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A study of stormwater runoff from Alexandra township in the juskei river

Campbell, Linda Anne

1996
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DEDICATION

To my MSc, without whom I would have never have met Jon,
my future husband-to-be.

ACKNOWLEDGMENTS

I wish to thank the personnel of the Water Systems Research Group, especially Prof. D Stephenson for all the support and help that they have given me during this project. I also wish to thank Trevor Coleman for his input and chats and often for helping me see the light. Many thanks to Thelma and the staff at CYDNA laboratory for their analyses on my water samples. The financial support of the Water Research Commission (WRC) is also greatly appreciated.

suggested. In America the rivers are not as turbid as in South Africa, so there are lower concentrations of SS onto which the pollutants could adsorb.

During storm events the main process occurring is the entrainment of pollutants from the river bed. These are then washed downstream. Many pollutants like phosphates, lead, iron and organic nitrogen are associated with the SS and had similar pollutagraphs. Factors to determine the pollutagraph for each of these pollutants downstream of a pollution source were calculated and used in the modelling of these pollutants with WITQUAL, a water quality model developed by the Water Systems Research Group of the University of the Witwatersrand.

ABSTRACT

South Africa, like many other developing countries, is faced with rapid urbanisation with the associated increase in the pollution load. Much of this pollution is destined for our watercourses, that eventually run into storage reservoirs which may be used for drinking water or recreational purposes. This pollution is usually attributed to human waste products which include nitrogenous wastes, phosphates, micro-organisms, organic material and litter.

A 6km stretch of the Jukskei river just downstream of Alexandra Township, was used to determine the different biological, physical and chemical processes that pollutants undergo during natural assimilation, their rates and efficiencies of assimilation in rivers and their impact on the environment downstream of the urban area. "Grab" samples were taken over a period which included both low-flow and storm events. Due to the high concentration of nutrients in the run-off from Alexandra Township, the major changes seen were in the biological conversion of organic nitrogen compounds and ammonia to nitrates, in the BOD and in the concentration of dissolved oxygen in the river, with lows of 1.1 to 1.5 mg/l O_2 being recorded at Alexandra. A rapid rise in the concentration of faecal coliforms has been seen with a high of 31 million/100 ml being recorded at Alexandra in September, 1994. Sedimentation at the Alexandra site is also a common occurrence with a lot of adsorbed pollutants being effectively removed from the water column with the suspended solids.

The QUAL2E water quality model, used by the EPA in the United States, was used to model the reactions that the nutrients, BOD and DO undergo. BOD and DO were modelled very well with r^2 of 0.98 and 0.94 being calculated respectively. QUAL2E did not model the dissolved pollutants, dissolved phosphorus and ammonia very well with the observed results showing a greater reduction in these pollutants. A method by which these pollutants adhere to SS and settle out was

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

A.C. Campbell

2nd day of April 1996

A STUDY OF STORMWATER RUNOFF FROM ALEXANDRA TOWNSHIP IN THE JUKSKEI RIVER

Linda Anne Campbell

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, in fulfillment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 1996

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Most nutrients are not toxic in high concentrations, except for the nitrogen derivatives, ammonia and nitrite.

The largest source of nutrients is the particulate and dissolved nutrients contained in the runoff from urban catchments. Inorganic nitrogen and phosphorus are seldom present in high concentrations in natural surface waters. This is because most of the nitrogen and phosphorus is rapidly taken up by aquatic plants from the water or from the sediments, and converted into proteins, ATP and other organic cellular products. Nutrients undergo a number of processes in-stream that are regulated by water temperature and pH of the water. Under aerobic conditions the most important process taking place is the conversion of ammonia to nitrites and nitrates by the nitrifying bacteria. Conversely, under anaerobic conditions, denitrification i.e. the biological conversion of nitrates to nitrites and then to molecular nitrogen, is the most important process occurring. Denitrification takes place at dissolved oxygen concentrations of 1 - 1.5 $mg.l^{-1}$.

Sedimentation of nutrients is also an important process. At a pollution source, more than 30% of nutrients are in particulate form and these settle out under low flow conditions (Watertek, 1995). Dissolved nutrients may also adsorb onto suspended particulate material and sediment out with the suspended material. Most of inorganic phosphorus compounds settle out, so very little is usually present in the surface waters. Figures 1.2 and 1.3 show the nutrient cycles of nitrogen and phosphorus in natural surface waters.

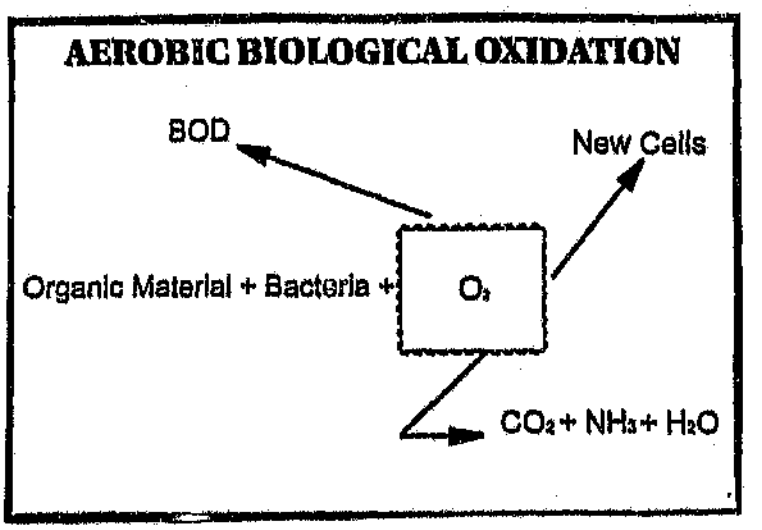

Figure 1.1 Aerobic Biological Oxidation

The organic pollutants were measured in terms of the Biochemical Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD). BOD is a measure of the amount of oxygen consumed by bacteria whilst oxidising organic matter under aerobic conditions and is measured in the laboratory using a five day bottle test. In this test, sampled water is placed in a bottle, the Dissolved Oxygen (DO) is measured at the beginning and at the end of five days and the difference between these two values is the oxygen used by the bacteria during that time or the BOD. The COD is the amount of oxygen that is required to oxidise all oxidisable substances in a sample of water and is usually done in the laboratory using a strong chemical oxidant.

1.3.6 Nutrients

Nutrients are any elements that are required for the normal growth and reproduction of plants. The inorganic forms of nitrogen and phosphorus are usually concentrated on as they are responsible for eutrophication in streams.

Most are chemically inert and are transported downstream with an equilibrium existing between the ions in the benthic layer and the ones in the river water. They are conservative constituents i.e. the mass of the pollutant is not altered by the chemical and biological processes occurring in the surface water and once they enter the river they may be diluted or dispersed but not changed in quantity.

These inert insoluble forms of inorganic ions often settle out and coat the bottom of the river resulting in inhibition of benthic biological activity or cause turbidity. If the water is turbid, it causes a deterioration in light transmissivity. Activity and growth of aquatic plants are inhibited even to the extent of complete elimination. Some inorganic contaminants such as sulphurous acid exert an oxygen demand, as oxygen in the water is used for the oxidation of the sulphurous acid to sulphuric acid.

1.3.5 Organic pollutants

Organic pollutants are non-conservative variables in that they undergo some form of chemical or biological change. The major effect that organic pollutants have on the aquatic system is the depletion of the store of dissolved oxygen in the water due the numerous oxidation reactions taking place. The organic pollutants are mainly oxidised by means of various bacteria in the water. For this, appropriate bacteria, nutrients and dissolved oxygen are needed with the bacteria forming new cells while the rest is converted to stable products (Figure 1.1). Other organic contaminants like pesticides are not easily broken down and are toxic to fish. These types of pollutants have an accumulative and lasting effect rather than Biochemical Oxygen Demand (BOD) whose effect on the environment is immediately seen. Contaminants like oils form a surface layer over the water causing a lower rate of reaeration, no respiration can take place and organisms begin to die.

penetration, with an associated decrease in photosynthesis in aquatic plants (Kirk,1985). Settling out of the suspended solids may smother aquatic plants and animals leading to retardation of benthic activities. Dissolved nutrients can also become adsorbed onto the suspended particles, and are transported downstream in this biologically unavailable form.

1.3.3 Conductivity and TDS

Conductivity is the measure of the ability of water to conduct an electrical current. This is closely linked to the concentration of total dissolved solids (TDS). In very dilute waters the conductivity is proportional to TDS, but this changes as the concentration of dissolved organic material increases, since dissolved organic do not conduct an electrical current. For South Africa as a whole, it has been found by the Department of Water Affairs and Forestry (DWAF) personnel (Dallas & Day,1993) that
TDS ($mg.l^{-1}$) = conductivity ($mS.m^{-1}$) * 6.6.

Ions most commonly found in natural waters are the cations calcium, magnesium, sodium and potassium and the anions bicarbonate, carbonate, chloride and sulphate. A small amount of inorganic material may be present as hydroxides (Dallas & Day, 1993). All these major ions were present in the water samples taken from the Jukskei river.

1.3.4 Inorganic pollutants

Inorganic pollutants are mainly in the form of ions and their major effect is on the pH and toxicity of certain materials like heavy metals (Krenkel & Novotny, 1980). At certain pHs, the valence of the metal is changed allowing it to be taken up by fish and other aquatic animals and stored in their fat stores thus accumulation of the heavy metal takes place. Once the aquatic animal or plant dies the heavy metals are again released into the water.

responsible for an increase of 56 to 89% of the mean pollutant loads in the river. A number of water quality variables were chosen for investigation in this study, with the emphasis on those which were considered to have the most severe impact on the river water quality. Table 3.2 has a list of the pollutants monitored in the Jukskei River.

1.3.1 Temperature and pH

Temperature plays an important role as it significantly affects physical, chemical and biological processes. Temperature also affects microbial activity and hence the rate at which organic waste is broken down by bacteria. It also affects the dissolved oxygen concentration in water. As the temperature increases the solubility of dissolved oxygen in water decreases. With the oxygen depletion also being accelerated by the increased microbial activity at high temperatures, one of the most important limiting factors to the waste assimilation capacity of a stream is thus the concentration of dissolved oxygen in the stream. This is why dissolved oxygen is seen as a surrogate variable for the general health of the aquatic system. (Thomann, 1987).

pH is important as it determines the chemical species in which many molecules and elements will be found in the water and thus the potential toxicity of these chemical species to aquatic organisms.(Dallas and Day, 1993). Examples of this are aluminium which forms the toxic Al^{3+} ion at low pH (<5) and ammonia which forms the toxic NH_3 molecule at high pH.

1.3.2. Turbidity and suspended solids

Turbidity can be described as a measure of the clarity of the water. Suspended solids and the resulting turbidity may originate in wastewater discharges, as well as from erosion processes. The solids may be of organic or inorganic nature. Continuous high-level inputs of suspended solids result in a reduction in light

1992). For this reason the nutrients, dissolved oxygen, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and faecal coliforms were chosen as the more important pollutants to monitor. Lead and iron were also monitored as they were found to be the metals of greatest concentration in the runoff off the catchment (Wimberley, 1992).

1.2 AIMS AND OBJECTIVES OF THIS STUDY

Under certain circumstances a river may be one of the alternatives for the treatment of urban runoff. In order to predict the efficiency of a river in the assimilation of waste from runoff, the pollutant assimilation equations determined from the Jukskei River study are used to see if it is a viable treatment option.

The aim of this study is thus to measure the waste assimilation capacity of the Jukskei River under different flows, and to see if modelled results follow observed results, and from this suggest what probable processes could be responsible for the waste assimilation capacity of the river. These parameters can then be applied to other rivers in order to predict the waste assimilation capacity of that river.

1.3 KEY ISSUES AND MAJOR POLLUTANTS

The major pollutants sampled were suspended solids, TDS, nitrogen, phosphorus, pathogens, metals and oxygen demanding pollutants. Nutrient and oxygen changes were concentrated on however, as most pollution in high-density developments like the townships are organic in nature. Wimberley's (1992) report on the pollution in Alexandra, clearly showed that the greatest impact on the Jukskei was in the increased concentration of nutrients and oxygen depletion arising from the discharge of organic material with a high oxygen demand. The results also showed that the urban runoff from Alexandra was

CHAPTER 1 : INTRODUCTION AND PROBLEM STATEMENT

1.1 INTRODUCTION

Alexandra Township is an example of the controversial informal settlements that have sprung up in South Africa as a result of the increasing demand for low cost housing which is as a direct result of the continuing urbanisation of the population. With this increase in population comes the related increase in pollution. Most of this pollution flows off the catchment into some water body which is usually a river.

The Jukskei River flows through Alexandra Township dividing it into two parts. The East Bank is comprised of mainly formal housing with one dwelling unit per stand being the most common type of accomodation seen. On the West Bank however, an informal settlement of free-standing and backyard shacks are superimposed on the formal settlement (Wimberley, 1992). Very rudimentary services (stand-pipes and portable toilets) are provided for the informal settlements. Insufficient management of these services has resulted in pollution discharging into the Jukskei River.

A number of at source and diversion treatment options are available for the treatment of pollution but all of these involve some sort of construction which is expensive. A river, if it is able to cope with the pollutant load is a very cheap alternative for treating pollution and this is important in low income areas like the townships that cannot afford the expensive engineering options. The main aim of this study was thus to show that a river could be viable as a treatment option if there are no other solutions especially in areas where the economic situation is such that expensive engineering treatment options are not possible.

Most of the pollution has been found to be due to sewage contamination with a high concentration of nutrients and faecal coliforms being seen (Wimberley,

Respiration - cellular respiration is the metabolic process whereby energy-rich substrates are oxidised; respiration of animals is the exchange of oxygen and carbon dioxide gases i.e. breathing.

Riparian - related to the river bank.

Salinity - the mass of dissolved inorganic solids in a kilogram of water.

Salinization - the process whereby the saltiness of the soils and rivers increase as a result of irrigation in arid areas.

Sediments - the soft sands, silts and muds on the bottom of rivers and lakes.

Suspended solids - Particles suspended in the water.

TDS - Total dissolved solids.

Trace element - an element occuring at < 1000 ppm in the earth's crust.

Turbidity - an expression of the optical ability of water that causes light to be scattered and absorbed (murkiness).

Water quality - the value or usefulness of water, determined by the combined effects of its physical attributes and its chemical constituents, and varying from user to user.

Water quality criterion - any definite limit of variation or alteration of water quality experty judged, on the basis of scientific data, not to have some specified, usually adverse, effect on the use of water by humans or on organisms inhabiting the water.

Water quality standard - a rule authoritatively establishing, for regulatory purposes, the limit of some unnatural alteration in water quality that is permitted or accepted as being compatible with some particular intended use or uses of water.

Water quality variables - any of those individual attributes or constituents of a given sample of water (e.g. salinity, temperature) that vary in magnitude and whose alterations alter water quality.

Major ions	- those ions (calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride and sulphate) that usually form the bulk of the total dissolved solids in inland waters.
Metal	- an element that is a good conductor of electricity and whose electrical resistance is directly proportional to the absolute temperature.
Micro-nutrients	- a term sometimes used for plant nutrients such as phosphorus, nitrogen, potassium and others.
Microbes	- micro-organisms such as bacteria and protozoans
Mineralisation	- the release of inorganic ions fom oxidised organic material.
Nitrification	- the aerobic oxidation of ammonia to nitrite and then to nitrate by nitrifying bacteria (*Nitrosomonas* and *Nitrobacter* bacteria).
Nitrogen fixation	- the process of converting N_2 gas to soluble forms (NO_2, NO_3) by bacteria.
NTU	- Nephelometric turbidity unit: a measure of turbidity.
Nutrient	- in aquatic biology usually a limiting nutrient: an element whose scarcity can limit plant growth e.g. compounds of nitrogen and phosphorus.
Periphyton	- the "slime" of (usually) microscopic organims growing on rocks and plants in the water.
pH	- The negative $\log_{10}$ of the hydrogen ion activity: a measure of acidity ($pH < 7$) or alkalinity ($pH > 7$)
Photosynthesis	- the process whereby plants convert CO_2 and water into large, energy-rich, organic compounds.
Pollutant	- a substance that contaminates.
Pollution	- defilement; unfavourable alteration of our environment, normally as a result of human actions; the presence of any foreign substance that impairs the usefulness of water.
Polyphenols	- large, complex, acidic organic molecules, characterised by a high proportion of phenol groups which often impart a dark colour to water.
Receiving waters	- waters receiving effluents.
Receiving water quality objectives	- the water quality towards which a regulatory body will aim or strive.
Redox reactions	- oxidation/reduction reactions.

is thus also a measure of the concentration of ions in the water.

Decomposition - the decay and breakdown of organic material, including the dead remains of plants and animals.

Denitrification - the anaerobic conversion of nitrate to nitrite and ammonia by fungi and bacteria.

Detritus - dead and decomposing plants and animals.

Ecosystem - interaction of organisms and their environment.

Effluent - the outflow of water which is usually wastewater.

Eutrophication - the process, usually anthropogenic, in which an excess of nutrients is added to water and an accumulation results in the rapid growth of plants.

Excreta - biological waste products: usually urine and faeces.

Fertilisers - these are chemical substances (composed of mainly nutrients) that are used to encourage the growth of plants.

Floodplain - low gradient land onto which a river regularly overflows its banks.

Geomorphology - the gross structure of land forms.

Gradient - the degree of slope.

Hardness - the combined concentration of calcium and magnesium in water.

Headwater zone - the upper reaches of a river.

Heavy metal - metals with an atomic mass greater than calcium (> 40.08).

Heterotrophic - using organic compounds as sources of carbon (fungi; animals). This is in contrast to **autotrophic.**

"Humic" substances - large, complex polyphenol-rich organic compounds derived as leachates from decomposing vegetation.

In vitro - in the laboratory

In vivo - in the field

Insecticide - a substance that kills insects.

Limnology - the study of the physical, chemical and biological properties of inland waters.

Lower reaches - the "mature" river with low gradient and usually with a soft bottom.

GLOSSARY OF TERMS AND ABBREVIATIONS

Adsorption - the physical adherence to the surface of a molecule or particle

Aerobic - in the presence of oxygen

Algae - any of a group of chiefly aquatic non-vascular plants i.e. those withthout roots, stems and leaves. (Many species of phytoplankton, seaweeds and scums).

Alkalinity - it is water's acid-neutralising ability and is obtained by adding anions of weak bases, hydroxyl, carbonate and bicarbonate ions.

Ambient - the surrounding environment e.g. the ambient temperature is the temperature of the surrounding air or water.

Ammonification - the breakdown of organic nitrogen to ammonia

Anaerobic - without oxygen

Anions - negatively charged ions

Anthropogenic - caused by human activity

Autotrophic - using inorganic carbon (usually CO_2) as the principle carbon source (plants and some bacteria); this contrasts with **heterotrophic.**

Benthic - living on the river bottom

Biocides - substances that kill living organisms.

Biomass - the mass of biological material.

Biota - the living organisms of a region or system.

BOD - BOD or the Biochemical Oxygen Demand is a measure of the amount of oxygen consumed by bacteria whilst oxidizing organic matter under aerobic conditions.

Buffering capacity - the resistance to change in pH as a result of the presence in water of weak acids and their salts e.g. the carbonate system

Catchment - the land area from which a river is fed. Same as a drainage basin or a watershed.

Cations - positively charged ions.

COD - Chemical Oxygen Demand: the amount of oxygen used to oxidise all oxidisable substances in a water sample with a strong chemical oxidant.

Conductivity - the ability of water to conduct an electric current which is dependent on the number of ions in the water. Conductivity

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concrete which has effectively taken away any natural habitats that were there and cut the river off from its banks (Davies, O'Keeffe & Snaddon, 1994).

2.1.8 The Hennops River, Gauteng.

The Hennops River catchment extends from Chloorkop/Tembisa in the south to the Centurion Lake in the north. The Hennops River Valley was chosen for this study as it is representative of a variety of land users (Hoffmann, 1995).

Routine sampling consisted of taking "grab" samples during daylight hours at selected sites. Sampling frequency was bi-weekly during the dry season (April - September) and weekly during the wet season (October - March). Stormwater sampling consisted of "grab" samples at selected sites.

The major source of pollution was found to be litter and faecal contaminants. This originated from deliberate pipe blockages in Tembisa, the high population d and poor living conditions in Ivory Park. The first flush effect was found t seasonal with the greatest increase in pollutant concentrations occurring after the first rains of the wet season. During base flow conditions Centurion Lake acted as a pollution reduction facility (Hoffmann, 1995) with mainly suspended solids and bacteria being removed. Microbiologically Centurion Lake is unacceptable and direct recreational contact should not be allowed.

It was concluded that the river water quality was unacceptable for use when compared to the selected water quality guidelines of the various users.

a rule relatively unpolluted but the low flows have resulted in the sediments being exposed, sediment and reed scouring, reed colonisation and reedbed colonisation by woody riparian vegetation.

2.1.6 Great Berg River, Western Cape

This river provides water for Greater Cape Town as well as providing mainly irrigation water to its own catchment. Degradation of this river has occurred as a result of irrigation return flows which has caused salinisation of the river, general nutrient enrichment due to agricultural runoff, increase in nutrients due to the inflow of domestic sewage from urban areas but especially Wellington and Paarl, industrial and wine farm effluents, trout farm effluents, invasion by alien aquatic and riparian vegetation as well as aquatic animals and pollution (high concentrations of nutrients, litter, decrease in dissolved oxygen) which is typical of informal settlements (Davies, O'Keeffe & Snaddon, 1994).

2.1.7 The Liesbeek, Cape Town

The Liesbeek River which is part of the Black River system in Cape Town, is an example of an urban river and the problems associated with them. This river starts on the eastern bank of Table Mountain and then flows for a few kilometres through the southern suburbs of Cape Town like Newlands, Rondebosch and Mowbray, before its confluence with the Black River. Just after passing through Kirstenbosch Gardens it begins to show signs of severe degradation. The natural riparian vegetation has been removed and alien plants like pine and oaks have been planted. Erosion of the channel has occurred due to people altering the natural course of the river. Two kilometres below Kirstenbosch the River has been canalised with

2.1.4 - Mbashe River, Eastern Cape

The Mbashe River flows through subsistence agricultural land in central Transkei. This river has not been utilised as a resource as it is remote from both industrial and urban centres. There are at the present no large impoundments on the river. A 11m weir was constructed at Collywobbles as a hydro-electric facility but floods resulted in the complete sedimentation of the weir within only 1 year of its construction. The catchment of the Mbashe river comprises friable soils derived mainly from Beaufort Shales and overgrazing and vegetation clearance has resulted in increased erosion and the sediment load of the river has increased dramatically with an estimation of $3 \times 10^6 m^3 a^{-1}$ (Davies, O'Keeffe & Snaddon, 1994).

2.1.5 Sabie River, Mpumalanga.

Many of the rivers in the Kruger National Park are under threat and 4 years ago an extensive research programme of all the rivers but mainly the polluted Olifants, the severely degraded and once perrenial Letaba, Luvuvhu and the Sabie was commenced. The Sabie River is the most important of these rivers as it has shown the first signs of overexploitation relatively recently and is one of the most biologically diverse river in South Africa (O'Keeffe & Davies, 1991).

The Sabie river has 3 priority uses. The upper catchment flows through extensive commercial forestry plantations of mainly Eucalyptus and Pine trees. The middle catchment is comprised of a number of socalled "homelands" including Gazankulu, Lebowa and Kangwane, while downstream it provides water to the southern part of the Kruger National Park. The river eventually flows east into Mozambique before joining the Komati river. Almost all the runoff is derived from the upper catchment. The demands of the growing populations of the 'homelands' has resulted in increased use of water for domestic and irrigation needs. The river is as

- Extensive agriculture occurs from the region just below Laing Dam to Bridle Drift where grazing and non-irrigated crops predominate. Mdantsane is included in this area, but its major impact on the river is downstream of Bridle Drift where sewage effluent is released. This causes an increase in nutrient concentrations and a decrease in dissolved oxygen which has resulted in a number of fish kills.

- Coastal Forest occurs just below Bridle Drift but the river is heavily polluted by sewage in this section from Mdantsane. The river runs through a deeply incised gorge or valley which contains the suburban development of East London as well as extensive agriculture. (Davies, O'Keeffe & Snaddon, 1994)

- Estuary which includes the urban area of East London including the estuarine harbour.

It was concluded that in various parts of the river heavy exploitation has taken place and the river's essential processes have become overloaded in parts of the river. The section between Zwelitsha and the inlet to the Laing Reservoir is the biggest problem due to organic and industrial effluents that are a health hazard to the rural users as well as to the fish in the river. A $1 mg.l^{-1}$ phosphate standard has been applied by the South African Department of Water Affairs and Forestry to all point-source effluents in the catchment of the Laing Dam (Van der Merwe & Grobler, 1990).

river was found to be increasing salinity (Hall & Gorgens, 1978), caused by irrigation runoff. The river has been modified to give a constant base flow of between 1 to 5 m^3s^{-1} for the convenience of the irrigation farmers. This was found to be the main cause of the salinity buildup as well as providing ideal larval habitat for the pest blackfly (*S.chutteri*).

2.1.3 Buffalo River, Eastern Cape.

The Buffalo River can be divided into six separate sections (Davies, O'Keeffe & Snaddon, 1994).

- Forest - the upper reaches of the river is in the Amatole mountains. This section is important for water supply, commercial timber, nature conservation and recreation (hiking and angling).

- The upper middle reaches which are important for agriculture (irrigated and fertilised vegetable crops). The water quality was found to decrease with an increase in TSS and nitrates being observed. This is a consequence of using fertilisers. (R.W.Palmer & O'Keeffe, 1990)

- Urban/Industrial which includes King Williams Town/Zwelitsha area. The major problem appears in this portion of the river where sewage and industrial effluent reduces the water quality to well below acceptable standards. During low flow periods, this urban/industrial portion acts as a closed loop because the Laing Reservoir (the mainwater supply) is situated downstream of the towns and consequently of their effluents. Algal blooms caused by *Microcystis* aeruginosa in this portion of the river are also a problem although they occur only infrequently (R.W.Palmer & O'Keeffe, 1990).

Table 2.1 - Pollutant export coefficients for COD, TKN & Ortho-P for various sources in Alexandra Township for the period August to November 1991.

Constituent	Source	Export coefficient (kg/ha/annum)
COD	Assumed Human Input	3 000 000
TKN	Assumed Human Input	600 000
Ortho-P	Assumed Human Input	100 000
COD	Storm Flow	3 000
TKN	Storm Flow	200
Ortho-P	Storm Flow	10
COD	Low Flow	1 000
TKN	Low Flow	180
Ortho-P	Low Flow	15
COD	Sewage	5 000
TKN	Sewage	400
Ortho-P	Sewage	90

(Modified from: Wimberley 1992, Palmer Development Group and U.C.T Water Research Group, 1992)

2.1.2 Great Fish River, Eastern Cape

This river serves no major industries or towns and its main value is in agriculture. As a result there is no organic or industrial pollution. The major problem with this

Wimberley mainly concentrated on the mass balances of pollution from Alexandra Township, the type of pollution and the pollutants that were problematic. He also monitored two positions on the Jukskei River: one at Corlett Drive just above Alexandra Township and one just below the culvert from Alexandra Township. 'Grab' samples were taken and the flow at that time was also monitored. Wimberley (1992) found the pollutant export coefficients for COD, TKN and Ortho-P for various sources (as shown in Table 2.1) and from this he concluded that human faeces were the major contributor to the nutrient loading from Alexandra Township which was the result of inadequate sanitary conditions in the Township. The major proportion of the nutrient loading is washed off the catchment during storm events.

Dissolved solids and heavy metals were continually washed off the catchment with an increase being observed during storm events. The buildup of pollutants on the catchment surface was seen as a worrying aspect due to the serious health risks that this posed. The pollution loading was seen to be of one to two orders of magnitude higher than any other catchments monitored overseas or in South Africa. It was observed that dilution of pollutants did take place when pollutants entered the Jukskei River. The pollutant mass balances showed that transportation of the pollutants out of the study area did take place. The greatest environmental impact was seen to be the large depletion of dissolved oxygen just downstream of Alexandra Township, the eutrophication of the river and the litter problem downstream. The greatest health risk is due to the large concentrations of faecal coliforms which is an indication of a large concentration of pathogens in the river.

The fate of the pollutants further downstream in the river were not determined. Wimberley recommended that a continuation in the monitoring exercise would be beneficial.

2.1.1 Jukskei River, Sandton (Gauteng)

A number of people have studied the pollution that is entering the Jukskei river from Alexandra Township. Van der Merwe (1993-1994) found that the biggest visual water quality problem was the amount of litter that is washed off from the Alexandra catchment. A more serious problem however, is the high concentrations of faecal coliforms that are found in the water (Van Veelen, 1994). This was also observed by Wimberely (1992). He found that 56-89% of the total pollutant load of the river came from the Alexandra which is only 10,1% of the total catchment area. Wimberely also monitored a number of other water quality constituents: heavy metals, suspended solids (SS), carbonaceous oxygen demand (COD), Total Dissolved Salts (TDS), pH, electrical conductivity (EC), lead (Pb), iron (Fe), *Escherichia coli* (*E. coli*), faecal coliforms (F.C.), ammonia (NH_4^+), nitrate (NO_3), nitrite (NO_2), total nitrogen (TN), soluble-PO_4, total PO_4, ortho-PO_4, sulphate (SO_4^{2-}), chloride (Cl^-) and total Kjeldahl nitrogen (TKN) (Wimberley, 1992). Storm flow in the culvert from Alexandra was found to be similar to raw sewage and dry weather flow to settled sewage for some of the pollutants.

The sources of these pollutants were also determined. Bulk fall-out samples were taken to measure the atmospheric contribution to the pollution load. The atmospheric contribution seemed to be mainly through washout by rainfall as well as through dry deposition. Inadequate cleaning of streets and refuse removal resulted in polluted surface runoff when rain fell. These pollutants were then transported to the stormwater culvert which eventually emptied into the Jukskei River. Sewer overflows and the inadequate sewage removal from portable or bucket toilets had resulted in sewage flowing into the culvert which emptied into the Jukskei River. Wimberley surmised that this problem was compounded by the high population densities in Alexandra, which lead to poor living standards and stressed engineering services.

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CHAPTER 2 : LITERATURE REVIEW

2.1 SOUTH AFRICAN WATER QUALITY CASE STUDIES

A number of rivers have been monitored in South Africa. The approach taken in all the studies is that a river must satisfy the standards that priority users of that portion of the river expect. Several of these studies have been undertaken in urban areas of South Africa (Green and Stephenson, 1988; Simpson, 1986) as well as in many overseas countries (Corderey, 1977; Whipple et al, 1978; Feller and Kimmins, 1979). All these studies follow a similar approach in that a catchment is chosen and monitoring points selected. Water quality samples are then taken at specific intervals within the monitoring period and the flow of the rivers are also often taken in order to determine the loading of the pollutants.

The water quality studies are then used to study the difference in pollution loads between stormflow and low flow, the "first flush" of pollutants, how the concentrations of pollutants compare to the recognised standards and which pollutants pose serious problems, the annual pollution load per hectare of catchment as well as the relationship between the amount of rainfall and the quantity or intensity of the rainfall or runoff.

From the literature, a few examples of case studies were chosen to show the different aims of various water quality studies as well as the methods of water sampling that can be used.

1.3.7 Dissolved oxygen

Dissolved oxygen is an important indicator of the health of a river, and is a significant factor in the evaluation of pollution impact. Ambient dissolved oxygen concentrations reflect the capacity of the river or stream to sustain a well balanced aquatic environment and is critical for the survival of aquatic biota.

A number of reactions in the stream are responsible for the decrease in the dissolved oxygen reserves. The most important are the microbial nitrogenous oxygen demand, the microbial carbonaceous oxygen demand, the microbial sediment oxygen demand and respiration of aquatic plants. The processes of reaeration (entrainment and diffusion) and photosynthesis of the aquatic plants replenish the oxygen reserves.

1.3.8 Microbiological pollutants

The primary purpose of determining the faecal coliform bacteria concentration in water is to indicate the possibility of recent sewage pollution and the possible presence of water-borne pathogenic organisms. Several diseases like cholera, dysentery, typhoid and gastro- enteritis are transmitted in the excreta of humans and animals. Two of the most common members of the coliform group are *Escherichia coli* and *Enterobacter aerogenes*. It has been shown that the major source of pollution in the reach of the Jukskei River adjacent to Alexandra is raw sewage. This is due to inadequate sewerage services in Alexandra which results in a large amount of sewage flowing into the Jukskei (Wimberley, 1992).

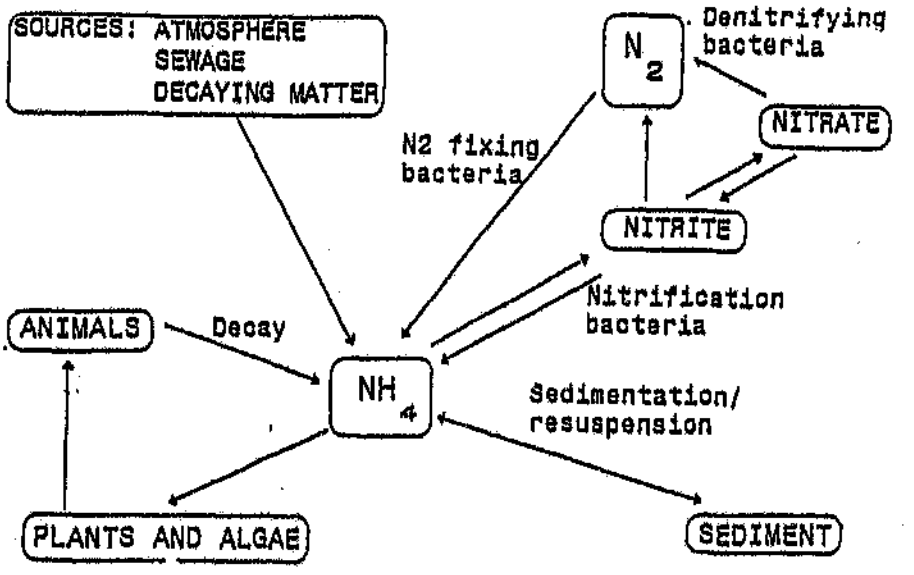


Figure 1.2 The nitrogen cycle in natural surface waters (Sawyer and McCarty, 1978)

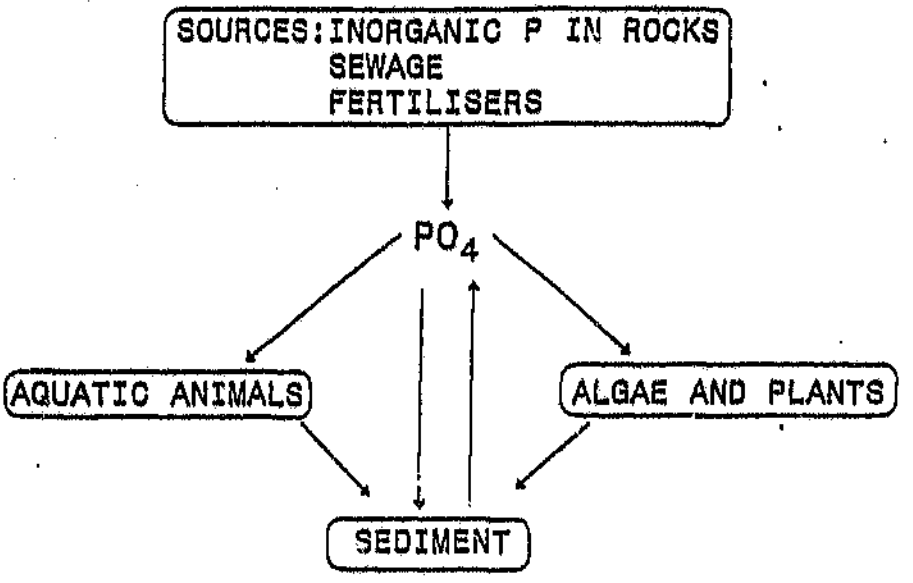


Figure 1.3 The phosphorus cycle in natural surface waters (Sawyer and McCarty, 1978)

However, due to the high demand and low availability of affordable housing in the PWV area, people continued to move into the Alexandra area, and an informal settlement has now sprung up which has no formal sanitation services. The Alexandra . vn Council has set up rudimentary services such as public stand-pipes and portable toilets (Sithole, 1991) which are serviced on a daily basis but many people living in areas like the Genisville squatter area (situated right on the banks of the Jukskei river), discard their sewage and litter directly into the river. Urban runoff from overflowing portable toilets, backyard businesses, washing of clothes and daily chores is a major source of pollution.

3.3 LOCAL AND REGIONAL CONDITIONS

The upper Jukskei River is about 23km long. The river reach flowing through Alexandra is 2300m, with the highest point at 1 535 m above mean sea level (mamsl) and the lowest point at 1 515 mamsl. This gives an average slope of 7.4m/km. The slopes between the monitoring points on the 6km reach of the Jukskei River from Alexandra to its confluence with the Modderfontein Spruit used in this study were determined. It was calculated that the slope changed from a 0.71% (1 in 140) slope near Alexandra, to a 0.60% (1 in 165) slope between Frankenwald and Buccleuch and eventually to a slope of 0.51% (1 in 197) slope from Buccleuch to the M odderfontein Spruit.

The river has a typical dry weather and storm flow regime. The river is a typical perennial river in that it flows continuously during the dry winter months as well as between storm events. In the summer months, a high volume of runoff flows into the river increasing the flow in the river. A difference in the flow of the Jukskei River between the summer of 1994 and the summer of 1995 was observed due to there being more rain in 1995. The flow in 1994 was on average around 2 $m^3.s^{-1}$ and in 1995 the flow ranged from 5 to 7 $m^3.s^{-1}$ as a consequence of the greater rainfall that fell on the catchment during the 1995 summer period.

The sub-surface soil conditions in the Alexandra area were investigated in 1980 by Partridge, De Villiers and associates (1980). Their report shows that the area is underlain by highly weathered and decomposed rocks of the Archaen granite type which forms the Johannesburg/Pretoria dome. Outcrops of medium

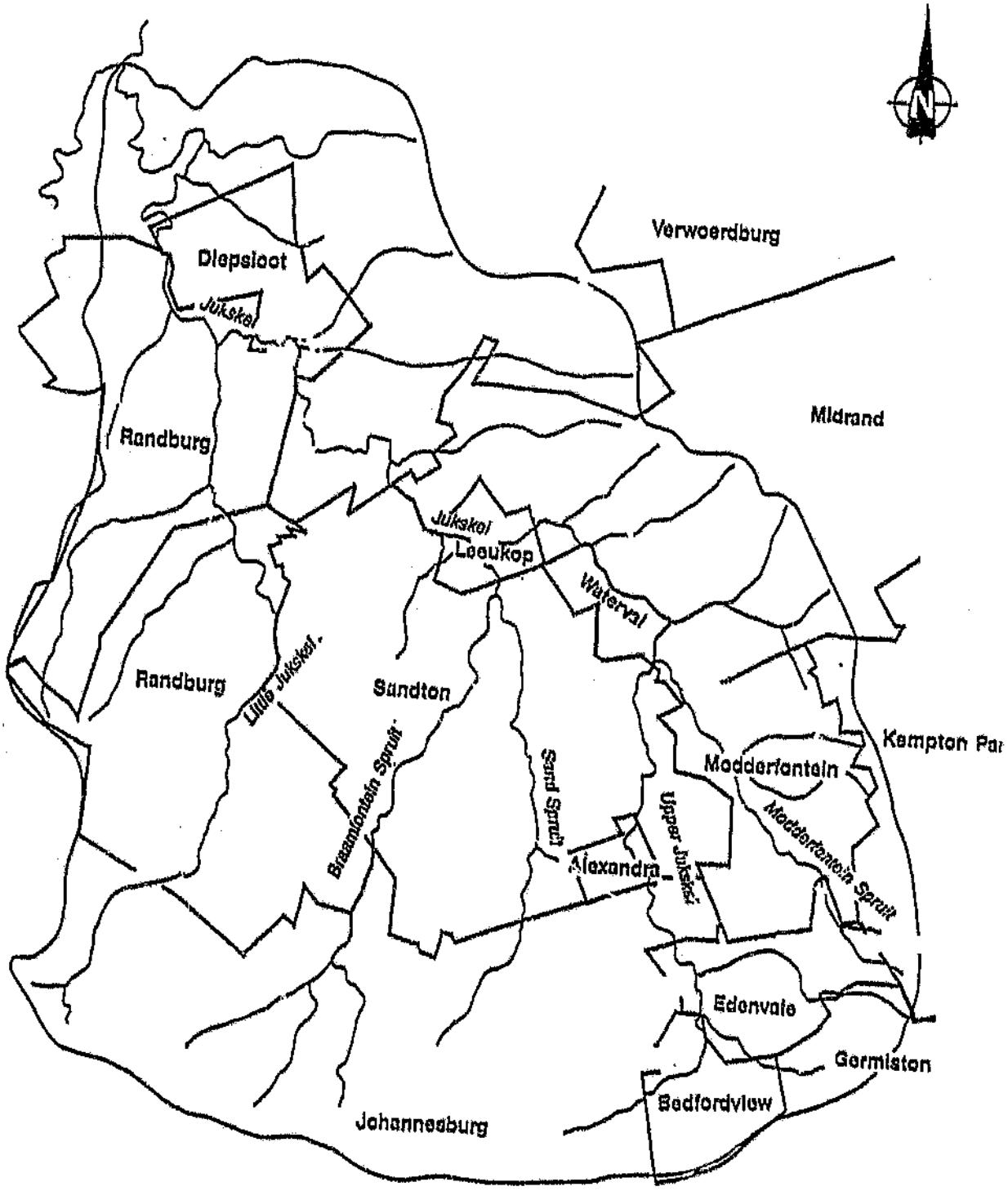


Figure 3.1 **The Jukskei River Catchment** **Scale 1 : 250000**
(BKS Incorporated Consulting Engineers)

CHAPTER 3 : DETAILS OF THE STUDY AREA

3.1 THE JUKSKEI RIVER

The Jukskei river is the largest of the three rivers draining the northern and north-eastern suburbs of the Witwatersrand (See Fig. 3.1). Its source is in the Bezuidenhout valley, east of Johannesburg. The Jukskei River then flows downstream past Lombardy East, Alexandra Township, past northern residential areas like Kelvin and Buccleuch and then through more rural areas like Waterval, Leeukop and Midrand. It is joined by the Modderfontein, Braamfontein and Sand Spruits before its confluence with the Crocodile river, which flows into the Hartebeespoort dam. The Jukskei River is an example of an urban catchment in which problems have arisen, as a result of rapid urbanisation, due to the development of a squatter camp on the west bank of the Jukskei river in Alexandra Township. The catchment covers an area of 800km^2 and includes many of the highly industrialised and urbanised parts of Johannesburg. (Fig 3.1)

3.2 DESCRIPTION OF ALEXANDRA TOWNSHIP

3.2.1 History of Alexandra Township

Development in the Alexandra area began in 1905. Between the years 1945 and 1948 there was a large influx of people to this area. This put a great strain on the environment as no formal sanitation services were yet available. Over the years a number of resettling policies have been implemented to try and limit the number of people flocking to and staying in this area (De Jaeger, 1990).

Between the years 1987 and 1990 a different approach was taken with the implementation of the Urban Renewal Plan. Full engineering services, including a water reticulation system, water-borne sewage, electrical reticulation and on-stand ablution facilities were provided to all dwelling units in the area.

- Identify the pollutants that were above acceptable water quality standards and that may be a health risk to the people drinking and using the Jukskei River water.
- Determine the main methods of assimilation in the river for each pollutant;
- Determine what factors affect the pollutant assimilation reactions;
- Determine the rate constants for the various chemical and biochemical assimilation reactions;
- How storm flow and low flow affect the assimilation of pollutants;
- How other model waste assimilation predictions compare to those observed in the Jukskei River (QUAL2E and Witqual);
- Decide if waste discharge poses a threat to the ecosystem of the river;
- Decide if the river can cope with and improve the quality of the runoff and to what extent. (The river may be a viable option for low cost treatment of polluted runoff).

2.3 CONCLUSIONS

From the case studies it can be seen that a large difference in the type of pollutants found in the receiving waters were observed. One of the major factors affecting the type of pollution, is the type of development that that portion of the catchment is undergoing. Another factor that should be taken into account is the type of geomorphology that the river runs through as this will affect the pH which affects the valence state that a number of metals may be in (e.g. aluminium is biologically available in the Al^{3+} form (at low pH) and ammonia is lethal in the NH_3 form (at high pH)). For example the waters on the highveld have a large concentration of carbonates and these buffer the pH, keeping it in the pH 7 range.

Wimberley (1992) was one of the first to monitor the types and concentrations of pollutants coming off an informal, high density developing area. It was decided to further this study, and determine how these pollutants would be assimilated in the river itself.

A number of people have studied the Jukskei River as it is typical of a river that has been polluted as a result of rapid urbanisation. It was found that most of these studies only monitored the pollutants to find those that caused problems, with none of them actually modelling the fate of these pollutants in the receiving waters. This is important as most of the pollution from rapidly developing urban areas ends up in the receiving waters from non-point source runoff and the receiving waters have to assimilate it. This study aimed at determining how the river did this and how far downstream it took for the pollutants to reach a stage where they no longer were at unacceptable concentrations for the users.

The main objectives of this Jukskei River study were to:

concentration was at a steady value. From 1970, it began increasing and since 1974 it had risen to an annual mean concentration of 6.02 mg.l^{-1} with the average increase over the whole study period being 0.12 mg NO_3N .l^{-1} per year. This increase was similar to the increase that was observed in the nearby River Frome. It was concluded that the addition of fertiliser to the watercress beds did not have a significant effect on the concentration of nitrates and it was thought that this was due to the natural buffering effect of the chalk in the Bere stream.

2.2.5 The American and Sacramento Rivers, USA.

A coordinated water quality monitoring program was set up on the American and the Sacramento Rivers in 1991 to detect the concentrations of toxic pollutants in the waters as the Sacramento River supplies more than 80% of the drinking water to both residents of the north and the south of California Sacramento (McEwen, et al, 1993). The American River provides drinking water to Sacramento City and several districts in Sacramento County. The aim of this program was to determine statewide water quality criteria for toxic pollutants. Field measurements of pH, temperature, electrical conductivity and dissolved oxygen were used as standard indicators of water quality (McEwen et al, 1991). A 24-hr composite sampling and cross-sectional sampling was done at each of the six sites chosen, both using a peri ..c or diaphragm pump. The sampling bottles and tubing were placed in hot 50% ..ric acid for several days. The equipment was then rinsed in high purity water and wrapped in polyethylene bags. Only acid-washed bottles thus came into contact with the water sample.

By using these sampling methods, much lower concentrations of the trace metals could be detected like chromium, copper, lead, nickel, arsenic, cadmium, selenium, silver and zinc could be detected in the Sacramento River.

from the wastewater treatment plants did not contribute heavily to the faecal coliform concentration. With heavy rainfall however, an increase in faecal coliforms were seen. This indicated that nonpoint sources and system overflows were responsible for the increase in faecal coliform concentrations. Higher concentrations of coliforms at the Lake Houston Dam than further upstream suggested that there was a possibility that there was upwelling of bottom water and organisms in the benthic layer were being reintroduced into the upper water layers.

2.2.4 Bere Stream, Dorset, Great Britain

This is an example of a chalk stream that rises from aquifers. These streams are generally regarded as stable biological habitats with a ratio of $\leq 6:1$ maximum to minimum discharge, which is in contrast to mountain streams, that can have a ratio greater than 40:1. For this reason watercress beds are planted on these rivers. The effects that these beds have on the nitrate concentration in the stream was determined over a period of 20 years from 1966 by the Institute of Freshwater Ecology in Dorset.

A large proportion of the flow of the Bere Stream is made up of the flow from the commercial watercress beds. The borehole water that is used on the watercress beds usually has sufficient nitrate present for watercress nutritional requirements, but does not supply enough phosphorus or potassium for optimal growth. These elements are supplied by the addition of fertilisers which includes nitrates. A study on the effect that this had on the nitrate concentrations further downstream was undertaken (Casey, 1990).

Weekly samples were taken at the same site below the watercress beds from 1966 to 1986. From this the long-term trends and variation in nitrate concentration, over the 21 years could be determined. In the first few years of the study, the nitrate

monitoring points downstream of the point of discharge but was below this level at the 1200m monitoring point.

All other parameters did not exceed the EPA standards although most of them increased a significant amount from the upstream values. The other parameters remained relatively stable. A large decrease in BOD, faecal coliforms, faecal streptococci and orthophosphate was seen at the 1 200m monitoring position. The water quality at 1200m below the discharge point was the same as 400m above. This indicated an apparent natural recovery in water quality.

2.2.3 Cypress Creek, Texas, USA

Large concentrations of faecal coliforms were detected in Lake Houston, which is the major source of drinking water for Houston, Texas. The source of the faecal coliform was thought to be effluent from a number of sewage treatment works in the area. Public health officials implemented a management plan to ensure proper operation of these plants. Symons, et al (1989), studied the effectiveness of these actions by sampling as soon as possible after a storm had occurred and continuing daily until the flow had returned to normal. "Grab" samples were collected, put on ice and taken to the Microbiology laboratory at Rice University. Here faecal coliform and Faecal streptococci densities were determined.

There are number of tributaries that flow into Houston Lake, but Cypress Creek was chosen for sampling as all the wastewater treatment works studied were situated on it. Samples were also collected at the various wastewater treatment plants.

It was concluded that as a result of the enforcement by public health officials to maintain a chlorine residual in the effluent that flowed into the tributary, overflows

- Sedimentation: Tidal rivers and estuaries are natural traps of sediment because the decrease in the velocity of the river allows sediment to settle to the bottom. The sediment load that the river carries is increased by man's activities such as land clearing, farming, mining and urbanisation. Today most of the sedimentation is caused by urbanisation and farming. The Survey estimated that the tidal Potomac River and the Estuary receive about 250 000 tons of sediment annually from tributary streams other than the Potomac River. This sedimentation has caused the closing of some ports and navigation channels as well as having an adverse effect on oyster fishing as many of the oyster beds that have been harvested for the last 30 years are now covered in sediment.

- The change in the environment of the Potomac River and estuary has had an adverse effect on many of the living organisms Algal blooms, low dissolved oxygen levels, fish kills, changes in fish species, decrease in the number of water fowl and a decline in submersed plants has occurred in the last 30 to 50 years.

2.2.2 Rock Creek Stream, Tennessee, USA.

Hollon, et al (1982) determined the water quality in a stream that received effluent from a 200-lot dairy farm which was monitored for a 22 month period. The station is drained by Rock Creek, which originates 4.5km to the south. "Grab" samples were collected at 2-week intervals from stations located 400m and 3km upstream and 100, 500, and 1200m downstream from the point of discharge. Samples were analysed for Biochemical Oxygen Demand (BOD), chlorides, dissolved oxygen, faecal coliforms, faecal streptococci, nitrate nitrogen, nitrite nitrogen, orthophosphate, total solids and pH. It was found that the permissible faecal coliform value of 2000 coliforms/100ml was exceeded at the 100 and 500m

water quality sampling stations were sampled every month. From these results the movement and assimilation of the nutrients could be determined.

The Potomac River, unlike many other east coast estuaries and rivers, is relatively free of pollution problems associated with manufacturing and chemical industries. The effects of processes such as sedimentation and nutrient enrichment can then be easily studied. Five major water quality problems were identified:

- Nutrient enrichment: Excessive discharge of nutrients (mainly organic carbon, phosphorus and nitrogen) from sewage treatment plants and nonpoint source runoff, caused low dissolved oxygen levels and blooms of blue-green algae to occur. Most of the phosphorus and some of the nitrogen settled out of the water just below the point of discharge. Organic carbon compounds were converted to carbon dioxide and water by bacterial processes. In 1980, the major sewage treatment plant implemented an advanced wastewater treatment in which ammonia was converted to nitrates (nitrification) and excess phosphorus and carbon are removed. Since algae prefers ammonia to nitrates as a source of nitrogen the rate of growth of the algae was reduced.

- Algal Blooms: The presence of blue-green algae resulted from of the enrichment of the estuary and the river with nutrients. Apart from covering the whole river and estuary, the decomposition of dead algae creates an oxygen demand that reduces dissolved oxygen reserve.

- Dissolved Oxygen: Low concentrations of dissolved oxygen in the Potomac River and estuary resulted from the large quantities of waste entering the system. Concentrations as low as 3mg.l^{-1} have occurred during the hot season. This has resulted in the river being unable to support a healthy fish population.

Zwartkops Village were found to yield little runoff, which was of good quality, which had little impact on the water quality of the river (MacKay, 1994).

2.2 INTERNATIONAL WATER QUALITY STUDIES

There are many examples of water quality studies world-wide. A few from different countries were chosen to show the different pollutants that cause problems and the methods that are used to sample the water.

2.2.1 The Potomac River and Estuary, USA

The Potomac River is the second largest tributary to the Chesapeake bay. It extends from its source in the mountains of West Virginia. USA, to its junction to Chesapeake Bay where the fresh water of the Potomac River mixes with the brackish water of Chesapeake bay in the Potomac Estuary. A 5-year interdisciplinary study was begun in the October of 1977. Its objectives were to provide a basic understanding of the physical, chemical and biological processes that the major pollutants underwent, to develop flow and transport models to predict the movement and fate of nutrients and algae as well as to develop efficient techniques for the study of estuaries and rivers (Callender, et al, 1981). From October 1978 to September 1981, the US Geological Survey conducted a water quality sampling program from Chain Bridge to Point Lookout where the Potomac River enters Chesapeake Bay.

The concentrations of nitrogen, phosphorus, and silica were measured by taking "grab" samples every week from five key sampling stations, while 21 intervening

2.1.9 Lower Swartkops River and Estuary, Chatty River, Motherwell Canal and Markman Canal, Eastern Cape.

The study area was defined as the Swartkops River and its catchment from Kruis River to the estuary mouth as well as the Chatty River with its catchment. The river flows through a number of townships, residential areas including Ultenhage, Rosedale, MacNaughton township, Kwanobuhle township, Despatch, Perseverance, Sumcay, Bar-None, Redhouse, Zwartkops Village, Amsterdamhoek, Tippers Creek, Port Elizabeth as well as several squatter camps.

Urbanisation of the Swartkops Catchment began early this century and the rate of urbanisation has far outstripped planned estimates. The emphasis is now on the provision of the most basic services to the rapidly increasing population moving into the area as speedily as possible (MacKay, 1994).

It was found that urban runoff was the most significant pollution threat facing the estuary at present. Ever increasing concentrations of phosphate-P in the upper estuary and increasing levels of faecal coliforms in the middle estuary have been observed since 1971 (MacKay, 1994)

The Chatty River was found to be the main source of dissolved nitrogen to the estuary. Both the Chatty River and the Motherwell Canal contribute the major portion of faecal bacteria to the estuary especially during the low flow periods. The sources of pollution were mainly found to be due to urban runoff and inappropriate design and maintenance of stormwater reticulation systems and outfalls. Raw sewage from sewer blockages was often found in the Kat Canal that carries runoff from Rosedale and MacNaughton townships, which empties straight into the river. Sewage Treatment Works at Kwanobuhle, Ultenhage and Despatch all discharge directly into the river which caused the river just below these treatment works to be highly eutrophic. Low density residential and commercial areas like Redhouse and

CHAPTER 4 : STEADY STATE RESULTS AND ANALYSIS

4.1 WATER QUALITY VARIABLES - RESULTS AND ANALYSIS

Water quality variables can be divided into physical, chemical and biological components. Box-and-whisker plots were used to represent the water quality variables' data.

The box-and-whisker plot is an effective way to display summary statistics graphically. By looking at the plot you can quickly determine the range of the data with the central box covering the middle 50% of the values between the 25% and 95% percentiles. The "whiskers" extend out to the extremes (minimum and maximum values), while the central line is the median. When unusual values occur far away from the bulk of the data, they are plotted as separate points. The whiskers extend only to those points that are within 1.5 times the interquartile range.

4.2 PHYSICAL WATER QUALITY VARIABLES

Conductivity, temperature and pH were monitored using the Checkmate field system at each site. See Appendix B for Photographs of the equipment used.

4.2.1 Temperature and pH

The temperature went from a low of 9.7 in July to a high of 28°C in January. See Figures 4.1 and 4.2.

Table 3.4 Technical Specifications of the Checkmate System

Mode	Range	Resolution	Accuracy
pH	0 to 14	0.01	± 0.01
Conductivity	0.00mS-19.99mS	0.01mS	± 0.5%
	20.00mS-199.9mS	0.1mS	
	200mS-1999mS	1mS	
	2.00mS-19.99mS	0.01mS	
TDS	0.00-10.00mg.l^{-1}	0.01mg.l^{-1}	± 0.5%
	10.00-100.0mg.l^{-1}	0.1mg.l^{-1}	
	100-1000mg.l^{-1}	1 mg.l^{-1}	
	1.0-10.00 g.l^{-1}	0.01 g.l^{-1}	
% O_2	0 - 200%	1 %	± 1%
mg.l^{-1} O_2	0 - 20.0 mg.l^{-1}	0.1 mg.l^{-1}	± 1%

Table 3.3 Pollutants monitored in the Jukskei River

Type of Variable	Organic or Inorganic	Variables measured	Analyses
Physical/Physico-chemical		pH	Checkmate pH sensor (In field).
		Temperature	Checkmate temperature probe (In field).
		Turbidity	CYDNA
		SS	CYDNA
		Conductivity	Checkmate conductivity probe (In field).
		TDS	Checkmate TDS probe (In field).
Chemical	Inorganic	Chloride	CYDNA
		Sulphate	CYDNA
		Alkalinity as $CaCO_3$	CYDNA
		Lead	CYDNA
		Iron	CYDNA
	Organic	BOD	M & L
		COD	CYDNA
	Nutrients	Kjeldahl Nitrogen	CYDNA
		Ammonia	CYDNA
		Nitrite	CYDNA
		Nitrate	CYDNA
		Total P	CYDNA
		Ortho - P	CYDNA
	Dissolved Oxygen	Dissolved Oxygen	Checkmate DO Probe (In field).
Microbiological		Faecal coliforms	CYDNA
		E. coli	CYDNA

period of the Jukskei river. Wimberley (1992) also found the low flow value to be in the range of 1 m^3/s.

The flow went to a high of 1.84 $m^3.s^{-1}$ after the rains on the 28th to the 31st of October. The high flow period was taken as being after these dates. Table 3.2 gives the flow measurements recorded both by means of the weir rating curve equation and those determined using a flow meter.

Table 3.2 Flow measurements recorded on monitoring days at the Old Alexandra Sewage Works weir.

DATE	WEIR CALCULATED FLOW IN $m^3.s^{-1}$	FLOW (FLOW METER) IN $m^3.s^{-1}$
12/07/1994		1.325
03/08/1994	1.485	1.436
10/08/1994	0.931	1.121
24/08/1994	1.071	1.056
07/09/1994	1.441	1.389
21/07/1994	1.071	1.069
28/09/1994	1.433	1.244
12/10/1994	1.277	1.393
01/11/1994	1.843	1.802
09/11/1994	1.672	1.522
16/11/1994	1.722	1.689
23/11/1994	1.275	1.329
07/12/1994	1.189	1.205
18/01/1995	1.734	1.693
01/02/1995	1.791	1.789
15/02/1995	1.345	1.279

3.5.3 Flow Measurements

The flow was measured at two different sites (See Fig 3.3). A sewer pipe crosses the river at the old Alexandra sewage works and it is encased in concrete to prevent vandalism. Erosion downstream and sedimentation upstream of this pipe has resulted in the formation of a broad-crested weir. This encased pipe was used by Wimberley (1992) in his study of pollutant loads from Alexandra Township.

Flow depth data was collected and converted to a flow rate using the depth-discharge curve which was developed by Wimberley (1992). This curve was calculated from the surveyed cross-section of the weir and the formula for a broad-crested weir, which is as given below:

$$Q = C * B * H^{1.5}$$

where Q = flow rate in m^3/s over the weir
C = weir coefficient which is 1.8 for a broad-crested weir.
B = width of the water over the weir in m
H = depth of flow over the weir in m

A broad-crested weir near the Marlboro road (See Fig 3.3) was also used for flow measurements. The accuracy of these weirs was also ascertained by measuring the flow with a flow meter. The flows at the Gibson Bridge and at the Marlboro Bridge were determined by taking flow readings every 1m at 60% of depth of water.

The monitoring of the Jukskei river commenced at the end of July 1994, and to date both the low flow and high flow periods have been monitored with sampling taking place every two weeks.

Flow measurements were made every two weeks at the two weirs described above. A median flow of 1.35 $m^3.s^{-1}$ was calculated for the period between the 12th of July and the 7th of September. This value was verified using a flow meter which gave an average value of 1.33 m^3/s. This represents the low flow

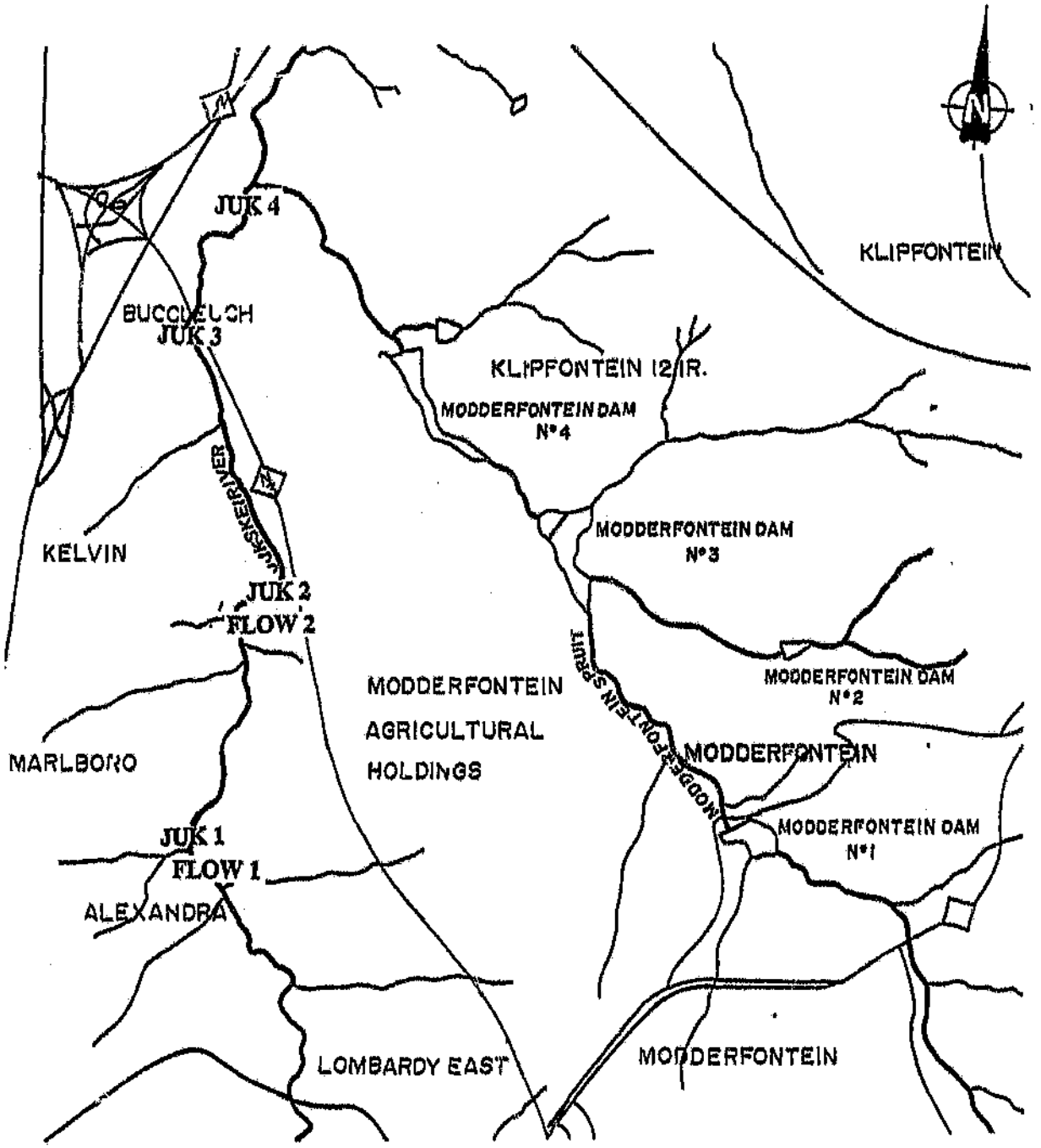


Figure 3.3 Monitoring and flow points on the Jukskei River. (1 in 50 000)

Chemical analyses of the water samples was undertaken by the Johannesburg Municipal laboratories (CYDNA) in Oaklands, while the 5-day BOD tests were carried out by M & L Laboratories in Doornfontein, Johannesburg. All chemical tests were carried out according to Standard Methods for the Examination of Water and Wastewater (APHA, 1987).

Measurements of pH, conductivity, total dissolved solids, temperature and dissolved oxygen were carried out on a 'grab' sample at each monitoring point using the Mettler-Toledo Checkmate field system. It consists of a hand-held meter module to which different sensors can be attached. Table 3.4 gives the technical specifications of the instrument.

Table 3.1 Monitoring points on the Jukskei river

MONITORING POINT	DISTANCE FROM ALEXANDRA SEWAGE WORKS IN km
WEIR AT OLD ALEXANDRA SEWAGE WORKS	0.0
FRANKENWALD WEIR NEAR MARLBORO DRIVE	2.1
GIBSON DRIVE BRIDGE	4.2
MODDERFONTEIN CONFLUENCE - OPPOSITE FIVE ACRES PLACE	5.8

Jukskei River. There are grid inlets all the way along the length of this culvert to trap the overland flow after storm events. Unfortunately shacks have been erected on top of these grid inlets. The shacks built on these grid inlets, the network of tarred roads in Alexandra and the inadequate services all contribute to high volumes of polluted urban runoff discharging directly into the Jukskei River (Wimberley, 1992).

After Alexandra the Jukskei River flows through a grassy area (Frankenwald) dotted with a few trees and then through the residential area of Buccleuch.

The Jukskei River was chosen for this study as most of the pollution comes in straight from Alexandra Township and for 6 km after this there are no major discharges into the river. The natural assimilation ability of the river for each pollutant type and the factors affecting each of them were then determined.

3.5. DATA COLLECTION AND MONITORING POSITIONS

3.5.1 Monitoring point positions

A reach of the Jukskei River, 6 km downstream of Alexandra township, (Fig 3.2) was chosen for this study. An extensive water sampling program, in which water was sampled every 500m along the river, was first undertaken, in order to investigate the reduction of nutrients and other pollutants over distance. From the results, four monitoring points were selected each about 2km apart from one another. Fig 3.3 and Table 3.1 show the positions of monitoring points on the Jukskei river.

3.5.2 Collection and Laboratory analysis of the water samples.

Sampling consisted of taking "grab" samples from the river. The pollutants monitored in the Jukskei river can be seen in Table. 3.3.

Autoclaved glass bottles were used to collect water for the faecal coliform and E. coli analyses, while the water for the chemical analyses was collected in clean PVC bottles. A small air space was left between the water and the cap.

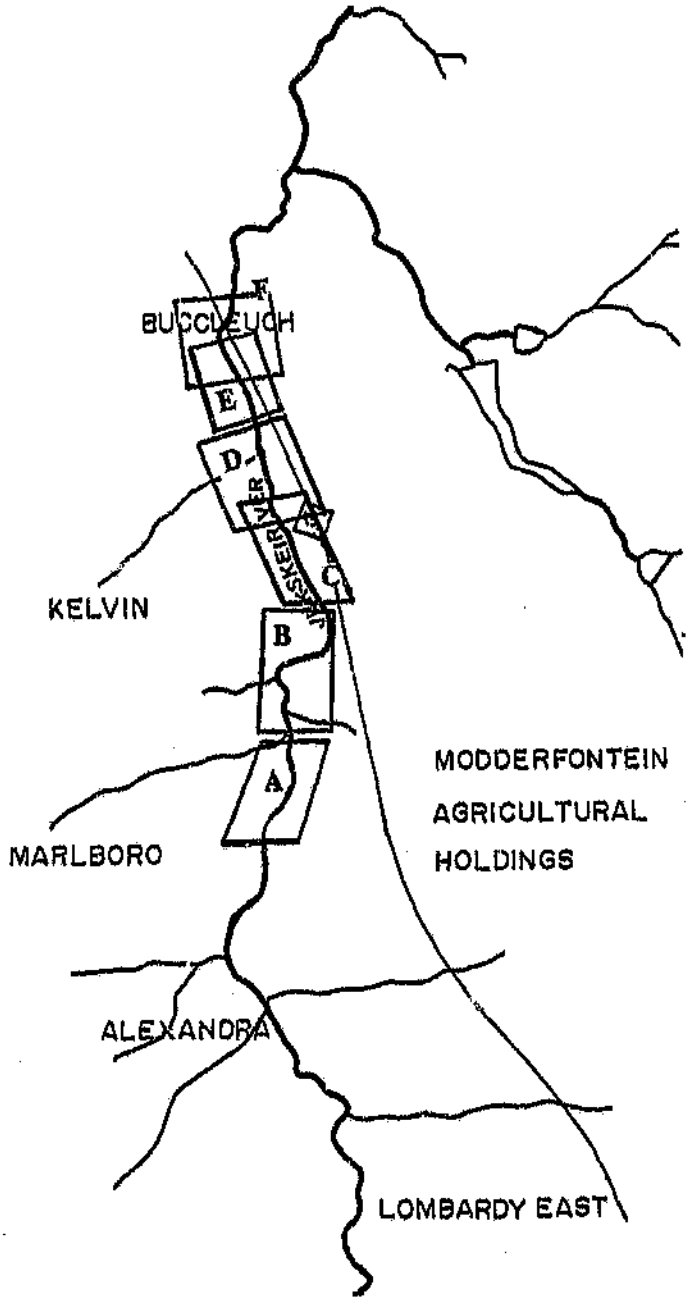
hazard was highlighted in March 1995 when soft soaking rains of 78mm washed away shacks and left about 600 people homeless.

A 90 ha area on the East Bank has been developed to cater for the middle to high income earners. A 300 ha portion of land that extends up to the N3 highway, was allocated for formal housing but during 1995 squatters began an informal settlement on this land. Attempts to remove them have proved unsuccessful.

The 1991 population estimate was 125 000 (255 people/ha)(Palmer Development Group, 1992), and in 1994 this has risen to over 320 000 people over an area of 4.9 km^2 which is only 0.6% of the entire catchment (612 people/ha) (Palmer Development Group, 1995). The population growth rate for 1980-1991 was officially 7.4% and unofficially 16.41 (Palmer Development Group, 1991).

Five different housing types have been identified in Alexandra: informal settlements (shacks), old formal settlements, new formal settlements, hostels and flats. There are over 50 000 residential units in Alexandra of which 30 000 are shacks with an additional 9000 hostel beds (Palmer Development Group, 1995). The services provided (street cleaning, refuse removal) are inadequate. Three community based contractors provide a service combining kerbside and communal clearing (Palmer Development Group, 1995). Inadequate local authority management structures and problems with the initial tender process has led to the contractors being under-funded and under-monitored, which has resulted in an inadequate service being provided. .

On the West Bank, the formal settlements have one dwelling per stand with piped water supplies and water-borne sewage systems. The informal settlements have been erected in the backyards of these formal settlements as well as other open spaces and therefore share the formal settlement's facilities or use stand pipes for water and bucket latrines. These bucket latrines should be collected everyday but due to political unrest, lack of funds, lack of maintenance and lack of management, these bucket latrines overflow straight into the Jukskei River or are emptied into the river by residents. The south-western catchment has a piped storm water reticulation system that discharges to a sub-surface culvert, which follows the flow of the natural valley and discharges directly into the



See Appendix D for the enlargements of Areas A to F with the main types of vegetation found in each.

Figure 3.2 **The 100m^3 portions of land used for the investigation into the vegetation along the banks of the Jukskei River**

to coarse textured grey to pink granite rock occurs in the river bed and on decomposing it forms a residual soil layer of loamy sand which varies in depth between 0.5 and 6.0 metres. The bedrock lies relatively close to the surface which gives rise to a perched water table. The resulting rocky bed of the Jukskei river just downstream of Alexandra thus allows for the rapid reaeration of the river with a corresponding reduction in the BOD load.

The vegetation in Alexandra is very sparse or absent and there are very few trees (Wimberley, 1992). A study of the vegetation along the Jukskei River banks from Alexandra to the Buccleuch was undertaken in order to ascertain what affect the vegetation could have on the pollutant assimilation in the river but especially on the nutrients in the river. Portions of land, each 100 m^3, were selected and the most common plants in each portion were determined. A number of unknown vegetation samples were taken to the Department of Botany in Wits University to be identified. Most of these were exotics like Acacia and Eucalyptus. The vegetation differed significantly between the east and the west banks of the river. The east bank near the N3 highway consisted mainly of grasses and the west bank had both trees and grasses. A number of reed beds where identified which would be beneficial in the assimilation of a number of the pollutants but the river in general was not very heavily vegetated and the vegetation would not have a profound effect on the assimilation capacity of the river. The vegetation identified along the banks can be seen in Figure 3.2 and Appendix D.

3.4 POPULATION GEOGRAPHY AND HOUSING

The Jukskei River divides Alexandra Township into two sub-catchments: the East and the West Bank. The total sub-catchment is approximately 740ha. The West bank of Alexandra covers an area of about 350 ha and the land consists of mainly formal and informal housing as well as tarred roads. The informal housing consists of mainly shacks and "make-shift" houses (Wimberley, 1992). These informal settlements have developed on previously vacant land and in areas demarcated as flood zones. More than 6000 people living in the Genisville and the old part of Alexandra are below the 50 year flood level and hundreds are living on land that forms part of the river channel itself. This

However, due to the high demand and low availability of affordable housing in the PWV area, people continued to move into the Alexandra area, and an informal settlement has now sprung up which has no formal sanitation services. The Alexandra Town Council has set up rudimentary services such as public stand-pipes and portable toilets (Sithole, 1991) which are serviced on a daily basis but many people living in areas like the Genisville squatter area (situated right on the banks of the Jukskei river), discard their sewage and litter directly into the river. Urban runoff from overflowing portable toilets, backyard businesses, washing of clothes and daily chores is a major source of pollution.

3.3 LOCAL AND REGIONAL CONDITIONS

The upper Jukskei River is about 23km long. The river reach flowing through Alexandra is 2300m, with the highest point at 1 535 m above mean sea level (mamsl) and the lowest point at 1 515 mamsl. This gives an average slope of 7.4m/km. The slopes between the monitoring points on the 6km reach of the Jukskei River from Alexandra to its confluence with the Modderfontein Spruit used in this study were determined. It was calculated that the slope changed from a 0.71% (1 in 140) slope near Alexandra, to a 0.60% (1 in 165) slope between Frankenwald and Buccleuch and eventually to a slope of 0.51% (1 in 197) slope from Buccleuch to the Modderfontein Spruit.

The river has a typical dry weather and storm flow regime. The river is a typical perennial river in that it flows continuously during the dry winter months as well as between storm events. In the summer months, a high volume of runoff flows into the river increasing the flow in the river. A difference in the flow of the Jukskei River between the summer of 1994 and the summer of 1995 was observed due to there being more rain in 1995. The flow in 1994 was on average around 2 $m^3.s^{-1}$ and in 1995 the flow ranged from 5 to 7 $m^3.s^{-1}$ as a consequence of the greater rainfall that fell on the catchment during the 1995 summer period.

The sub-surface soil conditions in the Alexandra area were investigated in 1980 by Partridge, De Villiers and associates (1980). Their report shows that the area is underlain by highly weathered and decomposed rocks of the Archaen granite type which forms the Johannesburg/Pretoria dome. Outcrops of medium

All parameters except for the reaeration rate constant were known so the equation was solved for r using the Solve For function on Quattro Pro. Typical reaeration constants for streams vary from 0.02 to 4 day^{-1} . Values of 0.1 to 1 day^{-1} are common in rivers and streams (Metcalf & Eddy, 1979).

Temperature has a definitive affect on the reaeration rate. To find the rate at other temperatures the equation below was developed.

$$r_T = r_{20} \times 1.024^{(T-20)} \quad \ldots\ldots\ldots \quad 4.3$$

Table 4.5 The determination of the reaeration rate constants

Date	Reach 1 r	Reach 2 r	Reach 3 r
03/08/94	1.13	0.297	0.157
10/08/94	1.402	0.404	0.210
24/08/94	1.14	0.291	0.150
07/09/94	2.384	0.812	0.473
21/09/94	2.053	0.646	0.357
28/09/94	2.006	0.623	0.342
12/10/94	1.193	0.353	0.192
01/11/94	1.72	0.507	0.273
16/11/94	1.334	0.414	0.290

From the Table 4.5 it can be seen that the reaeration constant between the Alexandra weir (JUK1) and Frankenwald (JUK2) is greater than in the other reaches. The gradient of the river bed is greater in this portion of the river. Several rapids in the reach cause an increase in turbulence, which leads to greater entrainment of oxygen. This results in an increase in the dissolved oxygen concentration. The river meanders and gradients are small in the reach between the Gibson Drive bridge (JUK3) and the Modderfontein confluence (JUK4). This is reflected in the reaeration rate determined for reach 3 which is around 0.2 day^{-1}.

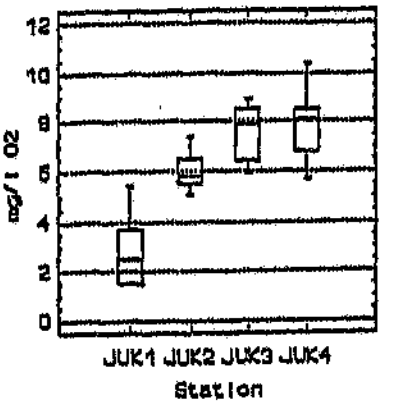


Figure 4.13 **Box and whisker plot of the DO concentration with distance during low flow (winter).**

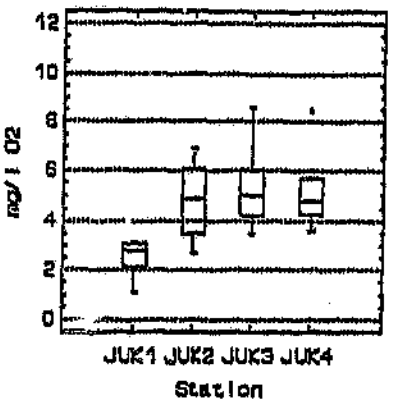


Figure 4.14 **Box and whisker plot of the DO concentration with distance during high flow (summer).**

The reaeration rate constants for each reach were determined using the Streeter-Phelps equation (Marjanovic, B, pers. comm). The Streeter-Phelps equation takes into account the decrease in the dissolved oxygen concentration due to BOD as well as the increase in the dissolved oxygen concentration due to reaeration.

$$D_t = \frac{k L_0}{r - k}(\exp^{-kt} - \exp^{-rt}) + D_0 \exp^{-rt} \quad \ldots\ldots\ldots \quad 4.2$$

where:

D_t = Dissolved oxygen deficit at time t
L_o = BOD at time zero
D_o = Dissolved oxygen deficit at time zero
k = BOD reaction rate constant
r = reaeration constant
t = time

Each of these parameters are unique to a specific water body although they may fall within a certain range. The chlorophyll concentrations in the water were determined at each of the monitoring positions (See Table 4.4).

Table 4.4 Chlorophyll concentrations in the Jukskei River.

Monitoring Point	Chlorophyll Concentration (μg/l)
JUK1	32
JUK2	41
JUK3	28

Chlorophyll concentrations are good indicators of algae concentrations in the waters and thus an indirect indicator of resipration and photosynthesis in particular waters. From the above results it can be concluded that respiration and photosynthesis sinks and sources from aquatic plants will play little part in the concentration of DO in the Jukskei River.

The mean concentration of dissolved oxygen at the Alexandra weir site (JUK1) is around 3.1 mg/l. On the 7th of September however, a very low DO of 1.5 mg/l was recorded. This corresponds to an increase in BOD and nutrients which would cause a decrease in DO to occur. For both the low flow and the high flow period a recovery in the dissolved oxygen is seen.

Apart from the oxidation of carbonaceous and nitrogenous organic matter, reaeration is the most important process affecting the dissolved oxygen concentration in a river. The Jukskei river has a rocky bottom which allows for reaeration by means of turbulence.

the drop is most likely due to dilution of the ions as they flow towards JUK2. During the low flow period, the concentration of $CaCO_3$ is greater due to less dilution. The drop in the low flow alkalinity is enhanced by the greater beginning concentration. The alkalinity concentrations for both the low flow and the high flow periods then reached a plateau and remained constant up to JUK4.

The sulphate and chloride concentrations also showed a drop between JUK1 and JUK2. The concentrations of ions like sulphate and chloride and the metals lead and iron did not change much between sampling days with the iron concentration always being around 0.4mg.l^{-1} and lead around 0.01mg.l^{-1}.

4.3.2 Dissolved Oxygen (DO)

While coliform bacteria is the surrogate variable for communicable diseases, DO is the surrogate variable for the general health of the aquatic ecosystem.

In a water body, the sources of DO are:

- Reaeration from the atmosphere.
- Photosynthetic oxygen production.
- DO in incoming tributaries.

The internal sinks of DO are:

- Oxidation of carbonaceous waste material.
- Oxidation of nitrogenous waste materials.
- Oxygen demand of the sediments.
- Use of oxygen for respiration by aquatic plants.

With the above sources and sinks, a general mass balance can be determined for DO in a segment volume V (Thomann, 1987),

$$V\frac{dc}{dt} = reaeration + (photosynthesis - respiration) - oxidation\ of\ CBOD, NBOD - SOD + Oxygen\ Inputs \pm Oxygen\ Transport \quad \ldots 4.1$$

copper originate from anti-freeze and brake-linings in vehicles and zinc from oil spills (Wimberley, 1992).

Many of the ions found in water can also originate from the atmospheric emissions from industrial plants and vehicles. It has been found that winds blowing off the mine-dumps on the Witwatersrand can contain high concentrations of sulphur and chloride (Coleman, 1991).

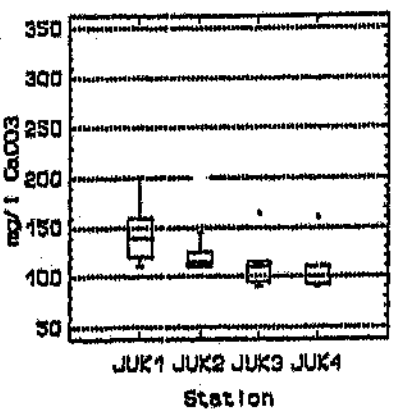


Figure 4.11 Box and whisker plot of the change of alkalinity with distance during low flow (winter).

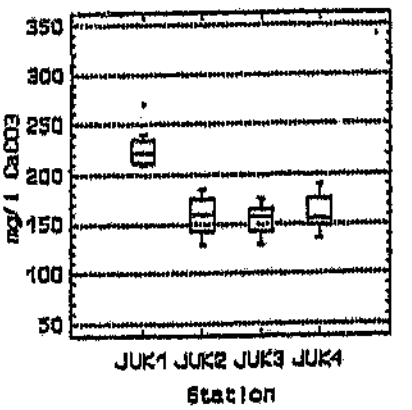


Figure 4.12 Box and whisker plot of the change of alkalinity with distance during high flow (summer).

The highest concentration of ions found were the bicarbonate ions, which were in the range of 200-250 mg/l for the Alexandra weir site (JUK1) and around 150mg/l at the Modderfontein confluence sampling point (JUK2). At the pH levels measured in the Jukskei river, the majority of the ions can be expected to be in the bicarbonate ion (HCO_3) form with a maximum concentration of bicarbonate ions being found at a pH of 8.3.

A drop in the alkalinity between JUK1 and JUK2 is seen. This corresponds to a similar drop in the TDS and conductivity results. As discussed in Section 4.2.3,

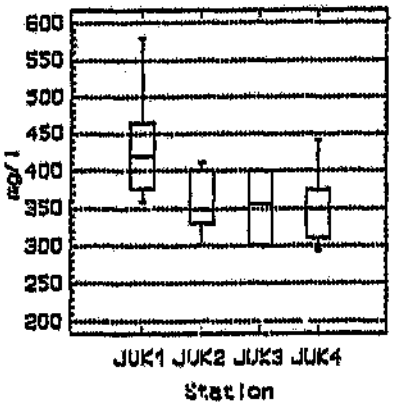


Figure 4.9 Box and whisker plot of the change of TDS with distance during low flow.

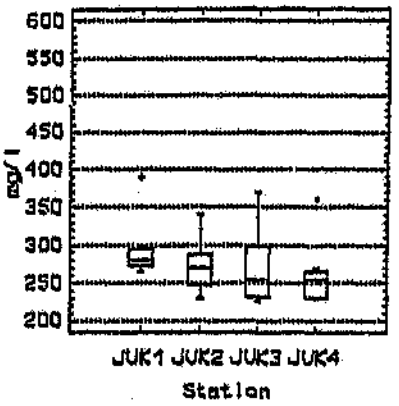


Figure 4.10 Box and whisker plot of the change of TDS with distance during flow.

4.3 CHEMICAL WATER QUALITY VARIABLES

4.3.1 Inorganic Pollutants

The inorganic ions routinely monitored for in the Jukskei river were fluoride, chloride, sulphate, bicarbonate ions in the form of $CaCO_3$, and the metals lead and iron. The Jukskei river is typical of a highveld river in that the most common ions are bicarbonate, magnesium and calcium ions as were observed by Dallas and Day (1993).

Sulphate found in the Jukskei river probably originates from the burning of litter in the catchment and chloride concentrations may originate from the washing of vehicles and clothes in Alexandra area (Wimberley, 1992). Most of the carbonate ions found in the river have their source in the weathering of rocks and the dissolution of carbon dioxide from the atmosphere (Dallas & Day, 1993). Heavy metals like lead and cadmium are washed off the street surfaces after deposition from vehicles' tyre wear (Wimberley, 1992). Other ions like

Table 4.3 Saturation indices for important solids

Sites	Fluorapatite	Calcite	Hydroxylapatite	$Ca_3(PO_4)_2$(beta)
JUK1	9.224	-0.2925	7.620	0.9648
JUK2	8.953	-0.2925	7.347	0.7821
JUK3	8.800	-0.0891	7.391	0.6792
JUK4	9.311	-0.0020	8.002	1.0230

As you can see, if anything, supersaturation increases as you go from JUK1 to JUK4. From the results it was concluded that little or no precipitation was possible. The most probable explanation would be that there is dilution occurring between the two monitoring stations. There are a number of agricultural smallholdings on the east bank of the Jukskei River near JUK1 which would contribute to dilution of the river water. At Linbro there is also a solid waste disposal site which has a small stream that flows into the Jukskei river just before JUK2. There are also a number of running taps and overflowing drains in Alexandra Township which eventually run into the river.

All possible dilution points were looked at along the River banks and it was concluded that the runoff from Linbro Landfill site would be the greatest source of dilution as it continually runs into the river just between the first and second monitoring point where the greatest reduction in TDS is seen (See Photographs in Appendix B).

Table 4.1 Physical parameters used in the GES computer model

Date	Sampling Point	Flow in m^3/s	pH	Temp. in °C	Conductivity in mS/m	TDS
03/08/1994	JUK1	1.49	7.6	14.2	75.3	362
	JUK2	1.49	7.6	13.3	65.1	329
	JUK3	1.49	7.8	14.3	60.8	98
	JUK4	1.49	7.9	13.6	60.4	310

Table 4.2 Anions and cations used in the GES computer model

Sampling Point	Chloride as Cl^- in mg/l	Sulphate as SO_4 in mg/l	Fluoride as F^- in mg/l	Alkalinity as $CaCO_3$ in mg/l	Calcium in mg/l	Sodium in mg/l
JUK1	61	92	0	225	48	43
JUK2	53	77	0	180	47	36
JUK3	50	69	0	160	46	30
JUK4	50	68	0	160	45	32
	Potassium in mg/l	Mg in mg/l	Lead in mg/l	Iron in mg/l		
JUK1	9.8	17	0.01	0.4		
JUK2	8.2	17	0.01	0.4		
JUK3	5.8	17	0.01	0.4		
JUK4	6.2	16	0.01	0.5		

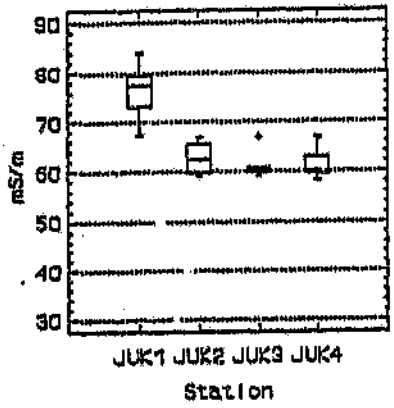


Figure 4.7 Box and whisker plot of the change of conductivity with distance during low flow (winter).

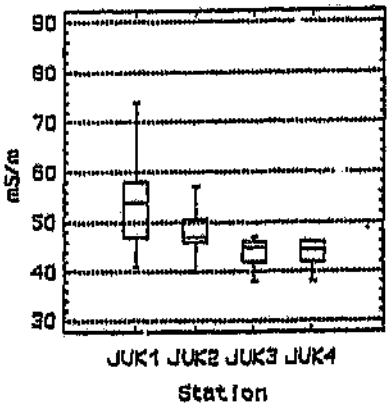


Figure 4.8 Box and whisker plot of the change of conductivity with distance during high flow (summer).

A Mann-Whitney test for difference of medians was carried out on the data and it suggested that in the wet season, the TDS difference between JUK1 and JUK2 was not statistically significant, while the TDS difference during the dry season was statistically significant, but at a low confidence level. The results in this study were compared to those measured by Wimberley (1992) and it was found that very similar medians for JUK1 for the dry and wet seasons were obtained (Wimberley got 402mg.l^{-1} compared to 420 mg.l^{-1} during the dry season and 279mg.l^{-1} compared to 289mg.l^{-1} during the wet season).

Rough equilibrium calculations were carried out on the data and at the measured pH, conductivity and alkalinity concentrations it is very unlikely that precipitation or any other chemical process would be occurring in the reach between JUK1 and JUK2. To make certain, the results obtained on the 3rd of August 1994 were put through an extensive chemical equilibrium model (GES). See Table 4.1 and 4.2 for the variables put into the GES computer model and Table 4.3 for the results obtained.

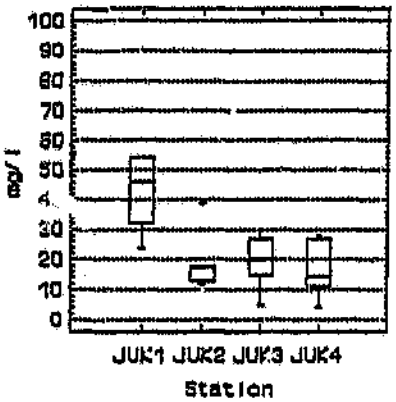


Figure 4.5 Box and whisker plot of the change of SS with distance during the low flow.

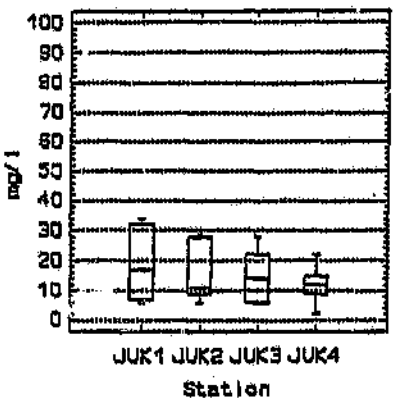


Figure 4.6 Box and whisker plot of the change of SS with distance during the high flow.

A greater drop in TSS is seen during the low flow period. This is due to the decrease in the velocity of the water causing more sedimentation to take place. Both the high and low flow TSS dropped to around 10 $mg.l^{-1}$ at JUK4, the last monitoring point.

4.2.3 Conductivity and Total Dissolved Solids (TDS).

Conductivity and TDS are conservative pollutants in that no change in their concentration with time and distance is expected i.e. $dC/dt = 0$. A large decrease in conductivity and TDS values, downstream of the first monitoring site (JUK1) was observed however. See Figures 4.7 to 4.10. A plateau then seemed to be reached after the second monitoring point at Frankenwald (JUK2), 2km downstream from the Alexandra weir (JUK1). As the conductivity decreases a corresponding decrease in chloride, sulphate and alkalinity in the form of $CaCO_3$ is seen, with each ion concentration reaching a plateau 2km downstream at the Frankenwald monitoring position.

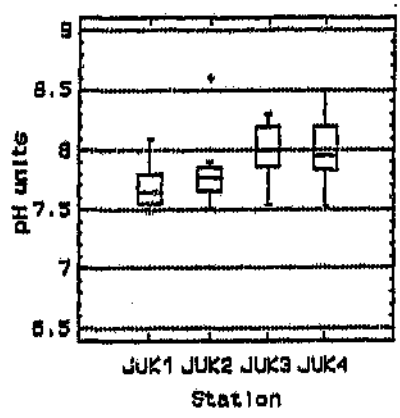


Figure 4.3 pH change with distance at low flow.

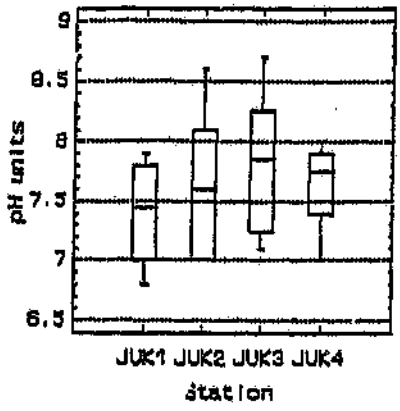


Figure 4.4 pH change with distance at high flow.

The rate of change of pH is determined by the buffering capacity of the carbonate-bicarbonate system (Dallas & Day, 1993) and as the Jukskei River is a typical example of a highveld river, there is a large concentration of carbonates in the water which helps to keep the pH within the 7 to 8 pH unit range.

4.2.2 Turbidity and suspended solids (SS)

The drop in the concentration of suspended solids is most probably due to the process of sedimentation (Figure 4.5). Just below the Alexandra weir there is a stretch of deep, meandering water which is ideal for sedimentation. Both suspended solids and turbidity decreased along the longitudinal length of the river. Turbidity went to highs of 22 and 30 NTU on the 21st of September and the 12th of July respectively while the sites downstream of the Alexandra near Buccleuch site were around 6 NTU.

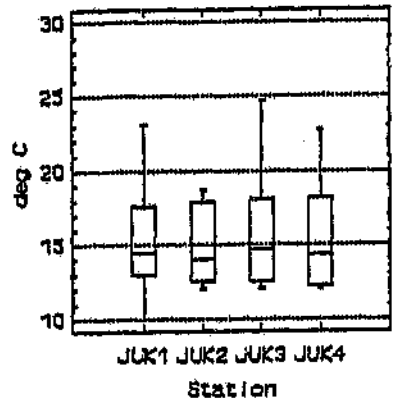


Figure 4.1 Box and whisker plot of temperature at low flow (winter)

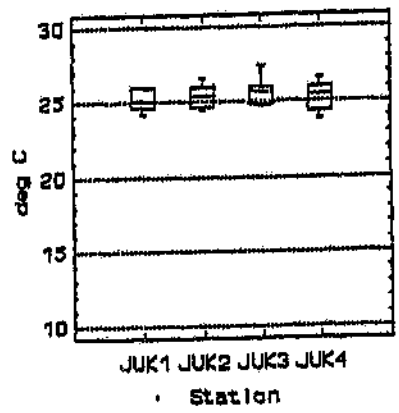


Figure 4.2 Box and whisker plot of temperature at high flow(summer)

Water is not a good conductor of heat so the temperature remains relatively constant during winter and during the summer months. This trend can be seen in the box and whisker plots which reflect the small variations in temperature with the median being around 14°C during the colder low flow periods and going up to between 25 to 26°C in the high flow periods.

The pH of the Jukskei river water was always in the range of 7 to 8, and there were no large variations in the pH from week to week. See Figures 4.3 and 4.4.

During the high flow, the pH range is much wider than in the low flow periods where the pH range is between 7.5 and 8.2 pH units. During the low flow periods, the water is flowing slowly and is colder than during the summer months so the biochemical reactions are taking place at a slower rate and the pH thus does not change so rapidly as seen in the high flow periods. Due to the lack of turbulence there is also less entrainment of air into the water column and certain oxidation reactions either cannot take place or take place at a slower rate.

In the Jukskei River at the JUK1 site, ammonia made up 65% of the inorganic nitrogen with the nitrate concentration only making up 10%. This indicates recent pollution of the river.

The total inorganic nitrogen concentration available as ammonia, nitrites or nitrates decreased by an average of 80% during the low flow period which suggests that two processes could be at work, denitrification whereby nitrogen gas is lost to the atmosphere and sedimentation where nitrates adsorbed onto SS sediment out, due to the low flow of the river.

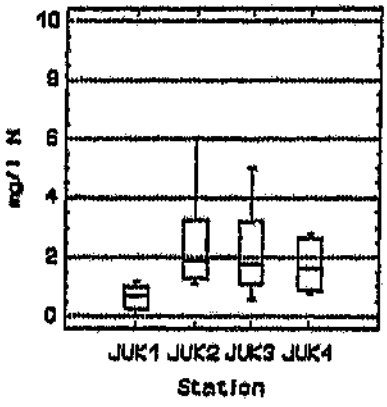


Figure 4.24 Box and whisker plot of the nitrate concentration with distance during low flow (winter).

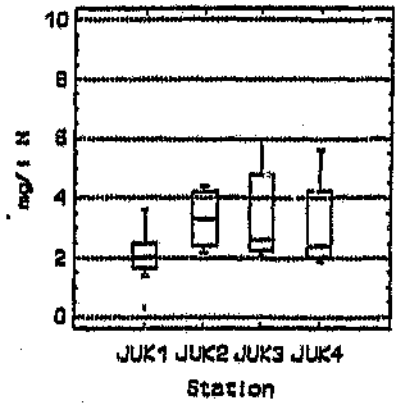


Figure 4.25 Box and whisker plot of the nitrate concentration with distance during high flow (summer).

During the high flow period the total inorganic nitrogen decreased by 64%. During high flow there is more turbulence so not as much sedimentation can take place.

The concentration of nitrates is low at the JUK1 site and increases up to JUK2 and JUK3 where it seems to reach a plateau before it decreases slightly at JUK4. At high concentrations of ammonia, the nitrification reaction is taking place at the highest rate. An increase in nitrates is thus observed. Once the concentration of ammonia starts to decline however, as it does at JUK2, the uptake of nitrates by plants is greater than the production of nitrates by the nitrification process and a decrease in nitrates is observed.

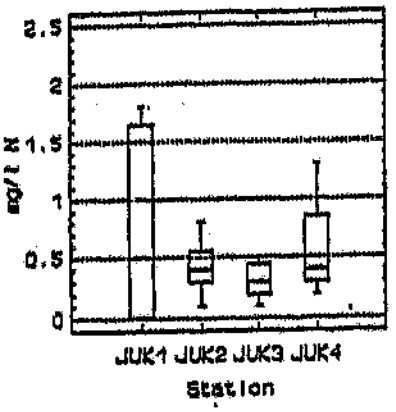


Figure 4.22 Box and whisker plot of the nitrite concentration with distance during low flow (winter).

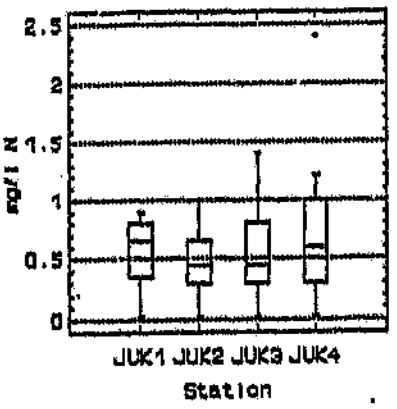


Figure 4.23 Box and whisker plot of the nitrite concentration with distance during high flow (summer).

The percentages that each inorganic nitrogen species makes up of the total inorganic nitrogen at JUK1 and JUK2 were calculated. At JUK1 the mean total Kjeldahl nitrogen was found to make up 92% of total inorganic nitrogen; ammonia making up 65%; nitrite 3% and nitrate 10%. The percentage nitrogen for TKN then dropped to 62% at the JUK2 site, ammonia to 33%, while nitrites remained at 3% and nitrates increased to 30%. See Figure 4.26. In un-impacted waters which are well oxygenated, >80% of the inorganic nitrogen will be in the nitrate form and ammonia will make up less than 20% of the inorganic nitrogen. With run-off into the waters the ammonia concentration may rise to greater than 40% of the inorganic nitrogen (Ashton, pers. comm.).

There are longer reaction times between stations which allows for greater conversion of TKN and ammonia and the flow is less so more sedimentation of particulate nitrogen and adsorbed nitrogen takes place. The longer flow time between stations also allows for the formation of a large colony of nitrifying bacteria.

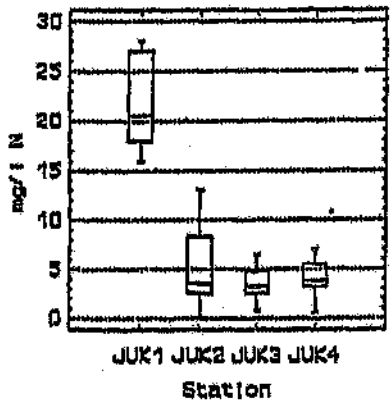


Figure 4.20 Box and whisker plot of the Ammonia concentration with distance during low flow (winter).

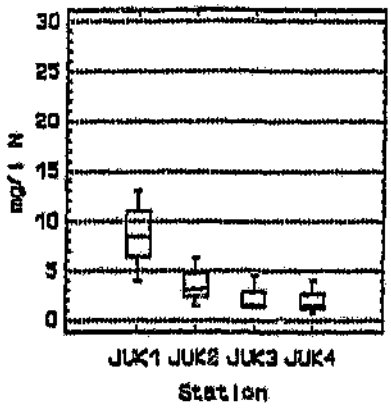


Figure 4.21 Box and whisker plot of the Ammonia concentration with distance during high flow (summer).

The concentration of nitrites in natural waters is never very high as the conversion of nitrites to nitrates is very fast and not much is accumulated. An increase in nitrite concentration is an indication that nitrification and/or denitrification is taking place. From the results an increase in nitrite concentration is observed. As the dissolved oxygen is always above the 1.0 $mg.l^{-1}$ limit for denitrification, the main reaction taking place must be nitrification.

As more ammonia is converted to nitrates, an equilibrium will result where the concentration of nitrite will remain at a certain equilibrium concentration. From Figures 4.19 and 4.20, the median for both the high flow and low flow periods are at their highest at JUK1, and drops to a constant value

Nitrogen compounds are related by means of a series of reactions known as the nitrogen cycle, which regulates the flow of nitrogen from inorganic forms in soil, air and water into living organisms and then back into inorganic forms. The six most important processes taking place are:

1. Nitrogen assimilation (nitrates and ammonia) by plants;
2. Heterotrophic conversion of organic nitrogen from one organism to the next;
3. Ammonification, the breakdown of organic nitrogen into ammonia;
4. Nitrification, the aerobic oxidation of ammonia to nitrite then to nitrates by the nitrifying bacteria;
5. Denitrification, The anaerobic conversion of nitrate to nitrite and ammonia by bacteria and fungi;
6. Nitrogen fixation, the biological fixation of molecular nitrogen to produce ammonia, which is then converted to nitrogen compounds in organisms.

Another reaction is the volatilisation of ammonia which is then lost to the atmosphere. This process occurs at high temperature and pH values. During this process, the ammonium ions are converted to the toxic un-ionised ammonia form ($NH_4^+ \rightarrow NH_3$) which is then lost as a gas into the atmosphere. The two reactions by which inorganic nitrogen is lost from the aquatic environment are the conversion of nitrites to gaseous nitrogen by denitrifying bacteria and the volatilisation of ammonia. The two most important reactions under aerobic and anaerobic conditions however, are the biological conversion between the inorganic forms of ammonia, nitrites and nitrates. During the high flow period, the drop in TKN and ammonia followed exponential curves with a 0.98 and a 0.99 correlation respectively. This corresponds to bacterial conversion of TKN and ammonia to nitrites and nitrates. During the high flow period there is a lot of entrainment of oxygen into the water due to turbulence. The dissolved oxygen is thus always kept above the limiting DO value of 1 to 1.5mg.l^{-1} ensuring that the main reaction taking place is nitrification by the Nitrobacter and Nitrosomonas bacteria.

$$TKN \rightarrow AMM\text{-}N \rightarrow NITRITE\text{-}N \rightarrow NITRATE\text{-}N$$

During the colder winter months a greater decrease in T .N and ammonia is seen between JUK1 and JUK2. A number of processes could be at work here.

is taking place. Oxidation of BOD is also taking place but this is not great enough for a significant change in the BOD values to be seen.

4.3.4 Nutrients : Nitrogen and Phosphorus

From Wimberley's (1992) report, it was found that the major source of high nutrient loads reaching the Jukskei river, was human and animal faeces. Sewage from blocked drains is flowing into the Jukskei river, or is washed off the catchment during rainfall events. The majority of the organic pollutants are thus in the form of proteins, carbohydrates and fats, or in the form of excretory products such as ammonia, urea and uric acid. The organic products are broken down by bacteria in the water into nitrates and nitrites, making them available to the various plants in an inorganic form. The above reactions only occur under aerobic conditions. If the dissolved oxygen concentration drops to below 1 mg/l, then the anaerobic denitrifying bacteria take over and nitrites, nitrates and ammonia are converted to nitrogen gas (N_2) which is then lost to the atmosphere. Changes in the ammonia or TKN concentration with distance downstream can be a useful indicator of the rate of conversion to nitrate-N.

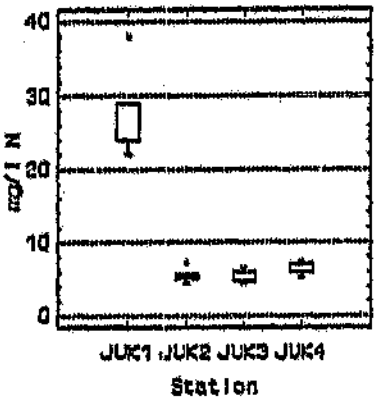


Figure 4.18 Box and whisker plot of the TKN concentration with distance during low flow (winter).

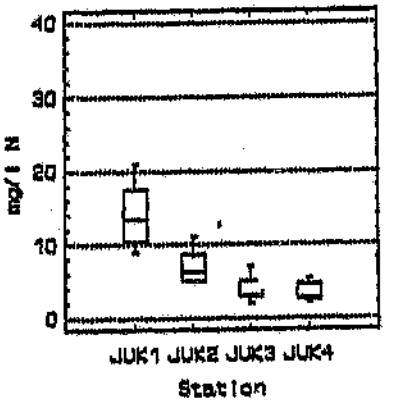


Figure 4.19 Box and whisker plot of the TKN concentration with distance during high flow (summer).

	28/09/1994	34	30	0.88
	01/11/1994	55	30	0.55
	16/11/1994	40	20	0.50
	18/01/1994	51	20	0.39
Average BOD:COD				0.55
JUK3	03/08/1994	41	20	0.49
	24/08/1994	65	60	0.92
	07/09/1994	45	20	0.44
	21/09/1994	120	30	0.25
	28/09/1994	54	30	0.56
	01/11/1994	40	30	0.75
	16/11/1994	30	10	0.33
	18/01/1994	36	20	0.56
Average BOD:COD				0.54
JUK4	03/08/1994	71	10	0.14
	24/08/1994	65	50	0.77
	07/09/1994	50	30	0.60
	21/09/1994	70	50	0.71
	28/09/1994	54	30	0.56
	01/11/1994	45	30	0.67
	16/11/1994	30	10	0.33
	18/01/1994	25	10	0.4
Average BOD:COD				0.48

From the table it can be seen that the BOD:COD ratio decreases with distance from Alexandra Township. The BOD:COD ratio is 0.53 at the Alexandra monitoring point which is indicative of recent sewage pollution. At the first monitoring point in Alexandra the BOD concentration is much higher than at the other monitoring points which indicates that sedimentation of some of the BOD

dilution takes place and the concentrations are less. The difference in the velocity can also be seen. The material undergoing the oxidation reactions spend more time in the water column between stations during the low flow periods so more of the oxidation reaction can take place and this is reflected in the graphs above. A large decrease in the COD concentration is seen between JUK1 and JUK2 during the low flow period. The corresponding decrease in the COD concentration during the high flow period is much less noticeable as the water is flowing so fast that only a small concentration of the material has been oxidised by the time it passes JUK2.

For polluted waters contaminated with raw sewage a direct relationship between COD and BOD can be established (Hoffmann, 1995). Most domestic waste waters have a BOD:COD ratio of 0.5:1. The ratios at each monitoring point were determined. See Table 4.9.

Table 4.9 Ratios of BOD to COD for each monitoring point

Monitoring Point	Date	COD in mg/l	BOD in mg/l	BOD:COD
JUK1	03/08/1994	100	50	0.5
	24/08/1994	140	60	0.43
	07/09/1994	225	100	0.44
	21/09/1994	150	60	0.40
	28/09/1994	88	60	0.68
	12/10/1994	60	30	0.50
	01/11/1994	60	60	1.00
	16/11/1994	55	30	0.55
	18/01/1994	66	20	0.30
Average BOD:COD				0.53
JUK2	03/08/1994	46	20	0.43
	24/08/1994	60	40	0.67
	07/09/1994	45	30	0.67
	21/09/1994	70	20	0.29

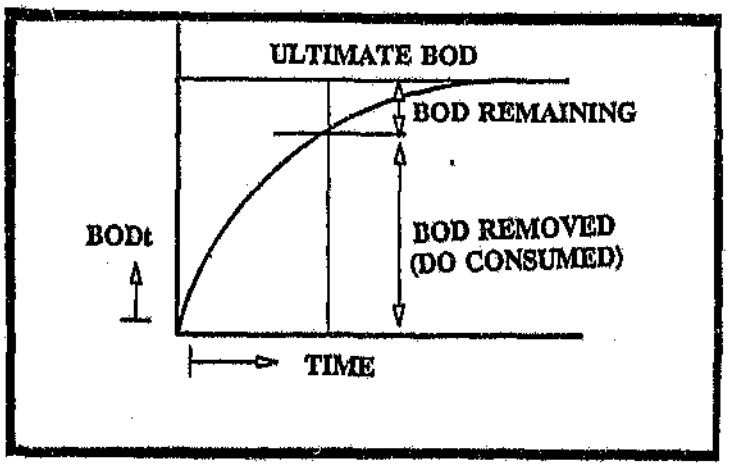


Figure 4.15 Rate of change of BOD with time

COD is a measure of all the material in the wastewater sample that can undergo oxidation. If a great enough concentration of dissolved oxygen is available a number of oxidation reactions can take place

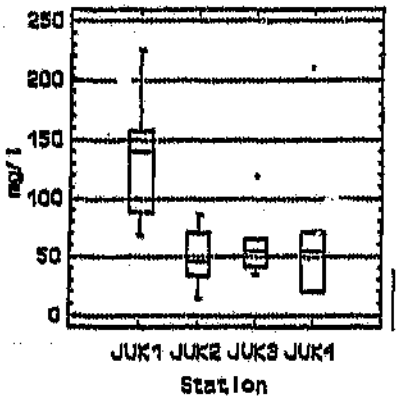


Figure 4.16 Box and whisker plot of the COD concentration with distance during low flow (winter).

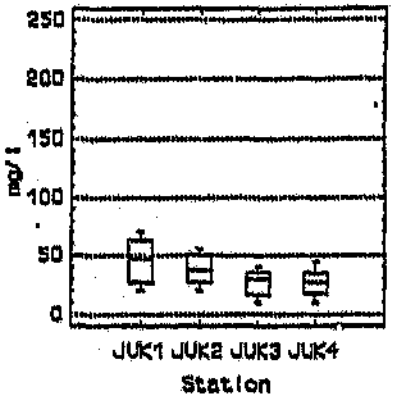


Figure 4.17 Box and whisker plot of the COD concentration with distance during high flow (summer).

The COD can be seen to be higher during the low flow period where greater concentration of the material takes place. During the high flow periods more

reported in literature. It has been reported that more than 60% of organic matter can settle out. In our plots of BOD an exponential type curve is obtained with a very steep decline in BOD between the first and the second monitoring points. This and the high values of k obtained is indicative of settling out of BOD.

An average k of 0.17 day^{-1} is usually used for natural waters if the k value is unknown but it may vary significantly with the type of waste being oxidised (Metcalf & Eddy,1979). k values have been found to range from 0.05 to greater than 0.3.

Table 4.8 Typical values of the carbonaceous rate constant, k.

Reference	k (/day)	Comments
Brown and Barnwell (1987) (QUAL2E)	0.02 - 3.4	
Thomann and Mueller (1987)	0.3 - 0.4	Untreated municipal wastewater
Thomann and Mueller (1987)	0.1 - 0.3	Secondary effluent
Thomann and Mueller (1987)	$0.3\ (H/(2.44))^{-0.434}$ for $0<H<2.44$m 0.3 for $H>2.44$m	H is water depth in m

Although the k values determined are high they can be used to predict trends. The high rate constants over August and September are as a result of the very low flow of the river and the resulting increase in the concentration of carbonaceous BOD which has to oxidised. BODs of 60 to 100 mg/l were recorded during these periods with the BOD dropping to 10 to 30 mg/l during the high flow period.

$$L_t = L \exp^{-kt} \ldots\ldots\ldots \quad 4.7$$

From the above equation after taking Logs we get

$$\log(L_t) = \log(L) - kt \log(e) \ldots\ldots\ldots \quad 4.8$$

which is the equation of a straight line with y intercept = Log (L) and the slope= -k Log(e). Regression analysis was used to give us the equation describing the straight line. See Table 4.7 below for results.

Table 4.7 The determination of the carbonaceous rate constants for the Jukskei river.

Date	k - the carbonaceous oxidation rate constant, day^{-1}	r squared
03/08/1994	7.767	0.8828
10/08/1994	11.659	0.8746
07/09/1994	6.530	0.8296
21/09/1994	1.090	0.8618
28/09/1994	11.796	0.6391
12/10/1994	10.97	0.6387
01/11/1994	12.282	0.6383
16/11/1994	13.696	0.9305
18/01/1995	13.203	0.9411

In this study the 5.8 km stretch of river was seen as a closed, mixed reactor in which organic matter measured as BOD was added at the top, oxidation of the organic matter took place within the reactor and the remaining organic matter was released. In a normal laboratory situation there is very little turbulence or settling of organic matter so the decrease in the BOD that is observed is as a direct result of oxidation of the organic matter by bacteria. Unfortunately in a river settling of organic matter is an important process that results in the decrease of organic matter and this can be seen in the values of k (BOD oxidation constants) determined. These values are much higher than those

4.3.3 Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The BOD test gives a measure of the oxygen utilised by bacteria during oxidation of organic material in the water sample. The test is based on the premise that all biodegradable organic material contained in the wastewater sample will be oxidised to CO_2 and H_2O. Hence it is a direct measurement of the oxygen requirements and and an indirect measure of biodegradable organic matter pollution.

The oxidation of carbonaceous pollutants in streams is usually described as being a first order rate reaction (Metcalf & Eddy, 1979). In a first order reaction the rate of oxidation is proportional to the concentration of oxidizable organic matter remaining and once a suitable colony of microorganisms has developed, the rate of the reaction is only controlled by the amount of readily available carbon available. The equation used to describe the reaction is:

$$L_t = L_O \exp^{-kt} \quad \ldots\ldots\ldots \quad 4.6$$

Where:
L = concentration of BOD remaining
L_O = the ultimate concentration of BOD
k = rate constant for a particular group of microorganisms.
t = time

There are several ways of determining k, the carbonaceous oxidation rate constant from a series of BOD measurements and these include the least-squares method which involves fitting a curve through a set of data points, so that the sum of the squares of the residuals (the difference between the observed values and the value of the fitted curve) must be minimum. Another method which is also often used is the Thomas method in which k is determined by plotting $(t/BOD)^{1/3}$ against t in days where k=2.61 slope/intercept (Metcalf & Eddy, 1979).

Values of k for each monitoring day were determined in this study by plotting the log (BOD at t) against time t in days.

A number of theoretical equations using the average depth and velocity have been developed with the best theoretical model in the absence of other information is the O Connor and Dobbins model. This uses the molecular diffusivity, the mean velocity and the mean depth to calculate the reaeration constant.

$$K_2 = \frac{(D_m u)^{0.5}}{d^{1.5}} \quad \ldots\ldots\ldots \quad 4.4$$

where D_m = molecuar diffusivity = 1.78×10^{-4} m^2/day
u = Mean velocity, m/s
d = Mean depth, m

This method was compared to the Streeter-Phelps method by determining the reaeration constants by both methods. See Table 4.6

Table 4.6 Comparison of Reaeration Constants determined by O'Connors and Dobbins' equation and Streeter-Phelps equation.

Monitoring Point	O'Connors and Dobbins	Streeter-Phelps
Marlboro	2.400	2.053
Buccleuch	2.052	1.560

The results are similar but the Streeter-Phelps equation underestimates the reaeration values compared to the O' Connor/Dobbins equation.

The Owens' formulation for Shallow Streams is also often used.

$$R = 21.6 \, x \, \frac{V^{0.67}}{H^{1.85}} \quad \ldots\ldots\ldots \quad 4.5$$

where: V = velocity of stream in ft/sec.
H = stream depth in ft

organisms. Pathogenic organisms cause diseases like typhoid, cholera, dysentery and infectious hepatitis. All of these are of human origin and may be transmitted through water. An infectious disease is one which can be transmitted from one person to another. During the transmission process, the organisms may be exposed to the environment, and their passage to the body of a new victim is then vulnerable to changes in the environment. By changing the human environment, reduction or prevention of the transmission of these diseases is possible.

In townships like Alexandra, people are living at close quarters and the sanitary conditions are bad. This an ideal environment for the spread of diseases especially among the younger and the older members of the community as they are the weakest.

4.4.5 Faecal coliform die-off rate constants in the Jukskei River.

The die-off rate of faecal coliforms in the water was calculated. Faecal coliform die-off is due to UV light, dilution, a hostile environment (i.e. in water and not in the human or mammal gut), predation and possibly lack of food. The logs of the coliform concentrations were plotted against time and the slope of the regression lines were determined. Using this the rate of bacterial decay for each sampling day was determined. See Table 4.12 below.

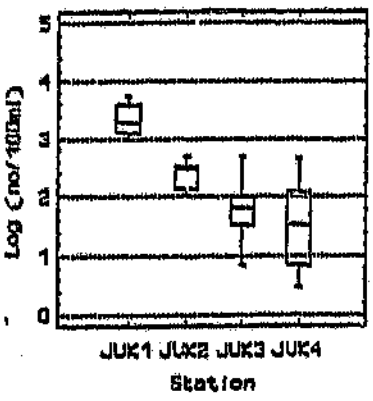


Figure 4.34 Box and whisker plot of the logs of *E.coli* concentration with distance during low flow (winter).

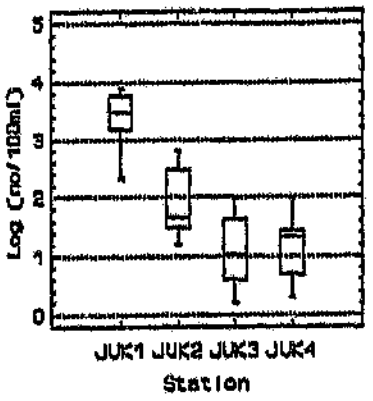


Figure 4.35 Box and whisker plot of the logs of *E.coli* concentration with distance during high flow (summer).

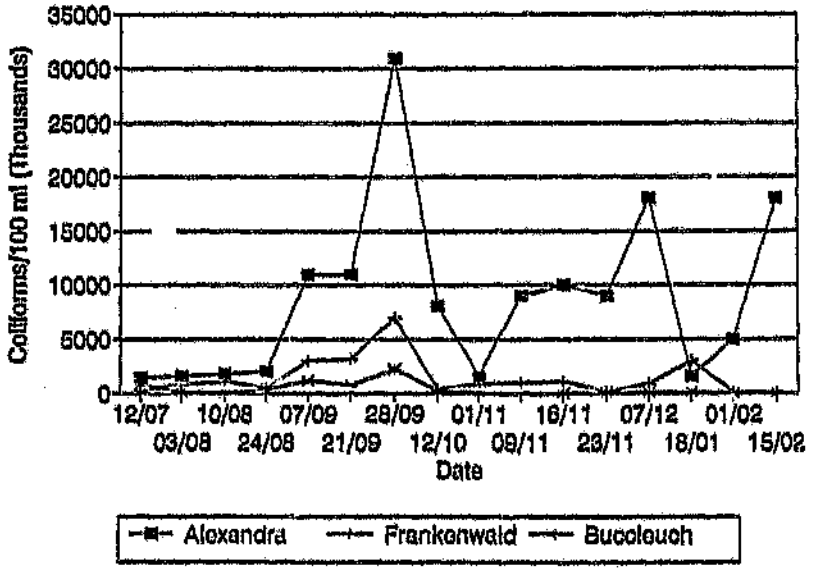


Figure 4.36 Faecal coliform concentrations measured at Alexandra, Frankenwald and Buccleuch over the monitoring period.

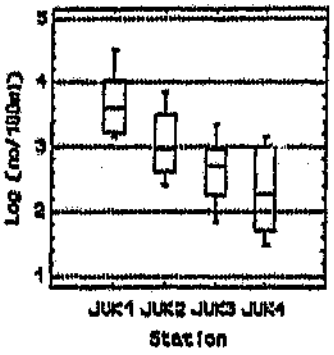


Figure 4.32 Box and whisker plot of the logs of faecal coliform concentration with distance during low flow (winter).

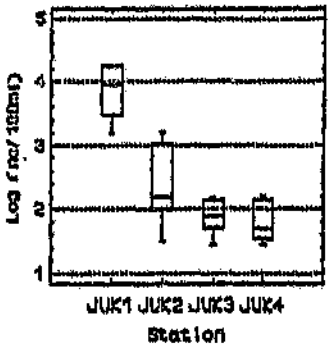


Figure 4.33 Box and whisker plot of the logs of faecal coliform conc. with distance during high flow (summer).

The faecal coliforms follow an exponential decay curve with distance downstream as expected. The concentration of faecal coliforms decreases with UV light and the foreign water environment.

The *E. coli* concentration is always slightly lower than that of the faecal coliforms but follows the same pattern as they flow downstream.

The Faecal coliform concentrations at three monitoring positions were plotted and a trend can be seen. During September just after the first summer rains a large increase in faecal coliform concentration was observed, which is due to the "first flush" effect and afterwards a decrease in the faecal coliform concentration was observed which is due to dilution.

By convention the most commonly used indicator organisms are the faecal coliforms comprised mainly of *Escherichia coli*, which are a sub-group of the faecal coliform group and occur almost entirely in faeces. Natural water contains active plant and animal life and will contain many bacteria (Cairncross & Feachem, 1993) of which most pose no significant health risk to water users.

4.4.2 Data collection and methodology

Water for bacterial analyses was sampled using a 250 ml autoclaved, sterile glass bottle. The water was then analysed for faecal coliforms and *Escherichia coli*. *E. coli* is the most commonly used indicator organism for the presence of enteropathogenic organisms in surface water bodies. The detection of a high *E. coli* count is an indicator of recent sewage pollution.

The tests were carried out according to the Standard Methods for the Examination of Water and Wastewater (APHA), (1989).

4.4.3 Results and analysis

Water samples were taken at all four monitoring sites. A very large increase in the concentration of coliforms and *E. coli* can be seen on the 7th of September. This corresponds to similar increases in most other water quality pollutants. It has been widely reported in the newspapers that the main cause of the rise in coliforms is the blockage of sewerage drains and this raw sewage is flowing straight into the river (Star, Wed, 01/02/1995 (Appendix C)).

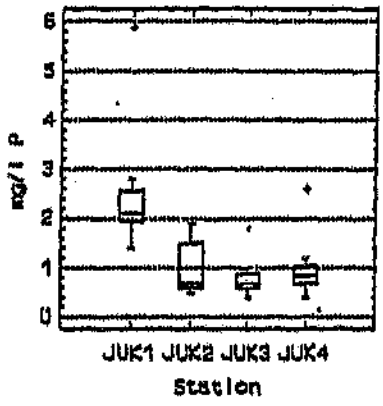


Figure 4.30 Box and whisker plot of the phosphate concentration with distance during low flow (winter).

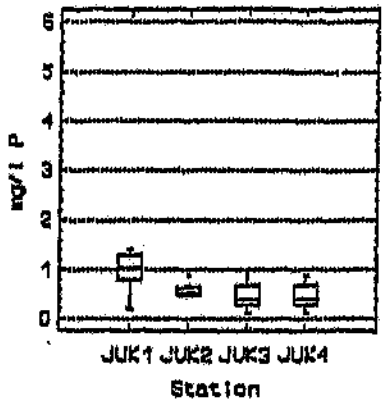


Figure 4.31 Box and whisker plot of the phosphate concentration with distance during high flow (summer).

4.4 MICROBIOLOGICAL ASPECTS

4.4.1 Introduction

The microbiological quality of water is typically expressed in terms of the concentration of occurrence of particular species of bacteria. Polluted water may contain pathogenic (disease-causing) bacteria, viruses or protozoa. The detection of all of these compounds is impossible, so it is normal practice to detect 'indicator' organisms. These are bacteria that are always excreted in large numbers by warm-blooded animals, irrespective of whether they are healthy or sick. The presence of these indicator organisms in water is therefore indicative of faecal contamination. If the water is faecally contaminated then there may be a chance that it may contain a pathogen and this may be a health hazard.

phosphates and are from the body wastes, bodies of dead aquatic animals and food residues. The other category, has a considerably higher concentration of ortho-phosphatees and represents runoff comprised mostly of domestic and industrial waste water discharges into the river and is an example of a polluted catchment.

The ratio of ortho-phosphates to total phosphates was determined for each of the monitoring sites. It was found that the average ratio changed from 0.5 to 0.4 further downstream. This is indicative of a polluted river. The water samples were analysed for total phosphorus and ortho-phosphates. Most of the phosphorus was found to be in the ortho-phosphate form.

There is never a very high concentration of dissolved phosphates in water as most are particulate in nature and are adsorbed onto suspended solids and sediment out and due to P being the limiting nutrient, uptake by algae/microflora is rapid.

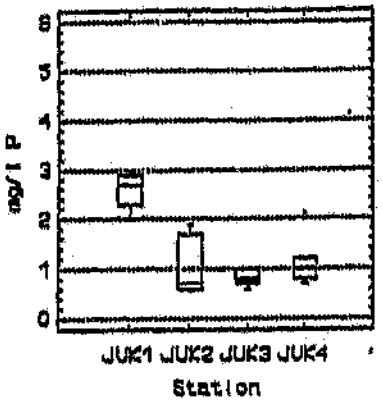


Figure 4.28 Box and whisker plot of the total phosphorus concentration with distance during low flow (winter).

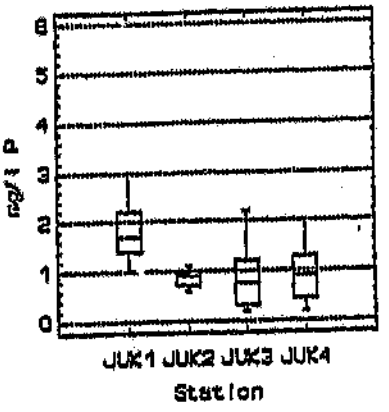


Figure 4.29 Box and whisker plot of the total P concentration with distance during high flow (summer).

Most of the phosphorus is in the form of phosphates in water. These adsorb onto suspended solids and precipitate out or are taken up by algae/microflora.

Table 4.10 Nitrification rate constants determined for the Jukskei river.

SAMPLING DATE	K_N determined by observed rate of change of TKN species between monitoring points. (mg O_2. l^{-1}. day^{-1})	K_N determined by using Warwick & Shetty equation. (Equation 4.7) (mg O_2. l^{-1}. day^{-1})
24/08/1994	46.92	31.50
07/09/1994	59.06	39.43
21/09/1994	36.72	24.83
28/09/1994	38.88	26.24
12/10/1994	20.90	14.48
01/11/1994	13.11	9.39
09/11/1994	9.98	7.35
16/11/1994	19.59	13.62
23/11/1994	12.32	8.88
07/12/1994	33.70	22.85
18/01/1995	16.39	11.54
01/02/1995	33.60	22.79

From the results in Table 4.10 it can clearly be seen that the nitrification rate constants determined by the rate of change of TKN with distance downstream are much higher than those determined using Warwick and Shetty's equation. Using the rate of change of TKN with time results in an overestimation of the rate of nitrification. Unlike direct calculation of the rate of change of TKN, Warwick and Shetty's method takes into account that the N species undergo a number of other transformations, such as plant uptake and ammonification, and not only nitrification although nitrification is the major process taking place.

Phosphorus is usually in shorter supply than nitrogen in aquatic environments and it is often the limiting growth factors for plants. The most biologically available forms of phosphorus are: orthophosphate (PO_4^{3-}), hydrogen phosphate (HPO_4^-) and dihydrogen phosphate ($H_2PO_4^-$). The relationship between ortho-phosphate and total phosphate can be grouped into two categories (Hoffmann, 1995). The one category has a small concentration of ortho-phosphates which represents flow from a natural catchment. Most of the phosphates are complex

where K_N = actual, zero-order, nitrification rate, units of mg O_2 l^{-1} day^{-1};
ΔTKN = observed change in total Kjedahl nitrogen concentration between monitoring points (mgN.l^{-1}) and
t_f = flow time between stations in days.

Equation 4.9 was used to predict nitrification rate coefficients in streams having average depth of flows of 0.66m. Another equation which took into account the average stream depth was developed (Equation 4.10).

To estimate the actual, zero-order, nitrification rate in channel cross-sectional areal units:

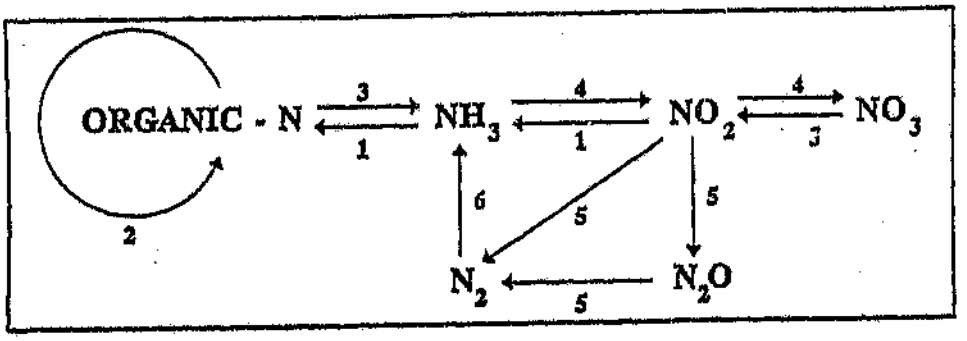
$$K_N = 0.76 \times (\Delta TKN * \frac{4.33}{t_f}) * D - 0.16 \text{ g } O_2 . m^{-2} . day^{-1} \ldots\ldots \quad 4.10$$

where K_N = Actual, zero-order, nitrification rate in mg $O_2.m^{-2}.day^{-1}$
ΔTKN = observed change in Kjeldahl nitrogen concentration between monitoring points (mg N.l^{-1})
t_f = flow time between stations in days and
D = depth in m

Nitrification is the most important process that occurs under aerobic conditions and at a pH range of 7-8 and is the major source of NBOD. Performing a complete nitrification and oxygen mass balance, requires a large amount of data, some of which may not be available. Equations 4.9 and 4.10 are thus of great use in the accurate and easy prediction of nitrification coefficients.

The Jukskei river is a shallow, rocky stream. This promotes the entrainment of oxygen in turbulent water flow. Thus sufficient dissolved oxygen concentration is available for the nitrification process to take place. The nitrification rate coefficients for each sampling day were determined. See Table 4.10 for results.

the laboratory or in the field, followed zero-order kinetics at ammonia concentrations greater than 2.5 $mg.l^{-1}$.



1. Nitrogen Assimilation;
2. Heterotrophic conversions of organic nitrogen from one organism to next;
3. Ammonification;
4. Nitrification (aerobic bacterial oxidation of ammonia to nitrates);
5. Denitrification (anaerobic conversion of nitrate to ammonia by fungi and bacteria) and
6. Nitrogen fixation (biological fixation of molecular nitrogen to produce ammonia)

Figure 4.27 The in-stream nitrogen cycle showing the various nitrogen transformations that take place.

Warwick and McDonnel (1985) compared the SNOAP computed coefficients with the simple estimations based on the changes in various nitrogen species with time and distance. They found that observed changes in TKN concentrations gave the most accurate prediction of in-stream nitrification. Warwick and Shetty (1988) developed two equations to determine the coefficient using the change in TKN concentration and travel time.

Equations used:

To estimate the actual, zero-order, nitrification rate coefficient:

$$K_N = 0.69\,x\left(\Delta\,TKN\,x\,\frac{4.33}{t_f}\right) + 0.82\ mg\ O_2\ l^{-1}\ day^{-1} \quad \ldots\ldots\ldots \quad 4.9$$

Ultimate NBOD reduction

This technique involves plotting ultimate nitrogenous BOD ($NBOD_L$) values versus flow times between monitoring points. The slope of the best fit line gives an estimate of the nitrification rate constant. There are a number of problems associated with this method. These include:

1. Inaccuracies in ascertaining the ultimate $NBOD_L$,
2. The 20-day BOD bottle test duration. The 5-day BOD bottle test is of no use because it takes 3-10 days for nitrifying bacteria to establish a colony for efficient nitrification to take place.
3. The 20°C temperature used in the bottle test is below the optimum range of 25-28°C for nitrifying bacteria (Warwick and Shetty, 1988).

Nitrogen species transformations

The change in concentration of individual nitrogen species with time in the downstream direction can be calculated. The nitrogen species which are used are total Kjeldahl-N (organic + ammonia), ammonia-N, nitrate-N and nitrite- plus nitrate-nitrogen (Warwick & Shetty, 1988). It is difficult to decide on which nitrogen species to use as many of the transformation rates for each of these compounds are not only dependent on the nitrification process but undergo a number of other processes in the nitrogen cycle. Examples are nitrate, ammonia and nitrite nitrogen species that are are also taken up by plants. See Figure 4.27.

The Stream Nitrogen and Dissolved Oxygen Analysis Program (SNOAP)

This model was developed by Warwick and McDonnel (1985). It predicts in-stream nitrification rates based on the observed changes in concentrations of all nitrogen species and in the dissolved oxygen concentration. The nitrogen mass balance equations include the following transformation pathways: ammonification, nitrification, bacterial and aquatic plant nitrogen assimilation, ammonia exsolution and denitrification. Nitrification is seen as having zero-order kinetics i.e. it is not dependent on the concentration of substrate. Wild, et al.(1971), Huang and Hudson (1974), Finstein and Matulewich (1974) and Curtis et al. (1975) all found that the nitrification process, whether studied in

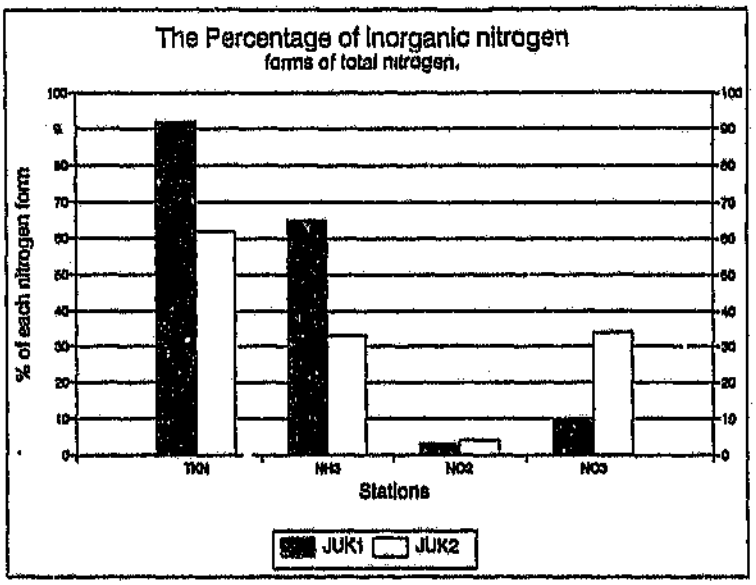


Figure 4.26 Box plot of the percentages that each nitrogen species makes of the total inorganic nitrogen concentration.

Nitrogenous Oxygen Demand

The NBOD value is the oxygen needed by nitrifying bacteria, Nitrosomonas and Nitrobacter, in the biochemical oxidation of ammonia and nitrites to the stable nitrate form. It has long been recognised that the nitrogenous biochemical oxygen demand (NBOD) is a major sink in the oxygen balance of streams (O'Connor and DiTorro, 1970). It is thus important that the degree and rates of nitrification are accurately assessed in order to determine the effect that NBOD will have on the oxygen balance.

It has been found that nitrification growth constants for both Nitrosomonas and Nitrobacter are around $0.5d^{-1}$ at 20°C (Sterrit and Lester, 1988).

Two methods have generally been used for the prediction of nitrification rates: a) Ultimate NBOD reduction and b) nitrogen species transformations. A third method, the SNOAP model was developed in 1985 (Warwick and McDonnell, 1985) and unlike the above two methods determines the nitrification rates by taking into account all the transformations that the nitrogen species can undergo.

In the Jukskei River at the JUK1 site, ammonia made up 65% of the inorganic nitrogen with the nitrate concentration only making up 10%. This indicates recent pollution of the river.

The total inorganic nitrogen concentration available as ammonia, nitrites or nitrates decreased by an average of 80% during the low flow period which suggests that two processes could be at work, denitrification whereby nitrogen gas is lost to the atmosphere and sedimentation where nitrates adsorbed onto SS sediment out, due to the low flow of the river.

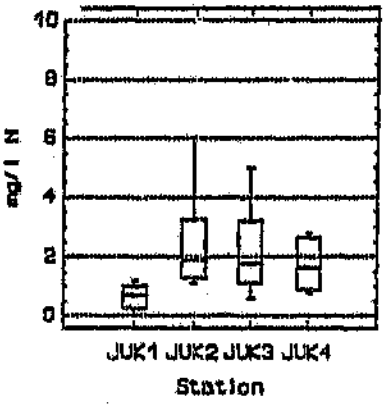


Figure 4.24 Box and whisker plot of the nitrate concentration with distance during low flow (winter).

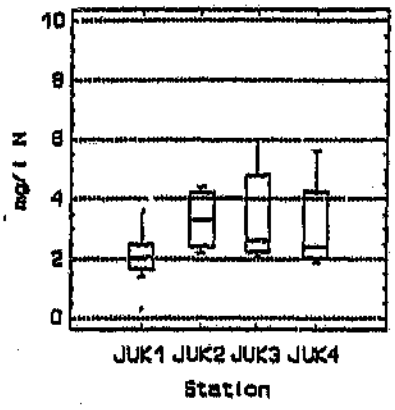


Figure 4.25 Box and whisker plot of the nitrate concentration with distance during high flow (summer).

During the high flow period the total inorganic nitrogen decreased by 64%. During high flow there is more turbulence so not as much sedimentation can take place.

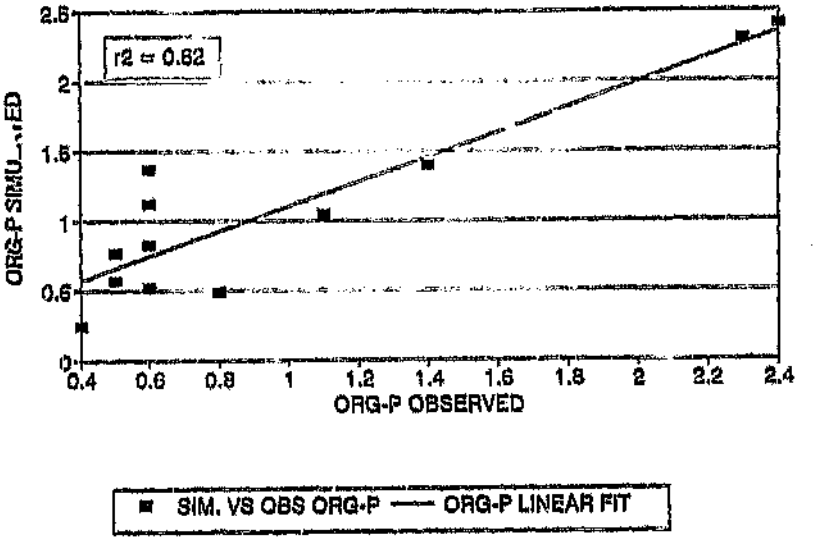


Figure 5.9 Scatter plot of observed and simulated organic phosphorus with the calculated regression line.

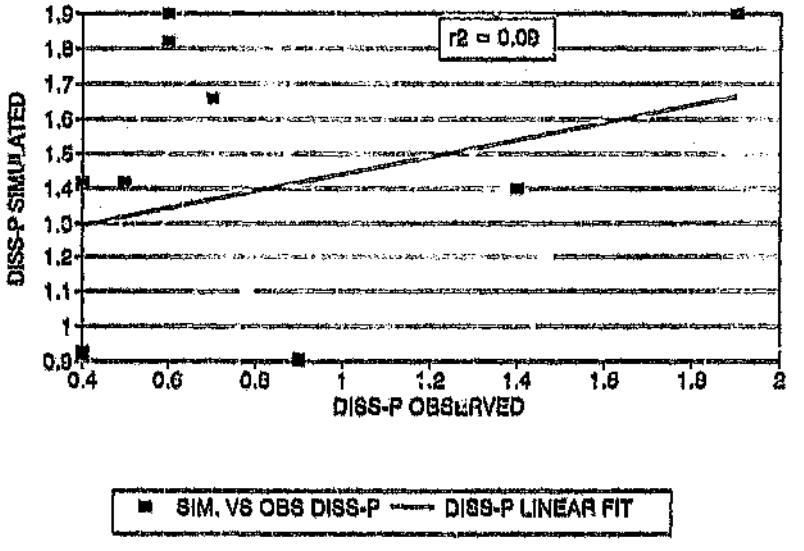


Figure 5.10 Scatter plot of observed and simulated dissolved P with the calculated regression line.

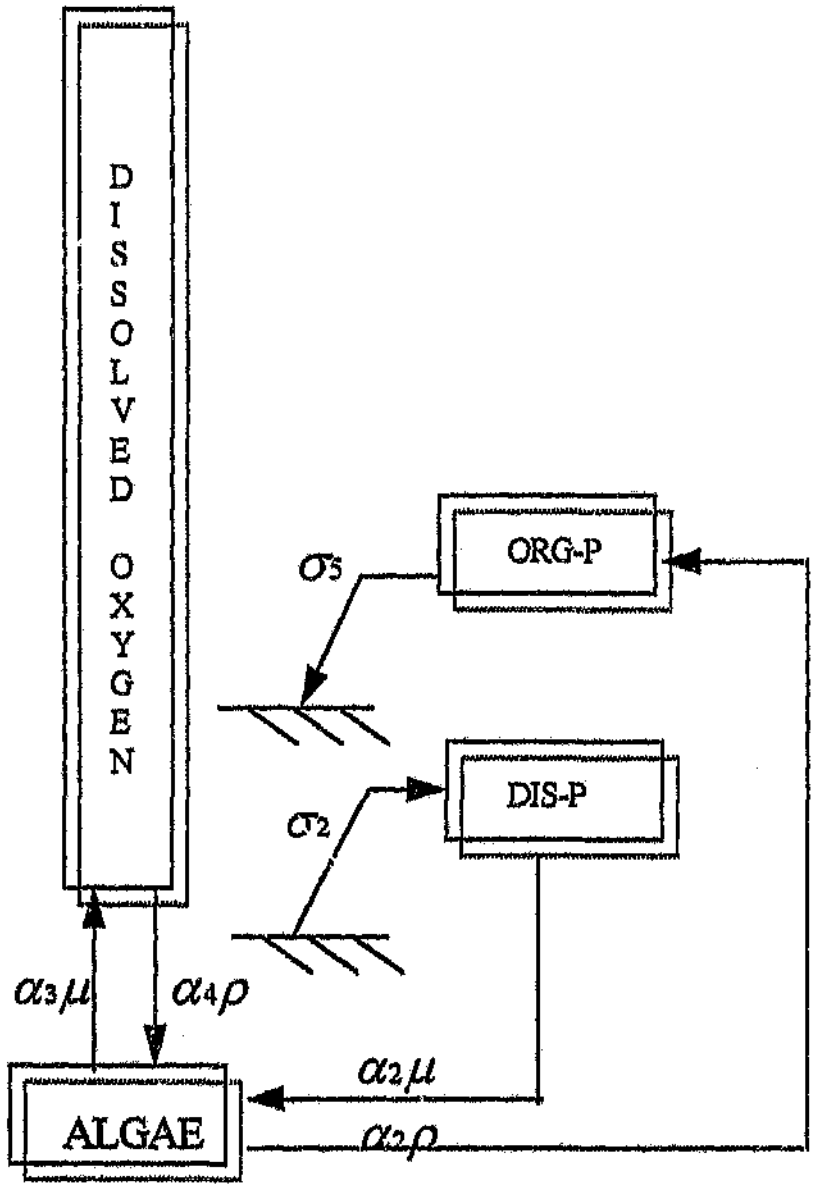


Figure 5.8 The Phosphorus reactions modelled by QUAL2EU

Table 5.2 Nitrogen coefficients used in the QUAL2EU modelling of the Jukskei River.

Date	Org-N Hydrolysis /day	Org-N Settling /day	NH3-N Oxidation /day	Benthal Source mg/m2/day	NO2-N Oxidation /day
24/08/1994	0.4	30	5	1	30
07/09/1994	0.4	30	0.1	1	10
16/11/1994	0.4	30	0.3	1	20
18/01/1995	0.4	15	5	1	10
QUAL2E Range	(0.02-0.4) Variable with reach& temp.	(0.001 - 0.1) Variable with reach& temp.	(0.1-1.0) Variable with reach& temp.	Variable	(0.2-2.0) Variable with reach& temp.

5.3 THE PHOSPHORUS CYCLE

Organic forms of phosphorus are generated by the death of algae, which is then converted to the dissolved inorganic state which is then available to the algae for primary production. In QUAL2EU the breakdown of organic phosphorus into dissolved phosphates is taken into account. Settling of organic phosphorus was seen to be important but the settling of dissolved phosphorus adsorbed to suspended solids is not taken into account in the QUAL2EU model and the dissolved phosphorus was not assimilated to the extent that was seen in-field. See Scatter plots 5.9 to 5.10 for the results. Figure 5.8 shows the reactions and mechanisms modelled by QUAL2EU.

such reaction is the adsorption of ammonia onto suspended solids which settle out. A large concentration of SS is seen on all monitored days and they are seen to settle out quite quickly between the first and the second monitoring point. Another possible sink for ammonia could be the volatilisation of ammonia. It was calculated that more than 13mg/l ammonia could be lost to the atmosphere by volatilisation. The ammonia simulated results only had an r^2 of 0.17.

The organic nitrogen and nitrite followed the predicted values very well. The r^2 for all the nitrogen species can be seen in Table 5.1.

Table 5.1 Regression analyses of simulated and observed results

Water Quality Variable	r^2
Org-N	0.68
Ammonia	0.17
Nitrite	0.86
Nitrate	0.88

Some organic nitrogen underwent hydrolysis with each day monitored having a hydrolysis constant of 0.4 per day. QUAL2EU gave a range of 0.001 to 0.1 per day for organic nitrogen settling. In all cases this was found to be too little, and greater settling values had to be used in order to show the decrease in organic nitrogen. See Figure 5.2 for the coefficients used for the nitrogen modelling.

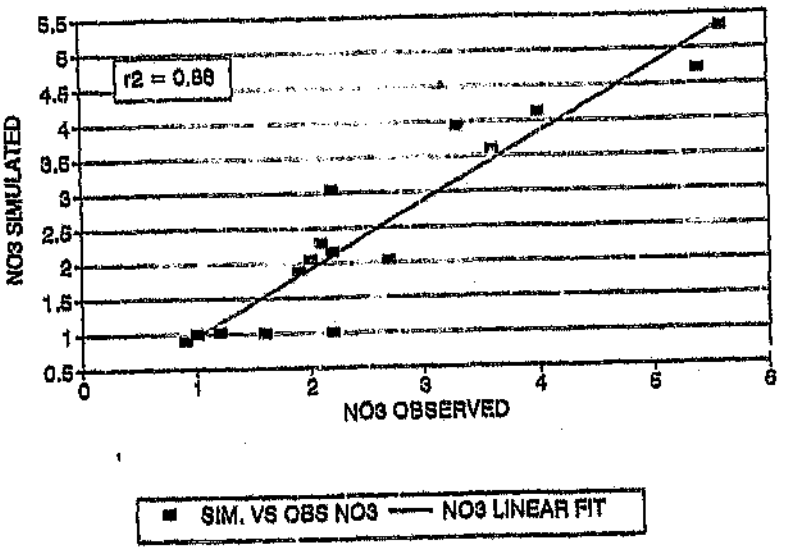


Figure 5.7 **Scatter plot of observed and simulated nitrate with the calculated regression line.**

Due to the high concentration of nutrients in the run-off from Alexandra Township, the major changes observed were in the biological conversion of organic nitrogen compounds and ammonia to nitrates. The QUAL2E model predicted the decrease in the concentration of organic nitrogen with the corresponding increase in the concentration of nitrates further downstream together with the slow recovery of the concentration of dissolved oxygen in the river. QUAL2EU did not model the sharp decrease in the concentration of ammonia. The ammonia decreased from a high of 27 mg/l on the 7th of September to a low of 7 mg/l. This trend was observed on all the days that were monitored. The QUAL2EU predicted that the ammonia would only decrease to a low of 26.94 with just nitrification and algal uptake being taken into account. The algal uptake was put to a maximum but this had little effect on the change of ammonia concentration with distance downstream. Other mechanisms must be happening which are not taken into account by the QUAL2EU model. One

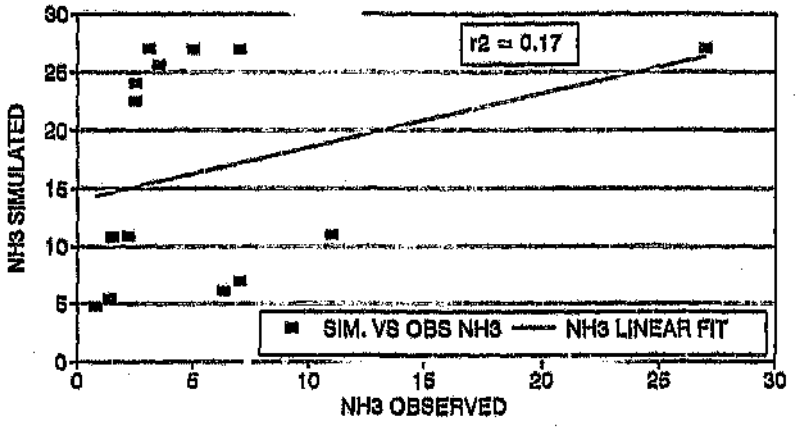


Figure 5.5 Scatter plot of observed and simulated ammonia with the calculated regression line.

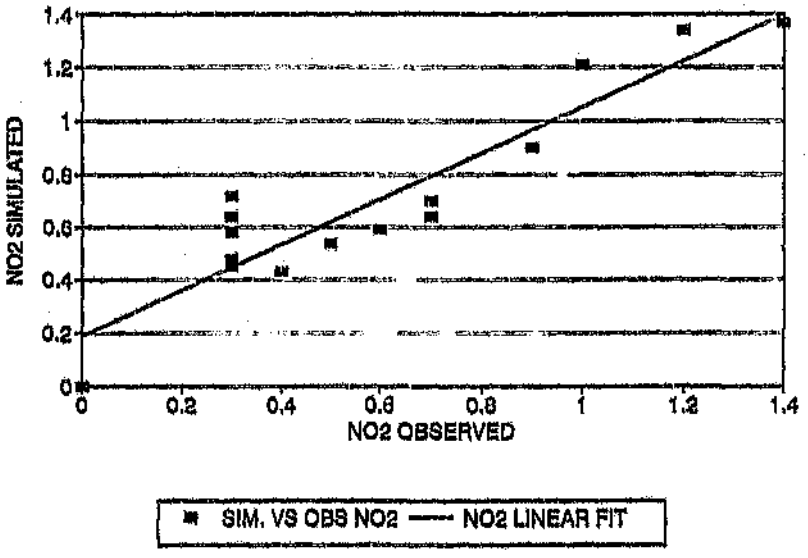


Figure 5.6 Scatter plot of observed and simulated nitrite with the calculated regression line.

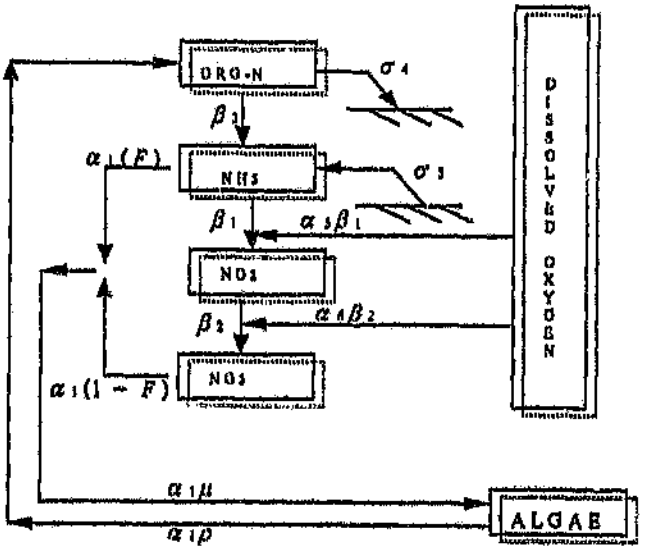


Figure 5.3 QUAL2EU modelling of nitrogen species

5.2.2 Results of QUAL2EU nitrogen modelling

Scatter plots of QUAL2EU simulated nitrogen species can be seen in figures 5.4 to 5.7.

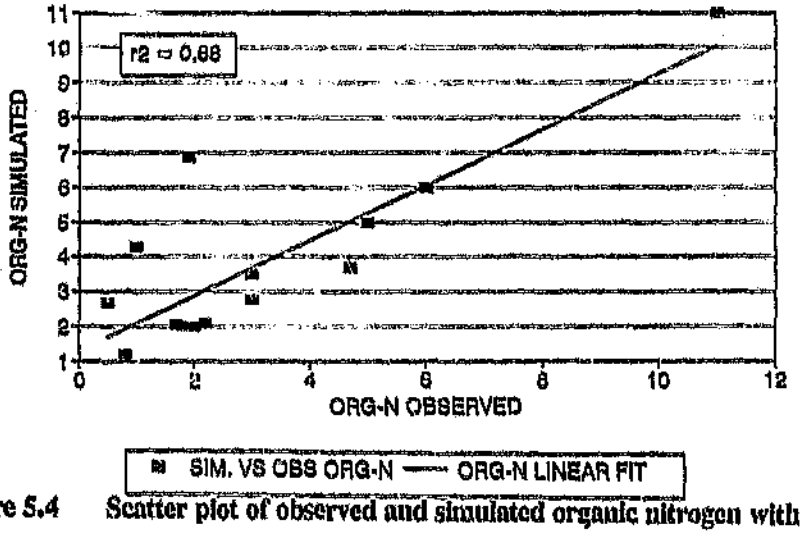


Figure 5.4 Scatter plot of observed and simulated organic nitrogen with the calculated regression line.

5.2 THE NITROGEN CYCLE

5.2.1 Introduction

Nitrogen may undergo various transformations in the river environment, the most important of which are:

- **assimilation** of NH_4 and NO_3 when utilised by plants and bacteria;
- **nitrogen fixation** by blue-green algae and bacteria through the use of nitrogen gas as a nitrogen source in the absence of NH_4 and NO_3;
- **adsorption** of especially NH_4 to inorganic and organic particulate and colloidal matter;
- **ammonification**, which is the mineralisation of organic N to NH_4;
- **nitrification**, which is the biochemical oxidation of NH_4 to NO_3;
- **denitrification**, the anaerobic conversion of NO_3 and NO_2 to nitrogen gas (N_2);
- **sedimentation** of nitrogen compounds adsorbed to inorganic particulate matter out of the water column;
- **volatilisation** of nitrogen compounds from the water surface, such as NH4 at high pH and N_2 formed during denitrification.

In QUAL2EU, the main reaction for the assimilation of nitrogen is seen to be the stepwise transformation of organic nitrogen from organic nitrogen to ammonia, to nitrites and eventually to nitrates which are the form in which algae and plants use to photosynthesise. In QUAL2E, all four compounds and the reactions that they undergo are modelled.

Sedimentation of organic nitrogen as well as the assimilation of ammonia and nitrates by algae are modelled. See Figure 5.3.

written. In the materials balance, both transport (Q.C) and dispersion ($A \frac{D_L}{\Delta x} \frac{\partial C}{\partial x}$) are considered as movers of pollutant mass along the stream axis. Mass of the pollutant can be added or removed from the stream system via internal sources and sinks such as benthic sources and biological transformations.(See Fig 5.2)

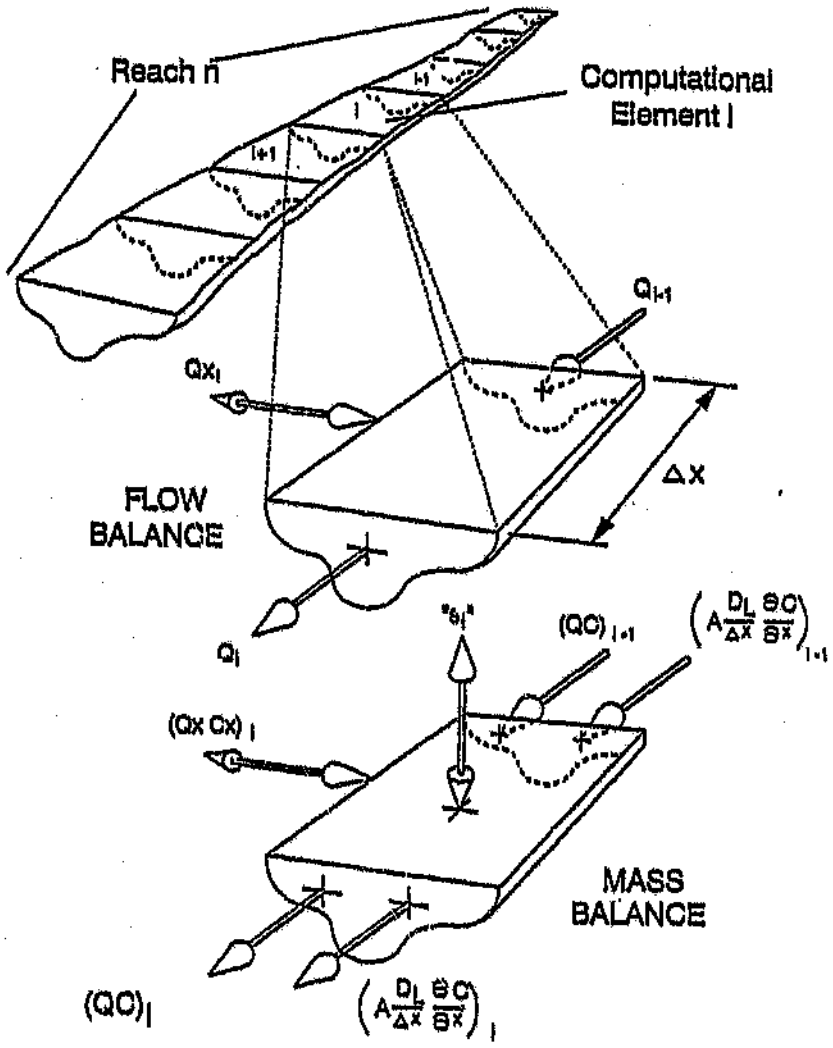


Figure 5.2 Discretised Stream System

A 6km reach of the Jukskei River was divided into six 1km computational elements. A stream can be conceptualised as a string of completely mixed reactors (computational elements), that are linked sequentially to one another via the mechanisms of transport and dispersion. Sequential groups of these reactors which have the same hydrogeometric properties, are defined as reaches.

The Jukskei River was divided into one reach and 6 computational elements. See Figure 5.1.

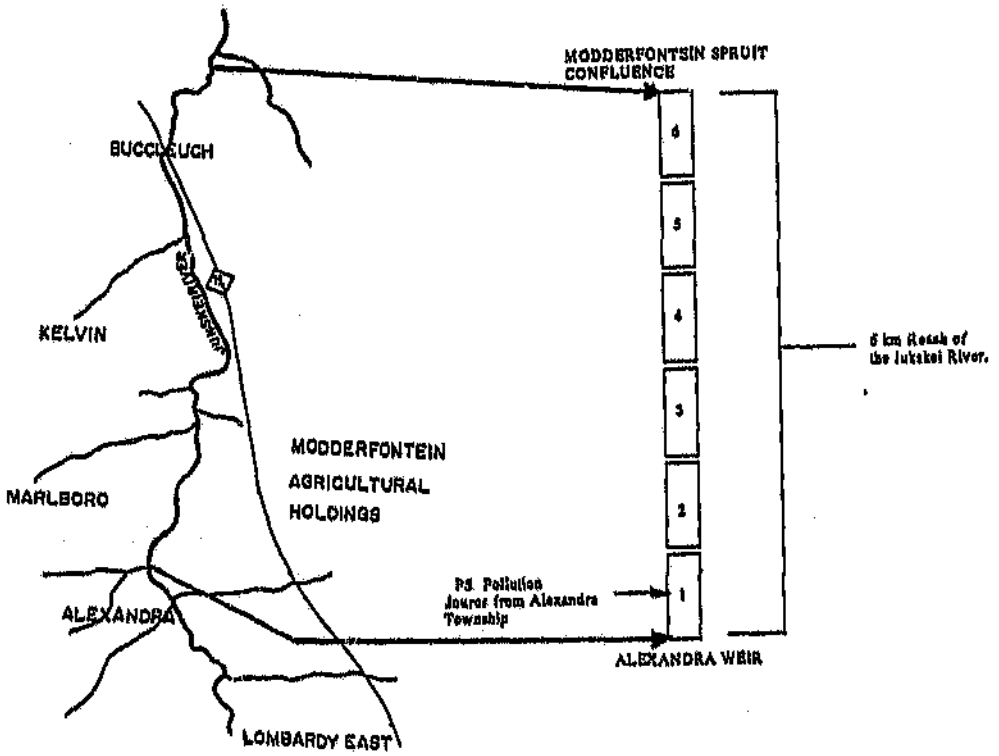


Figure 5.1 Jukskei River Network of computational elements.

For each of these computational elements, the hydrologic balance can be written in terms of the flow into the upstream face of the element (Qi - 1), external sources or withdrawals (Qxi), and the outflow (Qi) through the downstream face of the element. Similarly , a materials balance for the pollutant being modelled can be

CHAPTER 5 MODELLING OF THE JUKSKEI RIVER STEADY STATE RESULTS

5.1 INTRODUCTION

The changes in the water quality of a 6 km reach of the Jukskei River, just downstream of the Alexandra Township were monitored during both the dry and the wet seasons. QUAL2E, a steady-state water quality model was used to model the impact of waste loads on instream water quality. QUAL2E modelled the change of dissolved oxygen and associated processes like the bacterial conversion of ammonia to nitrates. These results were then compared to the field observed rate of change of these pollutants.

5.1.1 QUAL2E Modelling

The primary objective of any stream water quality model is to produce a tool which is capable of simulating the behaviour of the hydrologic as well as the water quality components of a stream system.

QUAL2E is a versatile and comprehensive stream water quality model. It simulates up to 15 water quality constituents in any combination and is typically used for the determination of the stream assimilative capacity and when used as a steady-state model, QUAL2EU can be used to study the impact of waste loads on instream water quality.

The hydrogeometric properties taken into account are: stream slope, channel cross section, roughness, depth, flow and side slopes.

Table 4.12 Coliform decay constants for the Jukskei river

Date	K_D, the decay rate constant in day^{-1}.	r squared.
12/07	36.0	0.895
03/08	54.5	0.974
10/08	39.1	0.978
24/08	32.4	0.920
07/09	45.4	0.917
21/09	50.2	0.967
28/09	34.1	0.974
12/10	30.5	0.883
01/11	29.0	0.813
16/11	39.6	0.964
23/11	38.6	0.853
07/12	47.0	0.902
18/01	33.1	0.772
01/02	40.1	0.857

The die-off rates calculated in this study are a combination of the settling out as well as the die-off of the faecal coliforms.

4.4.6 Conclusions

The conditions in Alexandra and in the Jukskei River are favourable for the transmission of diseases. Human excreta has been shown to be present in the discharge from the area (Wimberley,1992). The inadequate or unhygienic disposal of human excreta as well as insufficient personal hygiene makes Alexandra at risk to the transmission of diseases. The only solution is to introduce sufficient sanitary facilities for the collection and disposal of human excreta. This will greatly decrease the concentration of faecal coliforms being discharged into the Jukskei River which also affects the users further downstream. Fortunately, the die-off rate of faecal coliforms is quite high so that the users downstream are at less risk from the transmission of diseases.

- Lead as Pb
- Suspended solids
- Dissolved Oxygen
- COD
- TKN
- Ammonia
- Nitrite
- Nitrate
- Total Phosphorus
- Phosphate
- Faecal coliforms

For each water quality variable, the results of the storm events are compared to the winter and summer averages in Table 6.1.

Table 6.1 Comparison between storm events and the average winter and summer water quality values

Sample Point	Water Quality Variable	Winter (July - Sept)	Summer (Oct - Feb)	Storm event (21/04)	Storm event (19/10)	Storm event (20/11)	Storm event (29/11)
Marlboro Bridge (1)	pH	7.7	7.7	7.6	-	7.5	7.6
Gibson Drive	pH	7.9	8.3	7.9	-	7.5	7.5

CHAPTER 6 MODELLING OF STORM EVENTS IN THE JUKSKEI RIVER

6.1 STORM EVENTS : RESULTS AND ANALYSES

Samples for a number of storm events were collected but most of these were from thunderstorms in the late afternoon and the security problem around Alexandra, made it difficult to collect a complete hydrograph. The increase in a number of the pollutants could be seen, however.

A complete hydrograph was collected on the 29th of November 1995. This storm started at 9:40 in the morning and "grab" samples and flow readings were collected right through until 13:00. "Grab" samples were collected at the Marlboro Bridge which is just below Alexandra Township and samples were also collected further downstream (3.3 km) at Gibson Bridge in Buccleuch. The pollutographs at both of these bridges could then be compared and the changes in the concentration of pollutants and the processes that may be occurring, as they travelled between these two points could be identified.

Four separate storm/rain events were monitored. Water samples were monitored for the following water quality variables:

- pH
- Conductivity
- Alkalinity as $CaCO_3$
- Sulphate as SO_4
- Iron as Fe

It has also been suggested that a pathway by which ammonia sediments out should also be added to the model in order to model the significant decrease in ammonia between the first and second monitoring points at Alexandra and Frankenwald.

5.6.4 Conclusions

The Vaal River

- Within 500 m of the effluent discharge point complete mixing taken place.
- Within 500 m major losses of the PO_4 had taken place;
- Chemical equilibrium studies showed that adsorption to suspended solids, followed by sedimentation, was likely to be the major PO_4 removal mechanism, with precipitation/sedimentation mechanism a minor contributor to PO_4 removal;
- Lower flows are accompanied by higher PO_4 losses.
- It was thus suggested that a pathway by which PO_4 is adsorbed to the bottom sediments followed by settling out of the suspended solids, should be incorporated into further models.

The Jukskei River

- Within 2.1 km between the first and the second monitoring point of the Jukskei River a significant decrease in PO_4 was seen. After this a steady concentration of PO_4 was observed. This same pattern was seen in the Vaal River study.
- During the winter season when low flows were recorded a greater decrease in PO_4 was seen. This correlated to a similar decrease in suspended solids.

It can be concluded that the phosphorus processes in the Jukskei River are similar to the Vaal River and that in order to calibrate the QUAL2E model, a pathway by which PO_4 is adsorbed onto suspended sediment and then sediments out, should be incorporated into the model.

5.6.2 Sampling Sites and Data Analysis

The changes in the nutrient concentration below Sasol and Vanderbijlpark effluents were ascertained by sampling surface, middle and bottom water samples at various sites from Barrage to Lindequesdrift weir. Sampling was undertaken prior to the winter effluent releases, one during the 15 m^3/s, two during the 25 m^3/s release and one during the 40 m^3/s.

The changes in PO_4 and Total Phosphorus concentration along the reach were analysed to determine the losses.

5.6.3 Nutrient changes over distance

It was found that complete mixing of the effluent occurred approximately 3 km downstream from the point of discharge. Most of the PO_4 losses seemed to occur quickly, within 500 m of the point of discharge. This was also observed in the Jukskei River study, in which the greatest loss was seen between the first and second monitoring points and then levelling out of the concentration occurred.

In order to determine if there was any relationship between PO_4 loss and flow, the percentage reduction in nutrient concentration over the first 500m was calculated at different flow rates.

parameters had to be calibrated outside of the acceptable limits to account for these losses. This is similar to what was observed in the Jukskei River calibration of the QUAL2E model. New coefficients had to be recalibrated for each release, which is a disadvantage as it defeats the object of model calibration. It was concluded that there was a need to develop an understanding of nutrient loss processes in a river in order to represent them accurately in a model. In order to calibrate the model, further investigation into these losses was undertaken. From this investigation, modifications to the model were undertaken in order to account for these losses. The possible processes that Phosphorus can undergo are:

Losses:

- **assimilation**, which is the uptake of PO_4 by plants;
- **adsorption** of PO_4 onto surfaces, such as iron (Fe), Aluminium (Al), Manganese (Mn), calcium (Ca) and clay followed by **sedimentation** out of the water column;
- **precipitation** with e.g. $CaCO_3$;

Gains:

- **resuspension** of bottom sediment;
- **reduction** of iron (Fe), aluminium (Al), manganese (Mn) and calcium (Ca) oxides in anaerobic conditions;
- **desorption** of PO_4 from the surface of sediment particles;
- **mineralisation** during decomposition of organic matter, involving the conversion of organic P to PO_4;
- **inflows** from tributaries and surface washoff.

A field study that monitored the changes in nutrient concentration downstream of point sources at different flow rates was undertaken and the possible chemical and physical processes that could happen were reviewed.

5.5 CONCLUSIONS

QUAL2E did not view settling as a major sink of a number of the pollutants and it was found in the observed pollutant values that settling played one of the major roles, especially with organic nitrogen and BOD, as samples of the river bed showed large concentrations of these pollutants especially on the river bed at the first two monitoring points where most of the decrease in the concentration of these pollutants was observed . South Africa has very turbulent rivers with a lot of suspended solids to which a large concentration of pollutants like phosphorus and ammonia can adhere to and settle out. This was not modelled in QUAL2E and dissolved phosphorus and ammonia did not decrease as rapidly as observed in-field. Volatilisation of ammonia was also not taken into account in the QUAL2E model which again slowed down the simulated decrease in ammonia. BOD and DO were modelled very well with QUAL2E, with regression analyses giving r^2 of 0.98 and 0.94 being calculated respectively. Most of the DO was taken up by the benthic oxygen demand which supports the conclusion that a number of the pollutants settle out into the benthic layer where the oxidation reactions can take place.

The results obtained for the Jukskei River were compared to those that CSIR, Watertek, obtained in their modelling of the Vaal River.

5.6 COMPARISON OF RESULTS WITH QUAL2E STUDY DONE ON THE VAAL RIVER (WATERTEK, CSIR)

5.6.1 Introduction

Significant losses of nutrients were observed below point sources. For example, high ortho-phosphate concentrations in effluent released from Sasol and Vanderbijlpark, were not observed further downstream at Lindequesdrift. Something was happening between these two points. Some of the QUAL2E model

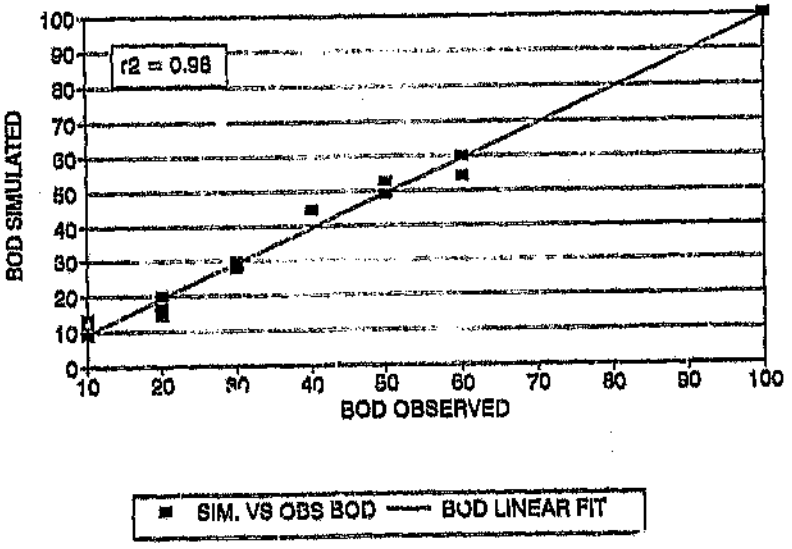


Figure 5.13 Scatter plot of observed and simulated BOD with the calculated regression line.

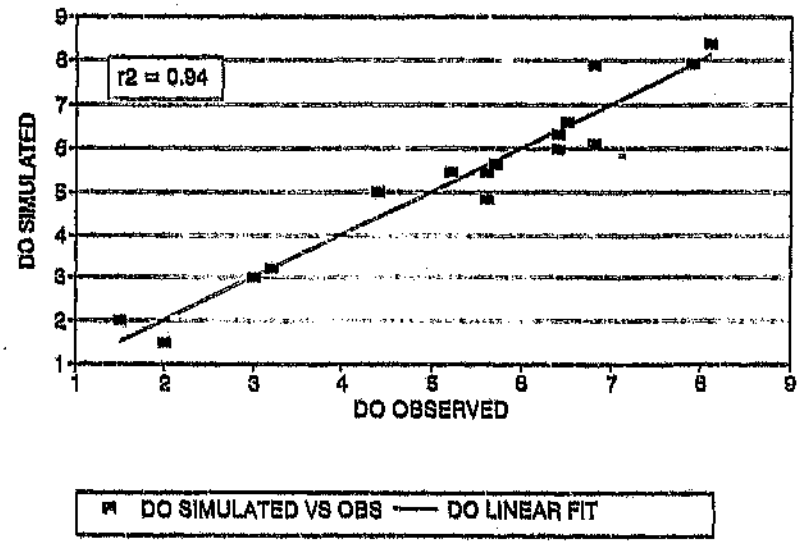


Figure 5.14 Scatter plot of observed and simulated DO with the calculated regression line.

Table 5.4 BOD and DO coefficients used in the QUAL2E model.

Date	BOD Deoxygenation coefficient / day	BOD Settling coefficient / day	SOD Rate	K2 Option	Reaeration coefficient / day
24/08/1994	3.4	5	60	3	4
07/09/1994	3.4	40	30	3	4
16/11/1994	2	20	30	3	4
18/01/1995	3.4	5	20	3	4
QUAL2E Range	(0.02-3.4) Variable with reach & temp.	(-0.36 - +0.36) Variable with reach & temp.	Variable with both reach & temp.		(0-100) Variable with reach & temp.

Scatter plots for BOD and DO can be seen in figures 5.13 to 5.14.

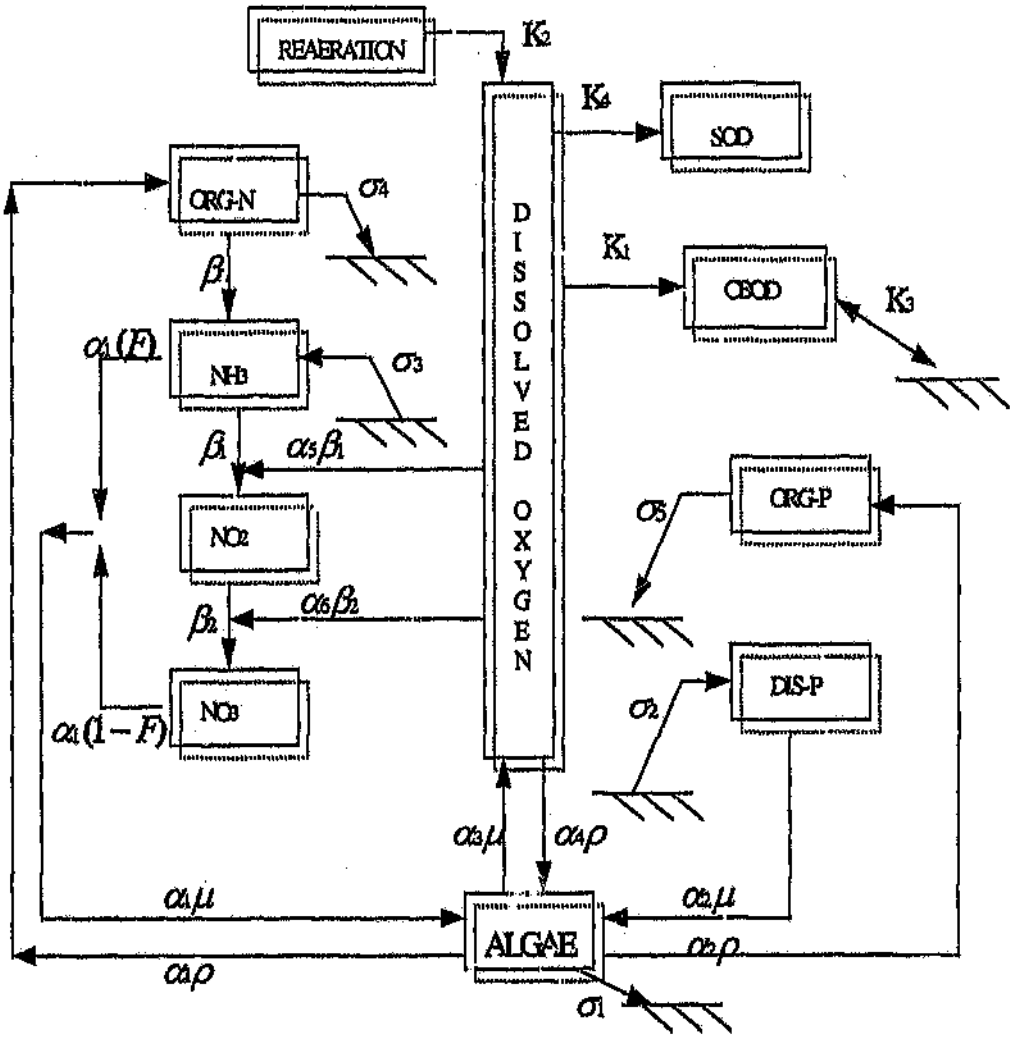


Figure 5.12 - QUAL2E sinks and sources of DO in the Jukskei River.

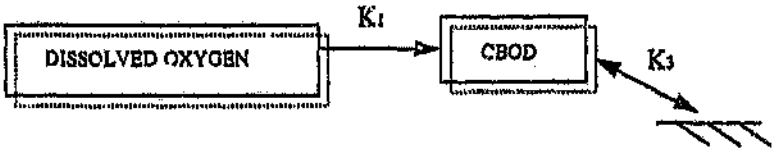


Figure 5.11 - QUAL2E modelling of BOD in the Jukskei River.

QUAL2E modelled the BOD of the Jukskei River very closely to the observed BOD values. An r^2 of 0.98 was calculated. The BOD coefficients except for BOD settling were all within the QUAL2E range.

The Dissolved oxygen trends predicted by QUAL2E were also very close to the observed trends. The dissolved oxygen values all increased with distance downstream. The greatest oxygen demand was seen to be the benthic bottom layer of the river. The SOD values were much greater than the QUAL2E range given.

The oxygen balance in a stream system depends on the capacity of the stream to reaerate itself. The major sources of oxygen, in addition to atmospheric reaeration, are the oxygen produced by photosynthesis and the oxygen contained in incoming flow. The sinks of dissolved oxygen include biochemical oxidation of carbonaceous and nitrogenous organic matter, benthic oxygen demand and the oxygen utilised by algae respiration. See Figure 5.12 for the sources and sinks of DO used in QUAL2E modelling of DO in the Jukskei River.

Table 5.3 Phosphorus coefficients used in the QUAL2E modelling of the Jukskei River.

Date	Org-P Decay / day	Org -P Settling / day
24/03/1994	0.7	45
07/09/1994	0.7	45
16/11/1994	0.7	45
18/01/1995	0.7	15
QUAL2EU Range	(0.01-0.7) Variable with reach & Temp.	(0.001-0.1) Variable with reach & Temp.

It was seen that the settling of organic phosphorus was much greater in-field than what QUAL2EU predicted. Values of 45 per day were used for three of the days monitored

5.4 QUAL2E MODELLING OF DO AND BOD IN THE JUKSKEI RIVER

The QUAL2E model assumes a first order reaction to describe deoxygenation of ultimate BOD in the stream. The BOD function also takes into account additional BOD removal due to sedimentation, scour and flocculation, which do not exert an oxygen demand.

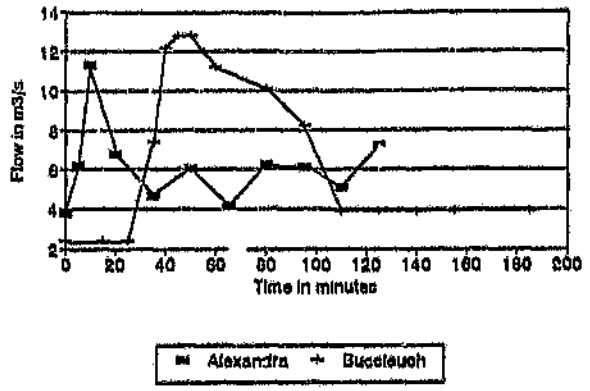
$$\frac{dL}{dt} = -K_1 L - K_3 L \quad \ldots\ldots\ldots \quad 5.1$$

where L-the concentration of ultimate carbonaceous BOD

K_1 = deoxygenation rate coefficient, temperature dependent, /day

K_3 = the rate of loss of carbonaceous BOD due to settling, temperature dependent, day.

a)



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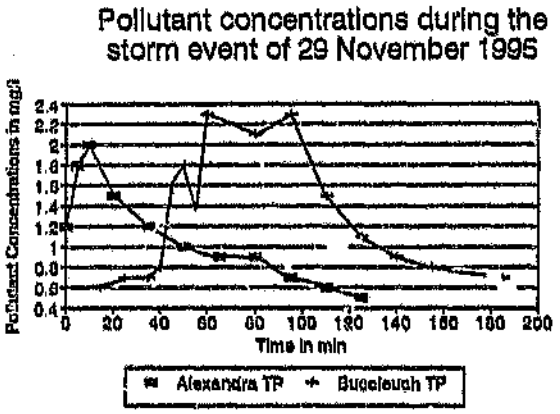


c)

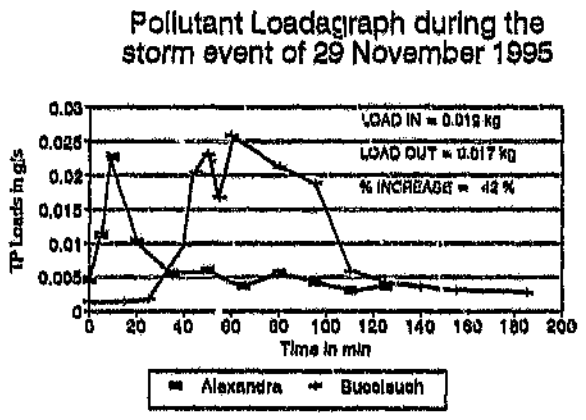
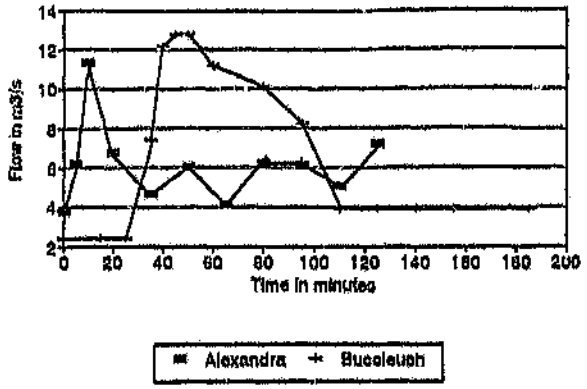


Figure 6.6 **a) Hydrograph b) Total Phosphorus Pollutagraph and c) Total Phosphorus loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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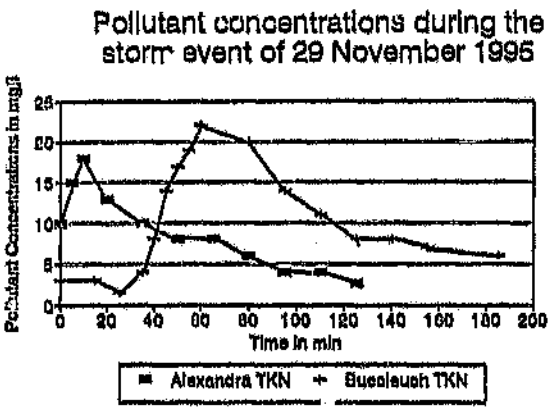


c)

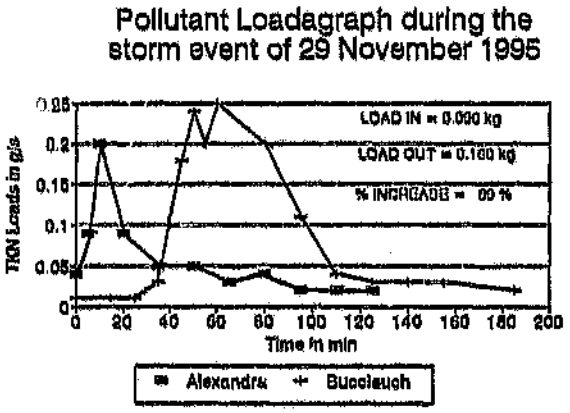
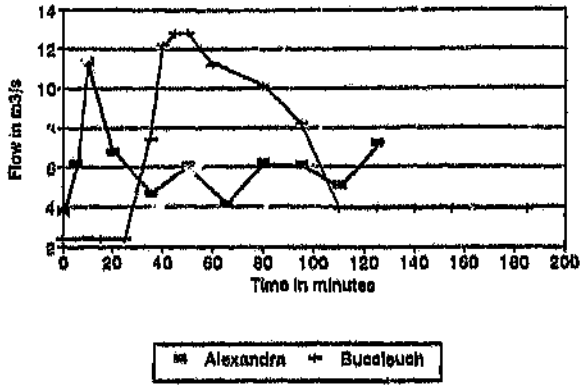


Figure 6.5 **a) Hydrograph b) TKN Pollutagraph and c) TKN loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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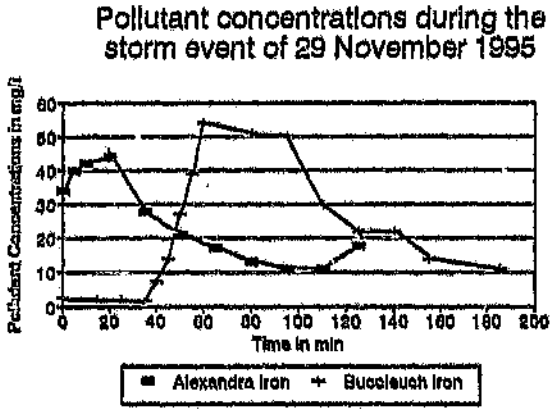


c)

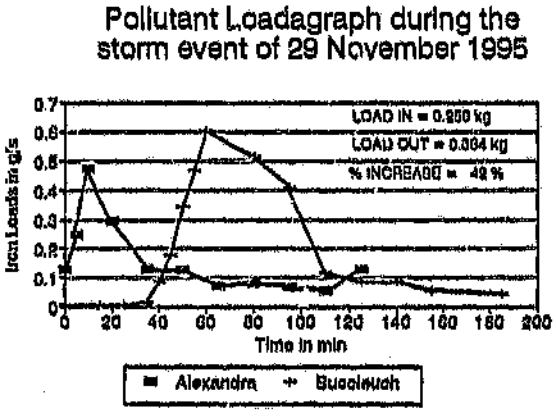
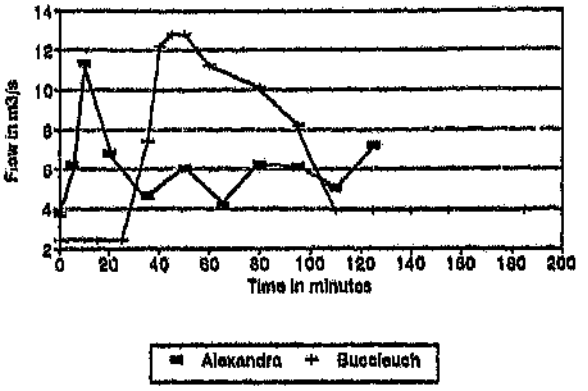


Figure 6.4 **a) Hydrograph b) Iron Pollutagraph and c) Iron loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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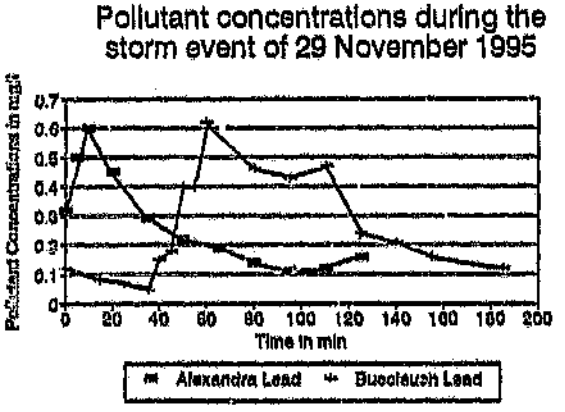

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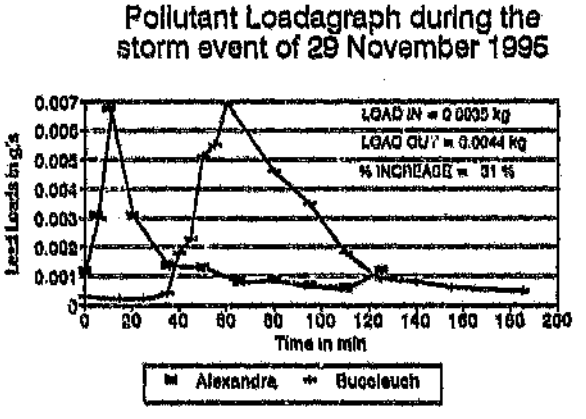


Figure 6.3 **a) Hydrograph b) Lead Pollutagraph and c) Lead loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

A number of pollutants are associated with SS and displayed similar trends and patterns as they travelled downstream. These pollutants include lead, iron, Total Kjeldahl Nitrogen and Total Phosphorus (See Figures 6.3 to 6.6).

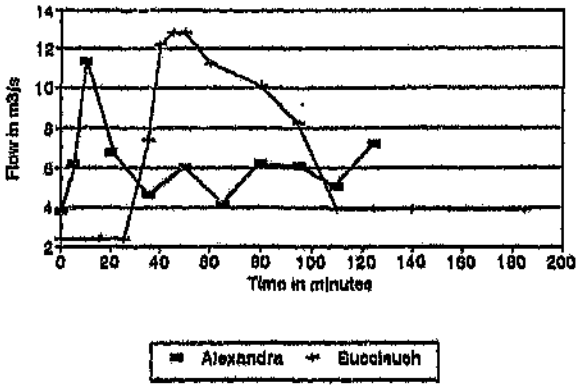
From the results it can be seen that lead and iron are part of the suspended solid fraction. Lead and iron are metals and may complex themselves to sand or organic particles in the SS fraction. They are effectively adsorbed onto other particles that form part of the SS fraction.

Organic phosphorus is often in particulate form and also forms part of the SS. TKN is made up of organic nitrogen and ammonia. A large proportion of the TKN is particulate in nature and forms part of the SS. This was also seen in the steady state results in which the decrease in the TKN concentrations followed the same trend as SS.

The pollutant loads for the above pollutants were also calculated and all increased from Marlboro to Buccleuch. Lead and iron loads increased by 31% and 42%, respectively. The Jukskei River flows parallel to the N3 highway. During the dry season, lead and iron from the vehicles using the highway are deposited and when it rains these pollutants are washed off onto the banks of the river and eventually into the Jukskei River itself. Some lead and iron may be associated with the river bottom itself and during rain events when the turbulence of the water increases, these pollutants could be entrained into the water, increasing the loads in the water.

The greatest increases in the pollutant loads were found with TKN and Total Phosphorus. During steady state, a large decrease in TKN and Total Phosphorus was observed and it was postulated that a large concentration settles out onto the river bed. During a storm event this large concentration of deposited nitrogen and phosphorus would be entrained back into the water.

a)



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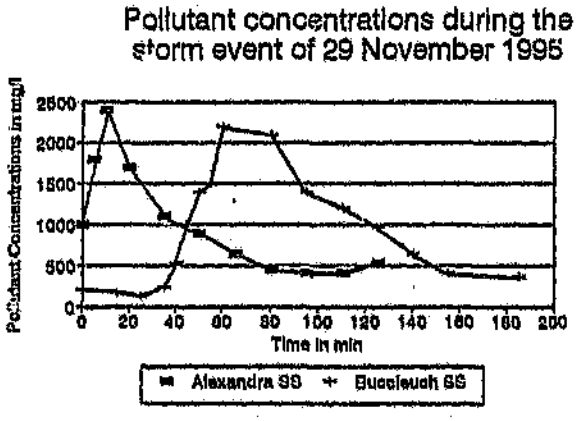

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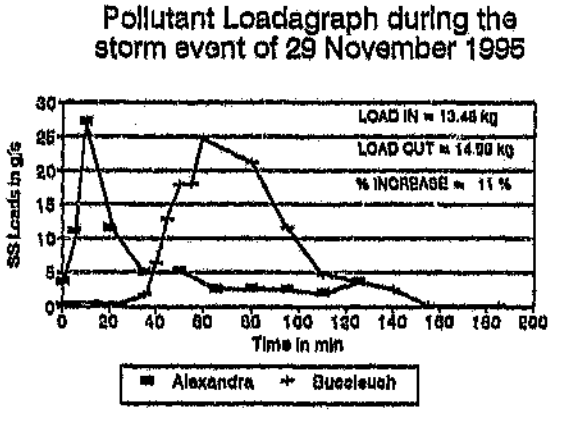


Figure 6.2 **a) Hydrograph b) Suspended Solid Pollutograph and c) Suspended Solid loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

conditions as they are larger in size. Settling times for a number of particles have been determined (Grobler, et al, 1981) for different particles and are given in Table 6.2.

Table 6.2 Settling Times for different particle sizes in still water

Particle Diameter (μm)	Settling Times
50	40 seconds
20	4 minutes
2 - clay	7 hours
1 - clay	25 hours
0.2 - clay	29 days

The suspended solid concentration at Marlboro was seen to be much higher than the winter or the summer steady state values. This is due to erosion of the catchment from rainfall and the eventual runoff into the river, as well as greater turbulence in the river causing entrainment of SS into the water column.

The pollutant loads at Marlboro and Buccleuch were calculated from the concentrations under the peaks of the pollutagraphs and the flows. It was found that the SS load at Buccleuch was 11% (Fig 6.2 c) greater than at Marlboro.

Buccleuch. The lateral inflow off the catchment was calculated as 1.47 m^3/s. Runoff from the roads at Buccleuch was seen flowing into the river (See Appendix B for photographs). The hydrograph took 37.5 minutes from Marlboro to Buccleuch (See Figure 6.1 for the plot of the hydrographs).

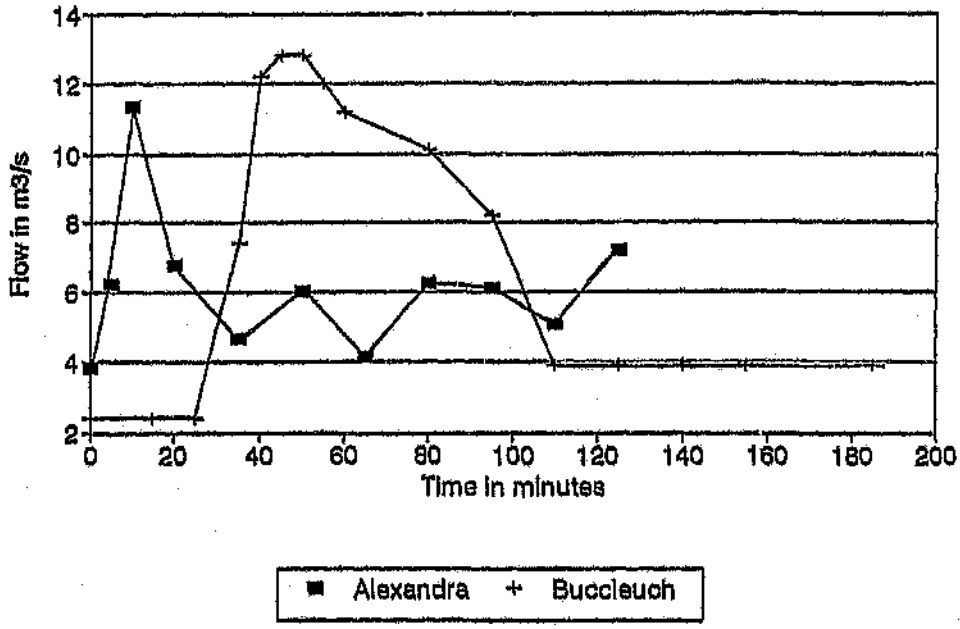


Figure 6.1 **Hydrographs measured at Marlboro and Buccleuch during the storm event of 29/11/1995**

6.2.2 Suspended Solids and associated pollutants during the storm event

The suspended solids is a measure of the portion of solids that are retained by a 0.5 μm filter and is made up of a mixture of a number of pollutants including organic material as well as inorganic compounds, of which the majority is very fine clays from the catchment soils. Particles like silt will settle out relatively fast during steady state

6.2 POLLUTANT ASSIMILATION DURING THE STORM EVENT OF 29/11/1995

Most studies just concentrate on the peak pollutant concentration found during a storm event and not the actual changes in pollutants as they move with the hydrograph. This was done for the storm event on 29/11/1995.

The assimilation of the various pollutants between the Marlboro Bridge (just below Alexandra) and the Gibson Drive Bridge in Buccleuch during the storm event of 29/11/1995 was ascertained. The Gibson Drive Bridge is 3.3 km downstream of the first monitoring point on Marlboro Bridge. Samples and flow readings were taken at each bridge simultaneously. Samples and flow readings were taken every 15 minutes during the base flow and when the flow was seen to be increasing this was increased to every 5 minutes. The hydrographs and the pollutagraphs for each bridge were then plotted and the changes compared. From these the assimilation and the possible processes taking place could be ascertained.

6.2.1 Hydrographs recorded

The flow peak at the Gibson Drive Road in Buccleuch was slightly higher than the flow recorded further upstream at Marlboro, Alexandra. This was attributed to lateral inflow from the catchment between Marlboro and Buccleuch. The catchment between these two monitoring points is made up of steep grassy slopes to the river. On the east side is the N3 highway which has an impermeable surface off which a large quantity of water would run and on the west side, the catchment is made up of mainly grass. The peak flow at Marlboro was 11.33 m^3/s and this increased to a peak flow of 12.8 m^3/s at

The difference in the nutrients can also be seen. TKN and ammonia are less than those found during the steady state winter and summer seasons. This is probably due to dilution. A large increase in total phosphorus is seen which is caused by entrainment from the bed.

The greatest difference seen is in the concentration of SS. This increased from a value of 53.6 mg/l during the winter season to 2400 mg/l during the storm event of 29/11/1995. During storm events accumulated pollutants and silt are washed off the catchment. Turbulent waters also causes entrainment of solids from the river bed. This results in an increase in SS.

The metals lead and iron also increase in concentration during storm events. This can be explained by the runoff from the catchment. Lead and iron are deposited on the roads and surfaces of the catchment and during a storm event these are washed off into the river where an increase in these pollutants is seen.

The faecal coliform count remains high during storm events. This is due to shorter retention times between the monitoring points as well as greater volumes of runoff from the catchment. The coliforms are exposed to very little sunlight during this period, so less die-off takes place.

Hoffmann (1995), also found that the concentrations of COD, total phosphates, faecal coliforms and suspended solids for most of the storm events were higher than the winter and summer values. This trend was also seen in the Jukskei River results but this could be due to the fact that the storm events that were monitored were close to the beginning of the summer rains when a large quantity of these pollutants had collected on the catchment surface and it would also depend on where in the catchment the storms fell.

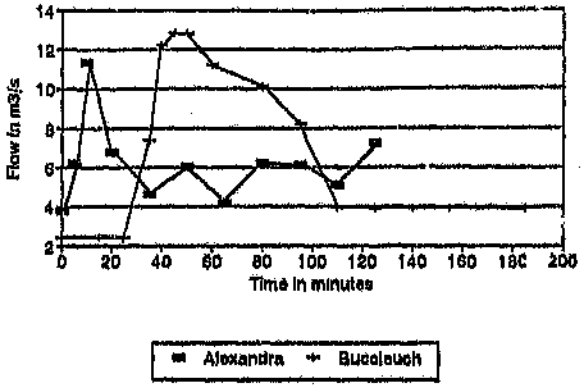
1	SO_4	77	51.4	120	32	85	58
2	SO_4	59.4	41.4	96	31	46	54
1	Cl	62.4	38.0	60	11	16	28
2	Cl	51.3	30.0	49	10	21	29
1	Iron	0.4	0.4	1.6	6.4	4.2	44
2	Iron	0.4	0.4	1.9	8.5	5.1	54
1	Lead	0	0	<0.05	0.08	0.09	0.6
2	Lead	0	0	<0.05	0.08	0.09	0.62
1	Faecal coliforms	31000 (x 1000 / 100 ml)	18000 (x 1000 / 100 ml)	-	-	-	>30000 (x 1000 / 100 ml)
2	Faecal coliforms	2200 (x 1000 / 100 ml)	200 (x 1000 / 100 ml)	-	-	-	>30000 (x 1000 / 100 ml)

Conductivity values during storm events decreased by nearly 50% from the winter and summer values. The most probable cause for this is dilution of the ions by the larger volume of water that flows during storm events. Higher conductivity values are seen during the winter season when the flow is low. The same trends were observed by Hoffmann (1995) in their study of the Hennops River.

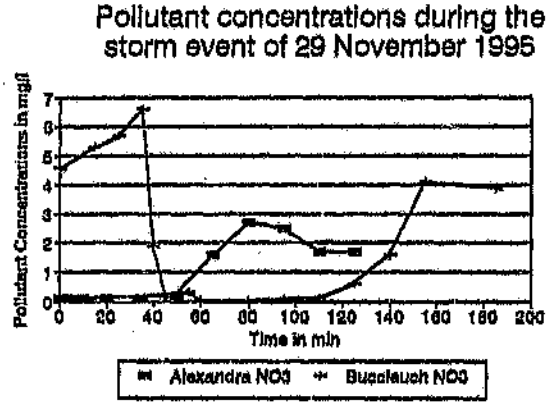
For the storm event of the 29/11/1995, a large increase in COD is observed. The COD concentration increases by 500 % at the peak of the storm compared to winter COD values. A large concentration of organic and inorganic compounds settle out and the bed of the river has a large concentration of oxidisable compounds. During storm events, entrainment of these compounds from the river bed occurs.

Bridge (2)							
1	Conductivity (mS/m)	76.2	57.5	83	-	31	40
2	Conductivity (mS/m)	61.1	47.5	67	-	37	44
1	COD	132.7	47.0	100	60	100	680
2	COD	59.1	25	60	40	180	600
1	TKN	28.8	15.3	-	2.8	8.4	18
2	TKN	5.3	3.9	-	1.4	7.6	22
1	NH_3	21.9	10.3	21	<0.5	0.7	5.5
2	NH_3	3.1	2.8	4.5	<0.5	1.7	7.3
1	Nitrite	0.86	0.39	5	0.18	0.7	1.1
2	Nitrite	0.34	0.34	0.3	0.18	0.6	2.8
1	Nitrate	0.6	2.02	5.8	1.5	3.4	2.7
2	Nitrate	2.34	2.52	6.9	1.8	4.4	6.6
1	TP	2.3	1.9	2.6	0.64	2.2	11
2	TP	0.66	0.83	1.2	0.62	1.8	10
1	Ortho-P	2.73	0.98	1.1	0.2	0.7	2
2	Ortho-P	0.84	0.45	0.4	0.18	0.7	2.3
1	Alka-linity	227.1	146.7	205	55	68	110
2	Alka-linity	151.4	114.2	155	55	77	140
1	SS	53.6	21.2	80	180	230	2400
2	SS	20.4	15.6	72	180	280	2200

a)



b)



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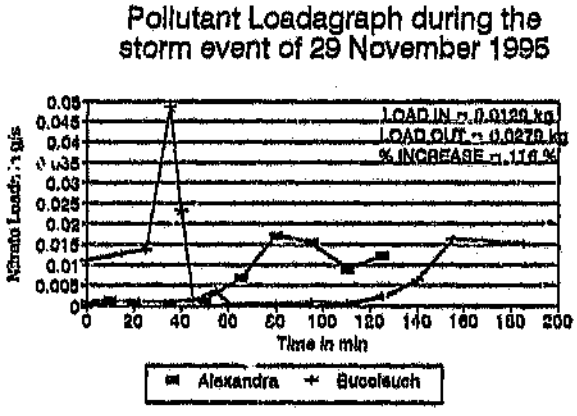
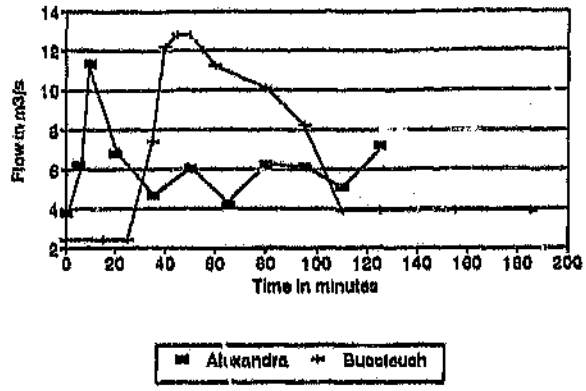


Figure 6.12 **a) Hydrograph b) Nitrate Pollutagraph and c) Nitrate loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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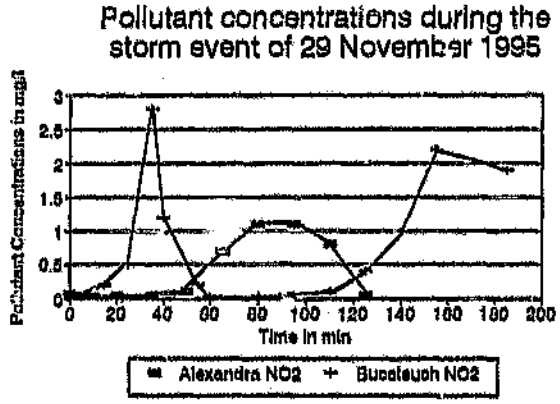

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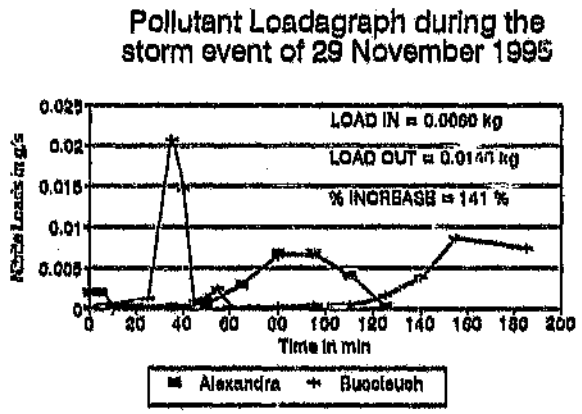
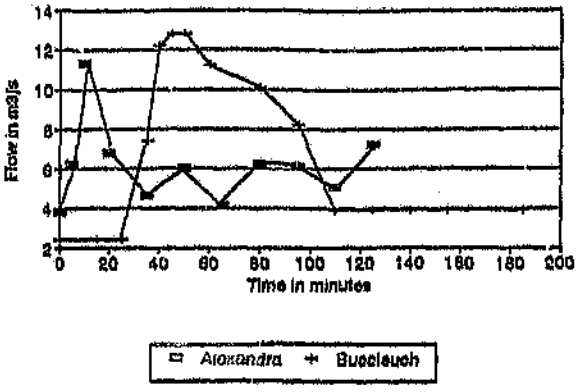


Figure 6.11 **a) Hydrograph b) Nitrite Pollutograph and c) Nitrite loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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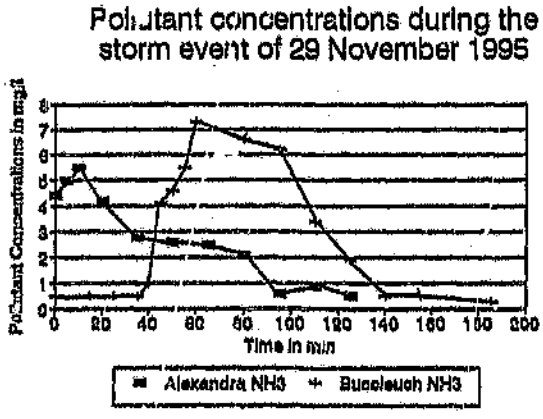


c)

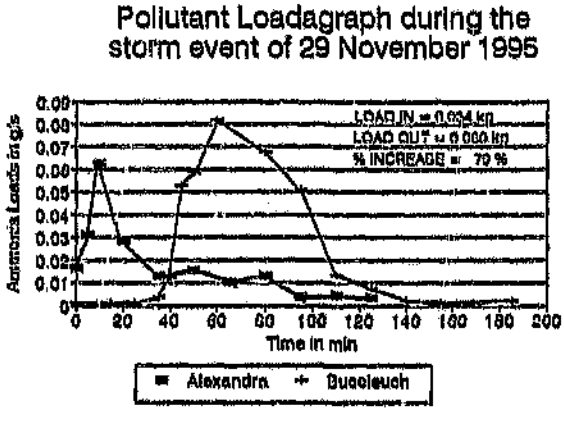


Figure 6.10 **a) Hydrograph b) Ammonia Pollutagraph and c) Ammonia loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

pollutants are organic nitrogen and ammonia. With time the nitrite in the river bed is mobilised by sub-surface flow and a peak results. The oxidation of nitrites to nitrates is very fast, so that the majority of the small concentration of nitrites that is in the SOD is oxidised to nitrate. For this reason a very small nitrate peak is seen as the hydrograph passes over the Alexandra monitoring point. As the hydrograph travels downstream more and more nitrogen oxidation products are available for entrainment. During the actual storm event there is little time for nitrification to take place as most of the nitrogen compounds are swept downstream before any significant oxidation can take place.

Organic nitrogen and ammonia are also released from the river bed but large concentrations are washed off the catchment and so a greater increase is seen between monitoring points.

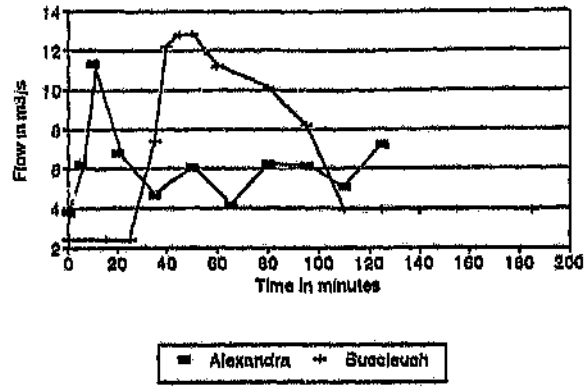
6.2.4 Nitrogen Pollutants

For both nitrates and nitrites it seems that the dilution is taking place. The concentration versus time graphs show the same trends. With the increase in the flow a decrease in nitrites and nitrates is seen and as the flow diminishes the nitrite and nitrate concentration starts to increase (Figures 6.11 and 6.12). This trend is seen at both the Marlboro and the Buccleuch monitoring points. Before the hydrograph has reached the two monitoring points, the original steady state concentrations at Buccleuch are higher than at Marlboro. From the graphs the steady state concentration at Buccleuch before the hydrograph came through is greater than at Marlboro. This is expected as during steady state conditions, the nitrification process is taking place between these two points with nitrites and nitrates being the oxidation products. Further downstream greater quantities of organic nitrogen and ammonia have been converted to nitrites and nitrates. From the steady state studies it has been shown that the nitrites remained constant while the nitrates increased by 33% between these two points. An increase in nitrates at Buccleuch is thus expected under normal conditions but the larger increase seen is due to the increase in flow and turbulence which causes some nitrates and nitrites to be entrained from the river bed.

TKN increased by 69% (Figure 6.5), compared to load increases of 79%, 141% and 116% for ammonia, nitrites and nitrates respectively. This indicates greater organic nitrogen pollution coming off the catchment at Alexandra. This also confirms what was seen in the pollutagraphs, that there was a greater initial concentration of nitrites and nitrates further downstream due to the nitrification of ammonia and organic nitrogen.

In the storm results no peak for nitrites was observed at Alexandra, with only a peak occurring after 50 minutes. This indicates that there were no nitrites in the top sediment sample that was washed downstream with the hydrograph. Most of the deposited

a)



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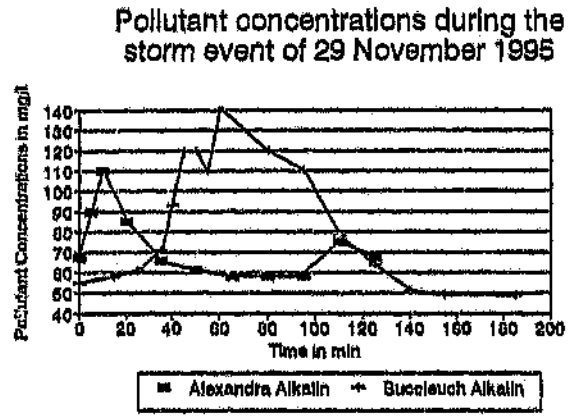

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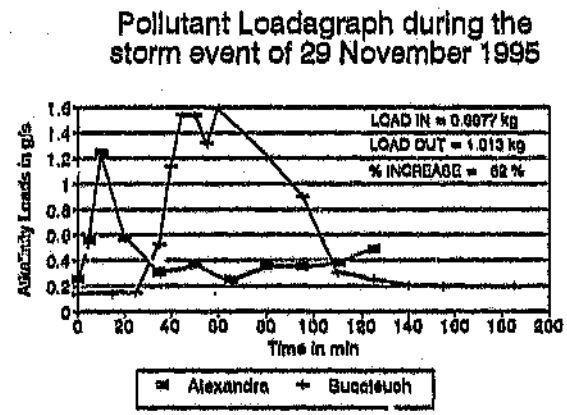
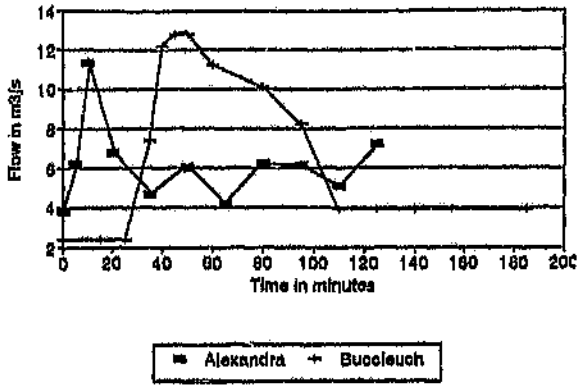


Figure 6.9 **a) Hydrograph b) Alkalinity Pollutagraph and c) Alkalinity loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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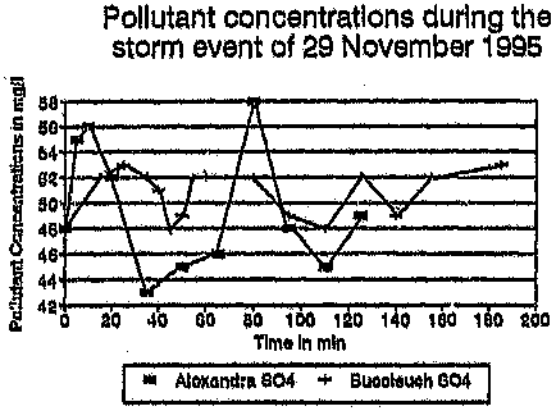

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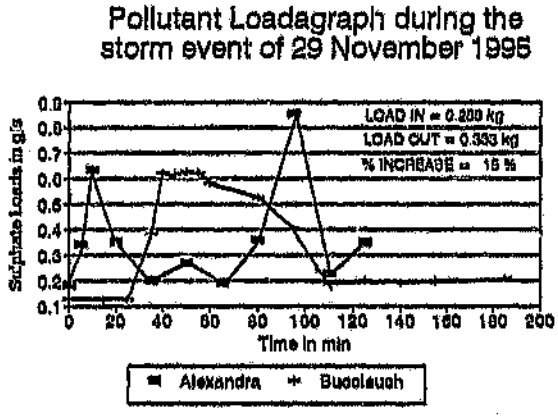
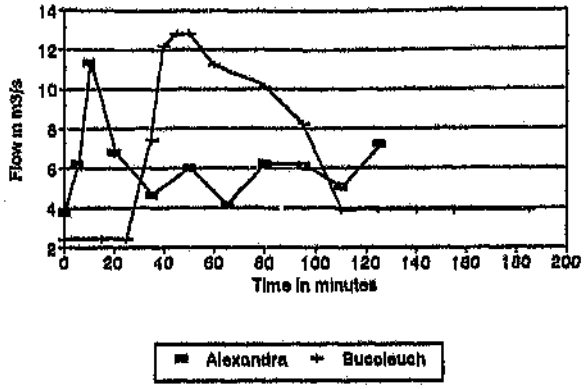


Figure 6.8 **a) Hydrograph b) Sulphate Pollutagraph and c) Sulphate loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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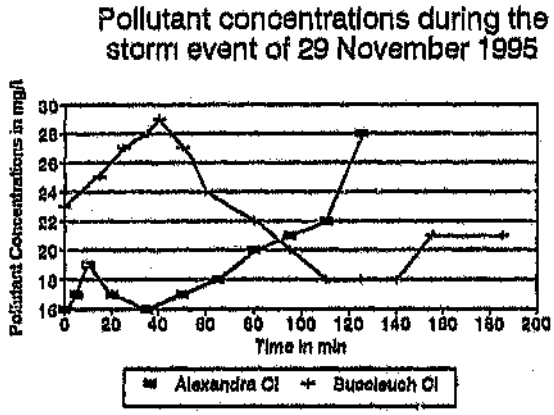

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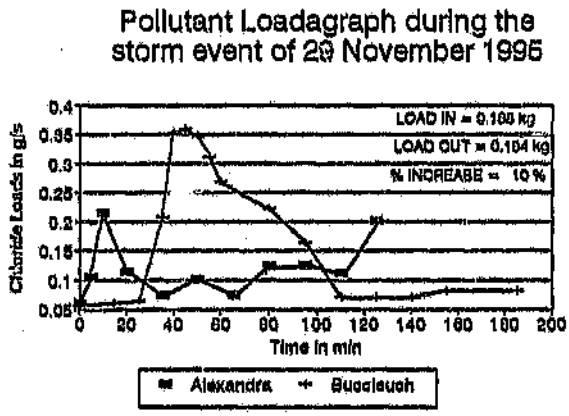


Figure 6.7 **a) Hydrograph b) Chloride Pollutagraph and c) Chloride loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

strongly to the particles in the soil. Sulphate is bound to a lesser extent and so is released after only 60 minutes compared to 75 minutes and more for the other ions.

From Table 6.3, $CaCO_3$ forms the greatest concentration of pollutants on the river bottom. With the increase in flow and thus turbulence a large concentration of $CaCO_3$ is entrained into the water column. An increase of 52% was calculated between Marlboro and Buccleuch (Figure 6.9).

little chang' ,r .he concentration of chloride. Chloride washoff from the catchment would take place so an increase in the load is seen but because of the larger quantities of water a decrease in this concentration would be observed, which is the case.

Sulphate did not seem to follow any particular trend. Dilution at Marlboro seemed to take place as a decrease in the concentration after the hydrograph went through. The sulphate concentration seemed to stay constant at Buccleuch with variations only occurring between 48mg/l and 53mg/l. Between Marlboro and Buccleuch sulphate is entrained from the river bed, as there is a large concentration of sulphate on the river bed (Table 6.3). The sulphate load is also increased by washoff from the catchment and from dissolved sulphate in the rain.

The loads of sulphate and chloride increased by 15% and 10% respectively (Figures 6.7 and 6.9). These increases are not that large. This is expected as there is little industry on the catchment which is the greatest producer of sulphate pollution, with most of the sulphate originating from detergents used in the washing of cars and clothes in the township.

Similar loadagraphs were seen for lead, iron, chloride and sulphate. In all the loadagraphs, there was a first peak as the hydrograph passed and then after 60 to 75 minutes the concentrations began to increase again. The sulphate loadagraph had a second peak after 60 minutes. The first peak was attributed to entrainment of the inorganic compounds from the deposited layer or SOD on the river bed. The second peak is assumed to be due to the fact that after the initial hydrograph has passed, the water passing over the river bed is cleaner and there are now less inorganic ions in the bed than in the water and leaching or mobilisation of the compounds in the river bed occurs and the individual ions are released into the water, so a second peak is seen. The mobilisation of the ions takes place at different rates as some ions are bound more

Table 6.3 Comparison of Pollutant Concentrations found on the river bed and in the water of the Jukskei River

Water Quality Variable	Marlboro (mg/l)		Buccleuch (mg/l)	
	Water	River Bed	Water	River Bed
Chloride	61	1280	50	704
$CaCO_3$	225	6144	160	13952
TKN	19	768	3	2560
Nitrate	0.6	112.8	3.5	12.8
Ortho-phosphate	2.8	51.2	1	90
Total Phosphorus	3.1	51.2	1.6	115
Calcium	48	2560	46	4864
Magnesium	17	256	17	384
Sodium	43	896	30	486
Potassium	9.8	602	5.8	384
Sulphate	92	5632	69	7552
COD	100	6400	41	9600

6.2.3 Sulphate, Chloride and Alkalinity

Chloride shows a decrease in concentration as the ·graph passed through the monitoring point which indicates that some dilutio :ing place. After the hydrograph has passed through the chloride concentration increased. Chloride is an example of a conservative pollutant in that during steady state conditions, there is very

The concentration of Total Phosphorus and TKN on the river bed compared to their concentration in the water was calculated for 03/08/1994. Samples of the river bed and water samples at Marlboro and Buccleuch were collected and analysed for a number of pollutants (Table 6.3). In order for a comparison to be made between the pollutant concentrations in the water and in the soil, the soil concentrations were converted from $mg.kg^{-1}$ to $mg.l^{-1}$. A soil layer of 1 cm by 1 cm and 10mm thick was taken and the soil volume determined. The mass of the soil slice was determined assuming a density of soil of 2650 $kg.m^{-3}$ and multiplying this by the volume of the soil slice used. The mass of the pollutant in the soil could then be determined by multiplying the concentration in $mg.kg^{-1}$ by the mass of soil. The porosity of the soil was assumed to be 0.4 (average for a sandy soil) and from this the volume of the voids was calculated. The soil is saturated in the river bed, so the void volume calculated would be the volume of water in the soil slice. The pollutant concentration in $mg.l^{-1}$ was then calculated by dividing the mass of pollutant by the volume of water in the soil.

From the table it can be seen that large concentrations of both TKN and phosphorus are found on the river bed which is probably due to sedimentation of these pollutants during the low flow periods. Turbulent waters during rain storms would cause these deposited pollutants to be entrained into the water causing the pollutant loads to increase. The increase in TKN and phosphorus could also be due to runoff from the catchment. Rotting vegetation on the river banks would increase the organic nitrogen and phosphorus when washed off the catchment.

steady state conditions. During storm events, the major process occurring is the entrainment of pollutants from the river bed.

Oxidation reactions for nitrogen and carbonaceous pollutants are also important but significant changes were only seen after some time as the reaction rates are slow. Most of these reactions take place in the benthic layer of the river bed. A major portion of the DO is used for these oxidation reactions.

A comparison between the Jukskei River and similar studies in South Africa was done (Table 7.2). Very high concentrations of lead and iron compared to other studies were seen. The faecal coliform concentrations were very similar to those seen in other similar areas. The high concentrations of faecal coliforms represent a health problem. From the studies however, these coliforms were seen to decrease quite rapidly as they are exposed to an alien environment in which there is intense sunlight and predation. Just 6km downstream, the majority of the faecal coliforms have been assimilated.

The ammonia and sulphate concentrations were similar to those observed in the Hennops River Valley study with the resulting oxidation products being similar to those seen in Khayelitsha. A high concentration of ammonia at Alexandra, where most of the pollution is discharged into the river, is seen. This decreases rapidly by nitrification to nitrates. The chloride concentrations were much lower than those seen in other studies. Many of these studies however, were in areas that are closer to the sea where high chloride concentrations are expected.

The problems that could arise due to the high concentration of nutrients, BOD and low DO concentrations are eutrophication of the waters, fish kills due to the low DO concentrations and aesthetically displeasing benthic sludge on the bottom of the river. There is no excess vegetation growing in the river itself and low concentrations of

factors that affected the assimilation of each pollutant and the processes by which each were assimilated were determined.

The results were run on the QUAL2E model which is used by the EPA in the USA. From these results, the possible processes of assimilation of each pollutant were determined as well as the possible reaction coefficients in the river.

Hydrographs and pollutographs were also collected during a storm event on 29/11/1996. 'Grab' samples were collected at 15 minute intervals increasing to 5 minute intervals as the hydrograph passed through the monitoring point. Two monitoring points were chosen. One at the Marlboro Bridge about 500m downstream of Alexandra Township and the other at the Gibson Bridge in Buccleuch which is 4.4 km downstream of Alexandra Township. The processes working during a storm event could then be determined. The SS results were used in the WITQUAL model.

The objectives of this study were to determine the factors affecting the assimilation of pollutants in the Jukskei River and to model them so that the waste assimilation in similar watercourses could be predicted as accurately as possible.

7.2 CONCLUSIONS

From the results it was found that microbiological pollution, nutrients and litter, typical of runoff from townships, were found to be the major pollutant problems. Settling of a number of the pollutants especially those adsorbed or complexed to the SS (phosphates, lead and iron) or in particulate form (organic nitrogen and BOD in the form of organic matter), was found to be a major removal process for non-point source pollution during

CHAPTER 7 : SUMMARY AND CONCLUSIONS

7.1 SUMMARY

The Jukskei River is the largest of three rivers draining the northern and north-eastern suburbs of the Witwatersrand. Its source is in the Bezuidenhout valley, east of Johannesburg. The River then flows past Lombardy East, Alexandra Township, past northern residential areas like Kelvin and Buccleuch, and then through more rural areas like Waterval, Leeukop and Midrand. It has its confluence with the Crocodile River which eventually flows into the Hartebeespoort Dam.

A 6 km section of the Jukskei River just below Alexandra Township was chosen for a study into the assimilation of pollutants from Alexandra. It had been shown by Wimberley in 1992, that a large proportion of the pollution in the river came from Alexandra. A study on the fate of these pollutants in the river was necessary to see how far downstream and by what processes these pollutants were assimilated. This 6 km reach was chosen, as it was as close to an ideal situation as possible in that the main source of pollution was Alexandra Township and no further large sources of pollution entered the system before the Modderfontein Spruit, 6 km downstream.

'Grab' samples were taken fortnightly in the dry and the wet seasons at four monitoring points. The first monitoring point was just below the first shacks in Alexandra and the last point was just before the confluence with the Modderfontein Spruit. The pollutants concentrated on were those that had been shown (Wimberley,1992) to be of concern. These included the nutrients both phosphorus and nitrogen; faecal coliforms, lead, iron, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand and SS. The

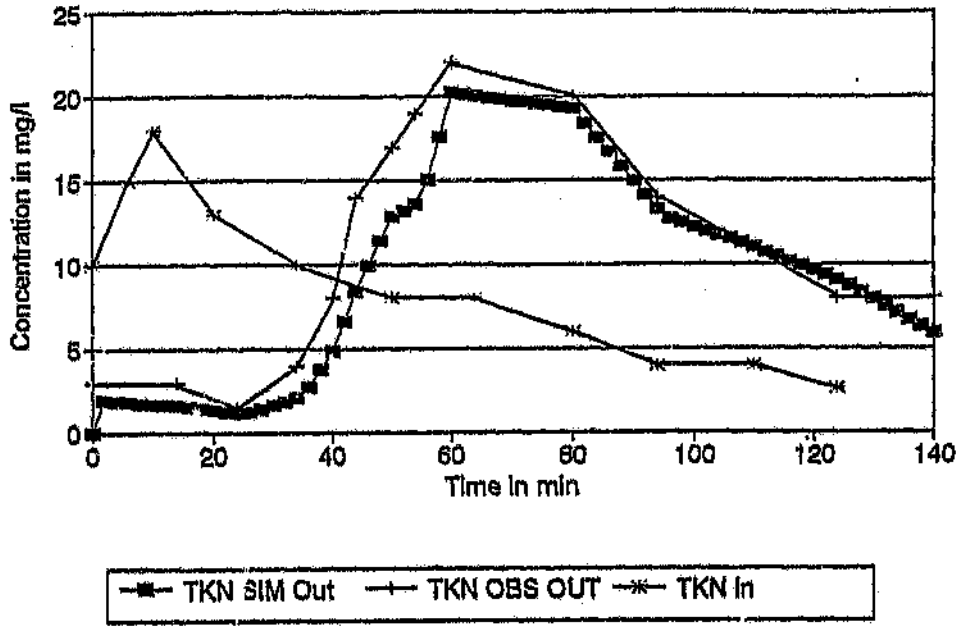


Figure 6.17 WITQUAL Simulation of TKN during the storm event of 29/11/1995

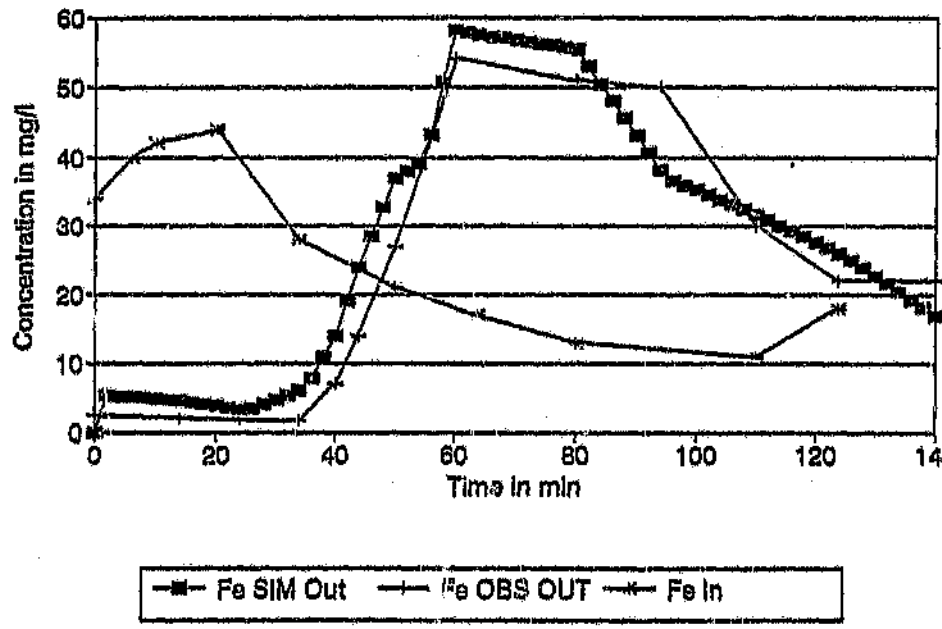


Figure 6.18 WITQUAL Simulation of iron during the storm event of 29/11/1995

the fraction associated with the SS remained constant. This suggests that there are only a limited number of sites to which lead can complex to.

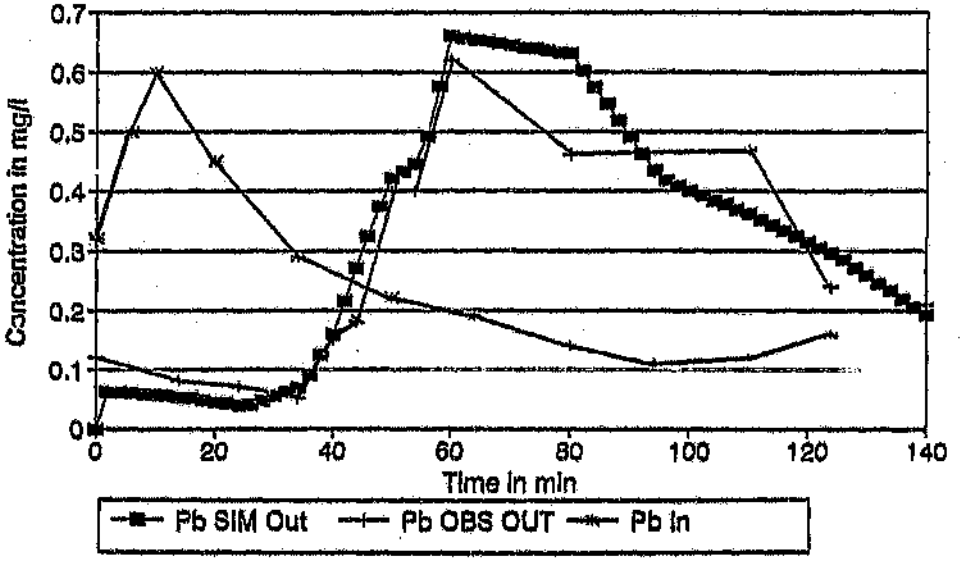


Figure 6.16 WITQUAL Simulation of lead during the storm event of 29/11/1995

TKN is comprised of mainly particulate organic nitrogen and during low flow conditions a large percentage of these particulates settle out onto the river bed. The increase in the factor of TKN from Marlboro to Buccleuch suggests that as the hydrograph flowed downstream more and more of this particulate nitrogen was picked up.

With iron there was a decrease in the fractions associated with SS as the SS loads increased. This suggests that less iron than other particulates were entrained as the hydrograph moved downstream, and a decrease in the factor was seen.

downstream. The concentration of one of the above pollutants at a particular SS concentration could be determined by multiplying the SS concentration by the factor.

Table 6.5 Factors for pollutants associated with SS during storm events

Monitoring Point	Lead	Iron	TKN
Marlboro	0.0003	0.0264	0.0092
Buccleuch	0.0003	0.0218	0.0130
Average	0.0003	0.0241	0.0111

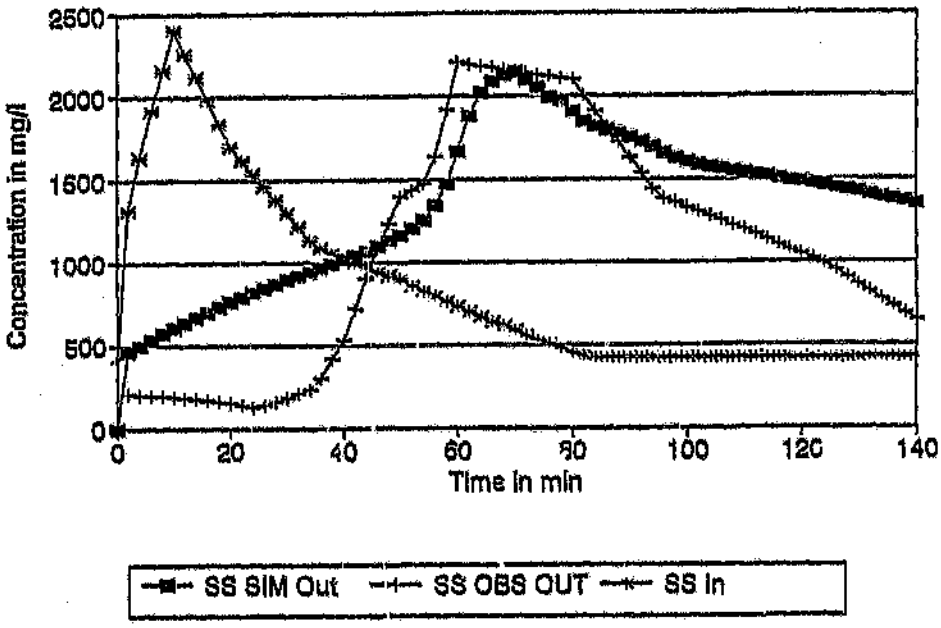


Figure 6.15 WITQUAL Simulation of SS during the storm event of 29/11/1995

The fraction of lead associated with the SS seems to stay constant between the two monitoring points. As the concentration of SS increases, the lead load also increased but

The net entrainment flux at the bed is given by

$$Net\ Ent = C_f\,(C_{ae} - C)$$

where C_{ae} (g/m^3) is the equilibrium concentration for the flow condition in the stream and C_f (m/s) is a mass transfer coefficient at the bed which accounts for the erodability and availability of material in the bed. An estimate of the equilibrium concentration is given by Yang (1979) based on a grading of the bed sediments.

A particle distribution study on the river bed was undertaken and the majority of the particles were found to be in the 1.2 mm fraction which is typical of sand. Three fractions were used in the model when modelling SS (Table 6.4)

Table 6.4 Grading used to model SS

Size of Particle (mm)	Fraction
3	0.25
1.2	0.65
0.43	0.1

The equation used was found to give a good correlation to the observed outflow of SS at Buccleuch especially at peak concentrations (Figure 6.15).

There are a number of pollutants associated with SS as seen in 6.2.2. When modelling these pollutants it is possible to use the same form of equation as used to model the SS as they follow the same trend. The fraction of each pollutant that is associated with the SS were calculated (Table 6.5) and these were used in the model to predict the downstream pollutagraph of these pollutants. These factors can then be used in the modelling of the above pollutants in order to postulate the increase in pollutants further

The conclusion that a large majority of the pollutants are entrained from the river bed was further supported by the analysis of the river bed which showed that there were greater concentrations of most pollutants on the river bed as opposed to in the water. The greatest load increases seemed to be with the nitrites and the nitrates but this is expected as during steady state conditions the concentrations of these pollutants are already larger than upstream due to nitrification taking place. Both nitrite and nitrate loadagraphs had very small peaks at Alexandra which further supports the above conclusion.

6.3 WITQUAL MODELLING OF SS AND ASSOCIATED POLLUTANTS

The WITQUAL model, developed by the Water Systems Research Group, University of the Witwatersrand, was used to model SS during a storm event. Plug flow routing is used to route the particulates down a trapezoidal sloped channel. The kinematic flow routing method with the matching of the actual and numerical diffusion is used in the model.

The continuity equation for the particulates used in WITQUAL is

$$\frac{d(AC)}{dt} + \frac{d(QC)}{dx} = W(Net\ Entrainment)$$

where

A (m^2) is the cross sectional area of the flow;

C (g/m^3) is the particulate concentration;

x (m) is distance;

t (s) is time;

W is a representative width from which the particulates are entrained or deposited;

Net Entrainment ($g/m^2/s$) is the net entrainment of particulates from the bed into the flow.

From the COD concentrations it seems that dilution is taking place. As the hydrograph passes, the COD concentration dips and recovers after the hydrograph has passed.

6.2.6 Faecal coliforms

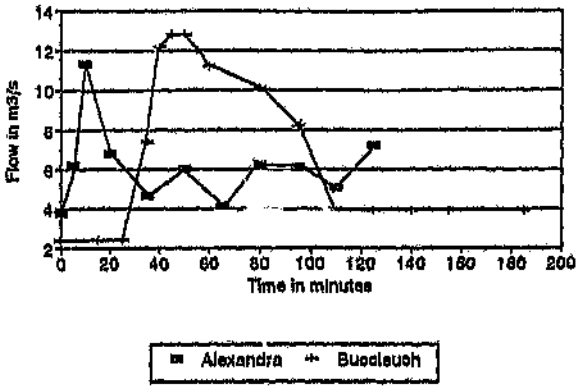
Unfortunately, due to the cost of microbiological tests only a few samples could be taken at each sampling time. The results showed that the concentration of faecal coliforms at Marlboro and Buccleuch both reached peak concentrations of greater than 3 million faecal coliforms per 100ml water. The faecal coliforms were thus carried downstream with no change occurring. There is no time between monitoring points for die-off of the faecal coliforms to occur. During rain events there is also less exposure to sunlight.

6.2.7 Conclusions

For all of the pollutants, an increase in the pollutant loads between monitoring points was observed. This is due to entrainment of especially SS and associated pollutants like lead, iron, TKN and phosphates from the river bed. An increase in the flow between monitoring points was also observed which is caused by lateral inflow off the catchment. This inflow also carries number of pollutants with it which is added to the river.

No oxidation reactions are possible as the time between monitoring points is too small for any significant changes to be seen. Most pollutants are thus carried downstream with more pollutants being entrained from the river bed by the turbulence of the water.

a)



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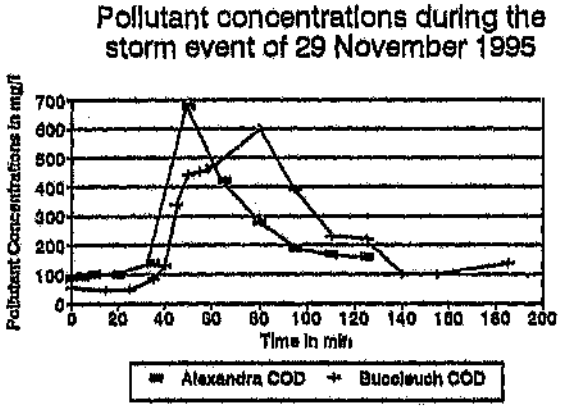

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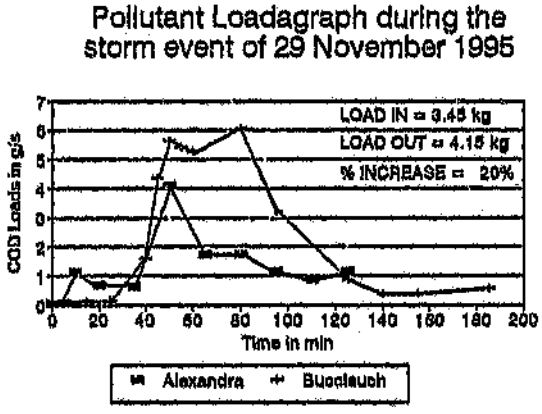
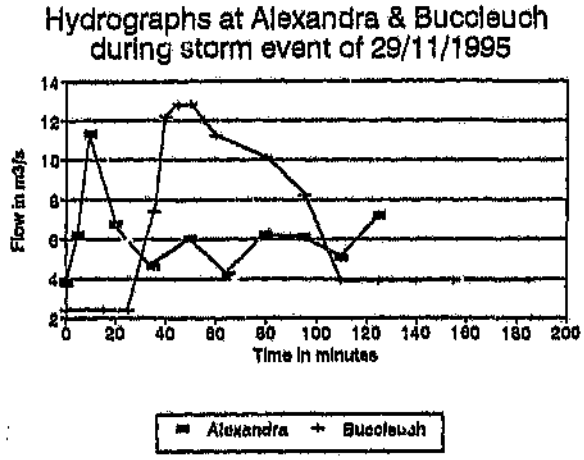


Figure 6.14 **a) Hydrograph b) COD Pollutagraph and c) COD loadagraph at Buccleuch and Marlboro during the storm event of 29/11/1995**

a)



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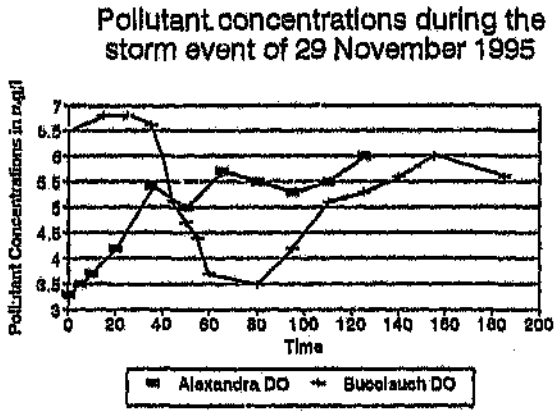


Figure 6.13 **a) Hydrograph and b) DO pollutagraph during the storm event of 29/11/1995**

The DO concentration is seen to increase quite rapidly after the hydrograph had passed which is due to greater turbulence and thus reaeration of the water. This causes more oxygen to be entrained into the water column with the resulting increase in the DO concentration.

6.2.5 DO and COD

As the hydrograph passed each monitoring point a dip in the Dissolved Oxygen (DO) concentration was seen. This is due the increase in the oxygen requiring pollutants. The large increase in the concentration of oxidisable pollutants, puts a greater demand on the amount of oxygen that is needed for oxidation reactions to take place. Only a small concentration of oxidisable pollutants will undergo oxidation however, as the oxidation reactions are slow and the river is flowing too quickly between the monitoring points for a large difference to be seen.

An increase in COD is seen with the load increasing by 20% between Marlboro and Buccleuch. This increase is partly responsible for the decrease in dissolved oxygen that is seen. From Table 6.3, it can be seen that the concentration of COD on the river bed is far greater than that in the water column. With the greater turbulence, this SOD (Sediment Oxygen Demand or COD on the river bed) is entrained into the water column and greater oxygen is required for oxidation to take place. As a result an increase in COD concentration between Marlboro and Buccleuch is seen.

The DO concentration at Buccleuch before the hydrograph passed through was greater than at Marlboro. This is expected as during steady state conditions there is less COD at the Buccleuch monitoring point as most has settled out or been oxidised by bacteria. Less oxygen is thus required for oxidation reactions and an increase in DO is seen between these monitoring points with the Buccleuch site have the greater DO concentration. A large drop in DO concentration is seen at Buccleuch as the hydrograph passes through as large concentrations of COD are carried with the hydrograph which requires large concentrations of DO.

v. For the Jukskei River, the water quality recovers quite rapidly with distance but the water is still a health risk to the water users.

- Diversion of pollution

Pond systems are one of the most widely applicable and advantageous methods of reducing pollution loads in hot climates. Pond systems provide a site in which runoff can be contained for a period of time. During this retention time processes like settling, oxidation of carbonaceous and nitrogenous waste, uptake of pollutants by algae and plants, aeration, and bacterial die-off can take place which results in a decrease in pollutant concentrations. This water can then be safely added to the river. The river is then able to cope relatively easily with this pollution load. The transmission of diseases is also lessened, as helminth eggs are removed by sedimentation in stabilisation ponds (Cairncross & Feacham, 1993).

Vegetated infiltration systems like buffer strips, grass swales and grass plots in which the pollutants undergo some oxidation as well as some filtration are also inexpensive treatment options. The nutrients can be used by the grass for photosynthesis.

Chemical treatment systems could also be used and include disinfection of the runoff with chlorine and other derivatives, metal chemical treatment and phosphate chemical treatment but unfortunately these methods have considerable ecological effects on the receiving stream.

Wetlands are becoming more popular in the treatment of water. A wetland filters the water, retains the water long enough that the oxidation reactions can take place and uses the nitrogen and carbon oxidation products as a source of nutrients.

Those of the excreta-related diseases that are also water-based can be controlled, at least partially, by improvements in water supply and hygiene and may also be affected by improvement in excreta removal, ranging from the construction or improvement of toilets to the choice of methods for transport, treatment and final disposal or re-use of the excreta. The transmission of water/excreta transmitted diseases can also be lessened by avoiding faecal contamination of the areas around the latrines. However, if the latrine is badly maintained with an earth floor that becomes soiled, it can become a focus for transmission. It is impossible to get all the Alexandra residents to improve their personal hygiene, as more and more people enter the area daily with the implementation of basic water supplies and sanitation falling behind the large influx of users. More awareness of the diseases that bad hygiene can transmit, could be the answer, with clinics in the areas giving advice. The provision of enough toilets, excreta treatment prior to re-use or discharge, health education, domestic water supply and improved housing would all help in the reduction of the transmission of these diseases.

An ongoing removal of solid waste from the catchment before it is washed off the catchment into the river would significantly reduce the litter problem. Contractors have been called in but this has not been successful. Presently people are being employed to remove litter from the river and surrounding areas as well as to unblock blocked drains and sewers.

Improve the sewage system to incorporate the informal settlements. This is a huge undertaking as there is continuous inflow of squatters to the area and it is difficult to keep up with this influx. This can therefore only be seen as a long term goal.

Another method, which is extensively used in other countries, is the fencing off of the river so people are prevented from using the water until it reaches a suitable water

7.3 RECOMMENDATIONS

It is recommended that further time and money should be spent in determining solutions to the various pollutant problems that have been identified in this report. It has been shown that the river itself can cope with most of the pollution which is added to it. At Alexandra where the major pollution is seen, the river does not assimilate the waste quickly enough for the effects on the aquatic life in the river as well as on the people in Alexandra who use the river water for drinking purposes, to be reduced. The greatest benefits of using the river as a treatment option are seen to be for the water users further downstream. In order for the Alexandra people to benefit a number of diversion or at - source pollution treatment options would have to be implemented. Several possible solutions are detailed in the following section.

7.3.1 Possible pollution control methods

- At source solutions

In Alexandra, a number of the bucket toilets are very badly maintained with a large volume of excreta overflowing into the river. Personal hygiene is also bad, with the majority of people not even using the bucket toilets, but instead urinating and defecating directly into the river itself. In order to solve the transmission of faecal transmitted diseases and to reduce the health risk to the people using the water further downstream, either for drinking water or recreational purposes, some sort of maintenance of the bucket toilets has to be implemented, which would reduce the overflow into the river. The blocked sewers should also be unblocked and maintained to prevent further contamination to the river.

Table 7.2 Comparison between the Jukskei River stormwater quality and other South African Studies

POLLUTANT	JUKSKEI RIVER[1]		HENNOPS RIVER VALLEY[2]				ALEXANDRA[3]	THREE ANCHOR BAY[4&5]	KHAYELITSHA[6]				MITCHELLS PLAIN[3&4]	ATLANTIS[5]		MOTHERWELL[7]
	Marlboro	Beecleuch	Tembisa Formal Housing	Tembisa & Ivory Park (unserviced sites)	Clayville Industrial	Total			Shacks	Serviced Sites	Formal Housing	Total		Residential	Industrial	
F.Coliforms per 100ml	3×10^4	3×10^4	2.2×10^5	5.3×10^5	2.5×10^5	4.6×10^5	-	2.6×10^5	1.2×10^5	2.7×10^5	2.2×10^4	3.4×10^4	4.1×10^4	-	-	5.4×10^4
NH_4-N (mg/l)	5.5	7.3	6.05	3.86	1.17	2.5	24.54	-	1.86	2.38	1.99	0.36	0.20	0.11	<0.1	-
NO_X-N (mg/l)	3.8	9.4	0.60	0.91	1.67	2.12	2.88	-	22.8	13.6	4.05	9.93	8.98	5.12	<0.1	5.2
P (mg/l)	2.0	2.3	1.90	1.46	0.89	2.15	3.68	-	<0.05	0.10	<0.05	<0.05	0.02	0.05	0.10	0.28
Alk($CaCO_3$) (mg/l)	110	140	60	99	88	11[8]	-	-	412	372	436	351	-	75	107	-
SO_4 (mg/l)	58	54	56	45.5	32	48.5	90	-	298	195	93	165	-	61	83	-
Cl (mg/l)	22	29	22	34.5	24.5	30.5	87	-	291	164	191	2.78	-	158	236	-
pH (20°C)	7.50	7.50	7.49	7.46	7.75	7.55	-	-	6.7	7.0	6.9	7.0	-	8.1	7.9	8.3
Fe (mg/l)	44	54	0.050	3.52	0.67	0.95	2.13	5.051	0.360	0.410	1.740	0.640	3.574	0.346	1.320	-
Pb (mg/l)	0.60	0.62	<0.05	<0.05	<0.05	0.05	0.20	0.54	0.020	0.020	0.030	0.060	0.097	0.031	0.070	-

Source of Data

1 Wright, Kloppers and Fricke (1992)
2 Wimberley (1992)
3 Simpson (1986)
4 Kloppers (1989)
5 Wright (1987)
6 Wright (1991)
7 MacKay (1992)
8 Hoffmann (1995)

* Peak concentration of pollutagraph during the storm event of 29/11/1996

there are greater initial concentrations of nitrites and nitrates further downstream due to the nitrification reactions that have taken place under steady state conditions. These results were confirmed in the pollutographs in which a large peak of ammonia occurred at Alexandra (which is further upstream) and no or very small peaks were observed for nitrites and nitrates. Further downstream this pattern changed, with peaks for nitrites and nitrates being observed.

- No significant nitrification takes place between monitoring points during the storm event as there is too little time for the reaction to take place.
- A large concentration of faecal coliforms was seen at both monitoring points with peaks of >30 000 000 per 100 ml being seen. Faecal coliforms in runoff off the catchment, as well as on the river bed, contributed to this increase in faecal colliform concentrations.

7.2.4 WITQUAL Modelling of SS and associated pollutants

- The kinematic flow routing method with the actual and numerical diffusion is used in this model.
- A good correlation with the observed downstream SS pollutograph was obtained.
- The fraction of each pollutant that is associated with SS was calculated from the storm event results and these were used in the modelling of lead, iron and organic nitrogen. Good correlations were obtained for all the variables studied.

7.2.3 Storm Events in the Jukskei River

- The pollutants that made the Jukskei River unfit for use during storm events were: COD (Industry); SS (Industry); Ammonia (Domestic & Aquatic life); Alkalinity (Industry); Chloride (Industry); Iron (Domestic, Industry, Irrigation, Livestock and Aqautic life); Ortho-phosphates (Recreation/contact); Total Phosphorus (Recreation/contact); Lead (Domestic, Irrigation and Aquatic life) and Faecal coliforms (Domestic, Recreation/contact and Livestock) (see Table 7.1).
- The concentrations of all the pollutants increased further downstream due to the entrainment of pollutants from the river bed.
- The process of entrainment of pollutants was confirmed by the analysis of samples from the river bed and water which showed that there was a much larger concentration of pollutants on the river bed. With the increase in the turbulence of the river during a storm event, these pollutants are entrained into the water.
- With the increase in COD, a corresponding decrease in DO was observed. The increase in DO after the hydrograph had passed was attributed to reaeration by the turbulent waters.
- Erosion of the catchment and entrainment of benthic sediments due to greater turbulence in the river resulted in the increase in SS that was seen.
- A number of pollutants were seen to be associated with SS. Organic nitrogen, lead, iron and phosphates all had identical pollutographs to SS but with different ranges in concentrations. This would be expected as these pollutants form part of the SS measured. These observations support our theory postulated for the steady state results, that many of the pollutants settle out on the river bed or adsorb onto SS and settle out.
- The greatest increases in loads were found to be of the nitrites and nitrates with increases of 141% and 116% being calculated respectively. This is expected as

were biochemical oxidation of nitrogen and carbonaceous compounds, benthic oxygen demand and oxygen used for respiration by algae. The benthic oxygen demand was found to be greater in the Jukskei River than in American Rivers.

- Nitrification of organic nitrogen, nitrites and nitrates was found to be an important process.
- Another pathway for ammonia is needed as the conversion of ammonia to nitrates is not fast enough to account for the large decrease in ammonia between the first and the second monitoring stations. Ammonia is usually in the dissolved state and does not adsorb onto SS so it was postulated that some ammonia may volatilise from the water into the air, thus causing a decrease to be seen. The amount of ammonia that could disappear by volatilisation was calculated and it was found to be up to 13 mg/l out of 22 mg/l ammonia.
- Most of the organic nitrogen settled out onto the river bed with some undergoing hydrolysis. A good correlation between the observed and the modelled results was obtained.
- The large decrease in the concentration of phosphates between the first and the second monitoring point was found to be due to the adsorption of phosphates onto SS and their subsequent sedimentation with the SS
- Watertek, CSIR, modelled the Vaal River using QUAL2E and they also found that some of the QUAL2E model parameters had to be calibrated outside of the acceptable limits to account for the losses in phosphates and nutrients that they observed. Chemical equilibrium studies showed that adsorption to SS followed by sedimentation was most likely to be the major removal mechanism for phosphates. This should be incorporated into other future models.
- From the above results it was concluded that rivers in South Africa seem to be more turbulent and to contain greater concentrations of SS which contribute to the adsorption and sedimentation of a number of pollutants. Settling out of pollutants is also an important process which should be taken into account.

Nitrate (mg/l)	6	"	"	"	100	10	0.60	2.02	2.7
Potassium (mg/l)	200	"	"	"	"	"	9.8	"	"
Ortho-phosphate (mg/l)	"	0.05	"	"	"	"	2.73	0.98	"
Total Phosphorus (mg/l)	"	0.08	"	"	"	"	2.3	1.9	11
Sodium (mg/l)	100	"	"	70	2000	400	43	"	"
Sulphate (mg/l)	200	"	400	"	1000	1000	77	51.4	58
Micro-constituents									
Lead (mg/l)	0.05	"	"	0.2	0.1	0.003	0	0	0.6
Microbiologic al constituents									
Chlorophyll a (ug/l)	1	15	"	"	"	"	41	32	"
Faecal Coliforms counts/100ml	0	<1000	"	"	1000	"	31×10^6	18×10^6	$>30 \times 10^6$

7.2.2 QUAL2E Modelling of the Jukskei River Steady State Results

- The settling process was not viewed as a major sink of a number of pollutants in QUAL2E.
- Settling of the organic carbon (measured in terms of BOD) and organic nitrogen was found to be an important process.
- BOD was modelled as a first order reaction to describe the deoxygenation of ultimate BOD in the river. QUAL2E also takes into account additional BOD removal due to sedimentation, scour and flocculation.
- DO predicted by the QUAL2E model was very close to the observed change in DO with distance and a r^2 of 0.94 was obtained. QUAL2E sources of DO were reaeration, photosynthesis and incoming DO from tributaries and the DO sinks

Table 7.1 **The Jukskei River water quality compared to selected water quality guidelines of various water user groups**

Water Quality Variable	Water User Groups						Jukskei River (Alexandra monitoring Point)		
	Domestic	Recreation /Contact	Indu -stry	Irrigation Class I	Live-stock	Aquatic Life	Dry Sea-son	Wet Sea-son	Storm Event
Physical Properties									
Conductivity (mS/m)	70	-	100	40	154	-	76.2	57.5	40
Total Dissolved Solids (TDS) (mg/l)	476	-	680	272	1950	-	434	323	-
Chemical Oxygen Demand (COD) (mg/l)	-	-	30	-	-	-	133	47	680
Dissolved Oxygen (DO) (mg/l)	5	-	-	-	-	-	2.88	2.47	3.3
pH	6.0-9.0	6.5-8.5	7.0-9.0	6.5-8.4	-	6.0-9.0	7.7	7.7	7.6
Suspended Solids (SS) (mg/l)	-	-	5	-	-	-	53.6	21.2	2400
Turbidity (NTU)	1	5	-	-	-	-	17	12	-
Micro-constituents									
Ammonia (mg/l)	1	-	-	-	-	0.4	21.9	10.3	5.5
Alkalinity (mg/l)	-	-	100	-	-	-	227	147	110
Calcium (mg/l)	150	-	-	-	1000	1000	48	43	-
Chloride (mg/l)	250	-	20	105	1500	106	62.4	38	28
Fluoride (mg/l)	1	-	-	2	2	1	0.4	0.2	-
Iron (mg/l)	0.1	-	1.2	5	10	1	0.4	0.4	44
Magnesium (mg/l)	70	-	-	-	500	1000	17	16	-
Nitrite (mg/l)	-	-	-	-	10	-	0.86	0.39	1.1

7.2.1 Steady state conditions

- The non-point source runoff from Alexandra Township pollutes the Jukskei River throughout the year.
- The pollution is predominantly of a microbiological nature with the corresponding high concentrations of bacteria, nutrients and organics. The pollutants that were cause for concern were found to be the nutrients (TKN, ammonia, nitrites, nitrates and phosphates); COD and the resulting decrease in DO and faecal coliforms.
- Table 7.1 contains a comparison of the selected water quality variables of water user groups and the average dry and wet season values in the Jukskei River at Marlboro and Buccleuch. According to the table, the Jukskei River water is unfit for use for certain water user groups. The water quality variables that exceeded the guidelines were Conductivity (Irrigation and Domestic), TDS (Irrigation), COD (Industry), DO (Domestic), SS (Industry), Turbidity (Domestic and Recreation/Contact), Ammonia (Domestic and Aqautic life), Alkalinity (Industry), Chloride (Industry), Iron (Domestic), Ortho-phosphate and Total Phosphorus (Recreation/Contact), Chlorophyll a (Domestic and Recreation/Contact) and Faecal coliforms (Domestic, Recreation/Contact and Livestock).
- From Table 7.2 it can be seen that the pollution seen in the Jukskei River is typical of pollution coming off a catchment on which informal housing has developed.

The social and economic differences between the developed and the developing world are the reasons why conventional water treatment systems may not be appropriate in a developing country like South Africa. In industrialised countries, water treatment options use capital - intensive designs with a high degree of mechanisation and automation. The prevailing economies in developing countries however, are labour intensive. In addition financing can be beyond the means of the population.

The main problem associated with non-point source pollution coming off catchments such as Alexandra, is that costly at - source diversion treatment processes would not be viable, as there is a constant influx of people to the area so there is always a shortage of amenities. The river may then be the only option available for treatment of the runoff being discharged into it.

The main aim of this study as stated in Chapter 1 was to find if the river could cope with the large pollutant loads coming off the catchment and to see if the river could be used as a treatment option in communities such as Alexandra where cost is of the utmost importance.

The results indicated that the majority of the pollutants that were a cause for concern are naturally assimilated within a short distance by the river itself i.e. after approximately 4km. Although the river assimilates the waste and the water users downstream benefit from this, the peop' 'n Alexandra get no benefit as the water still poses a health risk if used either for drinking or for recreatic nal uses. The only solution for the people of Alexandra is to treat the runoff before it enters the receiving waters as well as to increase the sanitary conditions of the facilities provided to minimise the amount of sewage spilling into the Jukskei River.

The following conclusions may be drawn from each section of the study:

chlorophyll-a were detected in the river, which shows that no eutrophication has take.. place, although quite luxuriant vegetation is seen along the banks of the river. Fish, especially the catfish (Barbel) were seen in the river which indicates that some aquatic life is still possible. The biggest problem however, seems to be the health threat to the people downstream.

Large concentrations of Ascaris eggs, which is indicative of human sewage pollution, were found down the whole length of the 6km re ch used for the study (van Deventer, R, pers. comm). Ascaris eggs are used as indicators of the presence of parasites in the water as they are present in large concentrations in polluted waters and are easily detected. After Ascaris eggs (roundworm) were detected, tests for other parasites were carried out.

Water-based diseases are due to infection by living organisms such as parasitic worms (helminths and nematodes), which depend on aquatic intermediate hosts to complete their life-cycles, bacteria and viruses. Parasites like tapeworm, trichuriasis (whipworm), hookworm and Schistosomiasis were detected in the Jukskei River water. All the diseases in the faecal-oral category are caused by pathogens transmitted in human excreta, normally faeces. A rapid rise in the concentration of faecal coliforms at the Alexandra Monitoring point has been seen with a high of 31 million/100 ml being recorded at Alexandra in September, 1994. The presence of these faecal coliforms indicate that there may be bacteria present that are transmitters of various bacterial diseases including a number of diarrhoeas and dysenteries, enteritis, cholera, typhoid as well as a number of other diseases. In order to combat these problems, various treatment options would have to be implemented. A number of these treatment options are detailed in the Recommendations sect' in this chapter.

	JUK3	4.7	19	-
	JUK4	4.8	15	-

TABLE 6 - MICROBIOLOGICAL PROFILE OF THE JUKSKEI RIVER.

DATE	SAMPLE POINT	COLIFORMS x 1000 / 100ml	E.coli x 1000 / 100ml
12/07	JUK1	1400	980
	JUK2	720	720
	JUK3	710	60
	JUK4	390	<10
03/08	JUK1	1600	1600
	JUK2	800	320
	JUK3	160	20
	JUK4	30	10
10/08	JUK1	1800	1300
	JUK2	1100	180
	JUK3	700	70
	JUK4	360	30
24/08	JUK1	2000	2000
	JUK2	440	140
	JUK3	350	70
	JUK4	70	30
07/09	JUK1	11000	5400
	JUK2	3000	500
	JUK3	1200	490
	JUK4	90	90
21/09	JUK1	11000	0
	JUK2	3200	0
	JUK3	720	60
	JUK4	90	90

	JUK3	-	54	30
	JUK4	-	54	30
12/10	JUK1	2.5	-	30
	JUK2	5.5	-	10
	JUK3	5.9	-	10
	JUK4	5.7	-	10
01/11	JUK1	2.6	60	60
	JUK2	3.3	55	30
	JUK3	4.4	40	30
	JUK4	4.1	45	30
09/11	JUK1	2.6	30	-
	JUK2	3.7	35	-
	JUK3	3.5	15	-
	JUK4	3.6	20	-
16/11	JUK1	3.0	55	30
	JUK2	5.6	40	20
	JUK3	6.4	30	10
	JUK4	4.8	30	10
23/11	JUK1	3.0	20	-
	JUK2	6.6	20	-
	JUK3	8.6	10	-
	JUK4	8.5	10	-
07/12	JUK1	1.1	70	-
	JUK2	2.7	50	-
	JUK3	4.0	30	-
	JUK4	4.8	40	-
18/01	JUK1	3.2	66	20
	JUK2	4.4	51	20
	JUK3	5.7	25	20
	JUK4	5.2	36	10
01/02	JUK1	3.2	39	-
	JUK2	5.4	29	-

	JUK4	3.0	1.3	0.8	2.2	1.2	0.5

TABLE 5 - OXYGEN PROFILE OF THE JUKSKEI RIVER

DATE	SAMPLE POINT	DISSOLVED OXYGEN IN mg/l	COD IN mg/l	BOD IN mg/l
12/07	JUK1	5.4	157	-
	JUK2	5.1	86	-
	JUK3	8.5	35	-
	JUK4	8.5	20	-
03/08	JUK1	3.7	100	50
	JUK2	6.3	46	20
	JUK3	8.9	41	20
	JUK4	10.4	71	10
10/08	JUK1	3.2	69	60
	JUK2	7.4	15	30
	JUK3	8.0	54	30
	JUK4	8.5	20	20
24/08	JUK1	2.0	140	60
	JUK2	5.6	60	40
	JUK3	6.4	65	60
	JUK4	6.8	65	50
07/09	JUK1	1.5	225	100
	JUK2	6.5	45	30
	JUK3	7.9	45	20
	JUK4	8.1	50	30
21/09	JUK1	1.5	150	60
	JUK2	5.8	70	20
	JUK3	6.8	120	30
	JUK4	6.8	70	50
28/09	JUK1	-	88	60
	JUK2	-	34	30

	JUK4	5.2	4.0	0.2	0.8	1.0	0.8
12/10	JUK1	22	22	0.1	1.1	2.0	1.4
	JUK2	7.2	5.8	0.4	1.1	1.0	0.7
	JUK3	6.5	6.5	0.5	1.4	1.0	0.7
	JUK4	7.0	7.0	1.3	1.3	1.2	0.9
01/11	JUK1	9	4.0	0.8	2.6	1.4	0.2
	JUK2	7.2	5.8	0.4	1.1	1.0	0.7
	JUK3	2.8	1.6	0.3	4.2	0.2	0.1
	JUK4	2.4	1.0	0.3	3.7	0.2	0.1
09/11	JUK1	9	6.0	0.4	2.0	1.0	0.7
	JUK2	8.0	5.0	0.3	2.3	1.0	0.6
	JUK3	3.0	1.7	0.3	2.5	2.2	0.4
	JUK4	2.6	1.5	0.5	1.9	2.0	0.4
16/11	JUK1	17	11	0.7	1.9	2.4	1.4
	JUK2	5.2	2.2	0.5	2.7	0.6	0.5
	JUK3	3.2	1.5	0.6	2.1	0.4	0.4
	JUK4	2.6	1.5	0.7	2.2	0.6	0.4
23/11	JUK1	21	11	<0.05	2.4	3.0	1.3
	JUK2	5.4	2.7	<0.05	4.4	0.8	0.6
	JUK3	5.6	4.0	<0.05	2.8	1.0	0.9
	JUK4	5.2	4.0	<0.05	2.6	1.2	0.9
07/12	JUK1	14	7.5	0.3	2.1	1.6	0.9
	JUK2	9.2	4.5	0.3	2.2	0.8	0.5
	JUK3	2.0	1.5	0.3	2.1	0.2	0.2
	JUK4	2.2	1.8	0.3	1.9	0.4	0.3
18/01	JUK1	12	7.0	0.9	3.6	1.4	0.9
	JUK2	11	6.3	1.0	4.0	1.1	0.9
	JUK3	4.4	1.4	1.4	5.4	0.5	0.4
	JUK4	4.0	0.8	1.2	5.6	0.5	0.4
01/02	JUK1	18	9.5	0.6	1.4	2.0	1.3
	JUK2	8.0	1.5	0.5	2.5	1.0	0.5
	JUK3	3.0	1.3	0.8	2.4	1.0	0.5

	JUK4	5.2	4.0	0.2	0.8	1.0	0.8
12/10	JUK1	22	22	0.1	1.1	2.0	1.4
	JUK2	7.2	5.8	0.4	1.1	1.0	0.7
	JUK3	6.5	6.5	0.5	1.4	1.0	0.7
	JUK4	7.0	7.0	1.3	1.3	1.2	0.9
01/11	JUK1	9	4.0	0.8	2.6	1.4	0.2
	JUK2	7.2	5.8	0.4	1.1	1.0	0.7
	JUK3	2.8	1.6	0.3	4.2	0.2	0.1
	JUK4	2.4	1.0	0.3	3.7	0.2	0.1
09/11	JUK1	9	6.0	0.4	2.0	1.0	0.7
	JUK2	8.0	5.0	0.3	2.3	1.0	0.6
	JUK3	3.0	1.7	0.3	2.5	2.2	0.4
	JUK4	2.6	1.5	0.5	1.9	2.0	0.4
16/11	JUK1	17	11	0.7	1.9	2.4	1.4
	JUK2	5.2	2.2	0.5	2.7	0.6	0.5
	JUK3	3.2	1.5	0.6	2.1	0.4	0.4
	JUK4	2.6	1.5	0.7	2.2	0.6	0.4
23/11	JUK1	21	11	<0.05	2.4	3.0	1.3
	JUK2	5.4	2.7	<0.05	4.4	0.8	0.6
	JUK3	5.6	4.0	<0.05	2.8	1.0	0.9
	JUK4	5.2	4.0	<0.05	2.6	1.2	0.9
07/12	JUK1	14	7.5	0.3	2.1	1.6	0.9
	JUK2	9.2	4.5	0.3	2.2	0.8	0.5
	JUK3	2.0	1.5	0.3	2.1	0.2	0.2
	JUK4	2.2	1.8	0.3	1.9	0.4	0.2
18/01	JUK1	12	7.0	0.9	3.6	1.4	0.9
	JUK2	11	6.3	1.0	4.0	1.1	0.9
	JUK3	4.4	1.4	1.4	5.4	0.5	0.4
	JUK4	4.0	0.8	1.2	5.6	0.5	0.4
01/02	JUK1	18	9.5	0.6	1.4	2.0	1.3
	JUK2	8.0	1.5	0.5	2.5	1.0	0.5
	JUK3	3.0	1.3	0.8	2.4	1.0	0.5

Table 4 - Nutrient concentrations in the Jukskei river

DATE	SAMPLE POINT	K-N IN mg/l	AMMONIA IN mg/l	NITRITE IN mg/l	NITRATE IN mg/l	TOT. PO_4 IN mg/l	ORTHO -PO_4 IN mg/l
12/07	JUK1		19	1.7	0.5	2.4	2.1
	JUK2		13	0.6	2.7	1.7	1.7
	JUK3		4.5	0.4	3.1	0.8	0.8
	JUK4		4.0	0.4	2.8	2.1	0.9
03/08	JUK1		19	1.6	0.6	3	2.8
	JUK2		11	0.8	3.8	1.9	1.9
	JUK3		3.0	0.1	2.6	1	1
	JUK4		3.5	0.5	2.6	1.2	1.2
10/08	JUK1		28	1.8	0.8	2.9	2.3
	JUK2		2.0	0.1	6.0	0.6	0.6
	JUK3		2.5	0.2	5.0	0.7	0.7
	JUK4		3.0	0.4	2.7	0.7	0.7
24/08	JUK1	29	27	0.9	0.9	2.3	1.9
	JUK2	4.5	2.5	0.3	2.2	0.6	0.6
	JUK3	4.8	2.5	0.3	3.3	0.6	0.5
	JUK4	6.0	3.5	0.3	2.0	0.8	0.7
07/09	JUK1	38	27	0	1.0	6.0	5.9
	JUK2	5.0	3.1	0.4	2.2	1.3	1.3
	JUK3	6.0	5.0	0.3	1.6	1.9	1.8
	JUK4	7.5	7	0.3	1.2	2.6	2.5
21/09	JUK1	24	17	<0.05	<0.1	2.7	2.1
	JUK2	3.5	2.5	0.5	1.5	0.6	0.5
	JUK3	6.0	0.8	0.9	1.2	0.8	0.4
	JUK4	6.0	0.5	1.2	0.8	0.8	0.4
28/09	JUK1	24	16	0	<0.1	2.8	2.0
	JUK2	5.6	4	0.3	1.1	0.7	0.7
	JUK3	4.5	3.5	0.2	1.0	0.7	0.7

12/10	JUK1	60	52	0.2			230
	JUK2	49	63	0.2			170
	JUK3	47	43	0.2			175
	JUK4	49	44	0.3			180
01/11	JUK1	27	45	0.25	0.06	1	110
	JUK2	26	40	0.25	0.1	0.9	110
	JUK3	23	41	0.26	0.04	0.8	90
	JUK4	22	46	0.25	0.04	0.9	90
09/11	JUK1	30	32	0.2			120
	JUK2	31	32	0.2			125
	JUK3	27	30	0.2			115
	JUK4	26	33	0.2			110
16/11	JUK1	41	39	0.1			160
	JUK2	32	27	0.1			120
	JUK3	28	25	0.1			110
	JUK4	27	23	0.1			110
23/11	JUK1		83	0.1			
	JUK2		58	0			
	JUK3		58	0			
	JUK4		58	0			
07/12	JUK1	33	48	0			140
	JUK2	30	42	0			110
	JUK3	25	40	0			95
	JUK4	25	43	0			93
18/01	JUK1	37	61				120
	JUK2	35	53				115
	JUK3	30	53				100
	JUK4	28	53				100
01/02	JUK1	39	62				150
	JUK2	36	56				110
	JUK3	26	56				110
	JUK4	59	54	0	<0.01	0.4	245

Table 3 - Concentrations of ions monitored for routinely in the Jukskei river

DATE	SAMPLE POINT	Cl⁻ IN mg/l	SO_4 IN mg/l	F⁻ IN mg/l	Pb IN mg/l	Fe IN mg/l	ALKALINITY AS $CaCO_3$ IN mg/l
12/07	JUK1	57	71	0	<0.01	0.5	210
	JUK2	54	64	0	<0.01	0.4	185
	JUK3	50	62	0	<0.01	0.5	155
	JUK4	47	61	0	<0.01	0.6	147
03/08	JUK1	61	92	0	<0.01	0.4	225
	JUK2	53	77	0	<0.01	0.6	180
	JUK3	50	69	0	<0.01	0.4	160
	JUK4	50	68	0	<0.01	0.5	160
10/08	JUK1	56	74	0	<0.01	0.5	240
	JUK2	43	65	0	<0.01	0.4	130
	JUK3	44	58	0	<0.01	0.4	150
	JUK4	46	61	0	<0.01	0.4	150
24/08	JUK1	59	82	0	<0.01	0.5	210
	JUK2	46	66	0	<0.01	0.4	140
	JUK3	46	61	0	<0.01	0.4	130
	JUK4	47	57	0	<0.01	0.4	150
07/09	JUK1	69	76	0	<0.01	0.4	270
	JUK2	52	64	0	<0.01	0.5	160
	JUK3	53	58	0	<0.01	0.4	170
	JUK4	50	59	0	<0.01	0.4	190
21/09	JUK1	75	72	0	<0.01	0.5	215
	JUK2	61	66	0	<0.01		145
	JUK3	68	58	0	<0.01	0.4	135
	JUK4	70	57	0	<0.01	0.5	135
28/09	JUK1	60	72	0.4	<0.01		220
	JUK2	49	54	0.4			160
	JUK3	48	50	0.4			160
	JUK4	30	49	0.4			170

	JUK2	29	230	7.0	11	518
	JUK3	15	227	7.1	7.2	470
	JUK4	13	232	7.7	8.1	458
G1/02	JUK1	7.0	289	5.8	5.2	58
	JUK2	6.0	230	6.9	4.8	46
	JUK3	6.0	227	7.4	5.0	45
	JUK4	2.0	232	7.1	4.8	46

TABLE 2 - Comparison of the concentration of inorganic ions in the soil of the river bed, the river bank and in the water.

ANALYSIS	RIVER BANK SOIL SAMPLES (all values in mg/kg)		RIVER BED SOIL SAMPLES (all values in mg/kg)		RIVER WATER (all values in mg/l)	
	Alex sewage works weir.	Bucc-leuch	Alex sewagework s weir	Bucc-leuch	Alex sewage works weir	Bucc-leuch
CHLORIDE AS Cl	200	110	480	120	61	50
ALKALINITY AS $CaCO_3$	2460	2180	960	1540	225	160
AMMONIA AS N	300	400	120	240	19	3
NITRATE AS N	<2.0	<2.0	<2.0	<2.0	0.6	3.5
PHOSPHATE AS P	12	14	8	14	2.8	1.0
COD AS 0	1400	1500	1000	1500	100	41
SULPHATE AS SO_4	840	1180	880	920	92	69
CALCIUM AS Ca	820	760	400	520	48	46
SODIUM AS Na	100	76	140	70	43	30
POTASSIUM AS K	58	60	94	50	9.8	5.8
MAGNESIUM AS Mg	80	60	40	40	17	17

	JUK2	13	410	7.7	6.9	67
	JUK3	30	400	8.0	6.0	67
	JUK4	16	390	7.9	5.4	67
28/09	JUK1	54	580	7.6	25	77
	JUK2	18	390	7.9	7.7	60
	JUK3	27	400	8.3	7.3	59
	JUK4	27	350	8.3	5.3	59
12/10	JUK1	24	420	7.8	3.7	78
	JUK2	39	330	8.6	6.4	65
	JUK3	15	590	8.8	6.0	61
	JUK4	11	360	8.5	3.9	64
01/11	JUK1	32	280	7.5	10	41
	JUK2	28	260	7.6	3.9	40
	JUK3	22	250	7.9	2.7	38
	JUK4	22	260	7.8	4.1	38
09/11	JUK1	18	280	7.7	20	46
	JUK2	11	280	8.0	15	49
	JUK3	7.5	270	8.1	11	45
	JUK4	12	270	7.8	11	44
16/11	JUK1	13	270	7.9	13	58
	JUK2	9	280	8.2	6.7	48
	JUK3	6	260	8.4	6.5	43
	JUK4	9	260	8	6.2	44
23/11	JUK1	6	390	7.9	10	74
	JUK2	12	340	8.6	7.2	57
	JUK3	28	340	8.7	8.8	57
	JUK4	12	360	8	8.1	58
07/12	JUK1		300	7.4	16	48
	JUK2		295	7.6	11	46
	JUK3		260	7.8	11	41
	JUK4		250	7.7	8.8	40
18/01	JUK1	34	389	6.8	15	529

APPENDIX A

JUK1 : ALEXANDRA SEWAGE WORKS WEIR - 0.0km

JUK2 : FRANKENWALD WEIR, MARLBORO DRIVE - 2.1km

JUK3 : GRAYS 'ON BRIDGE BUCCLEUCH - 4.2km

JUK4 : BEFORE MODDERFONTEIN CONFLUENCE - 5.8km

TABLE 1 - PHYSICAL PARAMETERS MEASURED IN THE JUKSKEI RIVER

DATE	SAMPLING POINT	SS/ mg/l	TDS/ mg/t	pH	TURBIDITY IN NTU	CONDUCTIVITY IN mS/m
12/07	JUK1	43	450	7.5	30	71
	JUK2	19	335	7.5	16	66
	JUK3	5	301	7.5	10	60
	JUK4	4	294	7.5	6.1	58
03/08	JUK1	45	362	7.6	7.2	75
	JUK2	22	329	7.6	4.8	65
	JUK3	6	298	7.8	4.5	61
	JUK4	4	310	7.9	3.8	60
10/08	JUK1	40	358	7.7	20	67
	JUK2	17	301	7.7	4.4	60
	JUK3	5	302	7.9	4.4	60
	JUK4	4	310	7.8	5.3	60
24/08	JUK1	52	420	8.1	9.0	78
	JUK2	12	360	7.8	8.9	59
	JUK3	18	310	8.0	5.3	60
	JUK4	13	350	8.0	5.1	60
07/09	JUK1	90	480	7.8	7.1	81
	JUK2	18	410	7.8	4.9	60
	JUK3	22	400	8.1	7.9	61
	JUK4	28	440	8.1	9.0	62
21/09	JUK1	32	390	7.5	22	84

Helminth eggs can also be limited by the heat of composting, or by prolonged storage (Cairncross and Feacham, 1993).

The engineering solutions proposed in the above section would probably only be of limited effectiveness in reducing the pollution load to the Jukskei River unless the social problems in Alexandra are met. The improvement of the general standard of living and reducing the overpopulation in the area would have more positive results.

7.3.2 Recommendations for further research

Further research into the provision of inexpensive treatment options to the townships would be invaluable for the reduction of pollution in the rivers. These would greatly reduce the risk of the transmission of diseases for the water users.

Due to the constant influx of people to the townships there is little chance that the provision of water-borne sewerage can keep up with the ever increasing demand. Diversion systems like ponds or wetlands could be implemented to collect the runoff and treat it before it is discharged into the water. Buffer strips and other vegetated infiltration systems could also be built to reduce the pollution potential. Chemical treatment systems like disinfection with chlorine and other derivatives could be used for the reduction of faecal coliforms. This would reduce the health risk to the downstream water users.

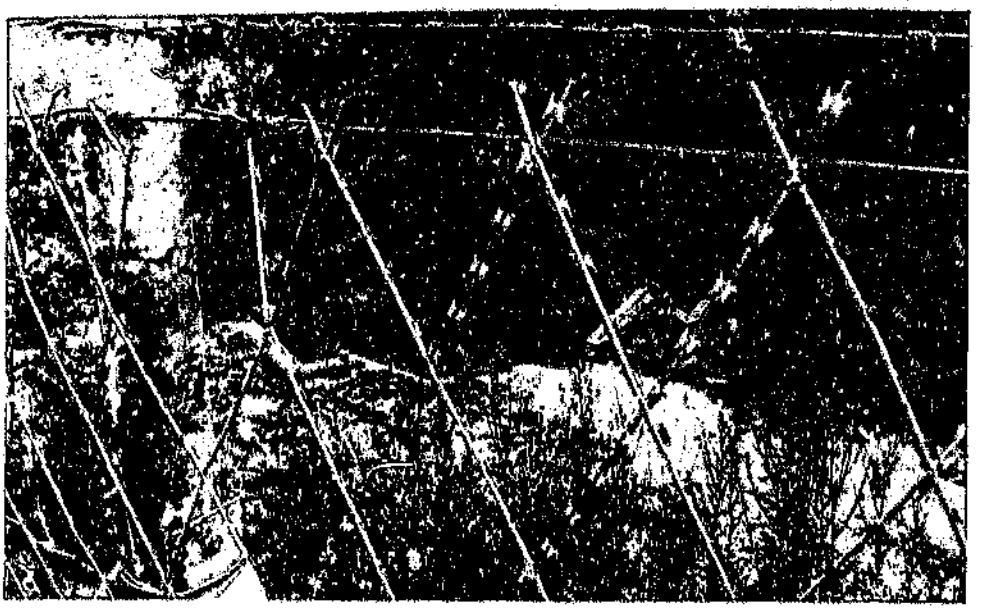
The different treatment systems used could then be evaluated in terms of their cost of building and maintaining the system, the pollution assimilative capacity of the treatment system and the effect it has on the river to which it is discharged. The ability of the system to withstand vandalism would also have to be a priority.



Water running off catchment into the Jukskei River at Buccleuch during the storm event



Runoff from Linbro Landfill Site



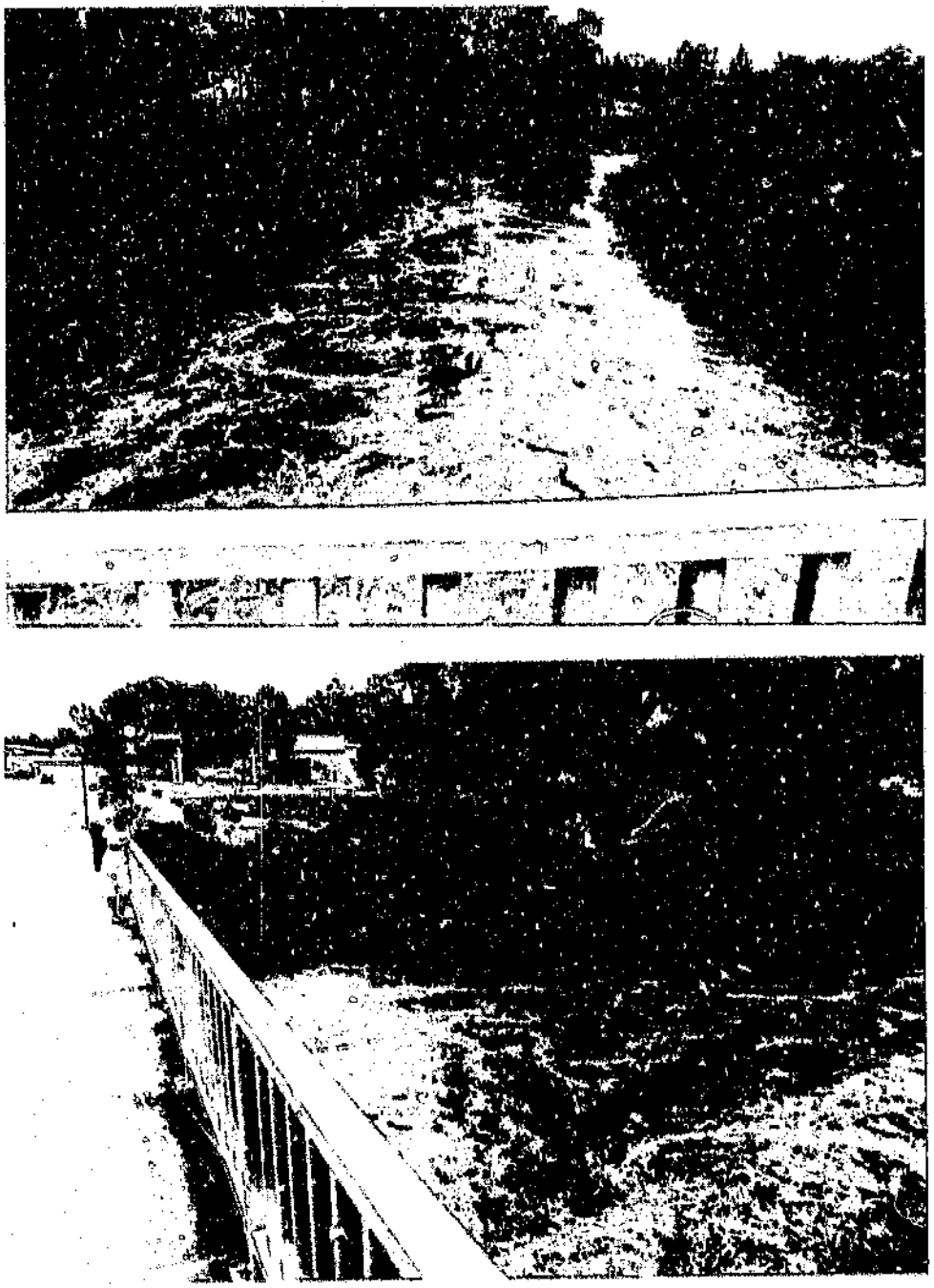
Culvert in Linbro Landfill Site into which water runs which is then carried to the Jukskei River just below Alexandra Township



Low - Lying Bridge in Buccleuch under water



Monitoring point 4 (Just before the Modderfontein Spruit Confluence) during the storm event



Buccleuch/Gibson Drive Bridge during the storm event

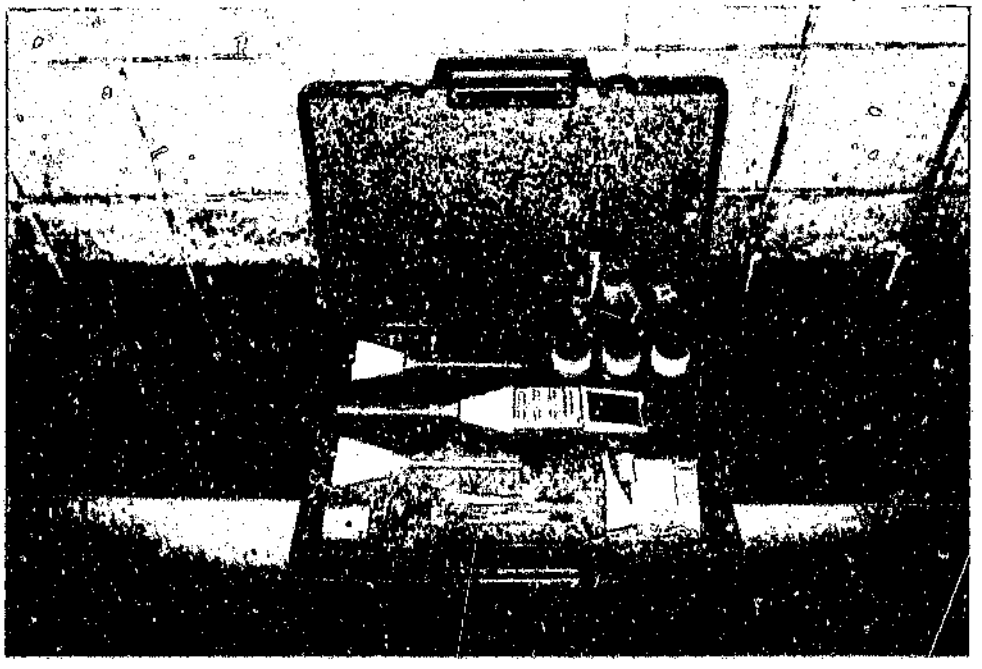
JUKSKEI RIVER STORM EVENT (29/11/1996)



Alexandra/Marlboro Bridge during the storm event



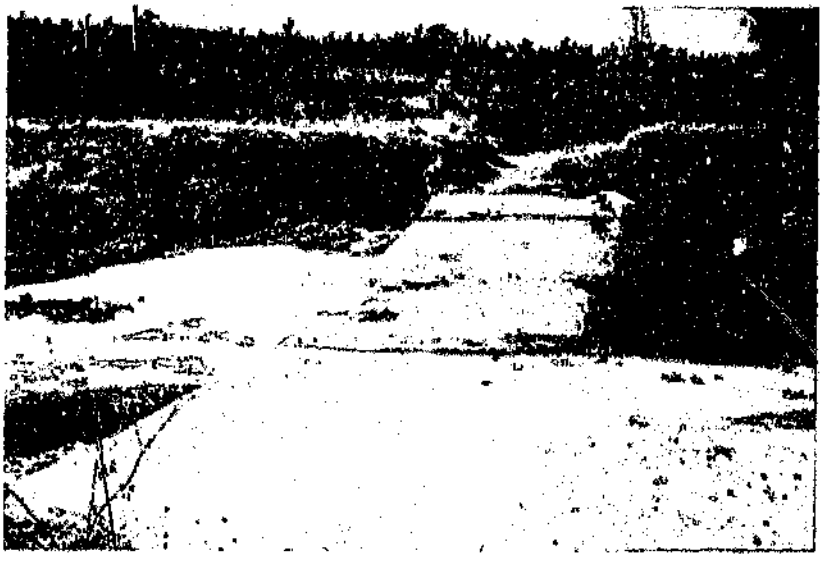
Monitoring Point 4 (JUK4) - (Modderfontein Confluence/Buccleuch)



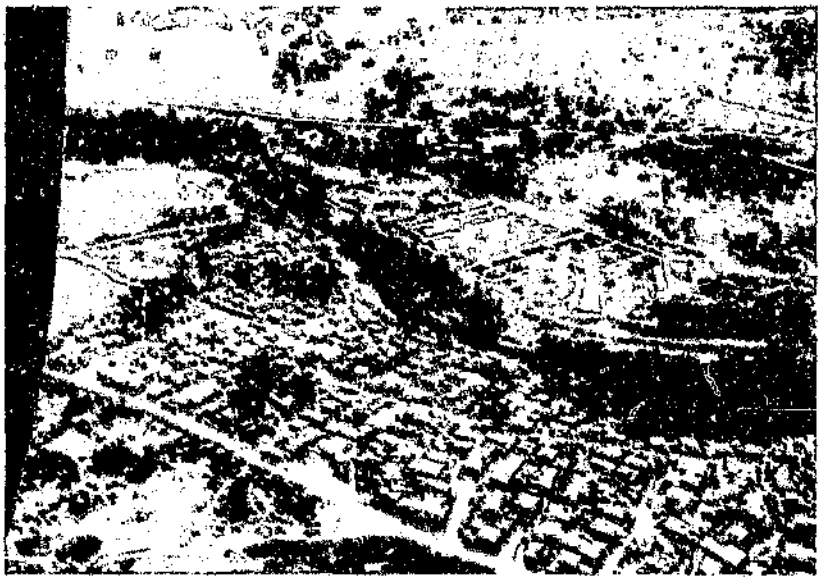
Checkmate System used for the in-field measurement of DO, pH, Conductivity and TDS



Weir used for flow measurements at Frankenwald (JUK2)



Monitoring Point 3 (JUK3) - (Gibson Drive/Buccleuch)



Old Sewage Works at Alexandra where first monitoring point was situated.

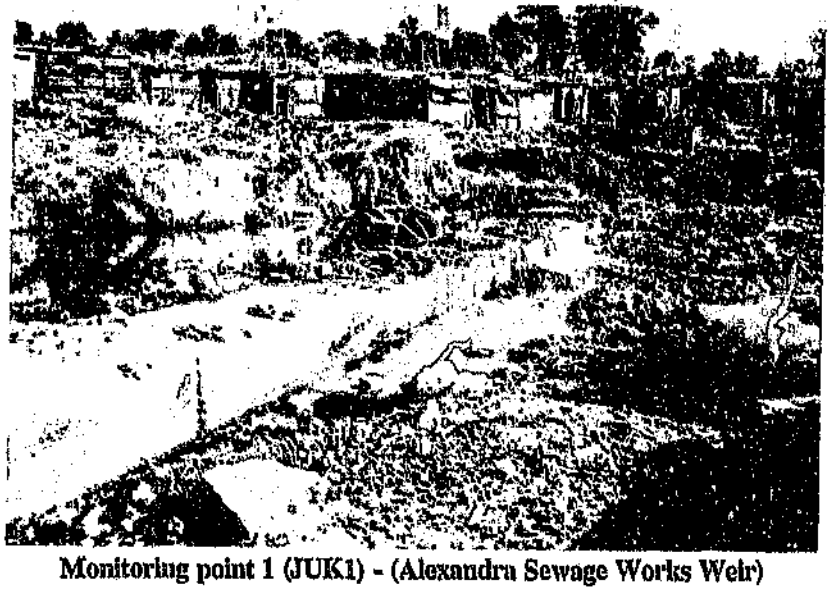


Monitoring point 2 (JUK2) - (Frankenwald/Marlboro Drive)



Squatters on the East Bank which is zoned for Formal Housing

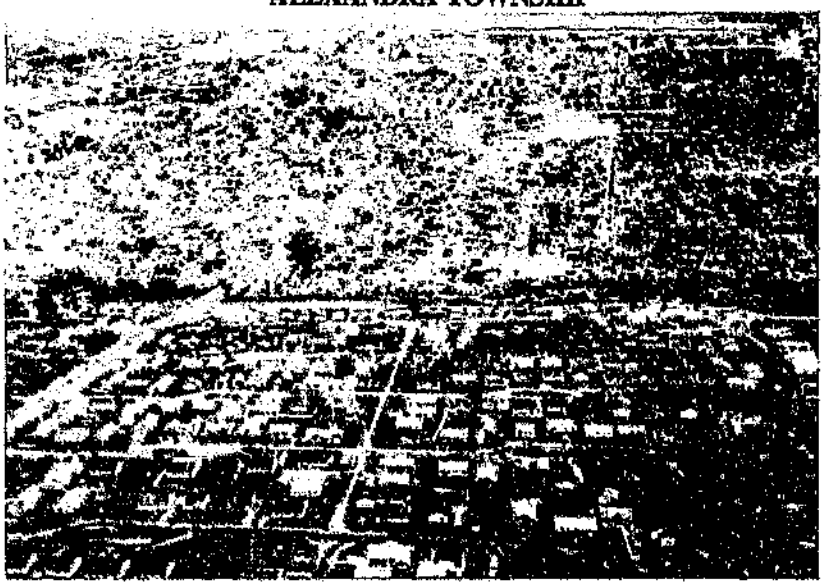
JUKSKEI RIVER MONITORING POINTS DURING LOW FLOW
(JULY - SEPTEMBER 1994)

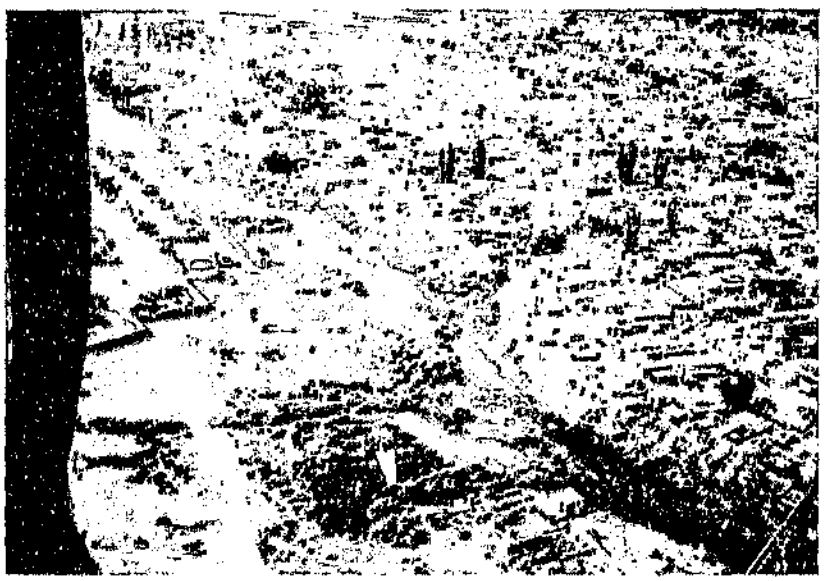


Monitoring point 1 (JUK1) - (Alexandra Sewage Works Weir)

APPENDIX B

ALEXANDRA TOWNSHIP





East Bank (Formal Housing) and West Bank (Informal Housing)

01/02	JUK1	5000	1500
	JUK2	140	100
	JUK3	52	5
	JUK4	35	2

28/09	JUK1	31000	3900
	JUK2	7000	330
	JUK3	2200	130
	JUK4	1400	170
12/10	JUK1	8000	1900
	JUK2	400	110
	JUK3	200	80
	JUK4	100	40
01/11	JUK1	1600	6000
	JUK2	950	650
	JUK3	100	43
	JUK4	160	22
09/11	JUK1	-	-
	JUK2	-	-
	JUK3	-	-
	JUK4	-	-
16/11	JUK1	10000	2700
	JUK2	1100	40
	JUK3	80	4
	JUK4	50	5
23/11	JUK1	9000	3000
	JUK2	160	16
	JUK3	60	11
	JUK4	35	5.7
07/12	JUK1	18000	8000
	JUK2	1000	1000
	JUK3	140	93
	JUK4	140	94
18/01	JUK1	1600	210
	JUK2	3000	300
	JUK3	150	1.6
	JUK4	65	26

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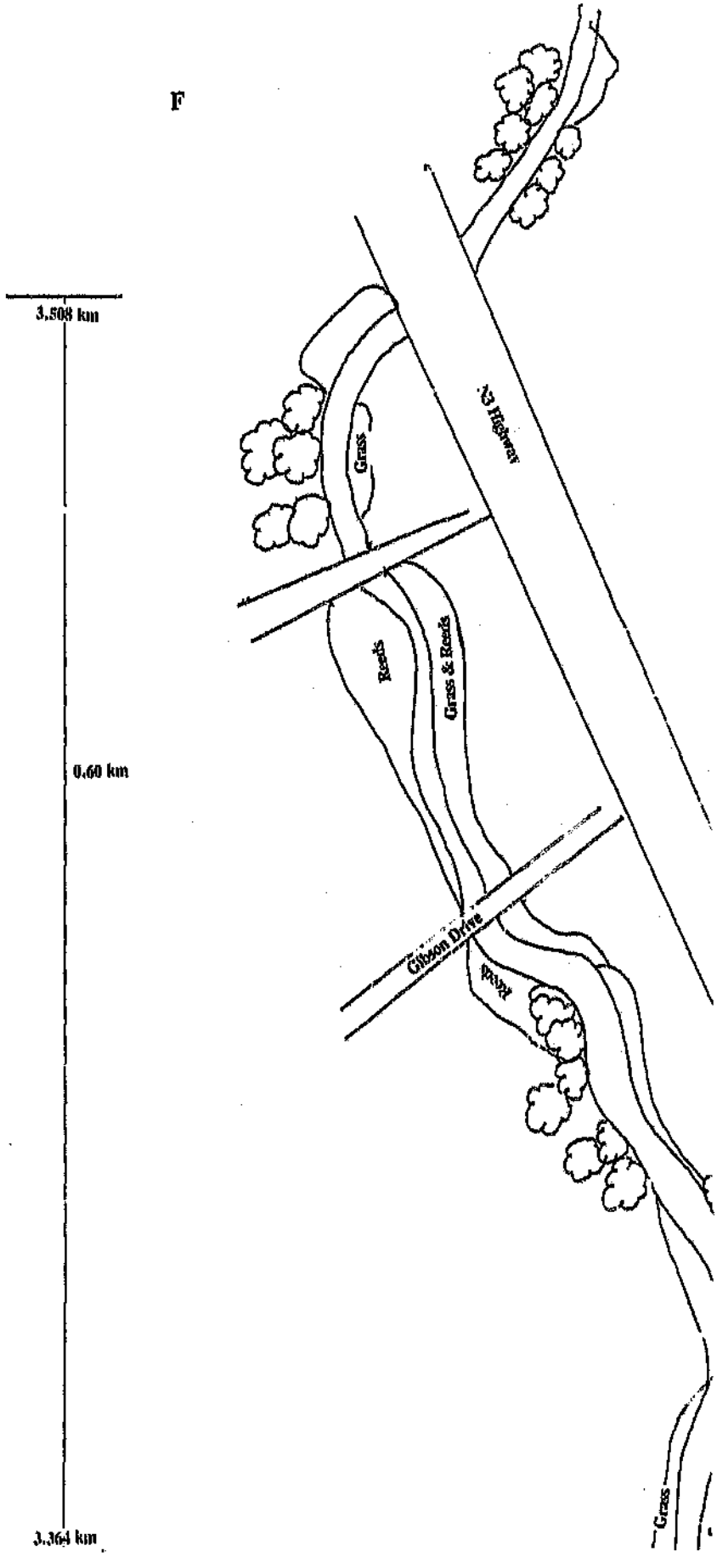
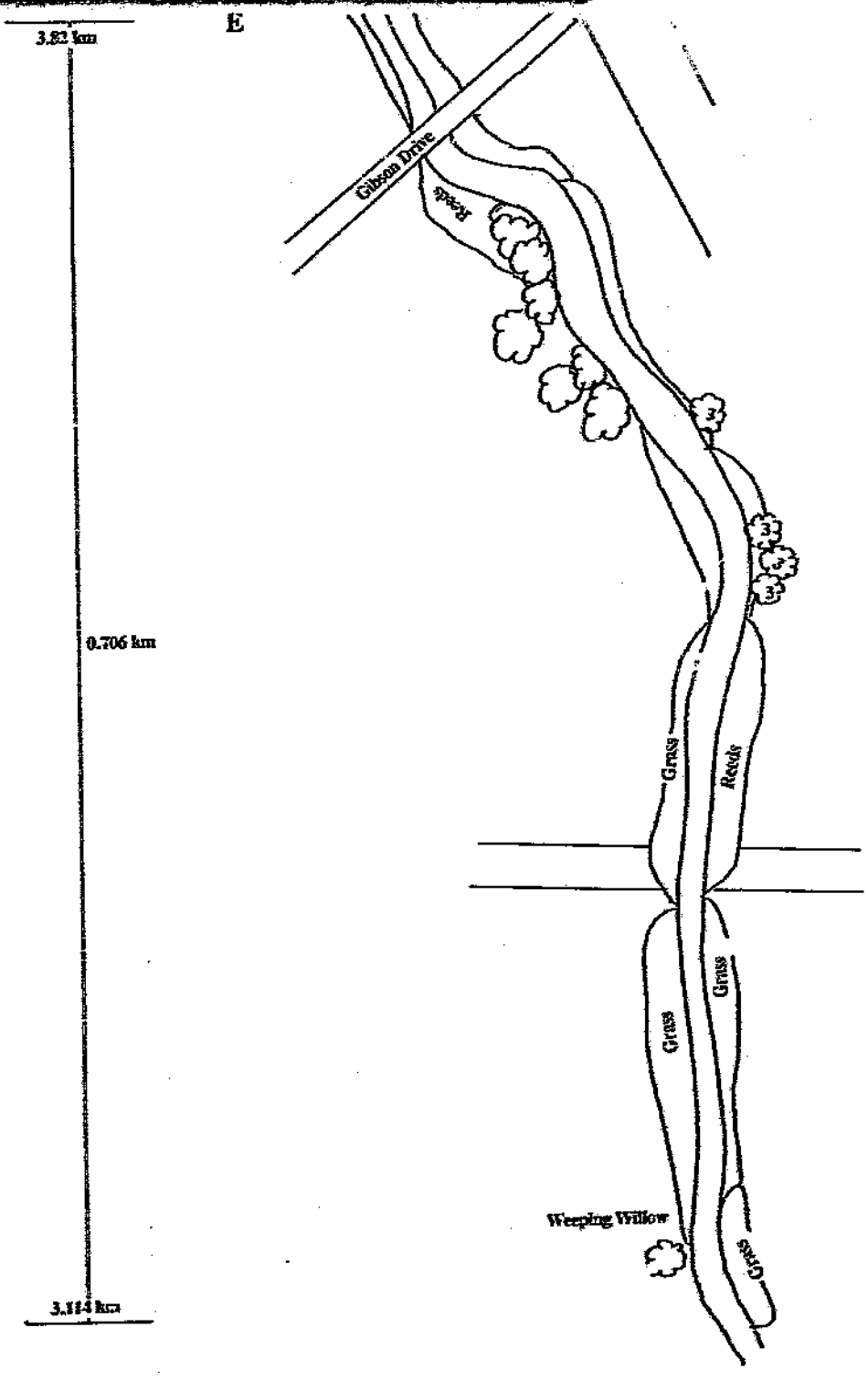
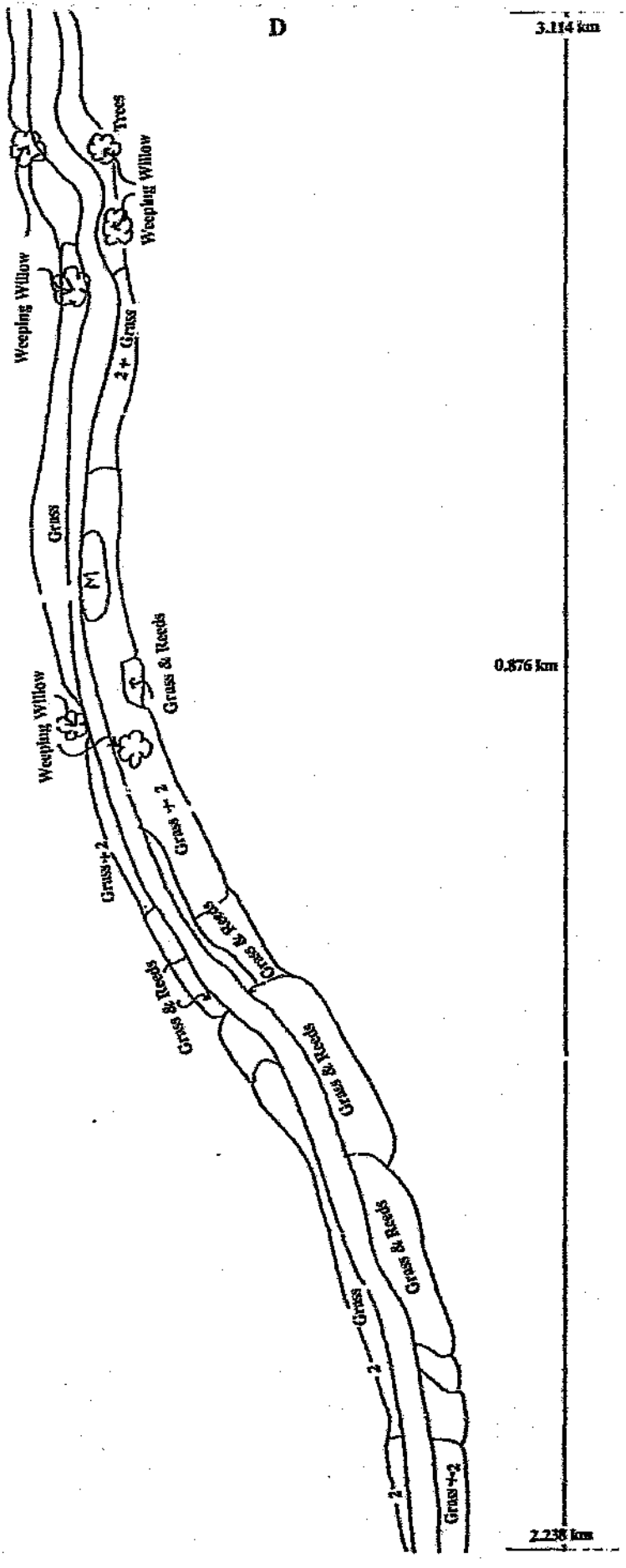
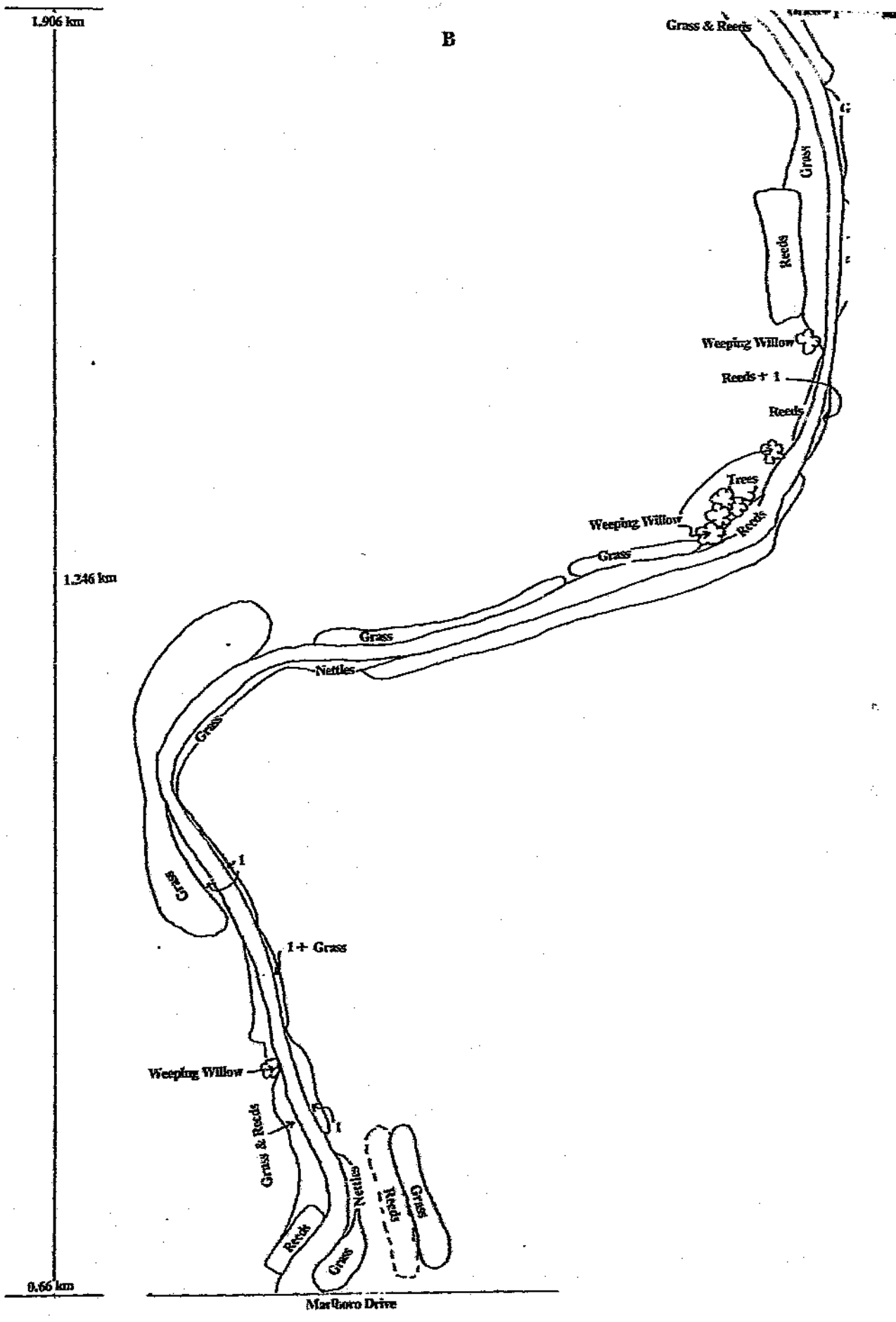

3.508 km
0.60 km
3.364 km
Grass
N3 Highway
Rocks
Grass & Rocks
Gibson Drive
gravel
Grass


E
3.82 km
0.706 km
3.114 km
Gibson Drive
Reeds
Grass
Reeds
Grass
Grass
Weeping Willow
Grass

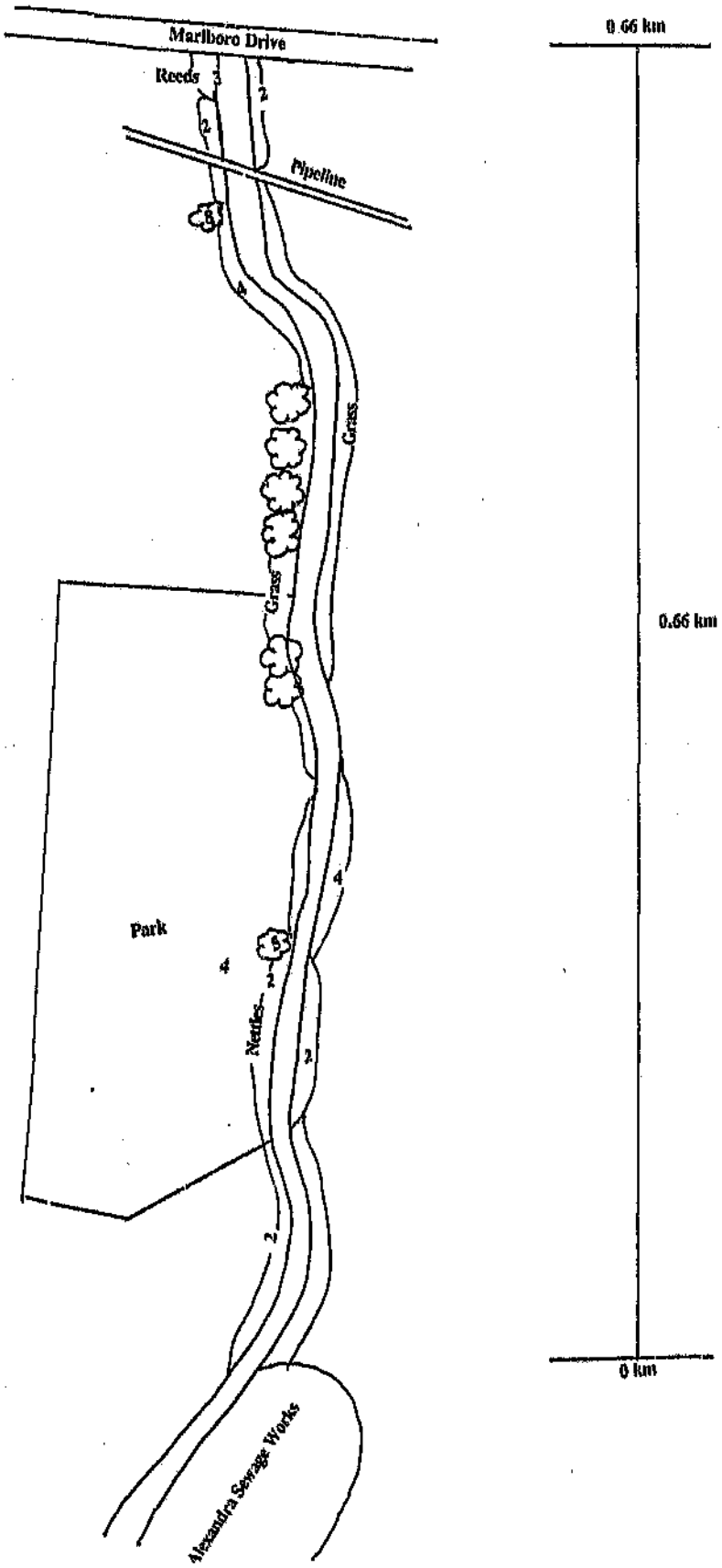

D
3.114 km
0.876 km
2.238 km
Trees
Weeping Willow
Weeping Willow
Weeping Willow
2+ Grass
Grass
M1
Grass & Reeds
Grass +2
Grass +2
Grass & Reeds
Grass & Reeds
Grass & Reeds
Grass & Reeds
Grass
2
2
Grass +2

C

2.786 km
0.88 km
1.906 km
Weeping Willow
Grass & Ree
Grass + 2
Grass & Reeds
Grass & Reeds
Grass & Reeds
Grass
2
Grass + 2
Grass + 2
Trees
Grass & Reeds
Grass
Grass
Grass & Reeds
Reeds


B
1.906 km
1.246 km
0.66 km
Grass & Reeds
Grass
Reeds
Weeping Willow
Reeds + 1
Reeds
Trees
Weeping Willow
Reeds
Grass
Grass
Nettles
Grass
Grass
1
1 + Grass
Weeping Willow
Grass & Reeds
1
Nettles
Reeds
Grass
Reeds
Grass
Marlboro Drive

A


Marlboro Drive
Reeds
Pipeline
Grass
Grass
Park
Nettles
Alexandra Sewage Works
0.66 km
0.66 km
0 km

APPENDIX D

RIPARIAN VEGETATION ALONG THE JUKSKEI RIVER

Key for the identification of the vegetation

1 - *Persicaria lapathifolia*

2 - *Persicaria lapathifolia*

1 & 2 are grasses. Where grass is labelled on the maps these are most often of the above species.

3 - Family Poaceae / Graminae

Labelled as 3 or Reeds on the maps. It looks like reeds but is actually a type of grass.

4 - *Acacia mearnsii*

5 - *Mirabilis jalapa*

6 - *Morus alba*

7 - *Argemone ochraleuca* ssp. *ochraleuca*

8 - *Eucalyptus camaldulensis*

Labelled 8 or trees on the map.

All of the specimens, with the exception of the reeds/grass are exotic plants and not indigenous.

The vegetation identified along portions of the Jukskei River banks from Alexandra to Buccleuch are set out in the following 6 pages.

Martin Creamer's
Engineering News
R5,00 Vol 15 no 14 April 13 1995 ISSN 0257-9848 Every Fri

Jukskei - River of Deat

Terence Creamer
Engineering News Staff Writer

The biggest natural disaster in the history of South Africa, involving an estimated 10 000 people, could happen any day as thousands of people continue to settle on the banks of the Jukskei river in the Gauteng township of Alexandra, three top Jukskei monitors reveal this week.

The Jukskei is extremely important to Gauteng, draining 11 municipal areas and has a million people living in its vicinity, 650 000 in Alexandra, they say.

However, more and more people are building houses very close to the river bank and the lack of planning has led to inadequate sanitation and refuse removal, turning parts of the river into a rubbish dump with an alarming bacteria count calculated to be 10 000 times higher than acceptable levels on certain parts of the river.

More than 6 000 people live below the 50 year flood level and hundreds are living on land that forms part of the river channel itself.

The hazard was highlighted last month when soft soaking rains of 78mm washed away shacks and left about 600 people homeless.

Water engineer Professor Will Alexander of the University of Pretoria tells *The Engineering News* a flash flood would put the lives of thousands at risk.

"Last month's flood was not big by any stretch of the imagination and yet hundreds of houses were washed away," Alexander explains.

There is increasing pressure from township community on the authorities to act and solutions are being researched by the Department of Water Affairs and Forestry.

The ANC Science and Technology Group has also entered the debate and is monitoring the river.

The group's chairperson [illegible] Rayner says overcrowding and the lack of infrastructural investment has produced a sewerage system grossly ill-equipped to provide services for the population and has created a situation dangerous to thousands.

"If the rains that fell last month were torrential and not soft it could have been the biggest disaster, in terms of loss of life, ever to hit South Africa," Rayner says.

It is impossible to predict when the river will flood, but when it does, Rayner estimates that up to 10 000 people and their homes will be at serious risk.

"If the rains are heavy enough and occur at night a large number of people will be drowned," Rayner adds, warning that what is happening to the Jukskei now may happen to the Vaal in the future unless drastic measures are adopted.

Alexander [illegible] against [illegible] the already [illegible] channel as [illegible] suggested.

He says the structure would just serve to narrow the channel and therefore raise the water level in the river.

In the event of flooding the wall would offer even less security than the bank does now.

Alexander says residents are aware of the dangers but refuse to move because of the shortage of land in the township.

Relocation of squatters is a highly contentious issue and matters are compounded in Alexandra as all vacant land on the East Bank is earmarked for formal development.

The pressure for open space has forced people to dump refuse into the river channel to create a platform of waste on which to build informal houses, he says.

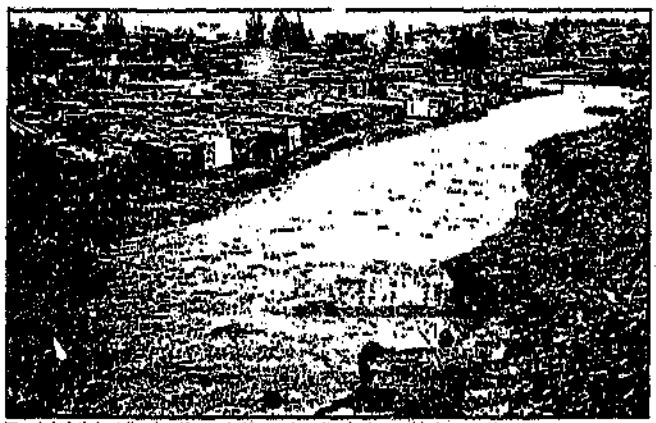
The Department of Water Affairs and Forestry, also concerned about the situation in Alexandra, has taken it upon itself to develop recommendations to the Gauteng legislature to solve the crisis.

> "Last week's flood was not big by any stretch of the imagination and yet hundreds of houses were washed away."
> Prof Will Alexander

Fred van Zyl from the department and chairperson of the Jukskei Steering Committee says the township has the highest density of single storey dwellings in the world and that flooding as well as the threat posed to the health of people is of concern.

The Jukskei is massively polluted mainly as a result of inadequate sewage treatment, overuse by people and abuse by industry.

Although only the Leeukop prison uses water from the river for irrigation the Jukskei's potential as a recreation source is being eroded daily.



The Jukskei river flowing through Alexandra after last month's heavy rains.

The most serious [illegible] in the quality of wa[illegible] high counts of Escl[illegible] coli (E coli) bacteria.

E coli, a bacterium wh[illegible] helps humans to digest [illegible] is found in human excre[illegible] and is a common measu[illegible] the level of pollution in [illegible]

Drinking water shoul[illegible] no E coli; water with up [illegible] counts/100ml can be use[illegible] irrigating vegetables an[illegible] dren can safely swim in [illegible] with less than 120 count.

Measurements for the Jukskei are astounding.

Water in Sandton has frightening 3 000 to 50 [illegible] counts while the water d[illegible] stream from Alexandra [illegible] more than partially dilu[illegible] human waste with betw[illegible] one and eight million co[illegible]

If drunk this water w[illegible] result in certain illnesses li[illegible] gastro-enteritis and may even kill y[illegible] children due to dehydration caused diarrhoea.

People that live on the banks of t[illegible] Jukskei do not have access to prop[illegible] litation and there has been no plann[illegible] the treatment of effluent.

Van Zyl says the department has [illegible] ous programmes to reduce pollution [illegible] is spending more than R1-million a[illegible] to combat the problem.

A campaign, Work-to-Win, has [illegible] launched involving 110 schools wh[illegible] fall inside the Jukskei catchment ar[illegible] community organisation and local authorities to clean up the river.

Another significant polluter is th[illegible] chemical contamination, mainly a[illegible] nia and nitrate - both toxic to aqua[illegible] - from the Modderfontein spruit.

High concentrations of these ch[illegible] cals have [illegible] treated fish life in the [illegible] and also play a role in killing the fi[illegible] the onset of winter at the confluen[illegible] the Crocodile and Jukskei rivers.

Sulphates, fluorides and nitrates [illegible] the Modderfontein spruit can also [illegible] human health.

While no water from the river is [illegible] ctially used for drinking, its water [illegible] for for household purposes.

The polluting companies are sp[illegible] millions to clean their systems and permits are being updated, enforc[illegible] stricter controls over chemicals th[illegible] into the Jukskei, says Alexander.

ENGINEERING NEWS CLUB [illegible] on the page [illegible]

APPENDIX C

NEWS

THE STAR / WEDNESDAY FEBRUARY 1 1995

Surrounding municipalities powerless to help

Jukskei: 'Nothing we can do'

METROPOLITAN council has not delegated powers to allocate money for clean-up of highly contaminated river

BY ANNA COX

Although the bacterial counts in the Jukskei River have reached crisis proportion, surrounding municipalities say they are unable to act as they have not yet been delegated powers by the Greater Johannesburg Transitional Metropolitan Council (TMC).

These powers are needed to allocate funds to clear blocked drains which are causing raw sewage to spill into the river daily.

Recent studies show that the bacterial count in the river is 12 million per 100 ml of water, while the normal count for water for recreational purposes should be 200.

Sandton administration public relations officer Deleen van Wyk said that at this stage Sandton officials did not have the authority to go into Alexandra to assist with the clearing of drains.

Nkele Ntingane, executive committee chairman of the North Eastern Metropolitan Substructure, which includes Sandton and Alexandra, said nothing could be done until powers had been delegated.

"Once this has been done, Alex will become a priority area for the new local authority. We realise the situation is very serious but there is nothing we can do," she said.

The Jukskei River water quality management steering committee has been monitoring the bacteria counts in the river in the past year.

Randburg, Sandton and Alexandra municipal officials, a representative of the Department of Water Affairs and a firm of consulting engineers serve on the committee, which meets once a month to discuss the problems. A full report is issued every two mor

F or Hermine van Dyk, who serves on the committee, said: "We are assisting and training unemployed youths, through the Work to Win project, on how to clear and maintain the drains and we have embarked on a major educational campaign teaching residents not to litter and pollute and not to throw things into drains. We need more funding to clear out all the drains."

Work to Win co-ordinator Moshe More said funding was a problem.

"We have been given R158 000 by the TMC, but it will only last us six months and we have only been able to do a small section of Alex. Already we can see the difference in the streets where the drains have been cleared.

"There is no longer dirty, smelly water running down the streets. We are educating people on a door-to-door basis and distributing pamphlets to teach people how to use the services properly. We want to see a clean environment of which we can all be proud," More said.



Health hazard . . . the water from the contaminated Jukskei River which flows through Alexandra is used daily by residents despite its high content of bacteria. Here Elizabeth Jacobs collects stones from the river to make a pavement outside her shack. Flooding of the shacks is an added danger. PICTURE: JODI BIEBER

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Name of thesis: A study of stormwater runofff from Alexandra township in the Jukskei River.

PUBLISHER:
University of the Witwatersrand, Johannesburg
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