.78	12.45	

(grey) No significant difference between the input and output means
I Improvement
D Deterioration
(yellow) Greater improvement / Lesser deterioration

3.4 DISCUSSION

Klip River Wetland

For the Klip River catchment, significant differences ($-1.96 <= z < +1.96$) were found between the input and output values for the following chemical parameters: chloride, manganese, sodium, nitrate, sulphate, phosphate, and COD. There was no significant difference for the aluminium, fluoride, iron and ammonia.

Chloride showed a significant increase from the input to the output points of the wetlands. Although the average input and output values are found in the Ideal range of the KF guidelines there is a significant increase in chloride concentrations (Appendix A1). This indicates that there is a deterioration in water quality with regards to chloride concentrations. High chloride concentrations may be due to industrial effluent entering the Klip River. Another source, to a lesser extent, may be the use of detergents by informal settlements, which they discard into the rivers, very close to the output point.

Manganese showed a significant decrease from the input to output points of the wetlands. It decreased from 0.33 to 0.15 mg/l (Appendix A1). Although both values are still in the KF guidelines Ideal range as well, there is a definite improvement in manganese concentrations after it flows through the wetlands. Increases in manganese concentrations in the wetlands are mainly caused by industrial and mining effluents entering the catchment.

Sodium showed a significant increase from the input to output points of the wetlands. Although it still stays in the Ideal range of the KF guidelines, there is a significant deterioration in water quality due to the increase in sodium concentrations at the output point of the wetlands. High sodium values can be attributed to industrial and mining effluents entering the catchment.

Nitrate showed a significant increase from the input to output point of the wetlands. The average values changes from the Acceptable to the Tolerable range of the KF guidelines. High nitrate concentrations at the output site are mainly due to the WWTWs that discharge their effluent into the wetlands, as well as the increasing informal settlements that occur in the Upper Klip that use the rivers for their domestic purposes. It can also be aggravated by agricultural runoff.

Sulphate showed a significant decrease from the input to output points of the wetland. Although the sulphate values for the input and output points are found in the Ideal range of the KF guidelines, there is an improvement in water quality at the output point of the wetland. This indicates that the wetlands have a positive effect on sulphate concentrations in the Klip River

Although phosphate stays in the Acceptable range of the KF guideline, it shows a significant increase from the input to the output site of the wetlands. High phosphate concentrations can be due to the WWTW's effluent entering the river in the course of the wetland. Also, industrial effluents entering the catchment can increase the phosphate concentrations as well, resulting in a high level of nutrients entering the wetlands, and thus not being able to cope. High phosphates can be further aggravated by the informal settlements, by people in the informal settlements discharging their waste directly into the wetlands. And, also agricultural runoff, mostly fertilizers can contribute to the high phosphate levels as well.

COD showed a significant increase from the input to output values of the wetland. COD value changes from the Ideal to the Acceptable range of the RW guidelines showing a deterioration in water quality. High COD values are due to the effluents of the WWTWs discharging into the course of the wetlands. This results in the wetlands not being able to cope with the high COD entering the wetlands.

Natalspruit Wetland

For the Natalspruit significant differences ($-1.96<=z<+1.96$) were found between the input and output values for the following physical parameters: chloride, fluoride, iron, manganese, sodium, nitrate, phosphate and sulphate. There was no significant difference for aluminium, ammonia and COD.

Chloride showed a significant decrease from the input to the output points of the wetlands. Although it stays in the Tolerable range of the KF guidelines, there is a definite improvement in chloride concentrations. High chloride concentrations at the input point can be due to the mining and industrial effluents entering the rivers.

Fluoride showed a significant increase from the input to output points of the wetland. Although the fluoride values stay in the Acceptable range of the KF guidelines, there is a significant deterioration in water quality. High fluoride concentrations can be due to industrial and mining effluents entering the catchment.

Iron showed a significant decrease from the input to the output points of the wetlands. Although the iron concentrations stay in the Ideal range of the KF guidelines, there is a definite improvement in water quality. High iron concentrations at the input point can be mainly due to the mines occurring in the upper reaches of the Elsburgspruit, and the industries occurring in the surrounding areas of the Elsburgspruit.

Manganese showed a significant decrease from the input to the output points of the wetland. It changes from the Tolerable range to the Ideal range of the KF guidelines, showing a substantial improvement in the water quality. High manganese in the upper reaches of the Elsburgspruit is probably mostly due to mining activities.

Sodium showed a decrease from the input to output points of the wetlands. It moves from the Unacceptable to the Acceptable range of the KF guidelines showing a substantial improvement in water quality. High sodium concentrations at the input points can be due to mining and industrial effluents entering the catchment.

Although the nitrate values stayed in the Acceptable range of the KF guidelines, it shows a significant increase from the input to the output points of the wetlands. High nitrate values can be due to the WWTWs and industrial effluents entering the catchment. It can also be due to the informal settlements present during the course of the wetlands, as well as due to agricultural runoff entering the catchment.

Sulphate showed a significant decrease from the input to the output point of the wetlands. It moves from the Unacceptable to Acceptable range of the KF guidelines, showing a significant improvement of water quality. High sulphates at the input point is largely due to the mining effluents entering the Elsburgspruit. The wetlands substantially decrease the sulphate concentrations entering at the input point.

Phosphate showed a significant increase from the input to the output point of the wetlands. It moves from the Ideal to Acceptable range of the KF guidelines. High phosphate values can be due to WWTWs and industrial effluent, informal settlements and agricultural runoff.

Seasonal variation

For the seasonal variation, the data were grouped into two groups: spring and summer and autumn and winter

For the Klip River wetlands, in the spring and summer group, significant differences ($-1.96<=z<+1.96$) were found to be between the input and output values for chloride, manganese, sodium, nitrate, sulphate and COD. (Appendix A4). There was no significant difference for aluminium, fluoride, iron, ammonia and phosphate. Manganese and sulphate showed improvements while chloride, sodium, nitrate and COD showed deteriorations in the spring and summer months.

For the autumn and winter group significant differences were found for chloride, manganese, sodium, nitrate, phosphate, sulphate and COD. There were no significant differences for aluminium, fluoride, iron and ammonia. Manganese and sulphates again showed improvements indicating no variability between the hot and cold months. Chloride, sodium, nitrate and COD showed deteriorations in the autumn and winter months showing no seasonal variability. Phosphate showed a significant deterioration in autumn and winter months as opposed to the spring and summer months.

For the Natalspruit wetlands in the spring and summer group significant differences were found to be between the input and output values for chloride, fluoride, iron, manganese, sodium, phosphate and sulphate. (Appendix A5). There were no significant differences for aluminium, ammonia, nitrate and COD. Chloride, iron, manganese, sodium and sulphate showed an improvement in the spring and summer months. Fluoride and phosphate showed a deterioration.
For the autumn and winter group significant differences ($-1.96 <= z < +1.96$) were found for chloride, fluoride, iron, manganese, sodium, nitrate, phosphate and sulphate. There were no significant differences for aluminium, ammonia and COD. Chloride, iron, manganese, sodium and sulphate again showed an improvement in the autumn and winter months showing no seasonal variability. Fluoride and phosphate showed a deterioration in the autumn and winter months as well. However, a significant deterioration was noted in nitrate in only the autumn and winter months. The spring and summer months showed no significant differences for nitrate.

Manganese (Figure 3.5e) showed a significant decrease from the spring and summer group to the autumn and winter group. All other parameters showed no seasonal variation. Although phosphate showed decreases from the spring and summer group to the autumn and winter group, significant differences were not found for the Klip River wetland spring and summer results. This may due to the degrade state of the Klip River wetland.

Comparison between the Klip River and Natalspruit Wetlands

The Klip River wetland shows a significant improvement only in Manganese and Sulphate. (Table 3.1). However the Natalspruit wetland in comparison shows a significant improvement in chloride, iron, manganese, sodium and sulphate. Although ammonia shows a higher percentage difference for the Klip River wetland (Table3.1) it does not show a significant difference $(-1.96<=z<+1.96)$ in the z test (Appendix A3). The reason it showed a higher percentage difference is due the maximum value of 11 mg/l that was obtained at the inflow point. This value was due to pollution incidents in the upper Elsburgspruit and was kept in the data set as it is a true indication of the occurrences in the catchment.

The Natalspruit wetland shows a greater percentage improvement for these chemical characteristics than the Klip River wetland. Reasons for the Klip River wetlands functioning more efficiently can be attributed to many factors. One of which may be the severely degraded state of the Klip River wetlands. It is being impacted upon by mines, numerous industries and WWTWs. Also, the higher percentage increases compared to the Natalspruit can be due to the diversion canal, as mentioned in the previous chapter, which does result in a portion of the water entering at the input point not being impacted upon by the wetland. The water in the canal flows faster through the canal than the water present in the wetland. The water in the canal therefore does not have a higher retention time in the wetlands, thereby having less contact time with the wetland vegetation, sediments and microorganisms, resulting in a lower ability to improve water quality.

However, even though both wetlands show a deterioration in phosphates and nitrates (Table 3.1), the Klip River wetland shows a lesser percentage deterioration. This implies that the Klip wetland removes more phosphates than the Natalspruit wetland. One of the reasons for the increase in phosphates at the outflow of the Natalspruit wetland can be attributed to the WWTWs that occur close to the output point of the wetland. The effluent of the WWTWs passes through a small portion of the wetland, thus spending less time in the wetland. It is therefore not impacted as much as the WWTWs in the Klip River wetland which occur towards the upper reaches of the wetland. And secondly, there are informal settlements that occur at the output point of the Natalspruit wetlands. The people from these settlements use the water from the Natalspruit for their domestic purposes and this can contribute to the deterioration in phosphates as well.

Higher phosphate concentrations in both the wetland's output point from the input point does not necessarily mean that the wetland is not functioning efficiently. The WWTWs between the input and output point that are discharging effluents that are especially high in nitrates and phosphates. Wetlands can assimilate these nutrients entering by acting as a sink, removing them from the aquatic environment via denitrification or by transformation. The significantly high rates of phosphate and nitrates in the output point indicate that the wetland is receiving more of these two parameters than it can assimilate.

3.5 REFERENCES

BAKER, C.J. AND MALTBY, E. 1995. Nitrate removal by river marginal wetlands:factors affecting the provision of a suitable denitrification environment. In: Hughes, J. M. R. and Heathwaite, A.L. (Eds). Hydrology and hydrochemistry of British wetlands, John Wiley and Sons, Chichester (UK), p. 291-313.

DAVIDSON, C. 2000. Catchment diagnostic framework for the Klip River Catchment, Vaal Barrage, October 1998 - September 1999. University of Witwatersrand, Witwatersrand, South Africa.

DE BUSK, W.F. 1999. Functional Role of Wetlands in Watersheds. Soil and Waterscience Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY. 1996. South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems. First Edition. Pretoria, South Africa.

MORRISON, G., FATOKI, O.S., PERSSON L. AND EKBERG, A. Assessment of the impact of point source pollution from the Keiskammahoek Sewage Treatment Plant on the Kieskamma River – pH, electrical conductivity, oxygen-demanding substance (COD) and nutrients. Water environment transport, Chalmers University of Technology, Goteborg, Sweden.

STANDARD METHODS. 1976. Standard methods for the Examination of Water and Wastewater (14 ed.). Jointly published by the American Public Health Association, America Water Works Association and Water Pollution Control Federation.

RAND WATER .1998. The Socio-Economic Value of Wetlands in Highly Industrialised Catchments: Development of a Programme for the Klip River Catchment. Vol. 2 no. 1. 64 pp. Rand Water Head Office, Rietvlei, South Africa.

Chapter 4

Selected microbiological characteristics

4.1 INTRODUCTION

Plants and soils in wetlands play a significant role in the purification of water. In West Bengal, India, 430 members of a Fisherman's Cooperative harvest one ton of fish a day from ponds that receive 23 million litres of polluted water daily from both industrial and domestic sources. Here, the wetland plants removed 99.9% of the faecal coliform bacteria (Ramsar Convention Bureau, 1997). Reductions in faecal organisms and pathogenic bacteria in the order of 90% have been reported by some authors (Seidel, 1976; Fetter *et al.*, 1978; De Jong, 1976).

Using this purification capacity of wetlands, Calcutta has pioneered a system of sewage disposal that is both efficient and environmentally friendly. (Ramsar Convention Bureau, 1997). Eight thousand hectares of East Calcutta marshes, which include tree fringed canals, vegetable plots, rice paddies and fish ponds, along with the assistance of 20000 people, daily work to transform one third of the city's sewage and most of its domestic refuse into 20 tons of fish and 150 tons of vegetables every year. This mobilisation of people and wetlands dispenses with the need for costly-engineered sewage systems, and brings great benefit to many people, and solves at least part of the sanitation problem in the city.

Wetlands also provide physical support, or substrates, for a multitude of chemical and microbiological processes, promoting nutrient removal and storage within the complex maze of micro-sites in the soil and vegetation cover. The total surface area available for microbial activity in the soil and the overlying dead plant material (litter or detritus) is extremely high in wetlands. Also, in contrast to terrestrial ecosystems, wetlands facilitate physical, chemical and microbiological processes by retaining water for extended periods within this biologically active zone. Another important characteristic of wetlands is the presence of anaerobic (oxygen-depleted) soils during periods of flooding, which gives rise to an aerobic-anaerobic interface, or boundary, near the soil surface. This juxtaposition of aerobic and anaerobic conditions provides an environment for unique chemical and microbiological reactions that greatly enhance the removal of nutrients from the inflowing water (De Busk, 1999).

In the Klip River catchment, WWTW's effluent, human settlements without sanitation, and animal waste runoff into river are the major causes of faecal coliform, disease-causing bacteria, and viruses in the catchment. Faecal coliforms, then, is one of the important characteristics to determine wetland efficiency with regards to water quality.

This chapter looks at the faecal coliform concentrations at the output sites of both the Klip River and Natalspruit wetlands. Rand Water does not analyse the faecal coliforms at the input sites of the wetlands, however, they do analyse the amount of faecal coliforms entering the wetlands from the WWTWs in the Klip River catchment. Faecal coliforms guideline values are expressed as counts/100ml.

Faecal coliforms (counts/100ml)	<1000	1000-5000	5000-10000	>10000

Total coliform and faecal coliforms are indicators of bacterial contamination of water. Total coliform are bacteria found in vegetation, animal wastes, sewage, and soil. Faecal coliforms are a group of bacteria that are found in the intestines of all warm-blooded animals. They are excreted in their faeces, and can indicate the presence of other disease causing pathogens in the water (i.e. dysentery, typhoid fever, salmonella, hepatitis A). Faecal coliforms bacteria are used internationally as an indicator of general water quality. Faecal coliforms in water therefore indicate a recent, nearby problem.

4.2 MATERIALS AND METHODS

4.2.1 Sample Analyses

The water from the sample point water was allowed to run into a 500 ml plastic bottle, pre-treated with sodium thiosulphate. The sample bottle was filled to 2 cm from the top of the bottle and was closed. The location, time, date and temperature noted on the bottle. The sample was transported back to the laboratory in a cooler box with cooler blocks. Faecal bacteria were detected using the Rand Water method 1.2.2.03.1. These samples underwent membrane filtration with M-FC Agar and were then incubated at 44.5°C for between ±18 to 24 hours.

4.2.2 Statistical Analyses

Faecal coliforms were determined every week for the study period at the output sites of both wetlands only and not at the input sites by Rand Water. However, the effluent concentrations of the WWTWs were monitored. For the Klip River wetlands, the Olifantsvlei and Bushkoppies WWTW effluents were analysed. Effluent from Goudkoppies is routed to Bushkoppies WWTW and is not discharged into the Klip River. For the Natalspruit wetlands, the Rondebult, Dekema and Vlakplaats WWTW effluents were analysed. For each wetland, the total incoming faecal coliform concentrations entering the wetland, (Appendix A7) was compared to the total faecal coliform concentration leaving the wetland, (Appendix A6). The z-test was used to statistically analyse all the data, as described on Materials and Methods, Chapter 2. (Appendix A6).

4.2.3 Seasonal Variation

The data was analysed for seasonal variation as described in Materials and Methods, Chapter 2. (Appendix A8).

4.2.4 Percentage Differences

The data was analysed for percentage differences as described in Materials and Methods, Chapter 2.

4.3 RESULTS

4.3.1 Klip River Wetland

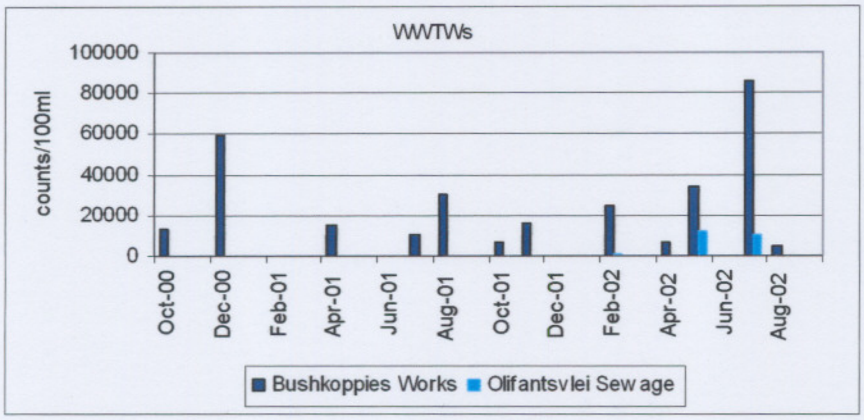

Figure 4.1 Faecal coliform concentrations at the WWTWs discharging in the Klip River Wetland.

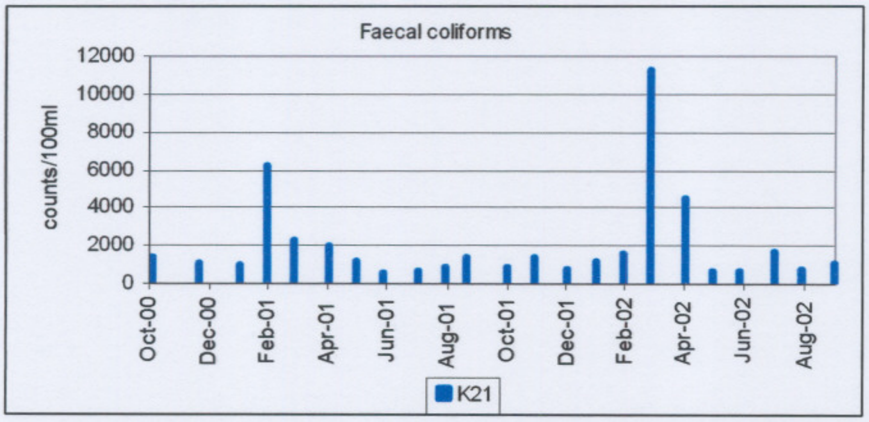

Figure 4.2 Faecal coliform concentrations at the output site K21 in the Klip River Wetland.

4.3.2 Natalspruit Wetland

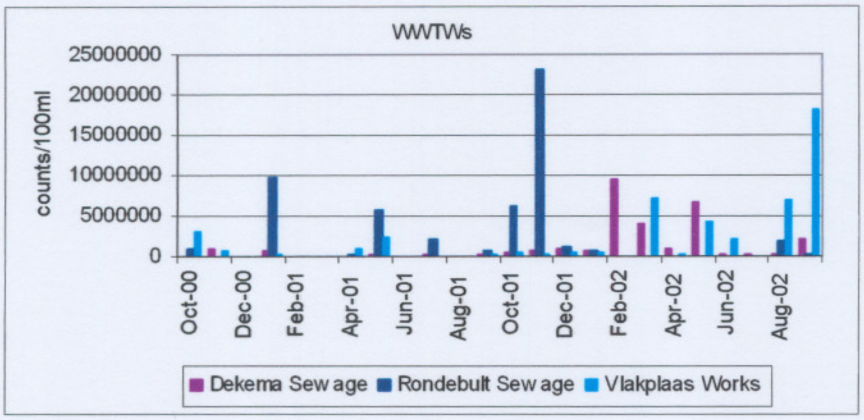

Figure 4.3 Faecal coliform concentrations at the WWTWs discharging in the Natalspruit Wetland.

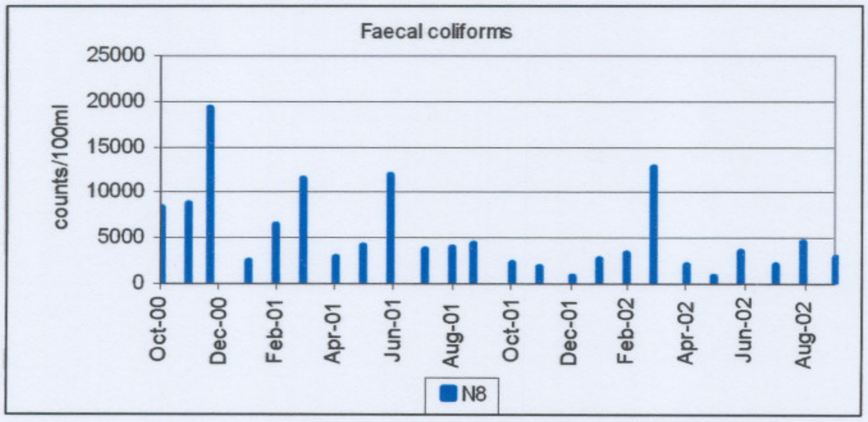

Figure 4.4 Faecal coliform concentrations at the output site N8 in the Natalspruit Wetland.

4.3.3 Seasonal Variation

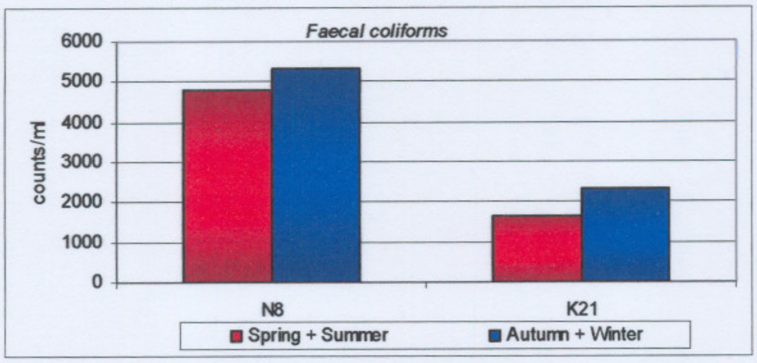

Figure 4.5 Seasonal variation for Faecal coliform concentrations in the Natalspruit (N8) and the Klip River (K21) Wetlands.

4.3.4 Comparison between Klip River and Natalspruit Wetlands

Table 4.1 Percentage differences between input and output means of the Klip River and Natalspruit Wetlands for faecal coliforms (Refer to Appendix A7 for individual WWTWs effluent faecal coliform concentrations).

Variables	Klip River Wetlands				Natalspruit Wetlands			
	Input	Output K21	%Diff	I / D	Input	Output N8	%Diff	I / D
Faecal coliforms (counts/100ml)	28482	1985	93	I	7500705	5071	99	I

(grey) No significant difference between the input and output means
I Improvement
D Deterioration
(yellow) Greater improvement / Lesser deterioration

4.4 DISCUSSION

According to the z test carried out, significant differences (-1.96<=z<+1.96) were found for both the Klip River and the Natalspruit wetlands between the total incoming faecal coliforms entering the wetlands via the WWTWs and the output points (Appendix A6). Besides the WWTWs, informal settlements that occur close to both the wetlands are increasing in size and are a major contribution to high faecal coliform concentrations in the catchment. Average values of the all the effluents entering the Klip River and the Natalspruit wetlands far exceed the Unacceptable range of the KF guidelines (Appendix A7). The output point for the Klip River wetlands is found in the Acceptable range of the KF guidelines while the output point of the Natalspruit wetland is found in the Tolerable range. Both output points show a marked improvement in water quality.

Seasonal Variation

The z test analyses of the seasonal variation for the output points over spring and summer, and autumn and winter show no significant differences in the faecal coliform concentrations (Appendix A8). However, an increase in faecal coliform concentrations at the output sites from the spring and summer group to autumn and winter group was noted. (Figure 4.5). This shows that more faecal coliforms are able to pass through the wetlands in winter than in summer. This may probably be due to the low temperatures during winter.

Comparison between Klip River and Natalspruit Wetlands

The Klip River wetland showed an overall improvement of 93%, indicating that there is 93% removal of faecal coliforms from the wetlands at the output site compared to the total number of faecal coliforms entering the wetlands at the input and WWTWs. The Natalspruit wetland showed an improvement of 99% indicating that there is 99% removal of faecal coliforms from the wetlands at the output site compared to the total number of faecal coliforms entering the wetlands at the input and WWTWs. Although the Natalspruit wetland is shown to function more efficiently than the Klip River wetlands in terms of percentage, it is important to note that the Klip River wetland has a lower concentration of faecal coliforms at the output points (Table 4.1). K21 is found in the Acceptable range of the KF guidelines while N8 is found in the Tolerable range. Natalspruit wetland therefore shows a greater improvement in terms of percentages because it is receiving approximately 260 times more faecal coliforms than the Klip River wetland. Combined average faecal coliform loads, for September 2002 (Table 4.1), that are entering the Natalspruit wetland from the WWTWs are 7,500,705 counts/100ml. This is unacceptable. The onus is on DWAF and the municipalities to monitor WWTWs on a regular basis to ensure that they comply with their permits.

4.5 REFERENCES

DE BUSK, W.F. 1999. Functional Role of Wetlands in Watersheds. Soil and Waterscience Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu.

DE JONG, J. 1976. The purification of Wastewater with the aid of rush or reed ponds. In: Tourbier, J and Pierson, R.W. Jr. (Eds.) Biological Control of Water Pollution. University of Pennsylvania Press. 133-139 p.

FETTER, C.W.Jr, SLOEY, W.E. AND SPRANGLER, F.L. 1978. Use of a natural marsh for wastewater polishing. Journal W.P.C.F. 50:290-307 p.

RAMSAR CONVENTION BUREAU. 1997. The Ramsar Convention Manual: Background papers on Wetland Values and Functions. Ramsar Convention Bureau, Gland, Switzerland.

SEIDEL, K. 1976. Macrophytes and Water purification. In: Tourbier, J and Pierson, R.W. Jr. (Eds.) Biological Control of Water Pollution. University of Pennsylvania Press. 109-121 p.

Chapter 5

SASS4 Index

5.1 INTRODUCTION

The analyses of physical and chemical water quality characteristics alone cannot provide an accurate indication of the overall condition of an aquatic ecosystem. Factors such as habitat alteration, creation of barriers that alter stream flow, water abstraction and the introduction of exotic species may have an influence on the ecological state of an ecosystem and this change cannot be determined by only physical and chemical analyses. Effective catchment management must therefore address the cumulative effect of all the changes that occur in aquatic ecosystems. Biological communities reflect overall ecological integrity (i.e. chemical, physical, and biological integrity). They have the ability to integrate the effect of different stressors and thus provide a broad measure of their aggregate impact (USEPA, 1996), and are therefore useful indicators in the assessment of ecosystem health.

According to Barber-James (2001) there are numerous advantages to using invertebrates for water quality assessments:

- They are largely sedentary, which allows for spatial analysis of pollution or disturbance effects; their presence or absence is indicative of conditions prevailing at the site sampled.
- Some are found in almost all water able to support life.
- They have a wide tolerance range to environmental conditions, although some species are highly sensitive while others are very tolerant of adverse environmental conditions.

- The length of their life cycle is of a suitable period for biomonitoring purposes, i.e. Long enough to observe recovery or recolonisation after an environmental change such as a toxic spill or chemical contamination.
- Many species are involved, resulting in a spectrum of responses to environmental stresses.

All these characteristics make invertebrates useful indicators in the assessment of ecosystem health. Invertebrates have been used with great success around the world in various biomonitoring programmes and aquatic studies, as indicators of environmental degradation or restoration (Barbour et al., 1999; Loeb and Spacie, 1994). The South African Scoring System (SASS), as used in this study is one of the most commonly used biological indexes in South Africa. SASS was originally adapted for South African conditions from the British Biological Monitoring Working Party (BMWP) system by F.M. Chutter in 1990 (Chutter, 1994). Since then, SASS has undergone numerous modifications and developments (from SASS2 to SASS4) under the support of the Rapid Biological Assessment Forum (RBA) after intensive testing in various parts of South Africa. It is also accepted and used in the River Health Programme of South Africa. (Dickens and Graham, 2001). As this study is based on historical data, the latest version, namely SASS5, was not used. This came into effect in 2001. Due to the differences in approach, it was not possible to recalculate the SASS4 data to SASS5 data.

5.2 MATERIALS AND METHODS

Sites were selected to coincide with the current water quality monitoring sites of Rand Water. Attention was especially given to select biomonitoring sites with a wide range of habitat and to assessing the impact of a specific pollution source in an area of concern. Invertebrate samples were collected at both the inflows and outflows of the Klip River wetland (sites K6 and K21 respectively) and the Natalspruit wetland (E7 and N8 respectively). As most of the natural fauna that used to occur in the Klip River catchment has disappeared as a result of man's activities (e.g. hunting, farming and rapid urban development) a reference site was chosen in the Suikerbosrand Nature Reserve. This should give some indication of the historical composition of the natural fauna of the Klip River Catchment. Rand Water Analytical Services completed all the analyses. The summer analyses for the two wetlands and the reference site were carried out in February/March 2001. The winter analyses were carried out in June/August 2001.

5.2.1 SASS sampling

The invertebrate organisms were collected in a 30 x 30 cm square net with a 1 mm mesh netting. The availability of biotopes at each site was identified on arrival, and each biotope was then sampled separately by different methods. Different biotopes were sampled as follows:

- Stones in current (SIC): Free/loose stones >2 cm to <30 cm (average size) which are found in the fast and slow flowing sections of the river. Samples were collected by putting the net on the bottom of the river, just downstream of the stones to be kicked, in a position where the current will carry the dislodged organisms into the net. This technique is called kicksampling. The kicking of stones continued for about 2 minutes to dislodge the invertebrates.
- Stones out of current (SOOC): Free/loose stones >2 cm to <30 cm (average size) which are found in sections of the river which are out of current. Samples were collected by kicksampling approximately one square meter of the riverbed.

- Sand (S): This included areas of the sand bank within the river, small patches of sand in hollows at the side of the river or sand between the stones at the side of the river. Samples were collected by means of stirring the sand by shuffling the feet, while continuously sweeping the net over the disturbed area to collect the dislodged invertebrates.
- Gravel (G): Gravel consists of stones <2 cm in size. Sampling was similar to that of sand.
- Mud (M): Mud consists of very fine particles. Mud usually settles to the bottom in still or slow flowing areas of the river. Sampling was similar to that of sand.
- Marginal vegetation (MV): This consists of vegetation hanging into or growing at the edge of the stream. This includes bushes, twigs and reeds. Sampling was done by holding the net perpendicular to the vegetation, with half the net in and half the net out of the water. The net was then swept back and forth for about 2 m in the vegetation.
- Aquatic vegetation (AQV): This consists of rooted, submerged or floating aquatic weeds. Sampling was done by pushing the net, in the water, against and among the vegetation in an area of ±one square meter of the riverbed.

All organisms collected from each biotope were then identified in the field with the use of existing manuals and identification keys. A SASS4 score was determined for each sample point based on the sensitivity of the family to poor water quality. The scores for each biotope are then summed to give a total SASS4 score. The relative abundance of organisms was also noted on the score sheet. ASPT (Average Score Per Taxon) scores were also determined by dividing the SASS4 score by the number of taxa.

Interpretation of the SASS4 and ASPT scores were based on a general categorisation of the scores in quality classes (Table 5.1).

Table 5.1: Categories used to classify SASS4 and ASPT into quality classes (Thirion *et al.*, 1995).

SASS4	ASPT	Condition
>140	>7	Excellent
100 - 140	5 – 7	Good
60 - 100	3 – 5	Fair
30 - 60	2 – 3	Poor
<30	<2	Very Poor

5.2.2 IHAS

IHAS (Integrated Habitat Assessment System) was also carried out to assist with interpretation of SASS4 scores particularly in respect of variability in the number and quality of biotopes available for sampling.

IHAS is divided into two sections:

1. Section one focuses on sampling biotopes and assesses the quantity and quality of the stones-in-current (SIC), vegetation (V) and other biotopes (includes stones-out-of-current (SOOC), gravel (G), sand (S) and mud (M)). The quality of each biotope, in terms of potential habitat for invertebrates is assessed and expressed as score. The scores for each biotope are then summed to give a total habitat score.
2. Section two assesses stream characteristics and attempts to appraise the site in terms of its suitability for SASS4 sampling and account for disturbances present at the site. Aspects such as stream width, depth and velocity are included as a means of characterising the stream.

Interpretation of IHAS scores is done by comparing the Total IHAS scores (*i.e.* Habitat Score and Stream Characteristics Score) with the maximum possible score, as expressed as a percentage. Three categories have been formulated to assist data interpretation of the total IHAS score (McMillan, 1998) (Table 5.2).

Table 5.2: Categories used to classify IHAS scores into quality classes (McMillan, 1998)

Total IHAS score	Condition
> 80%	Good
< 80% and > 70%	Fair
< 70%	Poor

5.3 RESULTS

5.3.1 Invertebrate Diversity

Table 5.3: Invertebrate taxa observed at the sample and reference points (REF).

TAXON	Sample Points									
	Summer					Winter				
	REF	K6	K21	E7	N8	REF	K6	K21	E7	N8
TURBELLARIA										
Planarians	P					P		P		
ANNELIDA										
Oligochaeta	P	P		P	P	P	P	P	P	P
CRUSTACEA										
Crabs	P	P	P	P	P		P	P		P
Shrimps			P					P		
EPHEMEROPTERA										
Baetidae	P	P	P		P	P	P	P		P
Leptophlebiidae	P					P				
Tricorythidae	P									
Caenidae	P	P	P		P		P	P		P
ODONATA										
Protoneuridae						P				
Coenagrionidae	P		P	P	P	P		P	P	P
Gomphidae				P				P		
Aeshnidae				P		P			P	
HEMIPTERA										
Notonectidae	P			P						
Pleidae						P	P			
Naucoridae	P	P	P		P		P	P		
Nepidae							P			
Belostomatidae	P		P					P		

P – Invertebrate present in sample

Table 5.3 *(continued)*

TAXON	Sample Points									
	Summer					Winter				
	REF	K6	K21	E7	N8	REF	K6	K21	E7	N8
Corixidae	P	P	P		P	P	P	P		
Gerridae	P	P	P							
Vellidae	P				P		P			
TRICOPTERA										
Hydropsychidae	P				P	P	P	P		P
COLEOPTERA										
Dytiscidae (adults)	P	P				P				
Elmidae/ Dryoptdae				P				P		
Gyrinidae (adults)	P	P			P		P	P		P
DIPTERA										
Tipulidae				P		P			P	
Culicidae						P				
Dixidae						P				
Simuliidae	P	P	P		P	P	P	P		
Chironomidae	P	P	P	P	P	P	P	P	P	P
Ceratopogonidae			P			P		P		
GASTROPODA										
Lymnaeidae				P		P			P	
Planorbidae									P	
Ancylidae						P				
PELECYPODA										
Sphaeridae						P				P
Number of taxa observed	19	11	12	10	12	20	13	17	7	9

P – Invertebrate present in sample

5.3.2 SASS4

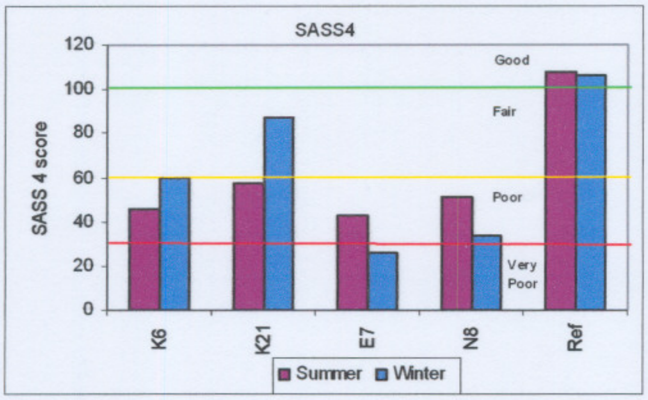

Figure 5.1 SASS4 scores for summer and winter months for the Klip River and Natalspruit Wetlands.

5.3.3 ASPT

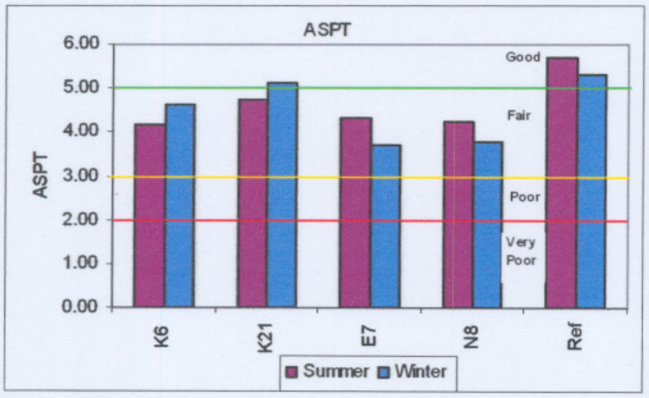

Figure 5.2 ASPT for summer and winter months for the Klip River and Natalspruit Wetlands

5.3.4 IHAS

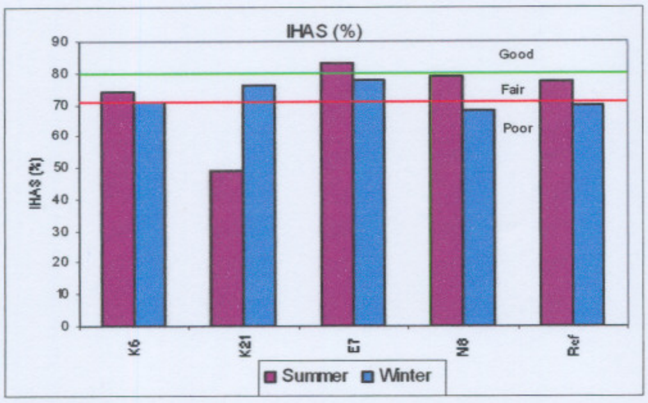

Figure 5.3 IHAS scores for summer and winter months for the Klip River and Natalspruit Wetlands.

5.3.5 Comparison between Klip River and Natalspruit Wetlands

Table 5.4: SASS4 scores, ASPT and IHAS scores determined for each sample and reference point (Good, Fair, Poor).

Sample Point	Variable	Summer	Winter
K6	SASS4	46	60
	ASPT	4.2	4.6
	IHAS	74	71
K21	SASS4	57	87
	ASPT	4.8	5.1
	IHAS	49	76
E7	SASS4	43	26
	ASPT	4.3	3.7
	IHAS	83	78
N8	SASS4	51	34
	ASPT	4.3	3.8
	IHAS	79	68
REF	SASS4	108	106
	ASPT	5.7	5.3
	IHAS	77	70

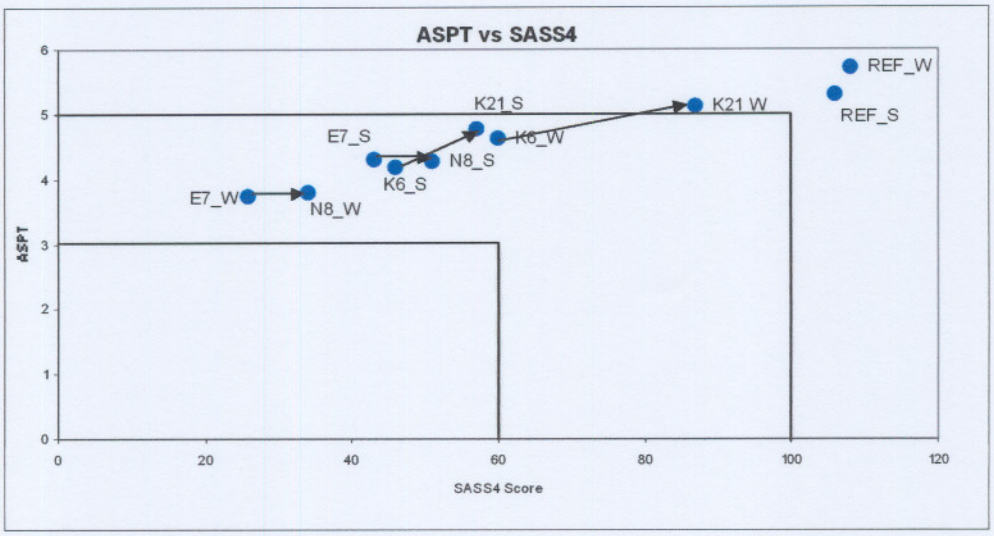

Figure 5.4 ASPT scores vs. SASS4 scores for the Klip River and Natalspruit Wetlands.

5.4 DISCUSSION

Invertebrates like insect larvae, snails, crabs, and worms etc. require specific aquatic habitat types and water quality conditions. Changes in the composition and structure of aquatic invertebrate communities are signs of change in the overall river system (WRC, 2002). Invertebrates have differential tolerances towards changes in the environment, with some groups being very sensitive to specific changes such as nutrient enrichment or metal pollution resulting in them being used as indicators of such change.

Klip River Wetlands

Invertebrate taxa that were found at the input and reference sites include, Oligochaeta, crabs, Baetidae, Caenidae, Naucoridae, Corixidae, Gyrinidae, Simuliidae and Chironomidae. Invertebrate taxa found in the reference and output sites include, planarians, Oligochaeta, crabs, Baetidae, Caenidae, Coenagrioniidae, Naucoridae, Belostomatidae, Corixidae, Gerridae, Hydropsychidae, Gyrinidae, Simuliidae and Chironomidae. (Table 5.3). There is an increase in invertebrate diversity from the input to the output sites of the Klip River Wetlands. Invertebrate taxa not found in the reference site and found in the output site include, shrimps, Gomphidae, Elmidae/Dryopidae and Ceratopogonidae.

There is an overall increase in SASS4 scores from the input to the output sites for both the summer and winter months. (Table 5.4). For summer, the SASS4 increases from 46, at the input site, to 57 at the output site. Although the SASS4 score remains in the poor category, it is closer to the boundary between poor and fair. For winter, the SASS4 score increases from 60, at the input site, to 87 at the output site. Although the SASS4 score remains in the fair category, slight improvement at the output site is shown.

IHAS scores for summer in the Klip River wetlands, drop from 74, at the input site, to 49 at the output site. (Figure 5.3). The input site falls in the fair category that is considered to be adequate and able to support invertebrate fauna, while the output site falls in poor category that is considered to be limited and unable to support a diverse invertebrate fauna. However, SASS4 scores show that although habitat quality is poor at the output site, there are more invertebrates present at the output site. For winter, although the IHAS scores stay in the fair category, there is slight improvement in habitat quality. Results show a change from a considerably impaired condition to a moderately impaired condition.

Natalspruit Wetlands

Invertebrate taxa that were found at the input and reference sites include, Oligochaeta, crabs, Coenagrioniidae, Notonectidae and Chironomidae. (Table 5.3). Invertebrate taxa found in the input site and not in the reference site include, Aeshnidae, Tipulidae and Lymnaeidae. Aeshnidae are usually found in poor quality water.
Invertebrate taxa found in the reference and output sites include, Oligochaeta, crabs, Baetidae, Caenidae, Coenagrioniidae, Naucoridae, Corixidae, Velidae, Hydropsychidae, Gyrinidae, Simuliidae and Chironomidae. There is a definite increase in invertebrate diversity from the input to the output sites of the Natalspruit Wetlands. The introduction of Baetidae in the output site shows an improvement in water quality.
Invertebrate taxa not found in the reference site and found in the output site include Sphaeridae.

There is an increase in the SASS4 score from the input to output points for both the summer and winter months. (Table 5.4). There is an overall increase in SASS4 scores from the input to the output sites for both the summer and winter months. For summer, the SASS4 4 increases from 43, at the input site, to 51 at the output site. Although the SASS4 score stays in the poor category, it does move to a slightly less poor condition. For winter, the SASS4 score increases form 26, at the input site, to 34 at the output site. Although the SASS4 score stays in the poor category, slight improvement at the output site is shown.

IHAS scores for summer in the Natalspruit Wetlands, drop from 83, at the input site, to 79 at the output site. The input site falls in the good category that is considered to be more than adequate and able to support diverse invertebrate fauna, while the output site falls in the fair category that is considered to be adequate and able to support invertebrate fauna. However, SASS4 scores show that although there is a deterioration in habitat quality from the input to the output site, there are more invertebrates present at the output site. For winter, the IHAS scores drop from 78, at the input site, to 68, at the output site. The input site falls in the fair category that is considered to be adequate and able to support invertebrate fauna to the poor category, that is considered to be limited and unable to support a diverse invertebrate fauna. Even though there is a deteriorated habitat quality at the output site, there is an improvement in the SASS4 scores, showing a slight improvement in invertebrate richness.

Comparison between the Klip River and Natalspruit Wetlands

Results show that the improved water quality seen in the previous chapters allow improved invertebrate richness even in cases where habitat diversity is low. Both input and output sites are being impacted, but the output sites are not impacted to the same extent as the input site. Figure 5.4 shows the data plotted on a ASPT vs SASS4 graph. From the graph it can be seen that all the input sites move towards the reference sites, i.e. a much better condition. Least change was noted from E7 to N8 in winter and most change was noted from K6 to K21 in winter.

5.5 REFERENCES

BARBER-JAMES, H.M. 2001. Freshwater biomonitoring using benthic macroinvertebrates. Department of Freshwater Invertebrates. Albany Museum. Grahamston. South Africa.

BARBOUR, M.T., GERRIRSEN, J., SNYDER, B.D. and STRIBLING, J.B. 1999. Rapid Bioassessment Protocols for use in streams and wadeable river: Periphyton, Benthic Macroinvertebrates and Fish. Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C, United States of America

CHUTTER, F.M. 1994. The rapid biological assessment of stream and river water quality by means of the macroinvertebrate community in South Africa. Pp 217-234.

DICKENS, C. and GRAHAM, M. 2001. South African Scoring System (SASS) Version 5 Rapid Bioassessment Method for Rivers May 2001. Umgeni Water. Pietermaritzburg. South Africa.

LOEB, S.L. and SPACIE, A. 1994. Biological Monitoring of Aquatic Systems. CRC Press LLC, United States of America. 381pp

McMILLAN, P.H. 1998. An Integrated Habitat Assessment System (IHAS v2), for the rapid biological assessment of rivers and streams. A CSIR research project, number ENV-P-I 98132 for the Water Resources Management Programme, CSIR, Pretoria, South Africa.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). 1996. Revision to Rapid Bioassessment Protocols for use in Streams and Rivers: Periphyton, Benthic Macroinvertebrates and fish. USEPA Internet Web Page: http://epa.gov/owow/monitoring/rbp/ch03main.html#Section 3.2.2

WRC. 2002. State of the rivers report uMgeni River and neighbouring rivers and streams, WRC report no. TT200/02, Water Research Commission, Pretoria.

Chapter 6

Load Analyses

6.1 INTRODUCTION

Load is defined as the mass of a substance transported by a current. It includes the suspended load of small particles in the water, and the bedload of large particles that move along the bottom. It is calculated as follows:

$$\text{Load} = \text{Flow} \times \text{Concentration}$$

Ideally in this study, load values instead of concentrations would be used to compare the physical characteristics as they take into consideration the flow of the river. Rand Water does not monitor flow values at the input sample points, so load values could not be calculated. However, Le Roux (2002) undertook a flow gauging exercise surrounding the Natalspruit Wetlands area in September 2002. Results from this data together with Rand Water, water quality data were used to determine load values.

6.2 MATERIALS AND METHODS

6.2.1 Sample Analyses

All concentrations of physical, chemical and microbiological values were determined as per materials and methods of Chapters 2, 3 and 4.

6.2.2 Statistical Analyses

Flow data for the Natalspruit and its tributaries was obtained from Le Roux 2002. The flow values for the rivers were determined for the 17-18 September 2002. An average of this value was used to determine the load values. Average September 2002 values were used for all physical and chemical data for all the sample points for the input and output points.

Flow data for the three WWTWs in the catchment were obtained from ERWAT. (Appendices A9 and A10). Average Faecal coliform concentrations for September 2002 from the WWTW effluent, together with average flow data from the WWTWs for September 2002 were used to determine the load values. Load values were calculated as below:

$$[\text{Concentration}]\ mg/L \times [\text{Flow}]\ m^3/s = g/m^3 \times m^3/s = [\text{Load}]\ g/s$$

E8 and N9 are tributaries entering the Natalspruit wetlands after the input point. (Figure 6.1). Load values were determined at points E7, E8, N9 and the three WWTWs. (Appendix A11). These were all added, as these loads were entering the wetlands at different points. The total incoming loads were then compared to the output load at N8. Although only WWTW's effluents are indicated in Figure 6.1 as they have permits from DWAF that allow discharges, it does mean that there are no other illegal discharges occurring as well. There are numerous industries and farms that discharge effluents into the wetlands that contribute to the nutrient loading.

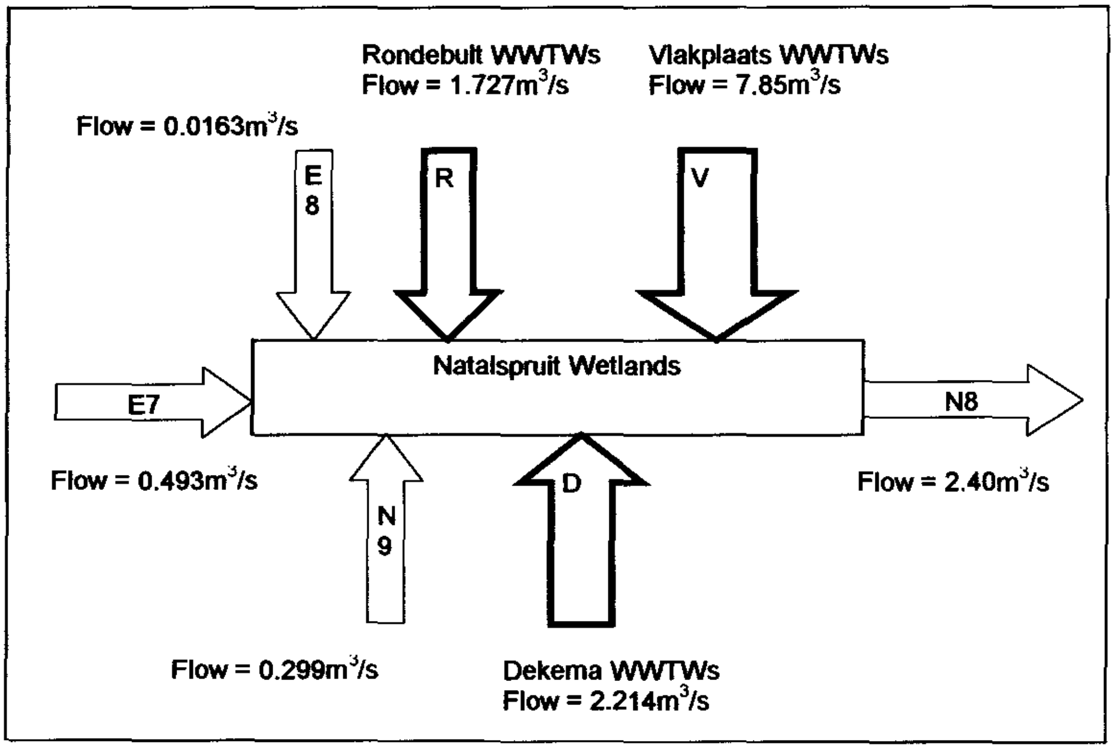

Figure 6.1 Flowchart to show flow values entering the Natalspruit Wetlands

6.3 RESULTS

6.3.1 Selected physical characteristics

Table 6.1 Differences of load value for the physical characteristics between the input and output sample point of the Natalspruit wetlands. (Refer to Appendices 10 and 11 for the individual concentrations of the three WWTWs and sample points E7, E8. N9).

Variable	Total incoming flow		Outgoing flow at N8		Improvement/ Deterioration
	Average Flow m^3/s	Load g/s	Average Flow m^3/s	Load g/s	
Conductivity	12.60	1517.28	2.40	291.02	Improvement
Dissolved Oxygen	12.60	28.39	2.40	12.72	Improvement
Suspended solids	12.60	472.14	2.40	73.81	Improvement

6.3.2 Selected chemical characteristics

Table 6.2 Differences of load value for the chemical characteristics between the input and output sample point of the Natalspruit wetlands (Refer to Appendices 10 and 11 for the individual concentrations of the three WWTWs and sample points E7, E8. N9).

Variable	Total incoming flow		Outgoing flow at N8		Improvement/ Deterioration
	Average Flow m^3/s	Load g/s	Average Flow m^3/s	Load g/s	
Aluminium	12.60	1.33	2.40	0.12	Improvement
Chloride	12.60	2170.51	2.40	226.82	Improvement
Fluoride	12.60	39.54	2.40	0.65	Improvement
Iron	12.60	50.95	2.40	0.07	Improvement
Manganese	12.60	11.43	2.40	1.82	Improvement
Sodium	12.60	1730.73	2.40	222.02	Improvement
Ammonia	12.60	176.65	2.40	4.86	Improvement
Nitrate	12.60	23.63	2.40	9.30	Improvement
Phosphate	12.60	1.23	2.40	0.79	Improvement
Sulphate	12.60	2034.69	2.40	906.08	Improvement
COD	12.60	1884.37	2.40	55.80	Improvement

6.3.3 Selected microbiological characteristics

Table 6.3 Differences of load value for the microbiological characteristics between the input and output sample point of the Natalspruit wetlands (Refer to Appendices 10 and 11 for the individual concentrations of the three WWTWs and sample points E7, E8. N9).

Variable	Total incoming flow m^3/s		Outgoing flow at Output (N8) m^3/s		Improvement/ Deterioration
	Average Flow	Load	Average Flow	Load	
Faecal coliforms (counts/100ml)	12.60	146409126	2.40	7128.59	Improvement

6.4 DISCUSSION

The water balance within the catchment is largely affected by human activities. There is not enough naturally occurring water in the Klip sub-catchments to provide for the needs of all the people, although there is enough water in this catchment due to the large return flow volumes from the mines, industries and WWTWs in the area (Davidson, 2000). Industrial effluents contribute approximately 60% of the flow into various purification works (Viljoen *et al*, 1985). Due to the industrial nature of the Natalspruit catchment industries contribute as point and non-point source, to the chemical loading in the wetlands. Seepage and run-off from the ERPM mine dumps also create a substantial load to the wetlands. There are approximately 82 mine dumps covering an estimated 800 hectares within the Natalspruit catchment area (Viljoen *et al*, 1985).

Flow diagram (Figure 6.1) shows the total input flow from all the tributaries and the three WWTWs to be 12.60 m^3/s. It does not take into consideration non-point source flow coming from the mines and industries. The output flow of the wetland, at sample point N8 is determined to be 2.40 m^3/s (Le Roux, 2002). This shows a loss of 10.20 m^3/s of water from the wetlands. Reasons for this loss can be attributed in some part to the following two factors. Firstly, the water loss coincided with the wet season, and could be attributed to hydrophilic properties of the newly inundated areas and the filling of isolated pools that are unable to drain when the water recedes (Viljoen *et al*, 1985). And, secondly, evapotranspiration could play a role in the loss of some water. Vega and Ewel, (1981) working on Lake Alice calculated that evapotranspiration accounted for about 6% of the hydrological budget of the lake. These authors consider evapotranspiration to be equivalent to evaporation from an open waterbody. A detailed water balance needs to be carried out in the Natalspruit wetlands to account for the large amount of lost water.

From the results, Tables 6.1, 6.2 and 6.3 show that there is an improvement in water quality in all the variables as the water moves through the wetlands. The total incoming flow is higher than the flow leaving the wetlands and this is mainly due to the flows entering the rivers from the WWTWs (Appendix A9). This, however, is true because of the low flow values at N8. The results below do not take into the concentration the load of the lost 10.20 m^3/s of water.

Physical characteristics

There is an improvement in conductivity, dissolved oxygen and suspended solids. Conductivity and suspended solids both show an improvement of 81 and 84% improvement respectively. Dissolved oxygen shows an improvement of 55%.

Chemical characteristics

Iron and fluoride show an improvement of 99 and 98% improvement respectively. Ammonia and COD both show an improvement of 97% and aluminium shows an improvement of 91%. Chlorine, sodium and manganese show an improvement of 90, 87 and 84% respectively. Nitrate and sulphates show an improvement of 61 and 55 %. Phosphate shows the lowest percentage improvement of 36%. Phosphates showed the highest increase at sample point N9. The sample point is downstream of the City Deep, Benrose, Denver, Heriotdale, Rosherville, Driehoek and Alrode industrial areas. These areas therefore contribute to the high phosphate load values.

Microbiological characteristics

Faecal coliforms show an improvement of 99.9%. This shows then that faecal coliforms are a good indicator of wetland's efficiency in terms of water quality.

Load values are crucial in determining whether a wetland is efficiently removing nutrients and compounds from the incoming water, however, it is just as imperative to determine a water balance for the wetland to take into account discrepancies in flow data or missing water volumes.

6.5 REFERENCES

DAVIDSON, C. 2000. Catchment diagnostic framework for the Klip River Catchment, Vaal Barrage, October 1998 - September 1999. University of Witwatersrand, Witwatersrand, South Africa.

LE ROUX, F.P. 2002. Report on the Flow Gauging "Snapshot" Exercise in the Klip River Catchment 17-18 September 2002. Division Hydrometry – Gauteng Region. DWAF. Pretoria, South Africa.

VEGA, A. AND EWEL, K.C. 1981. Wastewater effects on a water hyacinth marsh and adjacent impoundment. Journal of Enviromental Management, 5(6): 537-541.

VILJOEN, F.C., PHILLIPS, A.L., CHRISTODOULOU, L.S. AND HAYNES, R.E. 1985. An input output study of various constituents in the water after passage through a section of the Natalspruit wetland. Report no. 85/1. Rand Water. Johannesburg. South Africa.

Chapter 7

Conclusion and Recommendations

7.1 CONCLUSION

Pollution is a major threat to the Klip River catchment, as pollutants accumulate and concentrate in wetlands. Catchment run-off carries nutrients, sediments and pollutants into waterways and eventually the wetlands. Excess nutrients in water systems cause eutrophication, which result in changes to the biological and chemical processes in the wetlands. Different types of pollution discharges have diverse and complex impacts on the receiving wetlands. Wetland characteristics such as low flow, retention time, contact with vegetation and contact with sediment all impact the incoming flow. The objective of this study was to determine if wetlands improve the water quality of the water entering the Klip River and Natalspruit wetlands. This study shows that wetlands are complex systems in which many of the mechanisms responsible for the removal of various constituents that are not fully understood. Although some conclusions were made:

Selected physical and chemical characteristics

The Klip River wetland is impacted upon by mining in the upper reaches of the catchment; numerous industries that discharge effluent legally or illegally; three wastewater treatment works during the course of the wetland; and a number of informal settlements and agricultural plots. All of these negatively impact incoming water into the wetlands. Analyses of the wetlands show a significant improvement in conductivity, dissolved oxygen, manganese and sulphate concentrations. Some of the improvements can be due to simple dilution of concentrations as the water moves downstream of the effluent point. Improvements can also be due to the low flow rates; retention time of the wetlands; and contact time with vegetation and sediments of the wetland. A deterioration was found in the suspended solids, chloride, sodium, nitrate and phosphate and COD concentrations. Deteriorations can be due to the effluents from industries, WWTWs, informal settlements, urban and agricultural runoff entering the wetlands.

The Natalspruit wetland is impacted upon by mining just before the inflow point of the wetland; numerous industries; three wastewater treatment works during the course of the wetland; and a number of informal settlements, one of which is found very close to the outflow point of the wetland. Readings taken at the outflow point of the wetlands show a significant improvement in conductivity, pH, chloride, iron, manganese, sodium, and sulphate concentrations. Some of the improvements can also be due to simple dilution of concentrations as the water moves downstream of the effluent point. Improvements can also be due to the wetland characteristics mentioned above i.e. low flow rates, retention time and contact time with vegetation and sediments.
A deterioration was found in the fluoride, nitrate and phosphate concentrations. Deteriorations can be mainly due to the Vlakplaats WWTWs, and informal settlements found close the outflow point of the wetland. The effluents from these two impacts flow through the wetland over a shorter time period, thereby being effected by the wetland less than an effluent entering the wetland higher upstream, closer to the input point of the wetland.

Microbiological characteristics

Faecal coliforms decreased by 93% in the Klip River wetlands and by 99% in the Natalspruit wetlands. The discharges of effluent by WWTWs, discharges from informal settlements and animal waste runoff from farms, into the Klip River, results in the widespread waterborne diseases to be a major concern. Many informal settlements in the Klip River catchment are reliant in rivers as a source of water for domestic purposes, i.e. drinking water and washing of clothes. Water quality control using wetlands would therefore reduce the spread of pathogens, without the necessity of expensive purification plants and trucked-in clean water, and would reduce the burden of medical facilities by reducing the infection rate.

SASS4 Index

The SASS4 score provides an indication of improvement or deterioration in water quality and ecological integrity of the system. Also, the presence of some pollution-sensitive invertebrates at the output sites of the wetland clearly indicate an improvement in taxon richness. Although sensitive taxa are still absent in the output site suggesting that the wetlands are improving water quality to a certain extent but not to the point that the output point resembles the reference site. The IHAS score provides an indication of the habitat present for the invertebrates. A sample point with a high IHAS score would support a number of different invertebrates. The Klip River wetland shows that there was an increase in the SASS4 score from the inflow to outflow points for both the summer and winter months analysed showing a change from a considerably impaired condition to a moderately impaired condition. The Natalspruit wetland shows that there was a slight increase in the SASS4 score from the inflow to outflow points for both the summer and winter months analysed showing that it is in a considerably impaired condition. The Klip River and Natalspruit wetlands both show an in improvement in invertebrate richness, even at decreased habitat diversity, indicating that there is improvement in water quality.

Load analyses

Load analyses of the Natalspruit wetland showed improvements for all the physical, chemical and microbiological analyses carried out. An important point of note when considering the load data was that the total incoming flow into the wetland, was higher than the flow leaving the wetland. This was mainly due to the flows entering the rivers from the WWTWs. This results in a large volume of water not present at the outflow point, N8. Reasons mentioned in Chapter 6, are the filling of isolated pools, during the rainy seasons, that are unable to drain when the water recedes, and evapotranspiration. A detailed study would be required to determine an accurate water balance, to calculate a more precise indication of load analysis for the Natalspruit wetland. However, this study does provide a general indication of the load in the Natalspruit, which demonstrates an improvement in water quality.

Comparison between the Klip River and Natalspruit Wetlands

Although both the Klip River and Natalspruit wetlands are similar in terms of the impacts from the catchment i.e. both are impacted by 3 WWTWs, mining, industrial areas, agricultural runoff and informal settlements, many differences between the wetlands were noted. However, they are impacted upon at different points along the river and to different extents. One of the main reasons for the differences between the two wetlands are the difference in the wetland structures as mentioned in Chapter 1. Firstly, not all the water entering the Klip River wetland passes through the wetland, some passes through a canal running parallel to the wetland, thus not being impacted upon by the wetlands. And, secondly the Natalspruit wetland does not run continuously from the input to the output point. There is a break in the wetlands downstream of the Vlakplaats WWTWs, with a clearly defined stream running through the wetland for a short period. These two factors result in most of the differences between the two wetlands.

Water is a scarce resource in South Africa and, at its current supply and demand, will be fully utilised by 2025. Without sufficient water we cannot grow enough crops and support industrial growth, or develop a growing tourism industry. Our economy is therefore totally dependant on a continual supply of water of sufficient quality and quantity. Wetlands in this regard, play a vital role in managing water by purifying it, attenuating floods, regulating river flow, and recharging groundwater sources. Their health is therefore critical to sustainable development. They are also vital for biodiversity protection, tourism, environmental education, grazing, subsistence agriculture and as a source of food and plant materials for rural communities. Wetlands have an enormous monetary value. In spite of this value, some 50% of wetlands in South Africa have already been destroyed due to unsustainable development. In an arid country like South

Africa, wetlands are vital. (Nel, 2003). It is therefore imperative to make sure that they are functioning efficiently.

7.2 RECOMMENDATIONS

- One of the main shortcomings in the study is the absence of concurrent physical, chemical, microbiological, invertebrate and flow data. This would aid in determining the load values for particular parameters, which would give a more accurate idea of the actual concentrations of particular parameters in the rivers in real time. Chapter 6 looks at the load values of physical, chemical and biological characteristics of the Natalspruit wetlands. All of the parameters analysed show an improvement at the output points of the wetlands indicating an improvement in water quality. Load analyses of the entire Klip River catchment would have provided a more accurate indication of improvement in water quality.

- Another shortcoming in the study in that only two SASS assessments were carried out per site, providing only a snapshot of the condition in the system. SASS is a useful indicator of ecosystem health as it takes into consideration biological communities that reflect overall ecological integrity (i.e. chemical, physical, and biological integrity). They have the ability to integrate the effect of different stressors and thus provide a broad measure of their aggregate impact (USEPA, 1996). It is therefore recommended that more regular SASS monitoring be undertaken.

- Wetlands effectiveness is not easily determined by this study as wetlands are not only being impacted upon only at the input site and the specific WWTWs as allowed by DWAF. There may be numerous illegal discharges in the catchments taking place within the catchment as well. These discharges, which occur at different times in the year and are varied in nutrient concentrations are not recorded or reported, and pose a problem with regards to determining wetland efficiency. It is recommended that a more detailed study to determine wetland efficiency be undertaken in a smaller wetland not impacted upon in the body of the wetlands i.e. the water entering the wetlands is not being further impacted upon during the course of the wetland purification process.

- Although wetlands are able to assimilate pollutants and purify incoming water, care should be taken by WWTWs and industries discharging effluent into the wetlands not to exploit natural wetlands for their ability to remove pollutants from water. Persistent utilisation beyond natural purifying capacities will undoubtedly lead to the eradication of wetlands from the landscape (Stearns, 1978). Natural wetlands therefore should not be seen by WWTWs and industries as having infinite purifying capacities. Rather, it is recommended that they should consider creating artificial wetlands, designed specifically for purification purposes.

- Restoration of wetlands damaged by past mismanagement. This study shows that wetlands can help improve water quality by removing or retaining nutrients, organics, and sediment carried by runoff. The flow of water slows as it enters a wetland, which causes sediment in the water to settle out. Many chemicals (e.g. agricultural fertilisers and biocides, domestic wastes from informal settlements, industrial and WWTWs effluents) precipitate into sediment and remain trapped in wetlands. Plants and the biological processes present in a wetland breakdown and convert these pollutants into less harmful substances. It is recommended that the Klip River wetlands that has been severely degraded by past catchment activities be restored.

7.3 REFERENCES

STEARNS F. 1978. Management potential: summary and recommendations: In: Freshwater wetlands: ecological processes and management potential. (ed.) RE Good, DF Whigham and RL Simpson . Academic Press, New York.

NEL, M.2003. Wetlands are crucial to South Africa's survival. http://www.wetlands.org.za/news.htm=&NodeId=912&Id=23.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA). 1996. Revision to Rapid Bioassessment Protocols for use in Streams and Rivers: Periphyton, Benthic Macroinvertebrates and fish. USEPA Internet Web Page: http://epa.gov/owow/monitoring/rbp/ch03main.html#Section 3.2.2

Appendix A1: Summary and Statistical Data for the Klip River Wetland for 1 October 2000 to 30 September 2002

Variable	K6								
	n	Last recorded value	Mean	Standard Deviation	Minimum value	Maximum value	5 Percentile	50 Percentile	95 Percentile
Conductivity (mS/m)	44	82	70.00	7.40	47	83	57.75	71	79.85
Dissolved oxygen (mg/l O_2)	43	6.2	5.55	2.22	0.25	9.7	1.76	5.8	8.85
pH	44	8	7.94	0.28	7.3	8.5	7.415	8	8.3
Temperature (°C)	45	23	22.62	1.05	21	26	21	23	24
Al (mg/l)	39	0.05	0.08	0.07	0.05	0.35	0.05	0.05	0.227
Cl (mg/l)	40	23	24.63	6.73	11	40	13.9	25	34.25
F (mg/l)	38	0.03	0.21	0.10	0.03	0.58	0.0555	0.22	0.306
Fe (mg/l)	38	0.03	0.06	0.04	0.03	0.26	0.03	0.05	0.1245
Mn (mg/l)	36	1.1	0.33	0.31	0.03	1.7	0.045	0.255	0.7475
Na (mg/l)	39	48	26.87	10.45	6.4	52	8.04	27	43.5
NH_4 (mg/l N)	44	0.03	0.76	1.95	0.03	11	0.03	0.12	3.77
NO_3 (mg/l)	41	0.46	2.06	2.21	0.05	13	0.18	1.6	5.1
PO_4 (mg/l)	40	0.31	0.26	0.24	0.03	1.1	0.03	0.175	0.847
SO_4 (mg/l)	37	230	171.35	52.62	14	325	99.2	180	232
COD (mg/l)	44	5	11.95	6.63	5	29	5	12	24.55
SS (mg/l)	40	18	9.93	11.22	0.25	64	0.5	5	28.15
Variable	K21								
	n	Last recorded value	Mean	Standard Deviation	Minimum value	Maximum value	5 Percentile	50 Percentile	95 Percentile
Conductivity (mS/m)	92	61	63.34	3.71	51	71	56.65	64	68.45
Dissolved oxygen (mg/l O_2)	85	7.6	6.48	1.40	2.8	10	4.02	6.5	8.78
pH	92	8	7.86	0.26	7.1	8.3	7.355	7.9	8.245
Temperature (°C)	92	23	22.68	1.27	17	26	21	23	24.45
Al (mg/l)	84	0.05	0.08	0.08	0.05	0.53	0.05	0.06	0.2395
Cl (mg/l)	82	52	49.78	7.79	27	69	36.05	50	63
F (mg/l)	79	0.03	0.22	0.08	0.03	0.5	0.069	0.22	0.31
Fe (mg/l)	83	0.09	0.06	0.03	0.03	0.18	0.03	0.05	0.109
Mn (mg/l)	84	0.25	0.15	0.18	0.03	1.4	0.03	0.13	0.2885
Na (mg/l)	84	79	38.00	11.36	10	79	13	39	52.7
NH_4 (mg/l N)	92	0.03	0.18	0.65	0.03	5	0.03	0.03	0.532
NO_3 (mg/l)	83	5	4.78	1.43	0.05	9.1	3.03	4.6	7.28
PO_4 (mg/l)	85	0.35	0.39	0.25	0.01	1.7	0.092	0.33	0.726
SO_4 (mg/l)	79	88	105.91	23.72	12	160	81.9	105	137.5
COD (mg/l)	91	29	27.12	5.93	12	48	18	27	38.5
SS (mg/l)	83	57	39.47	21.28	13	140	17	36	70.2
FC (FC fc/100ml)	96	1730	1984.84	4713.19	245	42000	300	1080	5200

Appendix A2: Summary and Statistical Data for the Natalspruit Wetland for 1 October 2000 to 30 September 2002.

Variable	E7								
	n	Last recorded value	Mean	Standard Deviation	Minimum value	Maximum value	5 Percentile	50 Percentile	95 Percentile
Conductivity (mS/m)	42	335	305.48	49.91	185	390	220	312.5	379.5
Dissolved oxygen (mg/l O_2)	44	5.2	6.50	2.09	0.5	10	1.785	6.65	9.17
pH	45	6.8	7.36	0.35	6.5	8.1	6.8	7.4	7.9
Temperature (°C)	45	23	22.62	1.25	18	25	21	23	24
Al (mg/l)	39		0.12	0.21	0.05	0.92	0.05	0.05	0.736
Cl (mg/l)	41	100	98.63	21.04	36	145	65	98	135
F (mg/l)	40	0.32	0.23	0.12	0.06	0.68	0.07	0.225	0.3855
Fe (mg/l)	41	0.03	0.30	0.38	0.03	1.6	0.03	0.15	1.2
Mn (mg/l)	41	0.03	2.24	3.14	0.03	17	0.05	0.98	7.9
Na (mg/l)	41	155	135.32	45.55	26	270	64	135	190
NH_4 (mg/l N)	45	0.62	1.04	0.74	0.03	3	0.056	0.86	2.18
NO_3 (mg/l)	41	0.24	2.25	1.22	0.05	4.2	0.11	2.7	3.8
PO_4 (mg/l)	42	0.03	0.03	0.02	0.01	0.1	0.03	0.03	0.05
SO_4 (mg/l)	40	1970	1660.63	512.94	305	2410	798	1620	2343.5
COD (mg/l)	46	25	15.57	11.37	5	50	5	13	43.75
SS (mg/l)	33	25	20.52	9.64	11	58	12	18	34.2

Variable	N8								
	n	Last recorded value	Mean	Standard Deviation	Minimum value	Maximum value	5 Percentile	50 Percentile	95 Percentile
Conductivity (mS/m)	90	130	112.56	20.98	65	200	86.45	112.5	135
Dissolved oxygen (mg/l O_2)	82		6.60	1.61	1.3	10	3.6	6.65	9.185
pH	90	8.1	7.90	0.21	7.4	8.3	7.5	7.9	8.2
Temperature (°C)	90	23	22.77	1.07	20	26	21	23	24.55
Al (mg/l)	79	0.05	0.08	0.09	0.05	0.53	0.05	0.05	0.296
Cl (mg/l)	79	115	80.46	17.27	45	125	52.5	81	105
F (mg/l)	78	0.45	0.35	0.14	0.07	1.1	0.14	0.34	0.4915
Fe (mg/l)	79	0.03	0.06	0.04	0.03	0.22	0.03	0.05	0.124
Mn (mg/l)	79	1.4	0.35	0.35	0.03	2.5	0.03	0.27	0.831
Na (mg/l)	79	130	63.87	19.62	21	130	26	64	88.2
NH_4 (mg/l N)	91	4.1	1.22	1.19	0.03	4.2	0.03	0.9	4.05
NO_3 (mg/l)	82	3.8	3.34	1.28	0.05	6.5	1.21	3.6	4.895
PO_4 (mg/l)	82	0.31	0.49	0.63	0.03	5.1	0.121	0.335	1.1
SO_4 (mg/l)	78	410	320.37	114.70	90	870	118.5	325	486.5
COD (mg/l)	90	29	17.78	6.42	5	37	10.45	16	29.55
SS (mg/l)	67	39	22.57	20.99	10	140	10.3	17	42.5
FC (FC fc/100ml)	95	6800	5071.32	6542.58	180	41000	518	2650	18200

Appendix A3: Statistical Data of the input and output data of the Klip River and Natalspruit Wetlands for 1 October 2000 to 30 September 2002.

Klip River	Z value	[-1.96<=z<=+1.96]	Natalspruit	Z value	[-1.96<=z<=+1.96]
Conductivity (mS/m)	5.64	significant difference	Conductivity (mS/m)	24.08	significant difference
Dissolved oxygen (mg/l O_2)	-2.49	significant difference	Dissolved oxygen (mg/l O_2)	-0.28	no significant difference
pH	1.47	no significant difference	pH	-9.73	significant difference
Temperature (°C)	-0.31	no significant difference	Temperature (°C)	-0.66	no significant difference
Al (mg/l)	0.17	no significant difference	Al (mg/l)	1.27	no significant difference
Cl (mg/l)	-18.38	significant difference	Cl (mg/l)	4.76	significant difference
F (mg/l)	-0.98	no significant difference	F (mg/l)	-4.78	significant difference
Fe (mg/l)	0.59	no significant difference	Fe (mg/l)	3.97	significant difference
Mn (mg/l)	3.17	significant difference	Mn (mg/l)	3.83	significant difference
Na (mg/l)	-5.34	significant difference	Na (mg/l)	9.59	significant difference
NH_4 (mg/l N)	1.93	no significant difference	NH_4 (mg/l N)	-1.08	no significant difference
NO_3 (mg/l)	-7.17	significant difference	NO_3 (mg/l)	-4.58	significant difference
PO_4 (mg/l)	-2.85	significant difference	PO_4 (mg/l)	-6.47	significant difference
SO_4 (mg/l)	7.23	significant difference	SO_4 (mg/l)	16.32	significant difference
COD (mg/l)	-12.88	significant difference	COD (mg/l)	-1.22	no significant difference
SS (mg/l)	-10.07	significant difference	SS (mg/l)	-0.67	no significant difference

Appendix A4: Summary and Statistical Data to show Seasonal Variation for the Klip River Wetland for 1 October 2000 to 30 September 2002.

Variable	Spring and Summer								
	K6			K21			Statistical Analyses		
	Mean	n	SD	Mean	n	SD	(SDe7*SDe7)	Z value	[-1.96<=z<=+1.96]
Conductivity (mS/m)	67.04	23	8.59	62.34	47	4.04	3.56	2.49	**significant difference**
Dissolved oxygen (mg/l O_2)	4.49	21	1.85	6.36	43	1.58	0.22	-3.99	**significant difference**
pH	7.88	23	0.3	7.84	47	0.29	0.01	0.44	no significant difference
Temperature (°C)	23.13	23	0.92	23.17	47	1.13	0.06	-0.16	no significant difference
Al (mg/l)	0.08	18	0.07	0.08	39	0.09	0	0.08	no significant difference
Cl (mg/l)	22.96	23	7.13	48.51	47	8.79	3.85	-13.02	**significant difference**
F (mg/l)	0.22	22	0.07	0.24	46	0.07	0	-1.11	no significant difference
Fe (mg/l)	0.07	17	0.03	0.05	39	0.02	0	1.53	no significant difference
Mn (mg/l)	0.43	16	0.43	0.17	39	0.26	0.01	2.3	**significant difference**
Na (mg/l)	28.24	17	8.02	40.9	39	9.87	6.28	-5.05	**significant difference**
NH_4 (mg/l N)	1.09	22	2.59	0.18	47	0.74	0.32	1.62	no significant difference
NO_3 (mg/l)	1.54	23	1.47	4.36	47	1.38	0.13	-7.67	**significant difference**
PO_4 (mg/l)	0.3	21	0.31	0.42	46	0.22	0.01	-1.51	no significant difference
SO_4 (mg/l)	162.3	20	46.97	108.43	44	28.04	128.16	4.76	**significant difference**
COD (mg/l)	13.17	23	7.42	25.81	47	6.87	3.4	-6.85	**significant difference**
SS (mg/l)	11.61	19	14.52	42.3	40	19.48	20.59	-6.77	**significant difference**
Variable	**Autumn and Winter**								
	K6			**K21 Autumn and Winter**			**Statistical Analyses**		
	Mean	n	SD	Mean	n	SD	(SDe7*SDe7)	Z value	[-1.96<=z<=+1.96]
Conductivity (mS/m)	73.24	21	3.94	64.38	45	3.04	0.94	9.12	**significant difference**
Dissolved oxygen (mg/l O_2)	6.57	22	2.09	6.6	42	1.2	0.23	-0.05	no significant difference
pH	8	21	0.24	7.88	45	0.22	0	1.92	no significant difference
Temperature (°C)	22.09	22	0.92	22.18	45	1.21	0.07	-0.33	no significant difference
Al (mg/l)	0.08	21	0.06	0.07	45	0.06	0	0.17	no significant difference
Cl (mg/l)	26.88	17	5.58	51.49	35	5.92	2.83	-14.62	**significant difference**
F (mg/l)	0.19	16	0.13	0.2	33	0.09	0	-0.43	no significant difference
Fe (mg/l)	0.06	21	0.05	0.06	44	0.03	0	-0.2	no significant difference
Mn (mg/l)	0.24	20	0.14	0.14	45	0.07	0	3.38	**significant difference**
Na (mg/l)	25.82	22	12.08	35.49	45	12.06	9.86	-3.08	**significant difference**
NH_4 (mg/l N)	0.43	22	0.92	0.18	45	0.54	0.04	1.2	no significant difference
NO_3 (mg/l)	2.71	18	2.81	5.33	36	1.33	0.49	-3.75	**significant difference**
PO_4 (mg/l)	0.21	19	0.13	0.37	39	0.28	0	-2.9	**significant difference**
SO_4 (mg/l)	182	17	58.2	102.74	35	16.66	207.15	5.51	**significant difference**
COD (mg/l)	10.62	21	5.52	28.52	44	4.4	1.89	-13.03	**significant difference**
SS (mg/l)	8.42	21	7.11	36.84	43	22.73	14.43	-7.48	**significant difference**

Appendix A5: Summary and Statistical Data to show Seasonal Variation for the Natalspruit Wetland for 1 October 2000 to 30 September 2002.

Variable	Spring and Summer								
	E7			N8			Statistical Analyses		
	Mean	n	SD	Mean	n	SD	(SDe7*SDe7)	Z value	[-1.96<=z<=+1.96]
Conductivity (mS/m)	289.21	19	45.10	104.41	46	15.37	112.19	17.45	significant difference
Dissolved oxygen (mg/l O_2)	5.88	21	2.22	6.64	42	1.71	0.30	-1.37	no significant difference
pH	7.30	22	0.36	7.85	46	0.23	0.01	-6.57	significant difference
Temperature (°C)	23.14	22	0.99	23.20	46	1.13	0.07	-0.22	no significant difference
Al (mg/l)	0.07	18	0.04	0.08	37	0.09	0.00	-0.73	no significant difference
Cl (mg/l)	98.61	23	24.59	74.84	45	17.24	32.89	4.14	significant difference
F (mg/l)	0.27	22	0.12	0.38	45	0.13	0.00	-3.50	significant difference
Fe (mg/l)	0.41	19	0.50	0.06	37	0.04	0.01	2.99	significant difference
Mn (mg/l)	2.91	19	4.20	0.43	37	0.47	0.93	2.57	significant difference
Na (mg/l)	140.42	19	46.60	63.38	37	19.09	124.14	6.91	significant difference
NH_4 (mg/l N)	0.93	23	0.60	0.92	46	1.16	0.05	0.05	no significant difference
NO_3 (mg/l)	2.35	23	1.20	2.80	46	1.20	0.09	-1.48	no significant difference
PO_4 (mg/l)	0.03	23	0.02	0.53	44	0.81	0.02	-4.01	significant difference
SO_4 (mg/l)	1498.86	22	468.22	288.23	43	88.54	10147.47	12.02	significant difference
COD (mg/l)	14.70	23	11.43	17.33	46	7.15	6.79	-1.01	no significant difference
SS (mg/l)	17.38	16	5.67	25.36	33	19.21	13.19	-2.20	significant difference
Variable	Autumn and Winter								
	E7			N8			Statistical Analyses		
	Mean	n	SD	Mean	n	SD	(SDe7*SDe7)	Z value	[-1.96<=z<=+1.96]
Conductivity (mS/m)	318.91	23	50.61	121.07	44	22.78	123.15	17.83	significant difference
Dissolved oxygen (mg/l O_2)	7.06	23	1.83	6.56	40	1.53	0.20	1.11	no significant difference
pH	7.40	23	0.34	7.95	44	0.17	0.01	-7.34	significant difference
Temperature (°C)	22.13	23	1.29	22.32	44	0.80	0.09	-0.64	no significant difference
Al (mg/l)	0.17	21	0.27	0.08	42	0.08	0.00	1.51	no significant difference
Cl (mg/l)	98.67	18	16.08	87.88	34	14.46	20.52	2.38	significant difference
F (mg/l)	0.19	18	0.10	0.30	33	0.12	0.00	-3.49	significant difference
Fe (mg/l)	0.20	22	0.21	0.06	42	0.04	0.00	3.27	significant difference
Mn (mg/l)	1.66	22	1.71	0.29	42	0.18	0.13	3.76	significant difference
Na (mg/l)	130.91	22	45.23	64.31	42	20.29	102.81	6.57	significant difference
NH_4 (mg/l N)	1.17	22	0.86	1.54	45	1.14	0.06	-1.48	no significant difference
NO_3 (mg/l)	2.13	18	1.28	4.03	36	1.04	0.12	-5.46	significant difference
PO_4 (mg/l)	0.03	19	0.01	0.44	38	0.32	0.00	-7.83	significant difference
SO_4 (mg/l)	1658.33	18	507.48	359.86	35	131.15	14798.80	12.32	significant difference
COD (mg/l)	16.43	23	11.50	18.25	44	5.60	6.47	-0.71	no significant difference
SS (mg/l)	23.47	17	11.69	19.85	34	22.53	22.97	0.75	no significant difference

Appendix A6: Summary and Statistical Data for Faecal coliforms entering and leaving the Klip River and Natalspruit Wetlands for 1 October 2000 to 30 September 2002.

Variable	Inflow effluent into the Wetlands			Outflow of the Wetlands			Statistical Analyses		
Faecal coliforms	Klip River WWTWs			K21					
	Mean	n	SD	Mean	n	SD	(SDa*SDa)/ No of san	Z value	[-1.96<=z<=+1.96]
	18391.56	18	22479.93	1984.84	96	4713.19	28306250	3.08	significant difference
Faecal coliforms	Natalspruit WWTWs			N8			Statistical Analyses		
	Mean	n	SD	Mean	n	SD	(SDa*SDa)/ No of san	Z value	[-1.96<=z<=+1.96]
	2482986.83	52	4448113.56	5071.32	95	6542.58	380494955994	4.02	significant difference

Appendix A7: Summary and Statistical Data to show Faecal coliforms (FC/100ml) entering the Natalspruit and Klip River Wetlands from WWTWs for 1 October 2000 to 30 September 2002.

WWTWs	Mean	n	SD	Min value	Max value	5 percentile	50 percentile	95 percentile	Last recorded value
Bushkoppies Works	23578.92	13	24463	86	86000	2974	15000	69800	4900
Dekema Sewage	1603333.33	18	2607401	90000	9800000	141000	610000	7135000	2200000
Olifantsvlei Sewage	4904.40	5	6127	12	12500	24	1340	12120	12
Rondebult Sewage	3078665.59	17	5831842	165	23000000	313	670000	12360000	138000
Vlakplaats Works	2818705.88	17	4523921	18000	18000000	163600	620000	9360000	18000000

Appendix A8: Summary and Statistical Data to show Seasonal Variation of Faecal coliforms for the output points for both the Klip River and the Natalspruit Wetlands for 1 October 2000 to 30 September 2002.

Variable	Mean	n	SD	Mean	n	SD	Statistical Analyses		
	N8 S+S			N8 A+W			(SDa*SDa)/ No of san	Z value	[-1.96<=z<=+1.96]
Faecal coliforms	4805.85	47	6133	5331.25	48	6975.473636	1813995	-0.39	no significant difference
	K21 S+S			K21 A+W					
Faecal coliforms	1643.54	48	2017	2326.145833	48	6371.362979	930480	-0.71	no significant difference

Appendix A9: Summary and Statistical Data for the ERWAT WWTWs outflow in the Natalspruit Wetlands for September 2002.

Variable	n	Last recorded value Ml/day	Mean Ml/day	Minimum value Ml/day	Maximum value Ml/day
Dekema Sewage	30	25.10	19.09	13.69	25.10
Rondebult Sewage	30	18.13	14.89	8.05	18.13
Vlakplaats Works	30	66.27	67.68	62.35	75.01

Appendix A10: Summary of Load Data for the WWTWs for the Natalspruit Wetlands for September 2002.

Variable	Rondebult			Dekema			Vlakplaats		
	Mean concentration	Mean Flow	Load	Mean concentration	Mean Flow	Load	Mean concentration	Mean Flow	Load
Conductivity (mS/m)	125	1.73	215.88	78	2.21	172.69	120	7.85	942
Disolved Oxygen (mg/l O2)	4.6	1.73	7.94	4.3	2.21	9.52	0.66	7.85	5.18
Aluminium (mg/l)	0.05	1.73	0.09	0.05	2.21	0.11	0.05	7.85	0.39
Cloride (mg/l)		1.73		86	2.21	190.4	245	7.85	1923.25
F (mg/l)		1.73		0.06	2.21	0.13	5	7.85	39.25
Iron (mg/l)	0.14	1.73	0.24	0.19	2.21	0.42	6.4	7.85	50.24
Mn (mg/l)	0.54	1.73	0.93	0.28	2.21	0.62	1.1	7.85	8.64
Na (mg/l)	150	1.73	259.05	95	2.21	210.33	150	7.85	1177.5
NH4 (mg/l)	3.6	1.73	6.22	9.3	2.21	20.59	19	7.85	149.15
NO3 (mg/l)	3.4	1.73	5.87	6	2.21	13.28	0.42	7.85	3.3
PO4 (mg/l)	0.23	1.73	0.4	0.26	2.21	0.58	0.03	7.85	0.24
SO4 (mg/l)	170	1.73	293.59	120	2.21	265.68	54	7.85	423.9
COD (mg/l)	51	1.73	88.08	62	2.21	137.27	210	7.85	1648.5
SS (mg/l)	39	1.73	67.35	41	2.21	90.77	38	7.85	298.3
FC (counts/100ml)	138000	1.73	238326	2200000	2.21	4870800	18000000	7.85	141300000

Appendix A11: Summary of Load Data for sample points E7, E8, N9 and N8 for the Natalspruit Wetlands for September 2002.

Variable	E7			E8			N9			N8		
	Mean concentration	Mean Flow	Load	Mean concentration	Mean Flow	Load	Mean concentration	Mean Flow	Load	Mean concentration	Mean Flow	Load
Conductivity (mS/m)	340	0.49	167.69	157.5	0.02	2.58	55	0.3	16.45	121.25	2.4	291.02
Disolved Oxygen (mg/l O2)	5.95	0.49	2.93	8.95	0.02	0.15	8.9	0.3	2.66	5.3	2.4	12.72
Aluminium (mg/l)	1.48	0.49	0.73	0.05	0.02	0	0.05	0.3	0.01	0.05	2.4	0.12
Cloride (mg/l)	98	0.49	48.33	91.5	0.02	1.5	23.5	0.3	7.03	94.5	2.4	226.82
F (mg/l)	0.23	0.49	0.11	0.21	0.02	0	0.15	0.3	0.04	0.27	2.4	0.65
Iron (mg/l)	0.08	0.49	0.04	0.36	0.02	0.01	0.03	0.3	0.01	0.03	2.4	0.07
Mn (mg/l)	1.42	0.49	0.7	0.28	0.02	0	1.82	0.3	0.54	0.76	2.4	1.82
Na (mg/l)	160	0.49	78.91	79.5	0.02	1.3	12.15	0.3	3.63	92.5	2.4	222.02
NH4 (mg/l)	0.69	0.49	0.34	0.03	0.02	0	1.17	0.3	0.35	2.03	2.4	4.86
NO3 (mg/l)	1.52	0.49	0.75	0.63	0.02	0.01	1.4	0.3	0.42	3.88	2.4	9.3
PO4 (mg/l)	0.03	0.49	0.01	0.03	0.02	0	0.03	0.3	0.01	0.33	2.4	0.79
SO4 (mg/l)	2005	0.49	988.87	540	0.02	8.84	180	0.3	53.82	377.5	2.4	906.08
COD (mg/l)	15	0.49	7.4	8.5	0.02	0.14	10	0.3	2.99	23.25	2.4	55.8
SS (mg/l)	27	0.49	13.32	9.5	0.02	0.16	7.5	0.3	2.24	30.75	2.4	73.81
FC (counts/100ml)										2970	2.4	7128.59

Appendix A12: The South African Water Quality guidelines, Volume 7: Aquatic Ecosystems (DWAF). 1996. First Edition.

The Target Water Quality range (TWQR) is found in the left. The Chronic Effect Value (CEV) is found in the center and the Acute Effect Value (AEV) is found in the right. No value (NV) present indicates that there are no guidelines available for this characteristic.

Variable	TWQR	CEV	AEV
Conductivity (mS/m)	NV		
PH	Should not vary from the range of the background value by >0.5 of a pH unit, or by >5%		
Dissolved oxygen (mg/l)	NV		
Suspended solids (mg/l)	Less than 10% of the background total suspended solids concentration		
Temperature (°C)	Should not vary from the background average by >2°C or by >10%, whichever is more conservative		
Aluminium (mg/l) at pH>6.5	<0.01	0.02	0.15
Fluoride (mg/l)	<0.75	1.5	2.54
Iron (mg/l)	Not more than 10% of the background dissolved iron concentration		
Manganese (mg/l)	0.18	0.37	1.3
Sodium (mg/l)	NV		
Nitrate (mg/l)	NV		
Ammonia (mg/l)	<0.007	0.015	0.1
Sulphate (mg/l)	NV		
Phosphate (mg/l)	NV		
Chemical Oxygen Demand(COD)	NV		
Faecal coliforms	NV		