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NON-POINT SOURCE POLLUTION IN THE HENNOPS RIVER VALLEY

Report to the
WATER RESEARCH COMMISSION
by
WATES, MEIRING & BARNARD

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A CASE STUDY OF STORMWATER POLLUTION CONTROL IN A REPRESENTATIVE VALLEY

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EXECUTIVE SUMMARY

BACKGROUND

Sources and causes of pollution can be classified either as point[1] or non-point[2] contributors. Traditionally domestic and/or industrial waste water is collected in the sewer system and treated at the endpoint to the Specified Standards. However, where dealing with non-point (diffuse) sources the term "management" is used instead of treatment and removal. In the U.S.A., Best Management Practices (BMP) are employed and commonly imply non-structural or low-structural, typically on-site measures. These are effective in controlling non-point source pollution from the various land use activities.

There are no clear abatement strategies for non-point source pollution control in South Africa. This was cited in the Report on "Urban Stormwater Runoff on the Quality of Water Resources in South Africa" prepared by J.L. Barnard, Wates Meiring & Barnard. The result is that, in many instances where cost effective methods could have been used for combatting non-point source pollution, nothing was done.

The literature survey of the above report indicated that there are two approaches to this problem. The first being the quantitative approach, requiring detailed studies over long periods of time. The second approach is qualitative and identifies the worst cases of pollution. These cases are by eliminating 80% of the pollution load at 20% of the cost and thus referred to as the 80/20 approach.

Wates Meiring & Barnard recognised the need to evaluate the 80/20 approach as a method of initiating prescriptive measures for non-point source pollution in a representative valley and proposed the present study to the Water Research Commission.

1 *Point sources of pollution are defined as pollution that enters transport routes at discrete, identifiable locations and can usually be measured. Major point sources under this definition include sewered municipal and industrial effluents (Novotny, 1994).*

2 *Non-point sources are simply "everything else" and include diffuse, difficult to identify and quantify sources of pollution. It can result from any activity which produces contaminants that enter the receiving water body in an intermittent and diffuse manner related mostly to the occurrence of meteorological events.*

OBJECTIVES

The objectives of the study are as follows:

- Monitor point source and non-point source pollution in the Hennops River Valley during base flow and stormwater flow conditions for 12 months.

- Assess the pollution mass loads from the various land users.

- Identify pollution sources and their effects on the receiving water quality.

- Prepare pollution control strategies based on the 80/20 approach for improving the quality of polluted water from industries, informal and formal settlements in the Hennops River Valley.

- Present general abatement strategies for controlling non-point source pollution.

THE STUDY AREA

The Hennops River Valley was selected for this study as it represents a variety of land users. These are for example formal and informal housing, commercial and industrial development, point sources and agriculture. The catchment under consideration extends from its source at Kempton Park/Chloorkop in the south to the outlet of the Centurion Lake (Verwoerdburg Lake) in the north. The upper reaches of the catchment is of an entirely residential nature and contains formal housing (permanent structures) with waterborne sanitation and informal housing (shacks) with minimal services and on-site sanitation, (LOFLOS - low flush on-site anaerobic digester). The northern part of this catchment is a mixture of residential (Olifantsfontein), commercial and industrial (Clayville) development with waterborne sanitation. Stormwater from the industrial development drains into a concrete lined drainage channel which passes through the middle of Clayville in a northerly direction towards the Kaalspruit. This channel is a major tributary of the Kaalspruit during storm events, but is a minor contributor under dry weather conditions.

Beyond the confluence of the Kaalspruit and the Clayville tributary, the Olifantspruit catchment drains into the Kaalspruit. The Olifantspruit catchment consists mainly of agricultural holdings with on-site sanitation (a combination of septic tanks and french drains). Stormwater runoff is from agricultural and undeveloped land.

Downstream of the confluence of the Kaalspruit and Olifantspruit, the effluent from the Olifantsfontein Waste Water Treatment Works discharges as a major point source into the Olifantspruit. The catchment between the Olifantsfontein Treatment Works and the Centurion Lake is mainly of an agricultural nature. There are however some residential and office developments at Irene and Verwoerdburg CBD using waterborne sanitation.

MONITORING NETWORK

An initial field reconnaissance showed that the monitoring network would have to be on a macro scale. Both the nature of the catchment and the poor security situation discouraged the establishment of any monitoring structures. The different sub-catchments were investigated with respect to the stormwater runoff, different types of land users and activities. This was done so as to site the water quality monitoring points and rudimentary flow measurements.

The sampling had to be done manually during daylight hours as the security situation did not allow for the installation of automatic samplers. Routine sampling consisted of "grab" samples at the 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 five selected sites after a storm event in the catchment. Whenever possible in-situ flow measurements were conducted at the sites, but this was not always possible due to the high flows in the stream and the security situation in Tembisa and Ivory Park.

STUDY RESULTS

Non-point source runoff originating in the upper reaches of the Hennops River Valley catchment is polluted throughout the year. The base flow and storm event pollution is predominantly of a microbiological nature and is similar in concentration and unit export load to studies elsewhere in South Africa. The trace metal concentration compares well with the values observed in other similar studies.

The major source of pollution is solid waste and faecal contaminants. These are as a result of deliberate pipe blockages in Tembisa, the high population density, ineffective on-site sanitation facilities in Ivory Park, leachate from accumulated solid waste, inadequate maintenance of sewers and general lack of environmental awareness.

The findings of the study conducted by the University of the Witwatersrand on **"Sub-surface impact of low flush on-site anaerobic digesters in Ivory Park" (1993)**, concluded that there is a risk of polluting the sub-surface in Ivory Park. Measured levels of chemical contaminants such as nitrate were much higher than in allowable drinking water levels. A distinct plume of ammonia nitrite and nitrate, emanating from the soak-away and moving down gradient, was evident. In the long term, this pollution plume might have an impact on the receiving water quality.

The pollution contribution from the Clayville Industrial development is insignificant. Its impact on the receiving water cannot be detected due to the high base flow in the river and the considerably smaller catchment it serves. The point source contribution from the Olifantsfontein Waste Water Treatment Works dilutes the polluted base flow in the river.

The Centurion Lake functions as a pollution reduction facility during base flow conditions but was not as effective during storm events. The microbiological contamination during storm events is considerably higher than during base flow conditions. This can be attributed mainly to the shorter exposure of water in the lake and river system to sunlight.

The results indicate that the microbiological contamination of the water is the main source of pollution. Best Management Practices should now be implemented to reduce and control non-point pollution from the formal and informal housing sector in the of the catchment.

Table 1 compares the river water quality at the outflow of the Centurion Lake to selected water quality guidelines of various water user groups. According to the comparative table, the Hennops River water is unfit for use in all the selected water user categories. The water quality variables of concern for the various user groups are as follows:

- Conductivity, Cadmium - Irrigation
- Chemical Oxygen Demand, Suspended Solids, Chloride - Industry
- Faecal Coliforms, Ammonia, Cadmium, Mercury - Domestic
- Faecal Coliforms, Ortho- and Total Phosphate - Contact Recreation
- Faecal Coliforms, Cadmium, Mercury - Livestock
- Ammonia, Zinc, Cadmium, Chromium, Lead, Mercury - Aquatic Life

CONCLUSION

The study achieved most of the objectives proposed in the contract. This study was undertaken on a more macro-scale than other studies conducted in South Africa and focused on an area representative of several land uses, such as:

- formal and informal housing

Water quality variable	Units	Water User Groups: Domestic	Recreation Contact	Industry	Irrigation Class I	Livestock	Aquatic life	Hennops **: Dry Season	Wet Season
Physical and organoleptic properties									
Colour	mg Pt/l	20	-	-	-	-	-	-	-
Conductivity(EC)	mS/m (20 C)	70	-	100	40	154	-	60	48
Total Dissolved Solids(ECx6.8)	mg/l	476	-	680	272	1950	_	408	326
Chemical Oxygen Demand (COD)	mg/l	-	-	30	-	-	-	43	41
Dissolved organic carbon(DOC)	mg/l	5	-	-	-	-	-	-	-
Dissolved oxygen (DO)	% saturation	70	-	-	-	-	-	64	80
Odour	TON	10	-	-	-	-	-	-	-
pH	pH units	6.0-9.0	6.5-8.5	7.0-9.0	6.5-8.4	-	6.0-9.0	7.8	7.8
Suspended Solids	mg/l	-	-	5	-	-	-	66	153
Taste	TTN	1	-	-	-	-	-	-	-
Temperature	deg C	< 25	-	-	-	-	-	-	-
Turbidity	NTU	1*	5	-	-	-	-	-	-
Microbiological constituents									
Chlorophyll a	ug/l	1*	15	-	-	-	-	-	-
Standard plate count	counts/1ml	< 100*	-	-	-	5000	-	-	-
Total coliforms	counts/100ml	0*	-	-	-	-	-	-	-
Faecal coliforms	counts/100ml	0*	< 1000	-	-	1000	-	11689	61350
Clostridium perfringes	counts/100ml	0*	-	-	-	-	-	-	-
Coliphages	counts/100ml	< 1*	20	-	-	-	-	-	-
Enteric viruses	TCID50/10l	< 1*	< 1	-	-	-	-	-	-
Protozoan parasites *(Gardia.Cryptosporidium)*	cysts,oocysts/10l	< 1*	< 1	-	-	-	-	-	-
Macro-constituents									
Aluminium	mg Al/l	0.15*	-	-	5	5	0.25	-	-
Ammonia (NH3)	mg N/l	1	-	-	-	-	0.4	4.7	2.1
Total Alkalinity	mg CaCO3/l	-	-	100	-	-	-	154	57.17
Boron	mg B/l	0.5	-	-	-	5	1.5	-	-
Calcium	mg Ca/l	150	-	-	-	1000	1000	36.17	29.87
Chloride	mg Cl/l	250	-	20	_	1500	106	44.67	40
Copper	mg Cu/l	0.5	-	-	0.2	0.5	0.02	-	-
Fluoride	mg F/l	1	-	-	2	2	1	-	-
Hardness	mg CaCO3/l	300	-	200	-	-	-	-	-
Iron	mg Fe/l	0.1*	-	1.2	5	10	1	-	-
Magnesium	mg Mg/l	70	-	-	-	500	1000	13.55	13.8
Manganese	mg Mn/l	0.05*	-	-	0.2	10	1	-	-
Nitrite (NO2)	mg N/l	-	-	-	-	10	-	-	-
Nitrate (NO3)	mg N/l	6	-	-	-	100	10	5.7	3.3
Total Nitrogen (NO3/2&NH3)	mg N/l	-	-	-	5	-	-	-	-
Potassium	mg K/l	200	-	-	-	-	-	-	-
Orthophosphate (PO4)	mgPO4-P/l	-	0.05	-	-	-	-	2.47	0.71
Total Phosphorus(TP)	mgP/l		0.28					4.4	2.8
Sodium adsorption ratio (SAR)	meq/l^0.5	-	-	-	1.5	-	-	-	-
Sodium	mg Na/l	100	-	-	70	2000	400	62.67	31.57
Sulphate	mg SO4/l	200	-	400	-	1000	1000	43.17	40
Zinc	mg Zn/l	1	-	-	1	20	0.05	0.09	0.04
Micro-constituents									
Arsenic	mg AS/l	0.1	-	-	0.1	0.5	-	-	-
Cadmium	mg Cd/l	0.01	-	-	0.01	0.01	0.001	0.027	0.025
Chromium	mg Cr/l	0.1	-	-	0.1		0.02	0.035	0.05
Lead	mg Pb/l	0.05	-	-	0.2	0.1	0.003	0.05	0.05
Mercury	mg Hg/l	0.005	-	-	-	0.002	0.001	0.01	0.03
Molybdenum	mg Mo/l	0.05	-	-	0.01	0.01	-	-	-
Nickel	mg Ni/l	0.25	-	-	0.2	1	0.1	0.027	0.025
Selenium	mg Se/l	0.02	-	-	0.02	0.05	0.03	-	-
Tin	mg Sn/l	0.1	-	-	-	-	-	-	-

* Requirements for treated water only

** Monitoring station 15 (Centurion Lake Outlet)

Exceeds recommended limits

TABLE 1 - RIVER WATER QUALITY COMPARED TO SELECTED WATER QUALITY GUIDELINES OF VARIOUS WATER USER GROUPS

- industrial activities

- point sources

- commercial and high income residential developments

- agricultural activities

- underdeveloped land

Although water quality monitoring, data acquisition and evaluation were a major part of this study, the main objective was to assess and recommend the Best Management Practices in reducing pollution. These practices were based on the 80/20 approach, where 80% of the pollution is eliminated at 20% of the cost.

These guidelines are basic and can be used in other similar developments. The solutions proposed for non-point source (NPS) pollution are defined as Best Management Practices (BMP's) and can be divided into four categories:

- source control measures

- hydrological modification of the drainage area

- modification of conveyance system

- storage and treatment

BMP's are site-specific and several short term and long term control measures to improve the water quality in the Hennops River Valley for the various land users are presented in the report. These measures will prove useful in controlling NPS pollution and improving the water quality in the receiving water. As a general rule, control costs increase with the distance the runoff travels from the source to the point of treatment. It is therefore without exception essential that source control should be a priority in combatting pollution from developed areas as part of the long term strategy.

To be able to implement BMP's for the control of non-point source pollution it is necessary to establish a control institution based on the following framework:

- Appointment of a water quality management agency who can co-ordinate all matters relating to environmental management within the specific land use or economic sector.

- Formalised procedures should be developed for the implementation and auditing of the Environmental Management Programmes within the specific land use activity or sector. This will include Inter-departmental agreements after consultation on relevant matters. The Department of Water Affairs and Forestry should be consulted on all matters relating to water quality.

- Minimum Industry Standards should be developed for each of the major land use activities. Agreement should be reached on the Best Available Technology Not Entailing Excessive Cost (BATNEEC) for a specific sector or land user.

The local authorities may for example be elected to act as lead agent with respect to the implementation of Minimum Pollution Control Standards in all formal and informal urban settlements.

RECOMMENDATIONS

The type of urbanisation that has taken place in the of the Hennops River Valley is not unique to South Africa and can be compared to several catchments. Further studies, which entail intensive monitoring in similar catchments, serve no purpose unless pollution sources control measures are implemented.

Future research and work should focus on Integrated Catchment Management. The abatement strategies proposed should form part of that plan. This will bring many different disciplines together, including:

- land use planning (water supply and sanitation)

- flood control

- development

- stormwater management

Furthermore, it will be necessary to investigate and study the occurrence of diseases in the catchment as a result of polluted water. The direct medical costs and indirect related costs such as the loss of man-hours and productivity should be assessed and compared to the cost of control measures, waterborne sanitation and a potable water supply. A more comprehensive and detailed cost/benefit analysis of control measures can then be formulated.

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1. INTRODUCTION

Diffuse (non-point) pollution is the result of a variety of land use practices. Examples are farming, timber harvesting, urbanisation, construction, mining and waste disposal. This form of pollution is also caused by pollutants that wash off paved and unpaved surfaces in urban areas during rainstorms.

Much of the previous emphasis focused on "point source" pollution-discharges which flow directly from a defined effluent point to rivers, lakes or estuaries. Non-point sources have received little attention because these sources are often more difficult to identify, isolate and control. The very diffuse nature of the problem does not always allow simple technological solutions.

There are no clear guidelines for the control of non-point source pollution in South Africa, as was cited in the Report on "Urban Stormwater Runoff on the Quality of Water Resources in South Africa", prepared by J L Barnard. The result is that, in many instances where cost effective methods could have been used for combatting diffuse pollution, nothing as done.

A literature survey of the above report indicated that there are two approaches to this problem. Firstly the quantitative approach, requiring detailed studies over long periods of time. Secondly, the qualitative approach, which identifies the significant contributing source and solves this by eliminating a substantial fraction of the pollution load for a relatively small cost (referred to as the 80/20 approach).

Wates, Meiring & Barnard recognised the need to evaluate the 80/20 approach as a method of initiating prescriptive measures for stormwater pollution control in a representative valley.

The valley proposed was the Hennops River Valley which extends from Kempton Park/Chloorkop in the south to the Centurion Lake in the north. This area encompasses a variety of land users such as formal and informal housing, industries, point sources and agriculture. The objectives of the study were to assess the magnitude of non-point source pollution from various land uses, to identify significant pollution sources, to assess their resultant impact on the receiving water body, to evaluate the self-purification capacity of the stream and Centurion Lake and to provide guidelines for Best Management Practices based on the 80/20 approach.

2. LITERATURE REVIEW

A comprehensive literature survey was presented in the report on "The Effect of Urban Stormwater Runoff on the Quality of Water Resources in South Africa" by J L Barnard. In this literature review the nature and significance of non-point source pollution are examined.

The magnitude of non-point source (NPS) pollution across the world is immense. It is so complex, so large to characterise, so interconnected with poverty and human behavioural patterns that it defies proper assessment. Because of NPS pollution people suffer from disease, money invested in economic development is lost. Furthermore, future generation will need to spend large sums of money on environmental remediation.

Across Europe and North America, water pollution control goals have only partially been attained. While water quality has improved in the Seine, Potomac and Rhine Rivers, and Lake Erie is no longer "dead", surface and groundwater quality remains a serious problem because NPS pollution has not adequately been addressed. The limited NPS abatement programs which have been implemented have had only limited success. More comprehensive and enforceable programs are needed if water quality goals are to be achieved (Duda, 1989).

Developed countries have spent most of their effort controlling point sources or pollution discharges from industrial and municipal waste water outfalls. All other sources have been termed "non-point" sources. These include:

- agricultural activities
- urban and industrial runoff
- combined sewer overflows and leaks
- hazardous waste dump sites
- septic tank systems and soakaways
- mining and forest harvesting activities
- spills
- atmospheric deposition
- hydrologic modifications (dams, diversions, channelisation, overpumping of groundwater)

NPS pollution remains the most widespread water quality problem in the United States. In natural assessments compiled by the U.S. Environmental Protection Agency (1990), four times more waters were found to be polluted by agricultural activities than by municipal effluent discharges. Mining, urban stormwater and hydrological modifications also cause significant pollution in streams and lakes. The major pollutants are nutrients, pesticides, organic chemicals, sediment, metals, salinity and pathogens.

It is a well established fact that urban development creates many potential sources, both point and non-point/diffuse sources. Urban hydrologists have studied urban stormwater runoff quality problems for many years and several major research projects have been undertaken in South Africa (Simpson et al, 1978, Simpson et al 1980, Simpson 1986, Wright 1987, Wright 1991, Wimberly 1992 and Wright et al 1992). The studies have concentrated on both First World type catchments and Third World urban catchments.

In the Unites States, the most successful abatement strategies have involved declaring certain "non-point" sources to be "point" sources and regulating them under a permit system. The United States Clean Water Act (CWA), which was successful in excluding pollution from the point source, is now under review so as to address non-point source pollution as well.

Congress initially relied on voluntary action by landowners and on land-use planning by states, local governments and regional organisations to deal with NPS pollution. The Environmental Protection Agency (EPA) carried out a technical assistance function which was to assist in developing technical solutions for NPS pollution. These solutions are termed Best Management Practices (BMPs).

Non-point source has control generally been pursued through a voluntary process of educational planning and technical assistance, but this seems to have failed. Non-point sources are diffuse, difficult to measure and not amenable to treatment. As such, these sources are not easy to regulate.

A new development in the U.S.A. is the call for a **Watershed Management Approach** to restore the most severely polluted waterways. This is done using enforceable state programming and site-specific control plans. The Watershed Management Proposal would establish minimum standards requiring a combination of pollution prevention, source reduction and improved management practices affecting both point and non-point sources in all designated watersheds.

In less developed countries, the difference between point and non-point sources is also blurred. In particular, the problem of municipal sewage is commonly non-point in nature because collection systems - and even more so, sewage treatment plants - are non-existent. Indoor plumbing is rare; excreta and urine are deposited in urban alley ways. Even in the more affluent areas where pit latrines or septic tanks are found, overflowing and leaking systems contaminate groundwater and recharge ditches, streams and rivers with pathogens.

With more than a billion people worldwide suffering from waterborne diseases such as cholera, dysentery, typhoid and diarrhoea each year, urban and rural sewage is the most serious non-point pollution problem in poor nations. This includes South Africa. A second major NPS problem is land abuse and the resulting sediment export. This can be related to slash and burn agriculture, cutting trees to clear land and provide fuelwood as well as the vicious cycle of poverty in rural areas. These abused lands can no longer hold moisture, which leads to soil runoff, further soil erosion and the siltation of downstream waterways, impoundments, irrigation works and natural ecosystems. Poor practices associated with irrigation agriculture constitute the third most significant type of NPS pollution worldwide and contributes to salinisation and eutrophication.

The solution to NPS pollution is a more comprehensive approach to water resources management. This approach recognises the river basin as the appropriate unit for managing not only water quality, quantity and ecosystems but also the development initiatives of various economic sectors (Duda, 1993). In South Africa the Department of Water Affairs and Forestry (1991) has published a Water Quality Management Policy and Strategy document. This document contains the possible future trends and areas where policies and strategies may have to be adopted after proper evaluation.

Furthermore, the South African Department of Environmental Affairs, in conjunction with Industries and other Departments, is engaged in preparing a new Integrated Pollution Control Policy and Legislation which will be a more comprehensive approach in controlling "point" and "non-point" source pollution in a watershed.

3. BACKGROUND TO STUDY AREA

3.1 Catchment Description

3.1.1 Location and Topography

The Hennops River Valley catchment is situated between Pretoria and Johannesburg and stretches from Kempton Park/Chloorkop in the south to Centurion Lake in the north, as shown in **Figure 1.1**. The main river, Kaalspruit, has its source as natural springs in Norkempark and Birchleigh North, south-east of Tembisa. It meanders through Tembisa and Ivory Park in a northerly direction. Several tributaries which have their source at Chloorkop, Rabie Ridge and Eskom Training College, enter the river system here. The Kaalspruit flows along the western boundary towards Olifantsfontein, where a further tributary from the south-east enters the river. This tributary has two sub-tributaries, which enter Clayville at the southern boundary through two concrete channels. These two channels become one main stormwater channel through Clayville. This channel also receives runoff from industries and roads.

Downstream of the confluence of these two streams, the Olifantspruit enters the Kaalspruit south of the Olifantsfontein Waste Water Treatment Works. The Olifantspruit has its source in Glen Austin Extension 1 Agricultural Holdings. En route to the confluence, several minor tributaries enter the Olifantspruit which also emanate from agricultural land and smallholdings.

Two dams, which are used mainly for recreational purposes (fishing and water sports) and as irrigation water by the adjoining farmer, are situated on the Olifantspruit. After the confluence of the Olifantspruit and Kaalspruit, the effluent from the Olifantsfontein Waste Water Treatment Works discharges as a major point source into the stream. The stream continues to flow in a northerly direction through agricultural land and pastures towards Irene. South of Irene, the Sesmylspruit joins the Olifantspruit. The Sesmylspruit originates east of Kempton Park but which is impounded in the Rietvleidam. The dam overflow and some backwash water from the waterworks downstream of the dam is the main source of water in the Sesmylspruit. Downstream of the confluence, the Olifantspruit becomes the Hennops River which flows in a north-westerly direction through the Irene Golf Course, passing a Dairy Farm en route to Centurion Lake.

The Centurion Lake impounds and attenuates the incoming flow. The Lake has become a silt trap for the river and the effective volume has been reduced by about 50% due to the deposition of silt. The Lake was built on the original watercourse and no allowance was made for bypassing the Lake in case of excessive silt accumulation.

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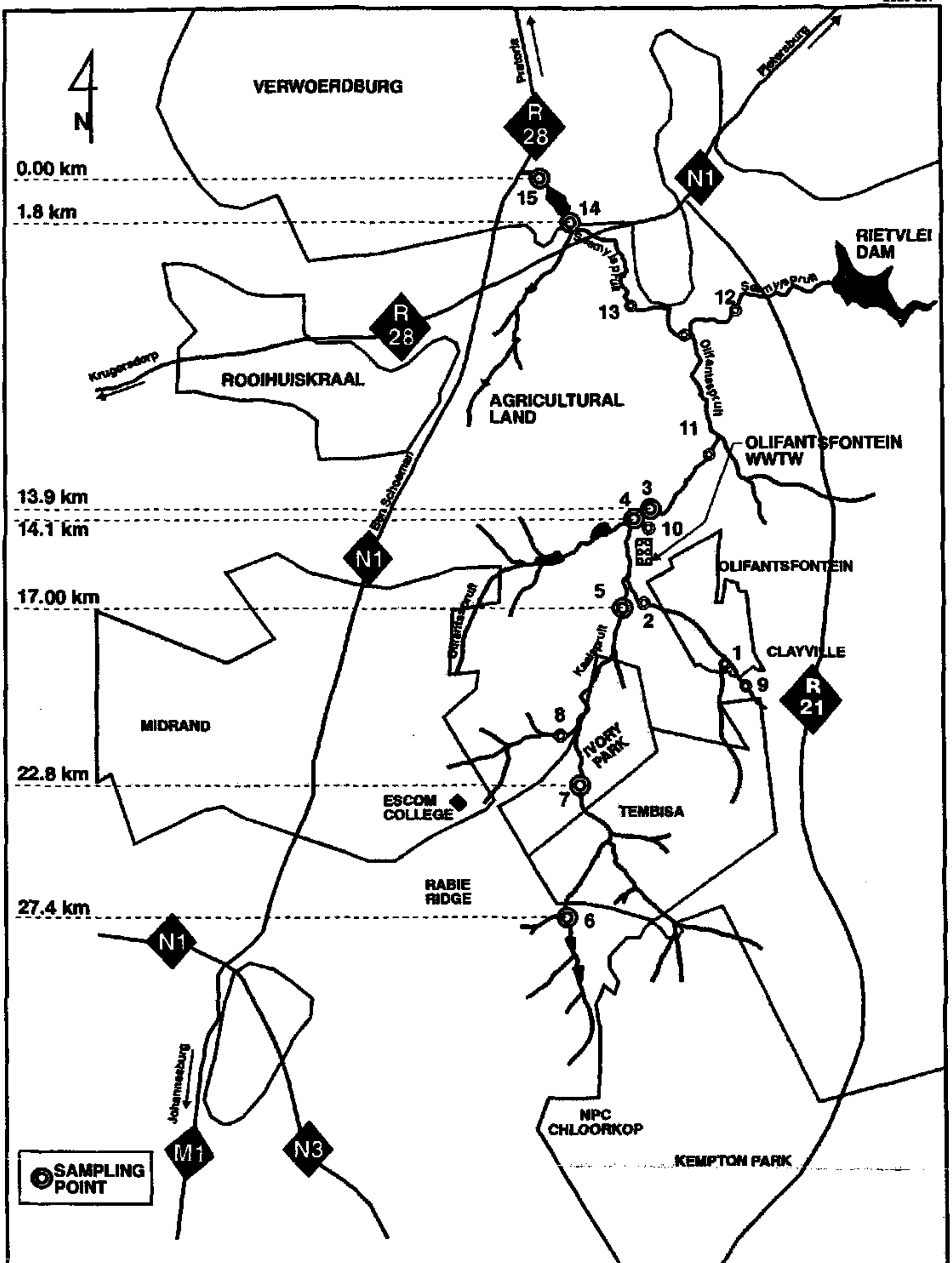


WMB

FIGURE 1.1 : HENNOPS VALLEY STUDY AREA

The Hennops River then drains in a westerly direction and flows into the Crocodile River which is the main water supply to the Hartebeespoort Dam.

The topography from Tembisa to the Centurion Lake reveals a moderate gradient falling in elevation, from 1620 m above mean sea level (mamsl) at the source to about 1420 mamsl at the Lake. The average gradient is about 1:140. This is a relatively steep river and should have good re-aeration capacity. The Lake was constructed 10 years ago at a cost of R5,2 million.

3.1.2 Climate and Vegetation

Hobbs (1988) determined the rainfall and climate according to Station 513/382 (Irene) and those values have been used in this report. The area experiences a sub-humid, warm climate. The mean daily maximum recorded is 24,1°C and the mean daily minimum is 7,6°C. The summers are warm and winters cool with moderate to severe frost.

Long term rainfall records reveal a mean annual rainfall of 689 mm. Most of the rainfall occurs as afternoon thunderstorms between November and March. The mean annual evaporation varies around 1 700 mm.

The natural vegetation in the area consists of sour, wiry grassveld dotted with trees. Most of the area is soil covered, but outcrops are present.

3.1.3 General Geology

The bedrock comprises, over the major portion of the stream, a combination of dolomite and chert from the Chuniespoort Group, Malmam Sub-group of the Transvaal Sequence. The Basement Complex granite underlies the southern end of the catchment.

3.1.4 General Geohydrology

The intact dolomite rock is essentially impermeable, but the water bearing properties of dolomite stem from the preferential development of carbonate dissolution channels along fault zones, fractures, joints and bedding planes. Generally, the more fractured and calcite nature of the chert-rich units (Monte Cristo and Eccles) reveals an apparently greater susceptibility to the carbonate dissolution process. This is because the chert layers support the strata and keep the leached zones open.

The presence of dykes and sills exercises considerable control on groundwater movement, with both the Pretoria and Sterkfontein dykes being associated with major springs. Shallow water levels are associated with sills and perched water tables also occur.

The general groundwater movement in the Monte Cristo Formation is from the south to the north. Water levels measured in the vicinity of the Olifantsfontein Waste Water Treatment Works have shown that movement is to the north-east and seepage may occur across the Sterkfontein dyke.

There appears to be a definite hydraulic connection between the river and the groundwater as the phreatic water table is more or less on the same level as that of the river (WMB, 1993). This is an indication of a river being in equilibrium, not losing or gaining water from the groundwater.

Groundwater samples were taken from two boreholes adjacent to the Kaalspruit south of the Olifantsfontein Treatment Works and analyzed for various water quality variables. The results are presented in **Table 3.1.**

The high Ca- and Mg-values are typical of the dolomite rock over which the streams in the region flow. The presence of Faecal Coliform bacteria in the samples indicates that there is a connection between the stream and the groundwater and that the bacteria in the stream are being transferred to the groundwater. In fact, much more so in the dolomite than in the syenite.

Even though there are no limits specified for the COD values, the mere presence of it is an indication of pollution.

3.1.5 Land Users and Activities

The catchment under consideration received non-point and point source pollution from various land users. These can be broadly classified as follows:

- Urban development
  - Residential
  - Formal and informal housing
  - Commercial and industrial
- Agricultural activities
- Waste Water Treatment Works

TABLE 3.1: BOREHOLE AND RIVER WATER QUALITY

Water Quality Variable	River 93/04/24	BH2 93/07/09	BH4 93/07/09
pH	7.85	7.60	7.45
Conductivity (mS/m)	49.6	46.5	90
Total Dissolved Solids (mg/ℓ)	-	296	576
$CaCO_3$ (mg/ℓ)	-	405	183
Alkalinity (mg$CaCO_3$/ℓ)	194	190	225
Calcium (mgCa/ℓ)	22	57	248
Magnesium (mgMg/ℓ)	12	126	157
Sodium (mgNa/ℓ)	45	14	22
Potassium (mgK/ℓ)	-	3.7	3.2
Nitrate (mgN/ℓ)	0.2	4.7	0.2
Chloride (mgCl/ℓ)	-	8	145
Sulphate (mgSO_4/ℓ)	15	7	15
Fluoride (mgF/ℓ)	-	0.1	0.1
Ammonia (mgN/ℓ)	11.3	0.2	0.6
Phosphate (mgP/ℓ)	2.0	0.1	0.1
Chemical Oxygen Demand (mg/ℓ)	54	< 10	28
Faecal Coliform/(counts/100ml)	200 000	100	300

3.1.5.1 Tembisa, Ivory Park and Rabie Ridge

In the southern part of the catchment, where the river originates, the main land users comprise several urban developments. These encompass the townships of Tembisa, Ivory Park and Rabie Ridge. The township of Tembisa consists mainly of serviced stands (formal housing) and some informal houses and has a population of about 500 000. The waste water emanating from the township drains into the eastern and western trunk sewers. These drain northwards to the Olifantsfontein Waste Water Treatment Works. According to the City Council of Tembisa, 85% of the roads within Tembisa are dirt roads and 15% are tarred roads. Most of the stormwater drains to the Kaalspruit.

The Township is also littered with municipal waste which has accumulated due to violence and the lack of funds. The estimated waste volume during June 1993 was 150 000 m^3. This can be a major contributor to the non-point pollution load during storms due to leaching.

Rabie Ridge consists of formal housing and all the stands are serviced. The population of Rabie Ridge is in the order of 7 000 . All the roads in Rabie Ridge are tarred and it has a well developed infrastructure. The waste water drains to the western outfall sewer at Tembisa.

Both Tembisa and Rabie Ridge are flanked on their northern boundaries by Ivory Park, which is an informal housing development. In this case, the developers provided a skeletal road system, a limited number of communal water supply points and on-site sanitation (LOFLOS-low flush on-site anaerobic digester). Housing consists mainly of squatter shacks. This area has inevitably degenerated into an uncontrolled shanty town with a very high population density. The estimated population is 200 000 living on 20 000 - 30 000 stands. Most of the on-site sanitation systems are in a poor state as they are not maintained. The untreated sewage discharges onto the roads which in turn drain towards the Kaalspruit.

3.1.6 Clayville

North of the abovementioned highly urbanised development is an undeveloped belt of natural vegetation up to the confluence with the tributary from Clayville. East of the undeveloped belt and north of Tembisa lies Clayville, which is the industrial centre of Midrand. This provides employment to the large surrounding population. Stormwater and runoff from paved areas discharges into the main concrete lined drainage channel which passes through the centre of Clayville in a northern direction. Under dry weather conditions, waste water flows in the channel which is connected to the stormwater system. This water can be attributed to the wash down water from paved areas. However, most of the highly contaminated water discharges into the sewer network to be treated with the domestic waste water at the Olifantsfontein Waste Water Treatment Works.

The typical industries in Clayville include abattoirs, food processing factories, beverage plastic pipe and pharmaceutical manufacturers and other light industries. The composition of the stormwater runoff usually consists of organic pollutants.

3.1.7 Olifantsfontein

Olifantsfontein is the residential area which is located north of Clayville and inhabited by the middle income bracket. The normal infrastructure is present. The population of Olifantsfontein proper is about 3 000.

On the northern boundary of Olifantsfontein is an industrial area which comprises Cullinan Refractories and a brick and tile manufacturer. All the surface runoff drains towards the Olifantspruit, downstream of the Olifantsfontein Waste Water Treatment Works.

3.1.8 Olifantsfontein Waste Water Treatment Works

The effluent from the Olifantsfontein Waste Water Treatment Works discharges as a point source pollutant into the Olifantspruit. This source is a major contributor to the permanent flow in the river and is in the order of 38 Mℓ/d. The final effluent quality has to comply with the Special Phosphate Standard. The treatment works purifies the waste water emanating from Tembisa, Ivory Park, Rabie Ridge, Clayville and Olifantsfontein. Although Ivory Park is not connected to a sewer network, a large proportion of the aqua privies are discharged into manholes on the main outfall sewers which flow to the Olifantsfontein Waste Water Treatment Works.

The Olifantsfontein Waste Water Treatment Works is capable of treating 38 Mℓ/d, but this flow will increase considerably once the extensions are complete. The total capacity of the treatment works will increase to 108 Mℓ /d.

3.1.9 Olifantsfontein to Centurion Lake

From Olifantsfontein Waste Water Treatment Works, the Olifantspruit flows towards Centurion Lake through a relatively undeveloped area. Although some agricultural activities take place along the banks of the river, most of the water used for irrigation purposes is not extracted from the river due to its poor quality. The farmers prefer borehole water for irrigation purposes.

The Irene Country Golf Club borders on the confluence of the Sesmylspruit and Olifantspruit and water is extracted for irrigating 60 ha of the golf course. After the confluence of these two rivers, the name changes to Hennops River.

Downstream of the Golf Club is the Irene Estate. This is a dairy farm and 80 ha of pastures are under irrigation as feed for the cattle. The water for irrigation purposes is obtained from the Rietvlei Dam in a dedicated pipeline at a rate of 2.45 Mℓ/d. Surplus water from irrigated land flows into the Hennops River.

Irene Estate is the last agricultural activity along the river before it enters the Centurion Lake.

At the upstream end of the Lake is a Chlorine Dosing Installation which is operated and maintained by the Town Council of Verwoerdburg. The main purpose of injecting chlorine into the river is to reduce the bacteriological contamination in the Lake so that the health risk associated with pathogens is reduced. The Lake is no longer used for water contact sports due to pollution and only pleasure boat trips and canoeing are allowed on the Lake. Although the chlorine dosing reduces the Faecal Coliform count in the river, the Lake Faecal Coliform count remains above statutory requirements. This can most probably be attributed to poor mixing, ineffective contact time and possible bacteriological reinoculation by the sediment.

3.1.10 Centurion Lake

Centurion Lake is surrounded by offices, garages, shopping complexes and a hotel which forms the attraction point of the Centurion Centre. Stormwater in this area is directed in pipelines or culverts towards the Lake without any pretreatment. During storms, all the stormwater runoff is discharged into the Lake. The original development of the Lake was for aesthetic and recreational purposes. It has unfortunately become a silt trap and pollution control facility for the Hennops River Valley catchment upstream of the Lake.

The developments which could have an impact on the Lake are serviced by waterborne sanitation. The waste water discharges under gravity to the Verwoerdburg Water Care Works which is located about 10 km downstream from the Lake on the banks of the Hennops River.

4. MONITORING NETWORK

4.1 Background

The Hennops River Valley from Tembisa to Centurion Lake has never been monitored on a regular basis so as to quantify the pollution load from the various sources within the catchment.

The Department of Water Affairs and Forestry and the Town Council of Verwoerdburg have taken grab samples in the river. This revealed that the river is polluted and that the water quality does not comply with the Statutory Requirements of the Water Act. The effluent from the Olifantsfontein Waste Water Treatment Works is monitored on a regular basis by the Department of Water Affairs and Forestry in order to check whether quality requirements are met. This comprehensive study is aimed at base flow and stormwater quality from the various land uses in the catchment and attempts to address the following issues:

- Type of pollution
- Magnitude of pollution
- Effect of pollution on the receiving water body
- Provide guidelines for Best Management Practices on the 80/20 approach.

4.2 Monitoring Network

The nature of the catchment and the poor security situation discouraged the establishment of any permanent monitoring structures. The different sub-catchments were investigated with respect to the stormwater runoff, different types of land users and activities. This was done in order to site the water quality monitoring sampling points. The selection of grab sampling locations was determined by the objective of quantifying the pollution load from various sub-catchments and facilities. The monitoring points of the study area are shown in **Figure 1.1.**

Fifteen (15) sites were selected for water quality monitoring and approximate flow measurements. The water quality sampling sites may be summarised as follows:

6 - To monitor the base and storm flow in a tributary of the Kaalspruit upstream of Tembisa. The overflow from the emergency storage dam below the evaporation ponds treating the NCP effluent will also discharge into this stream. This site also contains any runoff from Birch Acres in Kempton

Park.

7 - To monitor the base and storm flow in the Kaalspruit downstream of Tembisa Proper. This site also represents the runoff from the catchment upstream of the point.

8 - To monitor the base and storm flow in a tributary of the Kaalspruit. The effluent from the Eskom Waste Water Treatment Works discharges into this stream. This site also represents the runoff in this sub-catchment.

5 - To monitor the base and storm flow in the Kaalspruit downstream of Ivory Park. This site also represents the runoff south of the monitoring point. Sample taken in a defined section of the river.

9 - To monitor any storm flow from the south eastern part of Clayville. The sample was collected in a defined section of the eastern stormwater channel before it enters Clayville.

1 - To monitor the stormwater runoff from the northern part of Tembisa. The sample was collected in a defined section of the western stormwater channel before it enters Clayville.

2 - To monitor the base and stormwater runoff from Clayville. This site also represents the stormwater runoff from outside Clayville. Sample is taken under the bridge.

4 - To monitor the base and storm flow in the Olifantspruit River upstream of the Olifantsfontein Waste Water Treatment Works. This site also represents the runoff south of this monitoring point. Sample taken in the middle of the river in a defined section.

10 - To monitor the final effluent from the Olifantsfontein Waste Water Treatment Works. The sample was collected at the outflow channel from the Old Biotower Works and overflow weir from the maturation river.

3 - To monitor the base and storm flow in the Olifantspruit downstream of the Olifantsfontein Waste Water Treatment Works. This site also represents any runoff south of this point. Sample is taken in the river 50m downstream of the point source inlet.

11 - To monitor the base and storm flow in the Olifantspruit north of Olifantsfontein. This site also represents the runoff south of this point. Sample is taken at Pinedene Weir which used to be a DWA&F monitoring station.

12 - To monitor the base and storm flow in the Sesmylspruit downstream of the Rietvlei Dam. The sample was taken before the confluence with the Olifantspruit.

13 - To monitor the base and storm flow in the Hennops River west of Irene Estate. Sample is taken in a defined section of the river.

14 - To monitor the base and storm flow of the Hennops sub-catchment before the river flows into the Centurion Lake. Sample was taken at the bridge next to Centurion Lake Hotel in a defined section of the river.

15 - To monitor the base and storm flow of the outflow from Centurion Lake. Sample was taken under the bridge in the overflow channels.

The rain gauges located at the Olifantsfontein Waste Water Treatment Works and at Glen Austin Ext. 1 (Midrand) were used and the rain figures were recorded by the Operator and Author respectively. Due to poor security and vandalism it was not possible to establish other permanent rain gauges in the area.

Flow measurements were done on defined sections of the river. This was done using a propeller flow meter to measure the velocity of flow as well as the cross section of the water flow. Under dry weather conditions, **Monitoring Points 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12 and 15** were measured for flow but during stormwater flow conditions the flow was measured whenever possible at **Monitoring Points 6, 7, 5, 11 and 15.**

4.2.1 Routine Sample Collection

Sample collection involved the collection of water quality samples, the gauging of flows and rainfall. Sampling consisted of "grab" samples at the selected sites. Due to the number of sampling sites it would have been too expensive to install automatic sampling equipment. Sampling was done during daylight hours. The routine sampling was done on a Tuesday and the frequency of sampling was done according to the attached schedule **(Table 4.1).**

Specific weather conditions chosen were the dry period from April to September and the wet period from October to March. Random wet weather periods during summer were also monitored.

All samples were collected in plastic bottles which were obtained in a clean state from the laboratory. In the field, the bottle was again rinsed with the water to be sampled. No special sampling procedure such as filtering in the field was required for the major water quality variables. In the case of microbiological sampling, the bottles were glass and sterilized in the laboratory before sampling. The bottle was not rinsed in the field, but filled directly from the source, allowing for a small air space between the sample and the cap. Once collected these samples were immediately stored in a "cool box" and transported with the other samples to the laboratory within 8 hours.

During sampling the in-situ dissolved oxygen and temperature of the water was also measured using a portable WTW OX1 92 type meter.

4.3 Laboratory Analysis

Laboratory analysis is a complex and specialised activity as it involves the analysis of many water quality variables using several procedures. It also includes operational procedures such as sample handling in the laboratory, quality control and the recording of the analytical results. This part of the study was undertaken by Waterlab in Pretoria.

The frequency of sampling and water quality variables analyzed are indicated in **Table 4.1**. The samples were analyzed in the laboratory using the methods recommended by the Standard Methods for the Examination of Water and Waste Water Manual.

4.4 Stormwater Runoff Sample Collection

Samples were collected after a rainfall in the catchment. Sampling consisted of "grab" samples at five selected sites and flow measurements were done wherever possible. During high stormwater flows it was often dangerous to measure the flow in the river and for this reason flow figures are not always available after storm events.

TABLE 4.1 WATER QUALITY VARIABLES AND FREQUENCY OF SAMPLING

Water Quality Variable	Units	Apr. - Sept.	Oct. - Mar.	Monthly	Quarterly
		Bi-weekly	Weekly		
pH	-	•	•		
COD	mg/ℓ	•	•		
Conductivity	mS/m	•	•		
Ammonia	mg N/ℓ	•	•		
Nitrate	mg N/ℓ	•	•		
Total Phosphate	mg P/ℓ	•	•		
Faecal Coliform	count/100 ml	•	•		
Suspended Solids	mg/ℓ	•	•		
Dissolved oxygen (Field)	mg/ℓ	•	•		
Temperature (Field)	deg. C	•	•		
BOD	mg/ℓ			•	
Calcium	mg Ca/ℓ			•	
Magnesium	mg Mg/ℓ			•	
Sodium	mg Na/ℓ			•	
Sulphate	mg SO4/ℓ			•	
Chloride	mg Cℓ/ℓ			•	
Alkalinity	mg CaCO3/ℓ			•	
Ortho-Phosphate	mg P/ℓ			•	
Flow	ℓ/s	•	•		
Total Kjeldahl Nitrogen	mg N/ℓ				•
Mercury	mg Hg/ℓ				•
Manganese	mg Mn/ℓ				•
Iron	mg Fe/ℓ				•
Copper	mg Cu/ℓ				•
Nickel	mg Ni/ℓ				•
Zinc	mg Zn/ℓ				•
Cobalt	mg Co/ℓ				•
Chromium	mg Cr/ℓ				•
Lead	mg Pb/ℓ				•
Cadmium	mg Cd/ℓ				•

5. WATER QUALITY VARIABLES

The water quality profile changes significantly within the spatial extent of the catchment. The water quality will be presented in terms of physical, microbiological, macro and micro variables.

5.1 Physical, Microbiological and Macro Constituents

The polluted water quality is described by Chemical Oxygen Demand (COD), Suspended Solids (SS), Ammonia, Nitrate, Total Phosphate, Faecal Coliform, Dissolved Oxygen, Conductivity and pH. A brief description of these water quality constituents and their occurrence in the aquatic environment will be given below:

- **Chemical Oxygen Demand (COD)**

  The chemical oxygen demand (COD) is defined in Standard Methods as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. The COD therefore gives an estimate of the organic matter present in a water body.

  In the aquatic environment, organic matter has two main origins. Firstly, it may form within the water body itself through the growth and death of aquatic organisms. Secondly, the organic matter may originate outside the water body. The latter has its source in leaf litter from forests or dry grass blown or washed into the water course from the surrounding land. In addition to this naturally occurring source of organic matter, human activities, such as agricultural, stock farming and the production of industrial and domestic wastes are significant sources of organic matter in the aquatic environment.

  The COD test is non-specific and therefore does not indicate the nature of the organic matter nor does it distinguish between organic and inorganic matter in a sample. There is, however, a direct empirical relationship between COD and biological oxygen demand (BOD) for samples from a specific source.

- ***Biological Oxygen Demand (BOD)***

  The biological oxygen demand (BOD) is an empirical test in which standardised laboratory procedures are used to determine the relative oxygen requirements of waste waters, effluents and polluted waters. The test measures the oxygen required for the biological degradation of organic matter within a 5-day period.

- **Suspended Solids (SS)**

  The suspended solids test is a measure of the suspended organic and inorganic solids in the water. This will increase considerably after a storm due to the presence of silt, sand and clay.

- **Ammonia (NH_4-N)**

  Low concentrations of ammonia are present in most natural waters as a result of the normal biological degradation of nitrogenous organic substances (protein). High levels may be caused by agricultural, sewage or industrial effluents.

- **Nitrate (NO_3-N)**

  Substantial quantities of nitrates are present in soil, water and plants. Under aerobic conditions, organic nitrogen is oxidised by bacteria present in soils and water so as to produce nitrates.

  A significant source of nitrates in natural waters is the oxidation of animal excrement, vegetable and animal debris. Municipal and industrial discharges the decomposition of sewage wastes, leachate from waste disposal dumps and sanitary landfills as well as soil leaching in areas where inorganic nitrate fertilisers are used contribute nitrates to rivers and lakes.

- **Phosphorous (P)**

  Although soluble phosphates occur naturally in the stream, elevated levels can be attributed to agricultural, sewage and industrial effluents as is the case for ammonia. Total phosphorous includes all ortho-phosphates and condensed phosphates, both dissolved and particulate, organic and inorganic.

- **Faecal coliforms**

  Microbiologically polluted water has long been associated with the transmission of infectious diseases such as gastroenteritis, cholera, typhoid fever, hepatitis A and others. A feature of bacterial pathogens is a high infective dose (10 - 1000 or more organisms required to cause infection) while viral pathogens and parasites have low infective doses (1 - 10 organisms). The protection of public health through the control of microbial water quality is an important goal of Water Quality Management.

Faecal coliform and more specifically *Escherichia coli*, are the most common bacterial indicators of faecal pollution. Faecal coliform bacteria are almost definitely of faecal origin from warm-blooded animals. This correlation is strengthened if the presence of *E-coli* is confirmed (Grabow, 1986, Canadian Guidelines, 1987).

- **Dissolved Oxygen (DO)**

Dissolved oxygen is essential for the maintenance of aquatic life. The physiological efficiency of aquatic species such as fish is reduced when dissolved oxygen levels decrease in the water column. The depletion of dissolved oxygen in the water body may cause fish kills.

Dissolved oxygen concentrations fluctuate naturally, especially if a water body is not very turbulent. Under such conditions, the effects of respiration, photosynthesis and the slow rates of diffusion will result in a gradual change in oxygen concentration over a 24-hour period.

Dissolved oxygen in the water body can be depleted by aquatic pollution e.g. effluents with high organic loads. This will result in the anaerobic decomposition of organic materials.

- **Conductivity (mS/m)**

Electrical conductivity is a quantitive measurement of the ability of a solution to conduct an electrical current. This ability depends on the total concentration of ions in solution as well as the relative concentration and valencies, their mobility and the temperature of the solution. The solutions of most inorganic acids, bases and salts are relatively good conductors, whereas organic molecules are usually poor conductors. Electrical conductivity therefore gives an indirect measurement of the concentration of the dissolved solids in a river or water body.

The principle inorganic anions dissolved in water include the carbonates, chlorides, sulphates and nitrates. The principle cations are sodium, potassium, calcium and magnesium.

The salt content of the water is not expressed as electrical conductivity but as total dissolved solids (TDS). As a general rule for most South African fresh water bodies, the approximate TDS can be calculated from electrical conductivity according to the following formula:

$$\boxed{\text{TDS (mg/}\ell\text{)} = \text{electrical conductivity (mS/m)} \times 6.8}$$

- **pH**

The pH is involved in nearly every phase of water supply and waste water treatment and is often a vital factor in various industrial processes. Hence knowledge of pH in raw water supplies is essential since most water conditioning processes, such as acid-base neutralisation, water softening, precipitation, coagulation and disinfection are pH-dependant.

pH gives an indication of the acidic ($pH < 7$) or basic ($pH > 7$) nature of the water.

5.2 Macro and micro variables

The macro and micro water quality variables, as defined by the Department of National Health and Population Development (Aucamp and Vivier, 1990), are as follows:

WATER QUALITY VARIABLES	
Macro variable	**Micro variable**
Calcium	Mercury
Magnesium	Arsenic
Sodium	Nickel
Sulphate	Cobalt
Chloride	Chromium
Alkalinity	Lead
Phosphate	Cadmium
Manganese	
Iron	
Copper	
Zinc	

6. RESULTS AND ANALYSIS

6.1 Introduction

To be able to obtain meaningful results from the base flow and stormwater pollution in the Hennops River Valley catchment, it was necessary to monitor the flow and water quality for one year from March '93 to March '94.

The results are presented as follows:

- Water Quality Profile coupled to the summer and winter season, storm events and land use activities.
- Pollution load contributions during summer and winter from the various land use activities.
- Unit export load from the catchment.

6.2 Water Quality Profile

Due to the large number of monitoring points, which include minor tributaries, it was decided to present the monitoring results on the main river stream in box-and-whisker plots so that trends can be observed. The **monitoring points are 6, 7, 5, 4, 3, 11, 13, 14, 15.**

Figures 6.1 to 6.8 show box-and-whisker plots of all available COD, Ammonia, Nitrate, Total Phosphate, Suspended Solids, Faecal Coliform, Conductivity and Dissolved Oxygen measurements at the nine stations for the period March '93 to March '94. The boxes show the 95%, 50% and 5% probability concentrations. The arithmetic minimum, maximum and average concentrations for the winter and summer periods are summarised in **Tables 6.1 and 6.2.**

The **COD plot (Figure 6.1)** shows that there is a decrease in COD from **monitoring point 7 to monitoring point 15** during the dry season. The high COD concentration at monitoring point 6 can be attributed to the contaminated runoff and overflows from the NCP evaporation ponds. The COD concentration at the outflow from Tembisa at monitoring point 7 can mainly be attributed to the inflow of domestic waste water. The main sources are domestic waste water overflows from manholes as a result of deliberate pipe blockages by vandals and contaminated leachate from the large amounts of garbage in the streets.

Water quality variable	Sample station								
	6	7	5	4	3	11	13	14	15
pH									
Min :	6.6	7.3	7.4	7.3	7.3	7.6	7.6	7.6	7.6
Max :	8.2	8.4	8.3	8.1	8.0	8.2	8.2	8.2	8.3
Avg :	7.2	7.6	7.7	7.7	7.7	7.8	7.8	7.8	7.8
Num :	11	10	11	11	11	11	11	11	11
COD (mg/l)									
Min :	64	14	36	40	20	30	18	12	24
Max :	450	108	144	190	116	90	68	88	68
Avg :	199	66	69	75	63	55	39	42	43
Num :	11	10	11	11	11	11	11	11	11
NO3-N (mg/l)									
Min :	0.01	0.01	0.02	1.50	1.20	1.20	2.80	2.40	2.80
Max :	0.90	0.66	0.40	9.00	7.60	4.60	6.40	8.30	7.80
Avg :	0.33	0.16	0.13	4.80	4.26	2.80	4.71	5.91	5.45
Num :	11	10	11	11	11	11	11	11	11
NH3-N (mg/l)									
Min :	0.05	0.50	0.40	1.20	1.00	0.60	0.60	0.60	0.60
Max :	27.00	16.50	21.80	8.80	10.00	11.60	8.60	8.00	7.60
Avg :	5.70	10.06	13.15	5.92	5.80	7.16	5.39	4.51	4.46
Num :	11	10	11	11	11	11	11	11	11
F Coli (counts/100ml)									
Min :	40	10	11 040	8 200	8 000	4 150	150	220	390
Max :	3 120 000	1 890 000	1 140 000	458 500	331 000	275 000	680 000	81 000	135 000
Avg :	783 679	761 801	358 244	154 736	121 986	62 045	68 109	12 150	18 022
Num :	8	10	10	11	11	11	11	10	9
PO4-P (mg/l)									
Min :	0.8	2.8	2.8	3.1	4.2	3.0	2.5	1.1	2.9
Max :	29.7	11.5	9.3	8.8	8.2	10.2	12.1	13.2	9.6
Avg :	6.5	4.5	5.1	5.7	5.9	5.0	5.2	4.9	4.9
Num :	10	9	10	10	10	10	10	10	10
SS (mg/l)									
Min :	26	17	2	15	9	14	14	9	15
Max :	1 953	58	36	111	48	60	135	221	272
Avg :	336	34	24	42	28	32	43	51	85
Num :	8	8	8	8	8	8	8	8	8
DO (mg O2/l)									
Min :	0.80	2.20	1.90	3.15	3.30	3.60	3.80	2.90	3.50
Max :	12.40	9.10	6.60	9.20	8.80	8.12	9.80	8.50	8.50
Avg :	4.44	4.24	4.13	4.51	5.04	5.29	5.69	5.34	5.36
Num :	11	10	11	11	11	11	11	11	11
Conductivity (mS/m)									
Min :	70.5	22.0	42.5	46.0	45.7	49.7	48.5	36.7	40.9
Max :	355.0	71.2	215.0	89.5	67.5	81.0	65.0	70.5	74.5
Avg :	257.3	51.0	72.0	55.8	54.1	59.0	56.8	57.5	57.9
Num :	11	10	11	11	11	11	11	11	11
Temp (deg C)									
Min :	9.0	11.0	10.0	13.0	12.0	12.8	11.2	10.2	10.9
Max :	15.0	18.3	19.5	23.5	23.0	21.9	20.8	20.9	21.4
Avg :	12.4	14.4	15.3	18.8	18.1	18.0	16.1	15.8	16.2
Num :	11	10	11	11	11	11	11	11	11

Minimum, maximun and average concentrations and number of samples taken during winter **Table 6.1**

Water quality variable	Sample station 6	7	5	4	3	11	13	14	15
pH									
Min :	6.5	7.1	7.0	7.2	7.2	7.0	7.3	7.1	7.4
Max :	8.4	8.3	8.6	8.2	8.4	8.3	8.3	8.2	8.4
Avg :	7.4	7.6	7.6	7.7	7.8	7.7	7.8	7.7	7.8
Num :	20	19	25	22	22	25	22	23	23
COD (mg/l)									
Min :	20	32	24	28	28	24	16	16	12
Max :	250	192	204	112	192	224	144	136	90
Avg :	71	72	56	54	63	73	46	53	42
Num :	20	19	25	22	22	25	22	23	23
NO3-N (mg/l)									
Min :	0.07	0.10	0.10	0.20	0.80	0.60	1.50	1.60	2.00
Max :	0.70	1.50	2.50	4.80	4.00	3.70	6.10	7.00	5.00
Avg :	0.35	0.50	1.02	2.50	2.03	2.05	3.38	3.94	3.17
Num :	20	19	25	22	22	25	22	23	23
NH3-N (mg/l)									
Min :	0.40	0.80	0.80	0.80	1.60	0.80	0.60	0.40	0.40
Max :	13.00	14.60	15.80	15.00	15.00	12.80	6.40	5.80	5.20
Avg :	1.47	7.83	5.64	4.78	4.37	3.56	2.85	2.36	2.56
Num :	20	19	25	21	22	25	22	23	23
F Coli (counts/100ml)									
Min :	300	105 000	2 000	12 000	1 000	270	800	1 400	1 200
Max :	624 000	7 280 000	1 690 000	5 200 000	7 500 000	906 000	770 000	680 000	189 000
Avg :	72 213	2 080 211	365 464	862 259	908 314	231 250	173 080	166 814	52 036
Num :	20	19	25	22	22	24	22	23	22
PO4-P (mg/l)									
Min :	0.2	0.8	0.5	1.1	1.5	1.2	0.7	0.6	0.7
Max :	9.2	23.1	7.9	14.9	5.8	26.4	5.9	7.0	9.5
Avg :	1.6	3.2	2.3	3.8	2.9	3.7	2.4	2.3	2.6
Num :	20	19	25	22	22	25	22	23	23
SS (mg/l)									
Min :	3	10	8	20	18	20	11	25	29
Max :	121	958	1 580	810	810	1 975	1 736	2 290	1 045
Avg :	35	113	223	144	156	244	197	235	157
Num :	20	19	25	21	22	25	22	23	22
DO (mg O2/l)									
Min :	2.40	1.10	2.30	1.50	2.40	3.00	2.80	3.70	3.70
Max :	9.10	6.30	23.60	7.90	8.10	8.40	9.80	10.20	10.20
Avg :	5.82	4.26	6.09	4.89	5.24	5.97	5.73	5.80	5.77
Num :	19	17	17	18	19	21	21	21	20
Conductivity (mS/m)									
Min :	78.0	28.5	19.0	23.0	24.0	2.6	21.5	18.5	25.0
Max :	325.0	96.5	75.8	62.5	63.0	67.5	64.5	64.5	63.0
Avg :	149.1	62.2	51.5	51.4	50.5	50.0	52.1	51.8	51.9
Num :	20	19	25	22	22	25	22	23	22
Temp (deg C)									
Min :	16.0	16.2	17.2	16.5	16.8	17.7	5.4	5.3	5.3
Max :	21.6	23.5	25.6	27.7	26.8	29.1	25.6	24.5	25.7
Avg :	18.7	20.0	21.0	23.0	23.0	23.3	21.0	20.6	20.8
Num :	20	17	20	20	21	22	22	21	20

Minimum, maximun and average concentrations and number of samples taken during summer **Table 6.2**

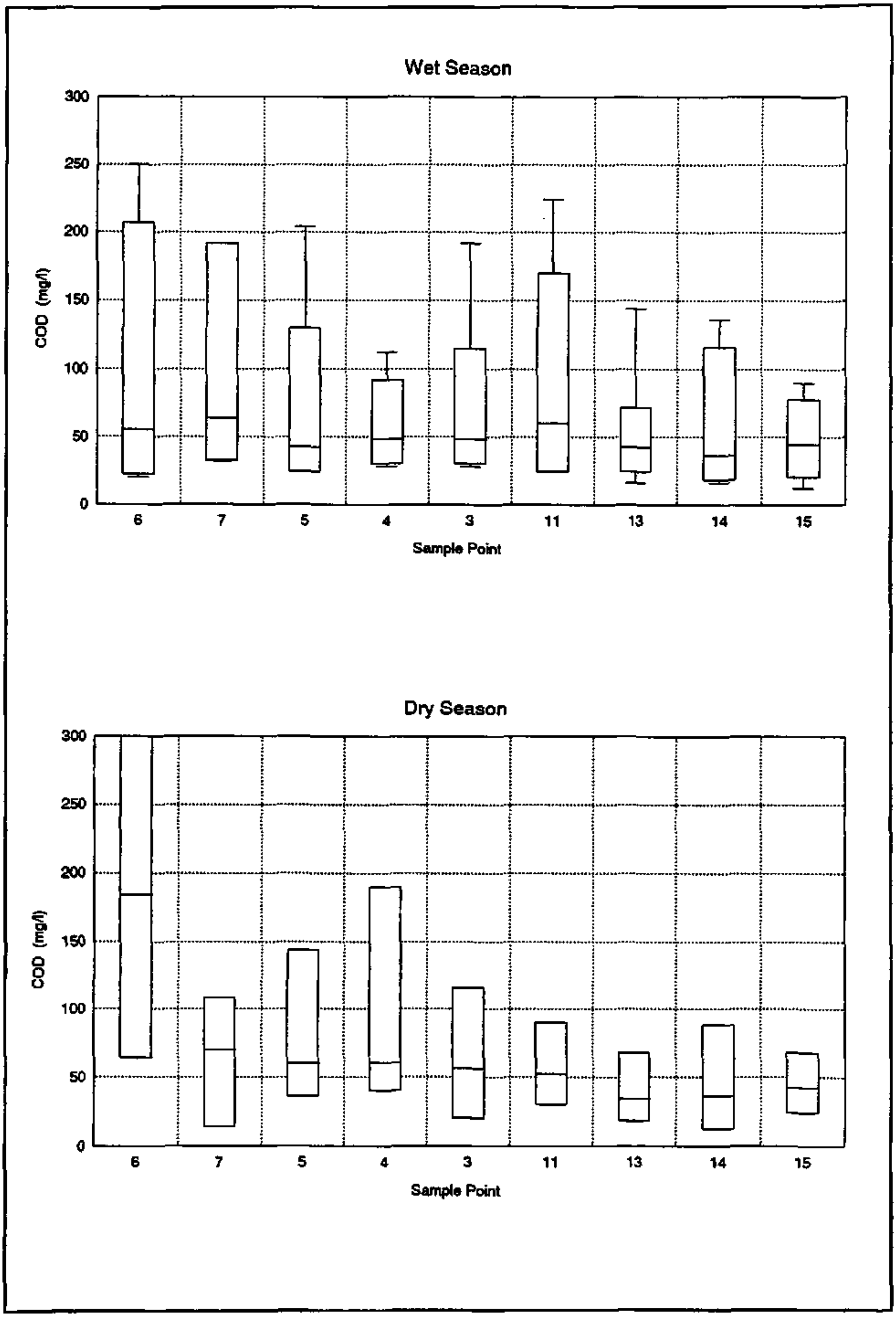


FIGURE 6.1 - BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF COD IN THE HENNOPS VALLEY

The wet and dry season COD concentrations decrease along the river flow and the quality is more or less the same. During summer the COD concentration at **Monitoring point 4** showed an increase. This is the result of stormwater runoff from Clayville entering the Olifantspruit downstream of monitoring point 5. At **monitoring point 3** the beneficial effect of the purified effluent from the Olifantsfontein Waste Water Treatment Works is noticed during winter. The concentration however remains approximately constant during the wet season. By the time the water reaches the Centurion Lake, the water quality has improved due to natural purification and dilution in the river. The summer and winter profiles and concentrations are very similar. This indicates that the non-point source runoff is also polluted and that dilution does not improve the water quality. During the wet season the General Standard limit of 75 mg/ℓ is frequently exceeded.

Figure 6.2 shows that during the dry season a marked increase in **ammonia** concentration up to **monitoring point 5** occurs. From here it decreases due to dilution, point source addition and nitrification in the river. The ammonia concentrations in the river system during the dry season are considerably higher than the wet season concentrations. This indicates the effect of dilution due to stormwater runoff. Ammonia concentrations during the wet and dry season exceeds the recommended in-stream limit of 0.4 mg/ℓ for aquatic life.

The **nitrate plot (Figure 6.3)** indicates a significant increase in nitrate concentration from the outflow of Ivory Park (point 5) to the inlet of Centurion Lake. The very substantial nitrate concentration increase between **monitoring points 5 and 4** can be attributed to nitrification in the slow flowing section of the river. This is the result of a downstream dam wall. The nitrate profiles and concentrations are similar for summer and winter conditions, except that the wet season concentrations are considerably lower. This can be attributed to the shorter retention time for nitrification and dilution due to stormwater runoff.

The **total phosphate plot (Figure 6.4)** indicates a reasonably constant concentration during the dry and wet seasons. During the wet season the total phosphate concentration is lower than the dry season concentration. This can be attributed to dilution. The effluent phosphate concentration from the Olifantsfontein Waste Water Treatment Works was higher than the stipulated 1 mg/ℓ and as can be seen from the results no in-stream dilution has been measured. The ratio of base flow to effluent was about 1:3. If the effluent complied with the Special Phosphate Standard than the river phosphate concentration would have been much lower i.e. ± 1.5 mg/ℓ. The poor performance of the Treatment Works can be mainly attributed to organic overload. Furthermore, one of the final clarifiers is out of operation due to ground settlement problems. Major upgrading work is under way and this should be completed by March 1995. This will result in a better

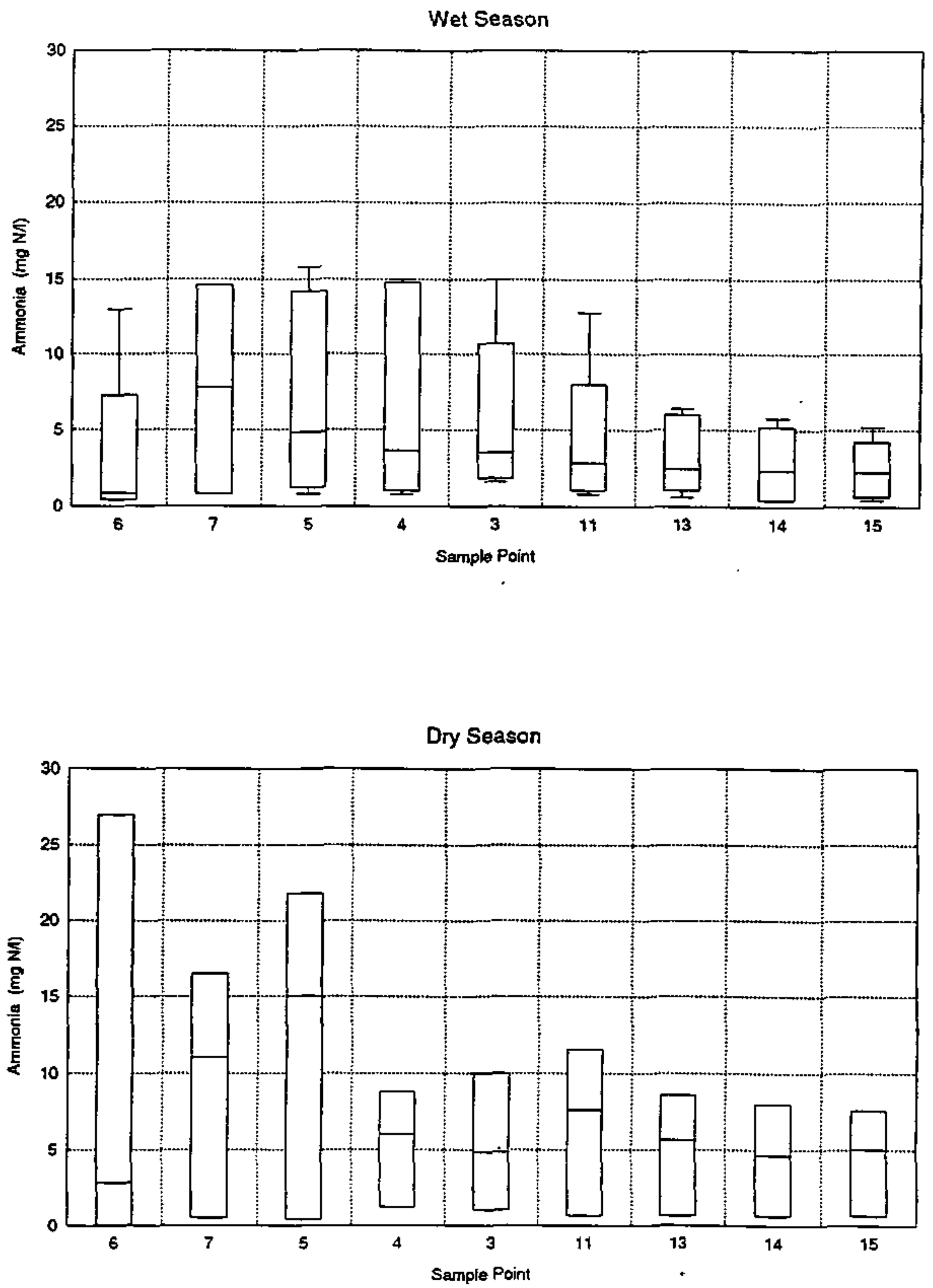


FIGURE 6.2 - BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF AMMONIA IN THE HENNOPS VALLEY

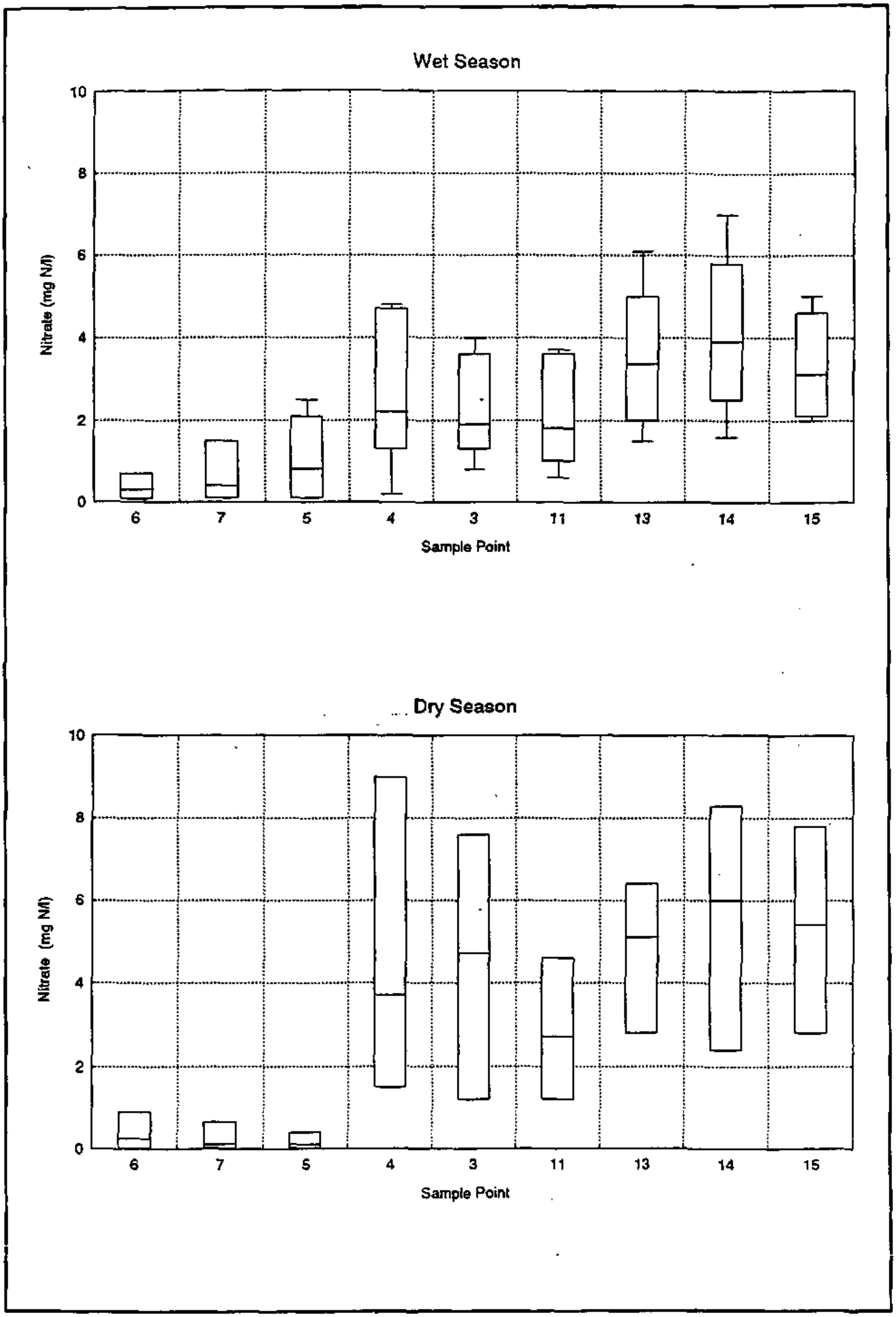


FIGURE 6.3 - BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF NITRATE IN THE HENNOPS VALLEY

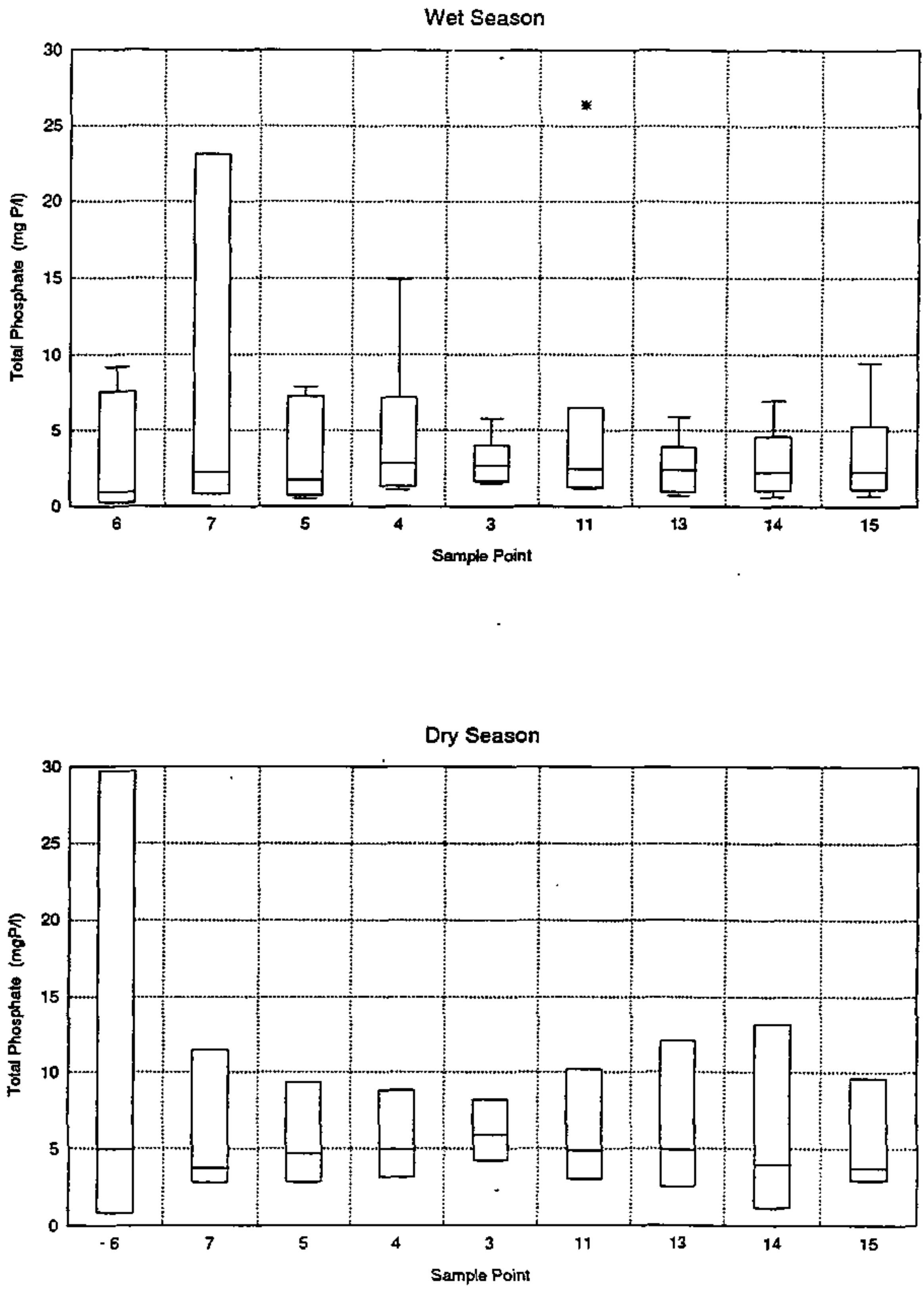


FIGURE 6.4 - **BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF TOTAL PHOSPHATE IN THE HENNOPS VALLEY**

quality effluent and should improve the quality of the river water.

Figure 6.5 shows a slight increase in **suspended solids** concentration from source to **monitoring point 11** with a subsequent decrease at the inlet of the Lake. A slight increase is evident in the Lake which can be the result of turbulence and mobilisation. This profile is noticed for both the dry and wet seasons. The wet season's maximum values are considerably higher than the dry season concentration. This can be attributed to the silt content in the water due to stormwater runoff (seasonal character).

The **Faecal Coliform plot (Figure 6.6)**, which provides an indication of microbiological pollution, is high in the of the catchment and reduce significantly en route to the Lake. This is due to natural die-off and dilution from the Olifantsfontein Waste Water Treatment Works. The wet season Faecal Coliform counts are considerably higher than dry season values. During both the dry and wet seasons, Tembisa is a major source of microbiological pollution to the river. The wet season increase in Faecal Coliform counts between monitoring points 4 and 5 can be attributed to the tributary from Clayville. The rapid decrease of Faecal Coliform counts between sampling points 3 and 11 can probably be attributed to die off due to residual chlorine in the effluent from the Olifantsfontein Waste Water Treatment Works.

The water quality profile indicates, in all cases, significant pollution from the urban development in the of the Hennops River Valley. During the wet season, the maximum concentrations of the various water quality variables are considerably higher than the dry season values. This is the result of polluted stormwater runoff. The Clayville sub-catchment appears to have a significant effect on the Faecal Coliform count in the Olifantspruit during the wet season, whereas all other water quality variables have a negligible effect.

The **conductivity plot (Figure 6.7)** shows high values at **monitoring point 6**. The reason can be the industrial waste water emanating from the NCP ponds. Fortunately, the impact of this water after its confluence with the Kaalspruit is negligible due to dilution with the good quality headwaters. From **monitoring point 5** to **monitoring point 15** at the outlet of the Lake, the conductivity measured of remains more or less constant during the winter and summer periods. The high conductivity measurements at **monitoring point 6** during the winter and summer periods indicate that some spillage occurs from the NCP evaporation and storage ponds.

The **dissolved oxygen plot (Figure 6.8)** indicates a higher concentration during summer. This is due to higher flows and, therefore, more turbulence resulting in more effective re-aeration. The dissolved oxygen saturation value of the water during winter is about 8.3

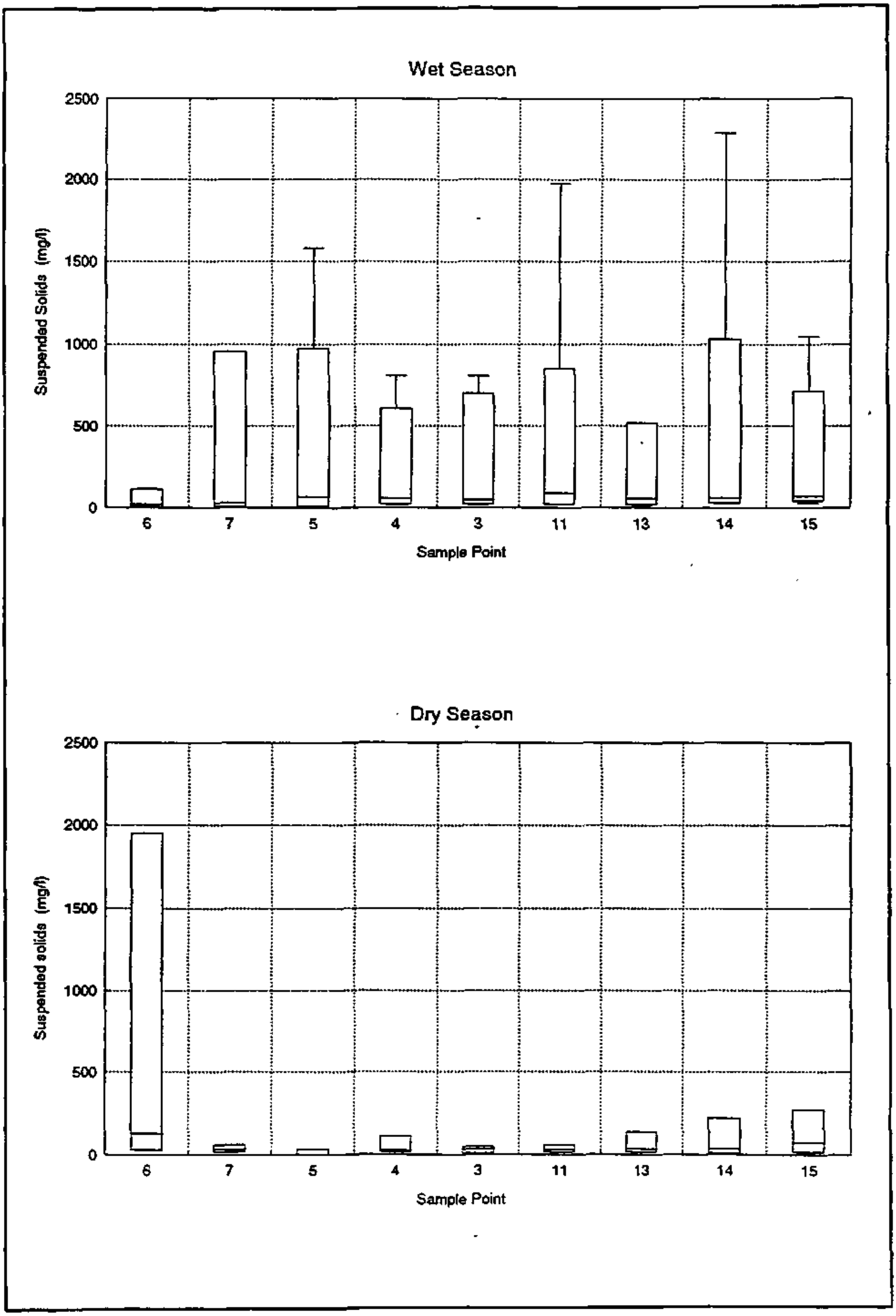


FIGURE 6.5 - BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF SUSPENDED SOLIDS IN THE HENNOPS VALLEY

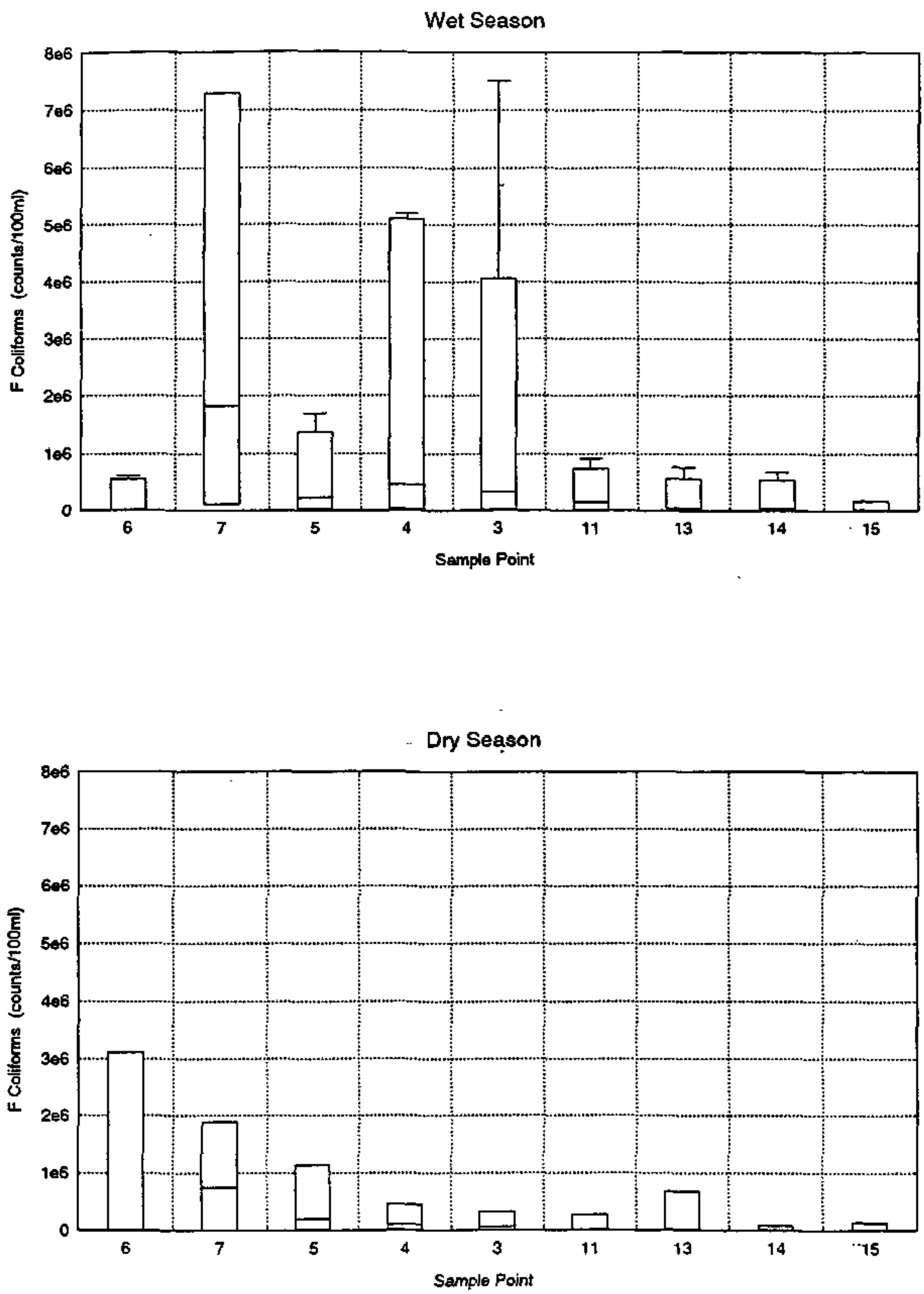


FIGURE 6.6 - BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF F. COLIFORMS IN THE HENNOPS VALLEY

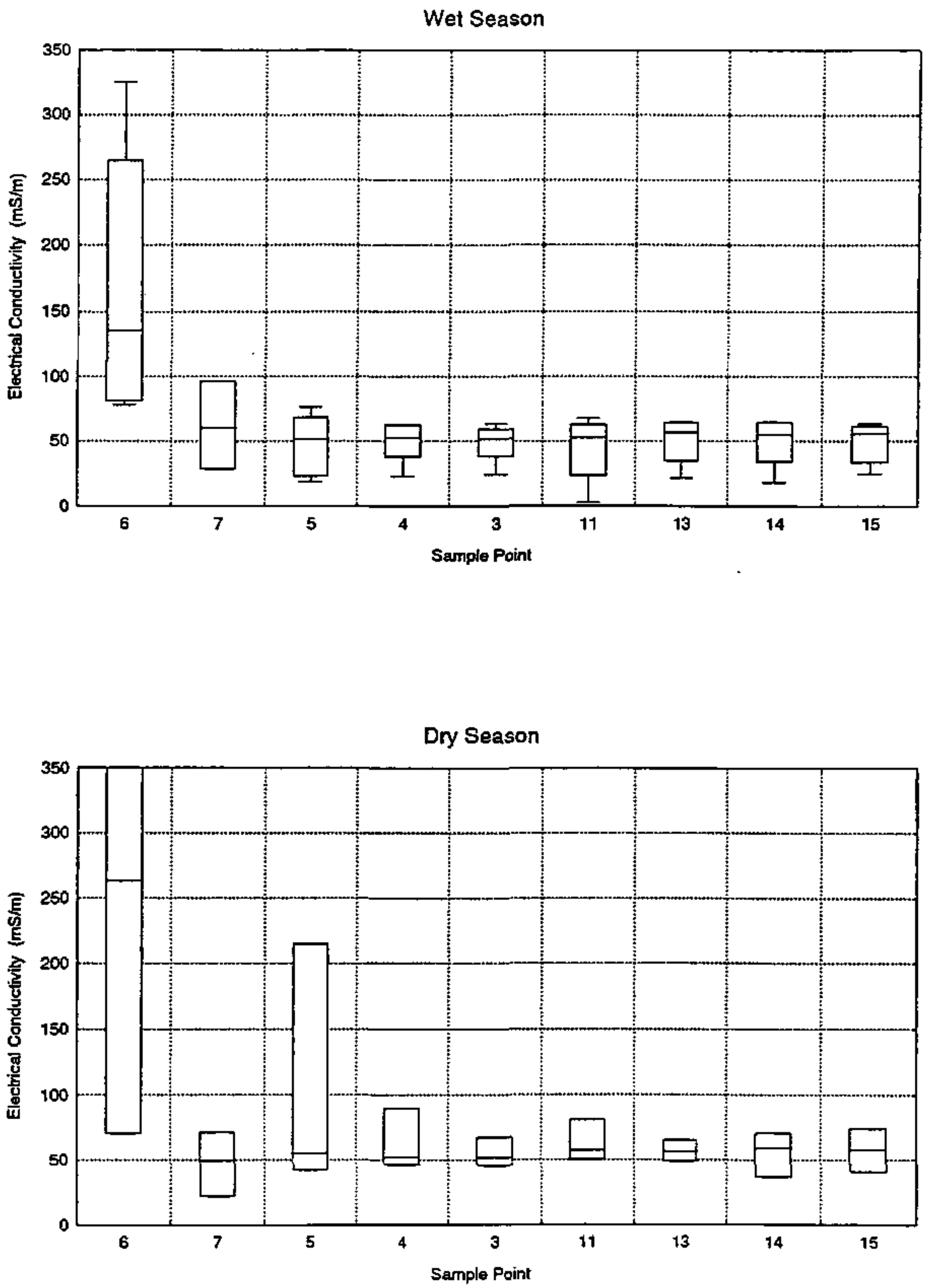


FIGURE 6.7 - BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF ELECTRICAL CONDUCTIVITY IN THE HENNOPS VALLEY

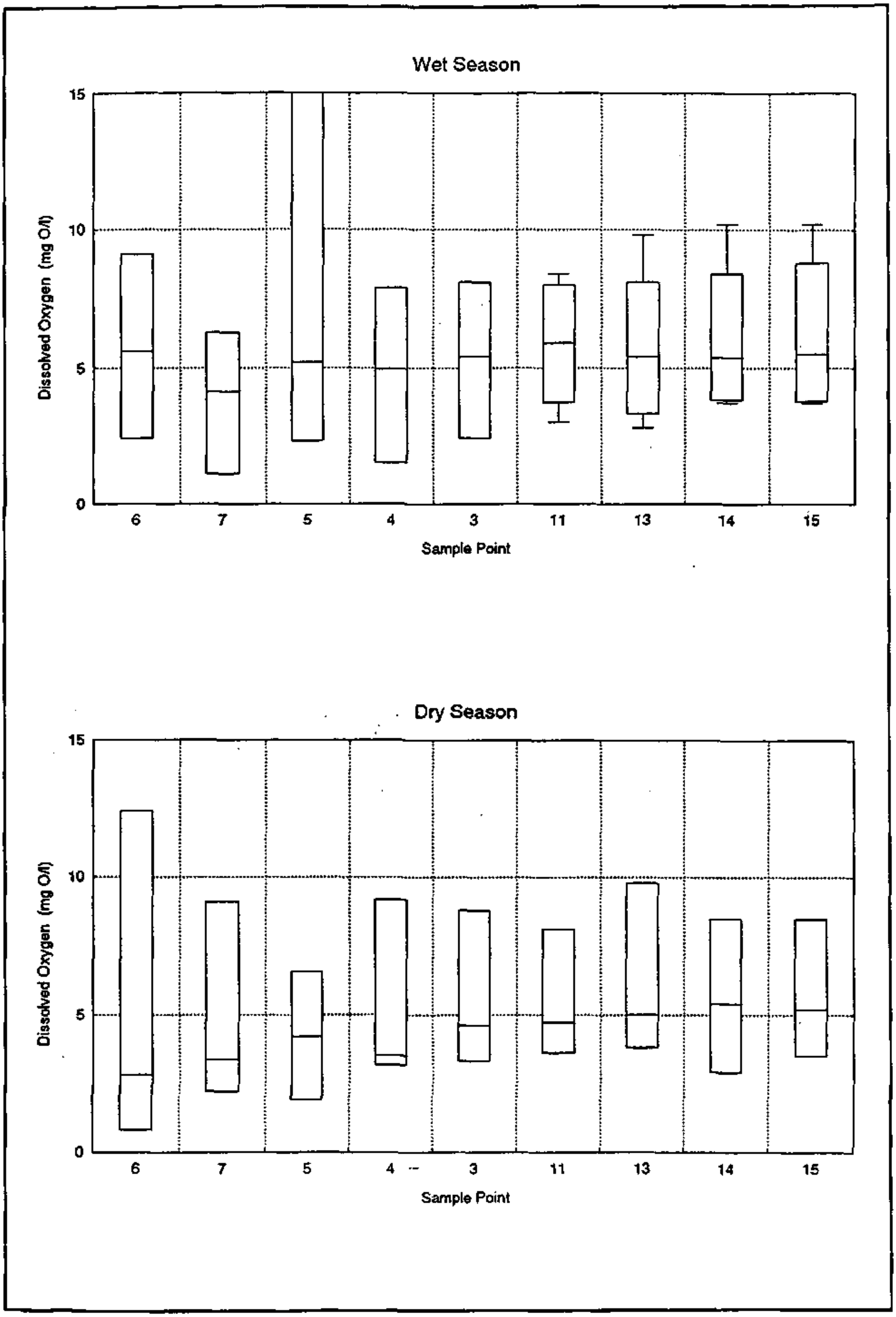


FIGURE 6.8 . BOX-AND-WHISKER PLOTS SHOWING WET SEASON AND DRY SEASON RUNOFF CHARACTERISTICS OF DISSOLVED OXYGEN IN THE HENNOPS VALLEY

Monitoring Point	Season	Calcium mg Ca/l	Magnesium mg Mg/l	Sodium mg Na/l	Sulphate mg SO4/l	Chloride mg Cl/l	Alkalinity mg CaCO3/l	OrthoPhos mg P/l
6	Summer	65.70	38.05	118.60	48.40	305.50	219.00	0.19
	Winter	114.50	32.50	332.50	13.97	722.83	165.17	0.84
7	Summer	39.80	15.57	24.80	31.00	48.00	95.67	1.80
	Winter	34.17	7.55	34.67	21.47	39.67	152.67	1.63
8	Summer	17.80	8.45	18.60	21.75	17.00	42.33	0.17
	Winter	29.23	12.43	53.83	9.15	39.83	165.00	0.15
5	Summer	38.90	14.14	36.14	34.43	46.50	72.50	0.72
	Winter	56.10	13.53	99.67	25.50	156.17	175.00	2.23
1	Summer	29.00	11.00	11.00	33.50	8.00	8.00	0.30
	Winter	-	-	-	-	-	-	-
9	Summer	39.15	17.10	16.88	27.16	16.00	68.75	0.73
	Winter	-	-	-	-	-	-	-
2	Summer	42.43	16.38	18.29	26.29	24.83	40.17	0.28
	Winter	35.73	7.60	91.50	33.00	90.83	183.33	2.40
4	Summer	33.88	11.06	32.00	40.43	36.40	36.40	1.78
	Winter	33.00	8.90	60.33	45.42	39.33	131.67	2.97
10a	Summer	36.28	16.38	51.67	42.17	48.80	48.80	5.57
	Winter	27.07	4.49	70.83	36.17	47.50	116.67	0.80
10b	Summer	27.63	12.05	46.14	44.86	39.50	50.83	4.13
	Winter	25.44	5.46	65.60	57.40	38.00	89.60	3.92
3	Summer	33.88	11.06	32.00	40.43	36.40	36.40	1.78
	Winter	33.00	8.90	60.33	45.42	39.33	131.67	2.97
11	Summer	36.90	14.57	37.14	41.14	42.83	63.50	1.30
	Winter	35.67	13.67	57.33	50.00	43.17	163.67	2.85
12	Summer	39.92	17.47	34.86	33.00	37.17	51.83	0.26
	Winter	40.80	13.80	61.40	46.20	49.80	161.20	0.42
13	Summer	38.00	13.95	34.14	39.86	39.67	61.33	0.87
	Winter	35.00	13.83	60.67	39.50	49.67	155.00	2.85
14	Summer	34.64	14.85	32.43	39.57	39.67	59.67	0.80
	Winter	35.93	13.96	62.50	43.00	47.50	148.33	2.68
15	Summer	29.87	13.80	31.57	40.00	40.00	57.17	0.71
	Winter	36.17	13.55	62.67	43.17	44.67	154.00	2.47

Average Summer and Winter concentrations of macro variables at all monitoring poits — **Table 6.3**

Monitoring Point	Season	Chromium mg Cr/l	Cobalt mg Co/l	Copper mg Cu/l	Cadnium mg Cd/l	Iron mg Fe/l	Lead mg Pb/l	Manganese mg Mn/l	Mercury mg Hg/l	Nickel mg Ni/l	Zink mg Zn/l
6	Summer	0.050	0.025	0.050	0.025	1.30	0.05	0.47	0.03	0.025	0.03
	Winter	0.035	0.027	0.043	0.027	0.32	0.06	2.08	0.00	0.027	0.13
7	Summer	0.050	0.025	0.050	0.025	0.86	0.05	0.86	0.03	0.025	0.03
	Winter	0.035	0.027	0.043	0.027	0.26	0.05	0.28	0.00	0.027	0.09
8	Summer	0.050	0.025	0.050	0.025	0.57	0.05	0.04	0.03	0.025	0.03
	Winter	0.035	0.027	0.043	0.027	0.10	0.05	0.07	0.01	0.027	0.10
5	Summer	0.050	0.025	0.050	0.025	3.52	0.05	0.81	0.03	0.025	0.03
	Winter	0.035	0.027	0.043	0.027	0.51	0.05	0.93	0.00	0.027	0.19
1	Summer	-	-	-	-	-	-	-	-	-	-
	Winter	-	-	-	-	-	-	-	-	-	-
9	Summer	0.000	0.000	0.000	0.000	0.00	0.00	-	-	-	0.00
	Winter	0.038	0.025	0.050	0.025	-	0.05	-	-	0.025	-
2	Summer	0.050	0.025	0.050	0.025	0.67	0.05	0.13	0.03	0.035	0.05
	Winter	0.035	0.027	0.043	0.033	0.76	0.05	0.40	0.00	0.027	0.28
4	Summer	0.050	0.025	0.050	0.025	0.76	0.05	0.38	0.03	0.025	0.03
	Winter	0.035	0.027	0.043	0.027	0.19	0.05	0.19	0.00	0.028	0.15
10a	Summer	0.050	0.025	0.050	0.025	0.04	0.05	0.05	0.03	0.025	0.03
	Winter	0.035	0.027	0.043	0.027	0.12	0.05	0.06	0.00	0.027	0.14
10b	Summer	0.050	0.025	0.050	0.025	0.12	0.05	0.05	0.03	0.025	0.04
	Winter	0.035	0.027	0.043	0.027	0.05	0.05	0.03	0.00	0.027	0.14
3	Summer	0.050	0.025	0.050	0.025	0.66	0.05	0.33	0.03	0.025	0.04
	Winter	0.035	0.027	0.043	0.030	0.18	0.05	0.16	0.33	0.027	0.12
11	Summer	0.050	0.025	0.050	0.025	0.95	0.05	0.38	0.03	0.025	0.10
	Winter	0.035	0.027	0.043	0.027	0.22	0.05	0.22	0.00	0.027	0.11
12	Summer	0.050	0.025	0.050	0.025	1.30	0.05	0.45	0.03	0.025	0.15
	Winter	0.035	0.027	0.043	0.027	0.05	0.05	0.05	0.00	0.030	0.09
13	Summer	0.050	0.025	0.050	0.025	2.20	0.05	0.88	0.03	0.025	0.10
	Winter	0.035	0.027	0.043	0.027	0.17	0.05	0.15	0.00	0.027	0.10
14	Summer	0.050	0.025	0.050	0.025	1.30	0.05	0.54	0.03	0.025	0.08
	Winter	0.035	0.027	0.043	0.027	0.31	0.05	0.16	0.01	0.027	0.08
15	Summer	0.050	0.025	0.050	0.025	0.63	0.05	0.46	0.03	0.025	0.04
	Winter	0.035	0.027	0.043	0.027	0.23	0.05	0.13	0.01	0.027	0.09

Average Summer and Winter concentrations of macro and micro variables at all monitoring points — **Table 6.4** mg/ℓ and during summer about 7.5 mg/ℓ. Due to the slightly more polluted water during the winter period and therefore a higher oxygen demand, the dissolved oxygen is less than the desired value. The winter dissolved oxygen saturation is 64% which is slightly lower than the desired value of 70%.

The average summer and winter concentrations of the macro and micro water quality variables of all the monitoring points are summarised in **Tables 6.3 and 6.4.** For most water quality variables, the wet season concentrations are lower than the dry season concentrations as a result of stormwater runoff and the effect of dilution.

6.3 Storm Events

Continuous sampling was not undertaken due to the number of sampling points. Grab samples were taken at selected locations along the river i.e. **monitoring points 6, 7, 5, 3, 11, 15 and 2.** Because of thunderstorms in the late afternoon, it was only possible to take samples the next morning during daylight hours. As a result of elevated flow in the river system, it was not possible to measure the flow manually. At the various sampling points, whenever possible, the instantaneous flow was measured.

The normal monitoring programme continued during the summer. Six separate storm/rain events were monitored during the season. The dates of sampling and associated rainfall at the selected sampling points were as follows:

Date	Rainfall
5/10/93	60 mm
8/10/93	19 mm
5/11/93	40 mm
23/11/93	24 mm
21/01/94	15 mm
15/03/94	8.5 mm

The first rains fell on 24 September 1994 with the first major storm occurring on 30 September 1994. On 5 October rain fell for two days and grap samples were taken. Grap samples were also taken after the other storm events. The rainfall that fell during the previous 24 hours was recorded before sampling commenced.

Water samples were analyzed for the following water quality variables:

COD	mg/ℓ	Suspended Solids	mg/ℓ
Ammonia	mgN/ℓ	pH	
Nitrate	mgN/ℓ	Dissolved Oxygen	$mgO_2/ℓ$
Total Phosphate	mgP/ℓ	Conductivity	mS/m
F. Coliform	counts/100mℓ		

For each water quality variable, the results of the storm events are compared to the winter and summer averages in **Tables 6.5 to 6.14.**

TABLE 6.5 CHEMICAL OXYGEN DEMAND - COMPARISON BETWEEN STORM EVENTS AND THE AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	CHEMICAL OXYGEN DEMAND COD mg/ℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	189	66	-	-	-	64	40	-
7	63	72	-	80	64	96	40	-
5	73	46	130	48	28	82	40	42
3	61	59	-	-	-	80	44	48
11	56	68	135	56	24	80	100	48
15	43	41	-	-	20	90	44	52
2	352	84	76	56	80	96	44	16

TABLE 6.6 AMMONIA COMPARISON BETWEEN STORM EVENTS AND THE AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	AMMONIA mgN/ℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	2.5	0.8	-	-	-	0.6	13	-
7	9.5	7.7	-	7.8	13.6	2.0	0.8	-
5	14.5	6.1	1.6	1.8	14.2	1.2	0.8	3.6
3	5.4	4.4	-	-	-	1.8	4.8	2.8
11	2.8	3.1	1.7	2.4	4	1.8	3.4	2.2
15	4.7	2.1	-	-	4.2	1.2	3.2	1.4
2	3.6	1.6	1.2	1.4	1.0	1.4	1.0	1.0

TABLE 6.7 NITRATE COMPARISON BETWEEN STORM EVENTS AND AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	NITRATE mgN/ℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	0.3	0.4	-	-	-	0.6	0.3	-
7	0.2	0.4	-	0.6	0.2	1.5	0.1	-
5	0.1	1.1	0.8	0.53	0.1	1.2	0.7	2.1
3	3.9	2.1	-	-	-	1.4	1.3	2.4
11	1.9	2.0	1.0	3.1	3.8	1.5	1.8	1.5
15	5.7	3.3	-	-	3.1	2.0	2.9	3.0
2	0.5	2.3	1.1	2.1	0.5	1.3	1.7	3.3

TABLE 6.8 TOTAL PHOSPHATE COMPARISON BETWEEN STORM EVENTS AND AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	TOTAL PHOSPHATE mgP/ℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	6.6	1.4	-	-	-	3.2	1.1	-
7	4.5	2.3	-	0.81	2.3	2.7	1.8	-
5	5.3	2.3	1.15	0.53	2.0	1.7	1.6	1.8
3	5.9	2.9	-	-	-	2.9	2.4	2.0
11	2.8	2.9	1.75	1.17	3.6	2.4	2.1	1.9
15	4.4	2.8	-	-	3.3	3.5	2.6	1.2
2	6.6	1.4	0.78	0.95	1.0	1.4	0.5	0.7

TABLE 6.9 FAECAL COLIFORM COMPARISON BETWEEN STORM EVENTS AND THE WINTER AND SUMMER AVERAGE VALUES

Monitoring Point	F. COLIFORM COUNTS/100 mℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	271 572	89 166	-	-	-	39 000	1 100	-
7	1 151 223	2 376 000	-	884 000	2 600 000	975 000	4 160 000	-
5	396 822	350 505	780 000	220 000	48 000	530 000	230 000	1 370 000
3	127 813	1 125 731	-	-	-	902 000	360 000	1 030 000
11	246 700	97 817	906 000	406 000	220 000	744 000	76 000	381 000
15	11 689	61 350	-	-	82 600	160 000	1 200	170 000
2	344 729	110 531	837 000	208 000	25 000	550 000	600 000	20 800

TABLE 6.10 SUSPENDED SOLIDS COMPARISON BETWEEN STORM EVENTS AND AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	SUSPENDED SOLIDS mg/ℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	371	25	-	-	-	121	5.0	-
7	29	33	-	35	46	468	27	-
5	22	115	1 580	160	39	696	71	233
3	25	137	-	-	-	705	60	170
11	98	131	1 975	262	25	851	127	102
15	66	153	-	-	6	1 054	55	315
2	118	76	515	69	116	472	11.5	6.4

TABLE 6.11 pH COMPARISON BETWEEN STORM EVENTS AND AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	pH							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	7.2	7.4	-	-	-	7.3	7.65	-
7	7.6	7.6	-	7.30	7.60	7.35	7.70	-
5	7.7	7.6	6.95	7.55	7.75	7.20	7.60	7.70
3	7.7	7.8	-	-	-	7.35	7.75	7.85
11	7.8	7.7	6.95	7.55	7.85	7.40	7.75	7.80
15	7.8	7.8	-	-	7.75	7.35	7.90	7.60
2	-	-	7.15	7.95	6.90	7.65	8.6	8.25

TABLE 6.12 CONDUCTIVITY COMPARISON BETWEEN STORM EVENTS AND THE AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	CONDUCTIVITY mS/m							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	290	267	-	-	-	78	83	-
7	49	64	-	82	62.3	28.5	54	-
5	53	59	11	45	63.8	22.5	46	55
3	55	46	-	-	-	80	50.5	53
11	62	51	23	48	57.8	24.5	52	56
15	60	48	-	-	56.3	25.0	56.5	44
2	88	59	15	42	13.0	21.0	62	60

TABLE 6.13 DISSOLVED OXYGEN COMPARISON BETWEEN STORM EVENTS AND THE AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	DISSOLVED OXYGEN mgO/ℓ							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	4.4	5.8	-	5.2	4.1	5.7	-	-
7	4.2	4.3	-	1.1	4.5	-	-	-
5	4.1	-	-	3.0	3.5	6.7	-	7.8
3	5.0	5.2	-	4.0	5.1	3.7	-	6.3
11	5.3	6.0	-	4.3	5.9	5.1	3.7	-
15	5.4	6.5	-	5.2	4.1	5.3	3.8	5.8

TABLE 6.14 FLOW COMPARISON BETWEEN STORM EVENTS AND THE AVERAGE WINTER AND SUMMER VALUES

Monitoring Point	FLOW ℓ/s							
	WINTER April - Sept.	SUMMER Oct. - March	STORM EVENTS					
			6/10/93	8/10/93	5/11/93	23/11/93	21/01/94	15/03/94
6	0.8	91.3	-	9.06	9.03	-	-	-
7	136.3	338.3	-	205.5	210.4	-	-	-
5	153.6	670.7	-	322.6	184.3	-	-	499.9
3	702.8	1 475.7	-	-	-	-	-	-
11	515.2	1 281.7	-	-	393.5	-	1 730.9	1 047.8
15	499.40	616.4	-	590.07	528.6	-	-	640.925

The concentrations of **COD, total phosphates, Faecal Coliforms and suspended solids** of the first storm event are considerably higher than the values of the other storm events. This can probably be explained by the first flush effect after a dry winter season. The microbiological counts and ammonia concentration during the first storm are very similar to the summer and winter average concentrations in the river system. Unfortunately, the base flow has been contaminated with raw sewage runoff as a result of pipe blockages in Tembisa and Rabie Ridge. During storm events, this problem is even more pronounced due to stormwater infiltration in the sewer system. To separate the pollution contribution from different diffused sources is impossible. The trend of the water quality variables during the summer season however indicates that during the subsequent storm events the concentrations for the various pollutants are similar to the winter and summer averages. A high suspended solids concentration can be expected during most of the storm events. This is explained by the suspended silt in the water as a result of surface runoff.

The microbiological counts remain high during storm events. This can be attributed to the shorter retention time in the system, increased mobilisation, and thus a shorter exposure to sunlight. Although the quality of the water in the river system deteriorated after the first storm event, it improved in subsequent storm events to the dry season state. It can, therefore, be stated that during the start of the rain season, the water quality will deteriorate due to accumulated pollutants in the catchment.

Due to good rains during the summer season, the summer average was, in most instances, higher than the values measured during the storm events. The flow measurements at

Pinedene Weir (**monitoring point 11**) do not compare with the in-stream flow measurements at **monitoring point 3. Monitoring point 11** is located downstream of **monitoring point 3** and should have a similar flow. The discrepancy in flow can be attributed to the shape of the weir and the difficulty in measuring the velocity and depth at various points. Both the winter and summer measurements at **monitoring point 15** are lower than the upstream flow measurements. The flow out of the Lake is measured in six channels. Some of the water is not measured during the wet season when storm events occur as it bypasses directly to the river via an emergency overflow. The flow measurements upstream of the Lake are instantaneous and do not reflect the daily average flows, whereas the Lake will depict a more balanced flow due to its retention time. At a volume of 150 000 m^3 the retention time is 1-3 days depending on the incoming flow.

6.4 Pollutant loads

The generation of NPS pollution is commonly expressed in terms of unit export loads. An export load reflects the mobilisation of a pollutant mass from a unit surface area during an average hydrological year. One of the most useful sets of data in water quality monitoring is pollutant loads, as these act as a summary value for both water quality and water quantity variables. The difficulties experienced in measuring the discharges from the various land use activities made the calculation of pollution loads impossible during storm events. It was therefore impossible to perform a comparison between all the sub-catchments as the flow was not measured at all the points.

Seven sub-catchments were selected as illustrated in **Figure 6.9.** The sub-catchments are represented by the **monitoring points 6, 7, 5, 2, 3, 11 and 15.**

The time series plots of the selected water quality variables and flows at the monitoring points of the sub-catchments for the summer and winter situations are graphically shown in **Figures 6.10 to 6.16** and are geographically presented in **Figures 6.17 to 6.22 in Annexure A.**

The grab sample pollutant concentration and corresponding flow rate, recorded at the time when the sample was taken, were used to compute the pollutant mass flux.

$$M_i = Q_i * C_i * 0.0864$$

where:

M_i = Pollutant mass flux (kg/day)

C_i = Pollutant concentration (mg/ℓ)

Q_i = Flow rate (ℓ/s)

$_i$ = Single event

The events for the summer and winter periods were averaged to indicate the pollution load and unit export load for each sub-catchment. These flow-weighted averages are summarised in **Table 6.15.**

The daily unit export load from the sub-catchments varies according to the activities that take place and the season of the year. The export load, maximum concentrations and average concentrations (with a few exceptions) are higher during the summer than the winter. The difference between the summer and winter loads can be attributed to the runoff from diffused sources.

The typical ranges of pollutant export loads from urban catchments are compared to three urban sub-catchments in the Hennops River Valley in **Table 6.16.**

6.5 Comparison of Stormwater Quality Results with other Urban Studies

Several urban stormwater studies have been undertaken in South Africa. These can provide a background for comparison purposes. *Wright et al (1992)* compared the Khayelitsha diffuse source pollution study with other South African studies ranging from First World type catchments to Third World type urban catchments containing formal housing, site and service stands and squatter areas. The Hennops River Valley study differs slightly from the Khayelitsha study in that it does not only look at Third World type urban catchments but also at industrial, commercial, agricultural and residential catchments.

The Hennops River Valley catchment study has now been divided into seven sub-catchments. The water quality from some of these sub-catchments will be compared to similar South African studies. As for the Khayelitsha study, this study was restricted to the total stormwater runoff leaving the sub-catchment. Because of the nature of the catchment and the security problems experienced, the study had to be undertaken on a much larger scale. For this reason, it was not possible to conduct intensive monitoring as with some of the other studies.

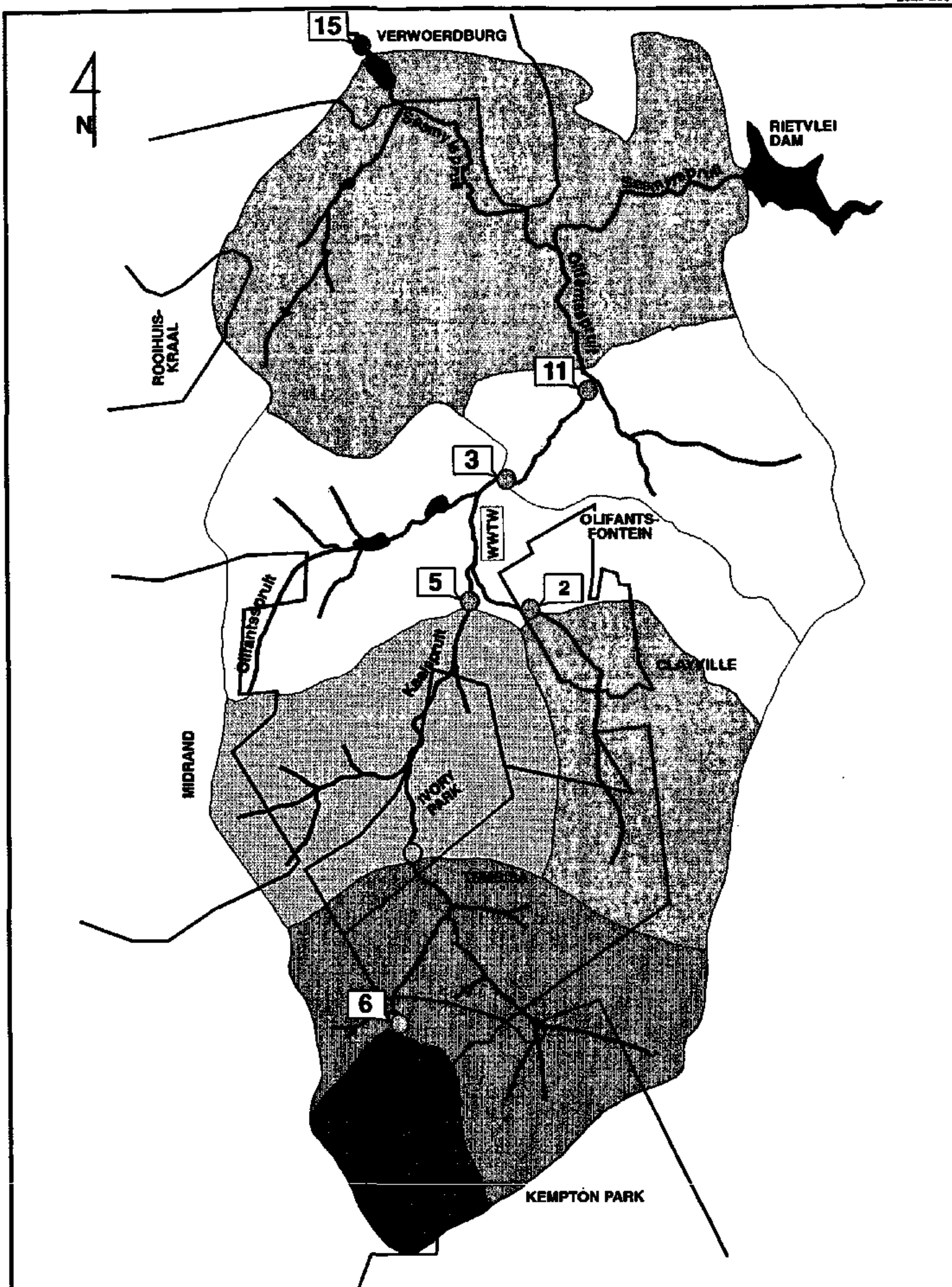


FIGURE 6.9 : HENNOPS VALLEY SUB-CATCHMENTS AND RIVER SYSTEM

TABLE 6.15: ACTUAL POLLUTION LOADS FROM THE SUB-CATCHMENT

SUB-CATCHMENT		Surface Area ha	POLLUTION LOAD (kg/d) UNIT EXPORT LOADS (kg/ha/d)									
			COD		NH_3-N		TDS		PO_4-P		SS	
			S	W	S	W	S	W	S	W	S	W
A-	NCP and Birch Acres - Monitoring Point 6	1 075.0	422 0.392	10.5 0.010	5.5 0.005	0.1 0.000	4336 4.03	228 0.21	17.0 0.016	0.1 <0.001	438 0.655	7.0 0.007
B-	Norkem Park, Birchleigh North and Tembisa - Monitoring Point 7	3 594.9	1626 0.452	788 0.219	196 0.055	122 0.034	9482 2.64	3652 1.02	44 0.012	55 0.015	897 0.250	345 0.096
C-	Eskom College, President Park Agricultural Holdings, Rabie Ridge, Ivory park and Tembisa - Monitoring Point 5	3 158.6	628 0.199	154 0.049	6 0.002	6.8 0.022	30 0.01	1138 0.36	32 0.010	15 0.005	13227 4.188	(6.8) -
D-	Clayville Industrial Area - Monitoring Point 2	2 391.9	1683 0.704	280 0.117	31 0.013	5 0.002	1143 0.48	658 0.28	22 0.009	6 0.003	10215 4.282	222 0.093
E-	Glen Austin Agricultural Holdings and Olifantsfontein - Monitoring Point 3	4 069.4	2516 0.618	2526 0.621	185 0.045	138 0.039	6647 1.63	16900 4.15	223 0.055	289 0.071	(9723) -	1041 0.256
F-	Olifantsfontein and Sterkfontein Agricultural Land - Monitoring Point 11	2 767.9	(3389) -	1274 0.460	(297) -	(144) -	-	0	(209) -	(192) -	(6937) -	9576 3.460
G-	Doornkloof Agricultural Land, Irene, Randjiesfontein, Verwoerdburg CBD - Monitoring Point 15	6 504.1	(1258) -	(3163) -	(12) -	11 0.002	-	(5058) 0.78	11 0.002	17 0.003	1122 0.173	(8223) -

S = Summer
W = Winter
( ) = Reduction in load

TABLE 6.16 UNIT EXPORT POLLUTION LOADS FROM URBAN CATCHMENTS (kg/ha/year)

Pollution constituent	North American cities (1)				Pinetown, Natal commercial (2)	Durban, Natal residential (3)	Hennops River Valley		
	Parks and green zones	Residential	Commercial	Industrial			Tembisa formal settlement	Ivory Park informal settlement	Clayville Industrial and Commercial
• Biological oxygen demand (BOD)	1.12	34	90	34	49	-	53.48	-	20.02
• Suspended solids	11.2	390	360	672	309	198	67.52	1125.18	1163.41
• Total nitrogen	0.22	9.0	11.2	7.8	7.54	3.90	16.85	9.26	4.73
• Ammonia-nitrogen	-	-	-	-	-	-	16.55	4.04	3.51
• Total phosphorus	0.04	1.6	3.4	2.2	1.33	0.58	4.87	3.120	2.59
• Ortho-phosphate	-	-	-	-	-	-	2.34	0.834	0.25
• Chemical oxygen demand (COD)	-	-	-	-	312	-	125.70	70.49	190.44
• Cadmium	0.002	0.013	0.016	0.024	-	-	0.057	-	0.004
• Chromium	0.003	0.026	0.028	0.044	0.09	-	0.098	-	0.003
• Copper	0.007	0.045	0.049	0.077	0.11	-	0.098	-	0.003
• Mercury	0.006	0.038	0.043	0.065	-	-	0.034	-	<0.001
• Nickel	0.004	0.029	0.032	0.030	-	-	0.057	-	0.001
• Lead	0.022	0.157	0.174	0.269	0.74	-	0.108	-	0.004
• Zinc	0.081	0.570	0.630	0.980	2.09	-	0.171	0.009	0.022
• Iron	-	-	-	-	10.6	-	1.322	-	0.041
• Manganese	-	-	-	-	0.26	-	1.417	-	0.008
• Total Dissolved Solids	-	-	-	-	-	-	484.01	184.55	125.13

1) Novotny, V. (1992)
2) Simpson, D.E. et al (1980)
3) Simpson, D.E. et al (1978)

Table 6.17 contains a summary of average stormwater quality in the different areas as compared to Hennops River Valley. Several of the studies monitored microbiological indicators and the results are remarkably similar to the Hennops River Valley values. The nutrient concentrations of ammonia and phosphate in the Hennops River Valley are higher than the values observed in most other studies, except Alexandra. The ammonia concentrations are very high and can only be compared to those of the worst shack areas in Khayelitsha *(Wright et al 1992)*. The salt content of the stormwater is considerably lower than observed by most other studies. The generally lower concentrations observed in the Hennops River Valley catchment can, to a certain degree, be attributed to the dilution effect of good quality groundwater. The nitrate concentrations are also low compared to the other studies.

The trace metal concentrations are similar to the values observed in the other studies.

The Hennops River Valley stormwater quality is similar to the catchment studies listed in **Table 6.17**. The Khayelitsha study differs slightly in that the salinity is higher compared to the other studies. The microbiological contamination is similar for all the catchment studies. At both the Hennops River Valley and Khayelitsha studies it has been observed that the base flow component is a major source of pollution. This is unlike the First World type catchments where the first flush appears to be the major problem. The type of land use activity and the physical condition of the watershed are key parameters in the different stormwater qualities between catchments and sub-catchments.

6.6 Comparison of Dry and Wet Season Water Quality Results with Various Water User Groups

Table 6.18 contains a comparison of the selected water quality variables of water user groups and the average dry and wet season values of the outflow from Centurion Lake.

According to the comparative table, the Hennops River water is unfit for use in all the selected water user categories. The water quality variables that exceed the water guidelines for the various water user groups are Conductivity (Irrigation), Chemical Oxygen Demand (Industry), Suspended Solids (Industry), Faecal Coliforms (Domestic, Contact Recreation and Livestock), Ammonia and Mercury (Domestic and Aquatic Life), Chloride (Industry), Orthophosphate and Total Phosphate (Contact Recreation), Zinc (Aquatic Life), Cadmium (Domestic, Irrigation, Livestock and Aquatic Life) as well as Chromium and Lead (Aquatic Life).

TABLE 6.17 COMPARISON BETWEEN HENNOPS RIVER VALLEY STORMWATER QUALITY AND OTHER SOUTH AFRICAN STUDIES

Determinand	HENNOPS RIVER VALLEY*				Khayelitsha[1]				Alexandra[2]	4&5 Three Anchor Bay	4&3 Mitchells Plain	Atlantis[6]		Motherwell[7]
	7 Tembisa Formal Housing	5 Tembisa & Ivory Park (unserviced sites)	2 Clayville Industrial	11 Total	Shacks	Serviced Sites	Formal housing	Total				Residential	Industrial	
F.coliforms per 100 mℓ	2.2×10^6	5.3×10^5	2.5×10^5	4.6×10^5	1.2×10^5	2.7×10^5	2.2×10^4	3.4×10^4	-	2.6×10^5	4.1×10^4	-	-	5.4×10^4
Na mg/ℓ	26	37	19.5	35.5	198	134	131	194	-	-	-	98	163	-
Ca mg/ℓ	27	37.5	43	33	232	122	136	129	-	-	-	38.4	42.5	-
Mg mg/ℓ	4	7.8	13.5	9.05	49	47	35	44	-	-	-	13.8	19.8	-
NH_4-N mg/ℓ	4.05	3.96	1.17	2.5	1.96	2.30	1.09	0.36	24.54	-	0.20	0.11	<0.1	-
SO_4 mg/ℓ	56	45.5	32	48.5	298	195	93	165	90	-	-	61	83	-
Cℓ mg/ℓ	22	34.5	24.5	30.5	291	164	191	2.78	87	-	-	158	236	-
Alk($CaCO_3$) mg/ℓ	60	99	88	110	412	372	436	351	-	-	-	75	107	-
NO_x-N mg/ℓ	0.40	0.91	1.67	2.12	22.8	13.6	4.05	9.93	2.88	-	8.90	5.12	<0.1	5.2
P mg/ℓ	1.90	1.46	0.80	2.15	<0.05	0.10	<0.05	<0.05	3.68	-	0.02	0.05	0.10	0.28
pH(20deg C)	7.49	7.46	7.75	7.55	6.7	7.0	6.9	7.0	-	-	-	8.1	7.9	8.3
EC mS/m	56.70	41.88	35.50	43.55	230	158	154	185	109	-	-	80	118	5
TDS(Calc)mg/ℓ	386	285	241	296	1472	1011	906	1184	801	-	-	512	755	32
Cd mg/ℓ	<0.025	<0.025	<0.025	<0.025	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01	<0.01	-
Cu mg/ℓ	<0.050	<0.05	<0.05	<0.05	<0.02	<0.02	<0.02	<0.02	-	0.101	0.018	<0.01	0.040	-
Fe mg/ℓ	0.050	3.52	0.67	0.96	0.360	0.410	1.740	0.640	2.13	5.051	3.574	0.346	1.320	-
Pb mg/ℓ	<0.050	<0.05	<0.05	0.050	0.020	0.020	0.030	0.060	0.20	0.540	0.097	0.031	0.070	-
Zn mg/ℓ	0.031	0.03	0.047	-	0.020	<0.02	<0.02	0.050	-	0.039	0.081	0.019	0.385	-

Source of Data

1 Wright, Kloppers and Fricke (1992)
2 Wimberly (1992)
3 *Simpson (1986)*
4 Kloppers (1989)
5 Wright (1987)
6 Wright (1991)
7 MacKay (1992)

* Average concentration of storm events during summer.

Water quality variable	Units	Water User Groups: Domestic	Recreation Contact	Industry	Irrigation Class I	Livestock	Aquatic life	Hennops **: Dry Season	Wet Season
Physical and organoleptic properties									
Colour	mg Pt/l	20	-	-	-	-	-	-	-
Conductivity(EC)	mS/m (20 C)	70	-	100	40	154	-	60	48
Total Dissolved Solids(ECx6.8)	mg/l	476	-	680	272	1950	-	408	326
Chemical Oxygen Demand (COD)	mg/l	-	-	30	-	-	-	43	41
Dissolved organic carbon(DOC)	mg/l	5	-	-	-	-	-	-	-
Dissolved oxygen (DO)	% saturation	70	-	-	-	-	-	64	80
Odour	TON	10	-	-	-	-	-	-	-
pH	pH units	6.0-9.0	6.5-8.5	7.0-9.0	6.5-8.4	-	6.0-9.0	7.8	7.8
Suspended Solids	mg/l	-	-	5	-	-	-	66	153
Taste	TTN	1	-	-	-	-	-	-	-
Temperature	deg C	< 25	-	-	-	-	-	-	-
Turbidity	NTU	1*	5	-	-	-	-	-	-
Microbiological constituents									
Chlorophyll a	ug/l	1*	15	-	-	-	-	-	-
Standard plate count	counts/1ml	<100*	-	-	-	5000	-	-	-
Total coliforms	counts/100ml	0*	-	-	-	-	-	-	-
Faecal coliforms	counts/100ml	0*	< 1000	-	-	1000	-	11689	61350
Clostridium perfringes	counts/100ml	0*	-	-	-	-	-	-	-
Coliphages	counts/100ml	<1*	20	-	-	-	-	-	-
Enteric viruses	TCID50/10l	<1*	<1	-	-	-	-	-	-
Protozoan parasites *(Gardia,Cryptosporidium)*	cysts,oocysts/10l	<1*	< 1	-	-	-	-	-	-
Macro-constituents									
Aluminium	mg Al/l	0.15*	-	-	5	5	0.25	-	-
Ammonia (NH3)	mg N/l	1	-	-	-	-	0.4	4.7	2.1
Total Alkalinity	mg CaCO3/l	-	-	100	-	-	-	154	57.17
Boron	mg B/l	0.5	-	-	-	5	1.5	-	-
Calcium	mg Ca/l	150	-	-	-	1000	1000	36.17	29.87
Chloride	mg Cl/l	250	-	20	105	1500	106	44.67	40
Copper	mg Cu/l	0.5	-	-	0.2	0.5	0.02	-	-
Fluoride	mg F/l	1	-	-	2	2	1	-	-
Hardness	mg CaCO3/l	300	-	200	-	-	-	-	-
Iron	mg Fe/l	0.1*	-	1.2	5	10	1	-	-
Magnesium	mg Mg/l	70	-	-	-	500	1000	13.55	13.8
Manganese	mg Mn/l	0.05*	-	-	0.2	10	1	-	-
Nitrite (NO2)	mg N/l	-	-	-	-	10	-	-	-
Nitrate (NO3)	mg N/l	6	-	-	-	100	10	5.7	3.3
Total Nitrogen (NO3/2&NH3)	mg N/l	-	-	-	5	-	-	-	-
Potassium	mg K/l	200	-	-	-	-	-	-	-
Orthophosphate (PO4)	mgPO4-P/l	-	0.05	-	-	-	-	2.47	0.71
Total Phosphorus(TP)	mgP/l		0.08					4.4	2.8
Sodium adsorption ratio (SAR)	meq/l ^0.5	-	-	-	1.5	-	-	-	-
Sodium	mg Na/l	100	-	-	70	2000	400	62.67	31.57
Sulphate	mg SO4/l	200	-	400	-	1000	1000	43.17	40
Zinc	mg Zn/l	1	-	-	1	20	0.05	0.09	0.04
Micro-constituents									
Arsenic	mg AS/l	0.1	-	-	0.1	0.5	-	-	-
Cadmium	mg Cd/l	0.01	-	-	0.01	0.01	0.001	0.027	0.025
Chromium	mg Cr/l	0.1	-	-	0.1		0.02	0.035	0.05
Lead	mg Pb/l	0.05	-	-	0.2	0.1	0.003	0.05	0.05
Mercury	mg Hg/l	0.005	-	-	-	0.002	0.001	0.01	0.03
Molybdenum	mg Mo/l	0.05	-	-	0.01	0.01	-	-	-
Nickel	mg Ni/l	0.25	-	-	0.2	1	0.1	0.027	0.025
Selenium	mg Se/l	0.02	-	-	0.02	0.05	0.03	-	-
Tin	mg Sn/l	0.1	-	-	-	-	-	-	-

* Requirements for treated water only

** Monitoring station 15 (Verwoerdburg Lake Outlet)

Exceeds recommended limits

TABLE 6.18 - RIVER WATER QUALITY COMPARED TO SELECTED WATER QUALITY GUIDELINES OF VARIOUS WATER USER GROUPS

6.7 Total Phosphate versus Ortho-phosphate

Phosphorous occurs in natural waters and in waste waters almost solely as phosphates. These are classified as ortho-phosphates, complex phosphates and organically bound phosphates. Detailed analysis of the water quality records at the sampling points in the Hennops River Valley indicates that the fraction of ortho-phosphates varies considerably and appears to depend to a large degree on land use activity. To obtain a correlation between ortho-phosphate and total phosphate, linear regression lines were developed for each monitoring point and these are shown in **Figure 6.23.**

The average concentrations of ortho-phosphate and total phosphate as well as the percentage of ortho-phosphate of the total phosphate for the sampling points are summarised in **Table 6.19.**

TABLE 6.19: SUMMARY OF ORTHO-PHOSPHATE AND TOTAL PHOSPHATE CONTENT

SAMPLING POINT	ORTHO-PHOSPHATE mgP/ℓ	TOTAL PHOSPHATE mgP/ℓ	PO4 PERCENTAGE OF TP
6	0.1	6.2	1.6
7	1.5	3.0	50.0
8	0.2	1.6	12.5
5	1.6	3.6	44.4
1	-	-	-
9	0.7	1.1	63.6
2	1.1	3.4	32.4
4	2.6	3.8	68.4
10A	2.2	3.5	62.9
10B	4.0	4.8	83.3
3	2.2	4.3	51.2
11	2.1	3.1	67.7
12	0.3	1.5	20.0
13	1.8	3.7	48.6
14	1.6	3.5	45.7
15	1.5	3.6	41.7

From **Table 6.19** it can be seen that the percentage of ortho-phosphate in the water at the various monitoring points ranges from 1.6% to 83%. In natural streams the large difference between ortho-phosphate and total phosphate is usually due to particulate organic phosphates and complex phosphates. They are contributed to the water by body wastes, food residues, raw sewage and the bodies of aquatic organisms. Industries and agricultural activities contribute complex and ortho-phosphates to the river.

From the correlogram **Figure 6.23**, it appears that the relationship between ortho-phosphate and total phosphate can be grouped into two categories. The one category has a small fraction of ortho-phosphate and consists of sampling points 6, 8 and 12 which represents flow from natural catchments. The other category has a considerable higher ortho-phosphate content which can typically be attributed to domestic and industrial waste water discharges into the stream. This category represents a polluted catchment.

The profile along the stream from **monitoring point 7** to **monitoring point 4** shows a considerable increase in ortho-phosphate which can be attributed to the biological processes taking place in the river. At **monitoring point 3**, downstream of the effluent discharge from the Olifantsfontein Waste water Treatment Works, the ortho-phosphate content decreases slightly as a result of the mixing of effluent with stream water. The ortho-phosphate content increases up to **monitoring point 11** from where it decreases further along its route to the Lake. This can be attributed to the increased biological activities in the river, where ortho-phosphates are taken up by micro-organisms as a nutritional requirement.

The above evaluation and analysis relate to the base flow during the monitoring year. The ortho-phosphate concentrations were only analyzed monthly and for this reason storm events were not specifically captured unless the monthly analysis was conducted after a storm event.

6.8 Biological Oxygen Demand versus Chemical Oxygen Demand

For polluted waters contaminated with raw sewage, a direct relationship between BOD and COD can be established. Most domestic waste waters have a BOD:COD ratio of 0.5:1. After biological treatment the ratio decreases to 0.17.

Detailed analysis of the water quality records at the sampling points in the Hennops River Valley indicate different ratios which can be associated with the specific source and land use activity. To obtain a correlation between BOD and COD, linear regression lines were developed for each monitoring point and these are shown in **Figure 6.24.**

The ratio of BOD/COD for the sampling points is summarised in **Table 6.20.**

Along the river profile (**monitoring points 7, 5, 11, 13, 14 and 15**) the BOD/COD ratio is in the order of 0.4 to 0.5 which is typical for domestic waste waters.

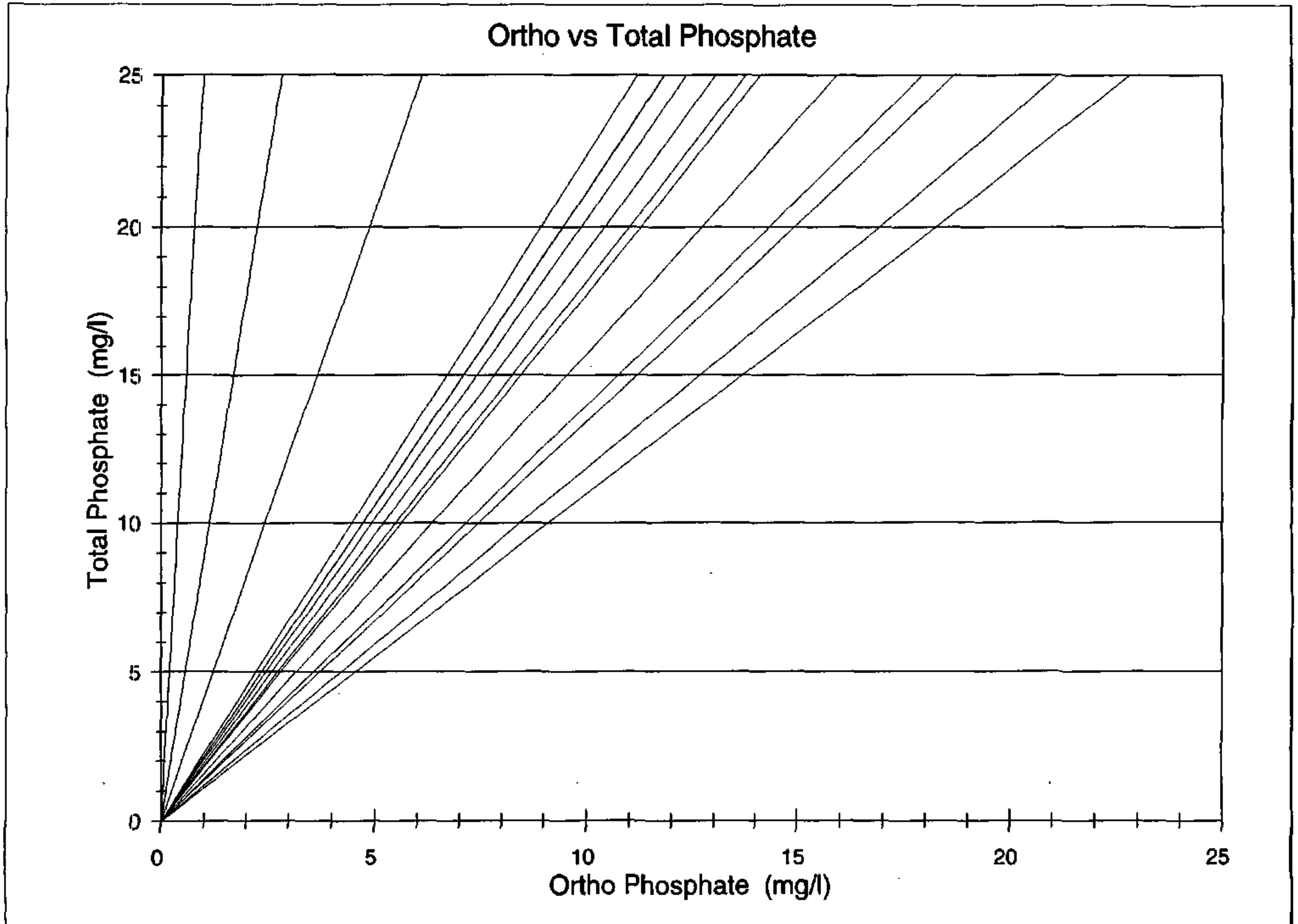


Figure 6.23 : Correlation between Ortho-Phosphate and Total-Phosphate at the monitoring points

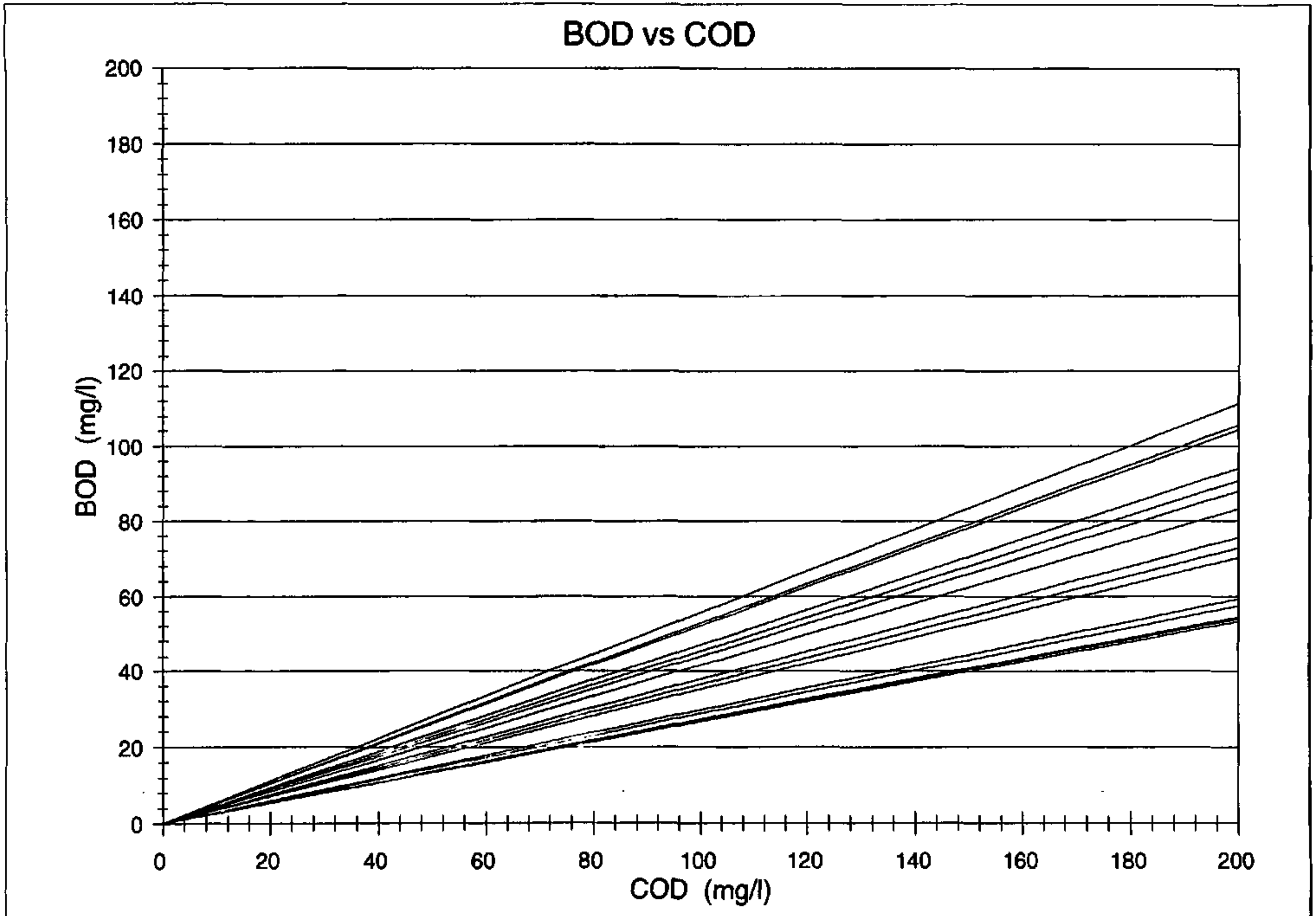


Figure 6.24 : Correlation between BOD and COD at the monitoring points

TABLE 6.20: SUMMARY OF BOD/COD RATIOS

MONITORING POINT	BIOLOGICAL OXYGEN DEMAND (mg/ℓ)	CHEMICAL OXYGEN DEMAND (mg/ℓ)	BOD/COD RATIO TP
6	53	125	0.42
7	31	63	0.49
8	11	35	0.31
5	25	61	0.41
1	-	-	-
9	12	45	0.27
2	145	248	0.58
4	23	71	0.32
10A	24	67	0.36
10B	31	64	0.48
3	24	63	0.38
11	26	51	0.51
12	10	34	0.29
13	19	45	0.42
14	27	58	0.47
15	21	44	0.48

The river water has a high biological oxygen demand which can be associated with the sewage pollution from Tembisa, Ivory Park and Rabie Ridge.

The lower BOD/COD ratio observed at **monitoring points 8 and 10A** can be associated with the final effluents from the Eskom College Treatment Plant and the Olifantsfontein Waste water Treatment Works respectively. Here most of the organic matter is slowly oxidised and only unbiodegradable carbonaceous material remains in the final effluent.

The lower BOD/COD ratio observed at **monitoring points 6 and 2** can be associated with industrial type waste waters where the organic material content is considerably lower than for a domestic waste water. The organic content is not due to raw sewage, but rather to contaminated waste water from various food processing factories, abattoirs and faecal matter from animals. Faecal coliforms are in the order of 60 000 counts/100 mℓ at **monitoring point 2** and 700 000 counts/100 mℓ at **monitoring point 6**. This indicates that the water is microbiologically polluted.

7. POLLUTION CONTROL STRATEGIES FOR THE HENNOPS RIVER VALLEY

7.1 Institutional Aspects of Water Quality Management

The Water Act 54 of 1956 regulates the use of natural surface and groundwater resources as well as the discharge of effluents back to the public streams. Any individual or company which releases an effluent into the public stream requires a permit in terms of section 13 of the Water Act. The Water Act concentrates on point source discharges and the Department of Water Affairs and Forestry may stipulate any reasonable requirements or restrictions on an operation producing effluent. It is, however, recognised that the Act is not effective as a legal instrument in the control of diffuse source pollution. Current permits are not required for non-point sources of pollution which may include urban runoff, irrigation return flow, mine seepage etc.

The Department of Water Affairs and Forestry reviewed national policy with respect to water quality management in 1990. A policy document was produced which substantially widens the approach to Water Quality Management to include the following hierarchy of management goals:

- Pollution prevention.
- Waste minimisation.
- Recycling and re-use.
- Minimum industry standards.

The new policy is embodied in the so-called receiving Water Quality Objectives Approach, which attempts to develop Water Quality Management Plans for a catchment. The total scope of land use activities are included in the development of effluent and discharge standards which can now be designed for each individual catchment. The Department of Water Affairs and Forestry has also recently produced water quality guidelines for the four major users : potable, industrial, recreation and agricultural use. Water quality guidelines for the protection of the natural environment are still being formulated. The Department of Water Affairs and Forestry realises that the key to the control of non-point sources lies within legislation dealing with a specific land use activity. This may be outside the scope of the current Water Act 54 of 1956. The approach to water pollution control in the mining industry is an example of this new approach. All mining activities are required to prepare an Environmental Management Programme in terms of the new Mineral Act of 1992. The Department of Mineral and Energy Affairs acts as the lead agent in the approval and auditing of Environmental Management Programmes in the mining industry. The lead agent is, however, required to obtain approval from several other Departments, including the Department of Water Affairs and Forestry, before approving the EMP on any specific mining operation. The Department of Water Affairs and Forestry uses this avenue to ensure that its water quality management objectives are achieved in catchments in which mining is an important land use. Minimum Water Pollution Control Industry Standards are also currently being prepared for the mining industry. These minimum industry standards will reflect the consensus between the Regulator and industry with respect to the best available pollution control technology not entailing excessive cost.

It is proposed that the same conceptual approach be adopted to control diffuse source water pollution emanating from other land use activities, including urban settlements, industrial operations, agriculture, construction etc. The proposed institutional control of water pollution emanating from other land use activities should therefore follow a general framework:

- Appointment of a lead agent Regulator to co-ordinate all matters relating to environmental management within the specific land use or economic sector.

- Formalised procedures should be developed for the implementation and auditing of the Environmental Management Programmes within the specific land use activity or sector. This will include Inter-departmental agreements after consultation on relevant matters. The Department of Water Affairs and Forestry should be consulted on all matters relating to water quality.

- Minimum Industry Standards should be developed for each of the major land use activities. Agreement should be reached on the Best Available Technology Not Entailing Excessive Costs (BATNEEC) for a specific sector or land user.

Local authorities may, for example, be elected to act as lead agent with respect to the implementation of Minimum Pollution Control Standards in all formal and informal urban settlements.

7.2 Introduction to Pollution Control Strategies

There are many approaches to the design of non-point source and stormwater pollution control systems. Only a careful study of the specific catchment will lead to guidelines for Best Management Practices based on the 80/20 solution i.e. spending 20% of the overall cost in order to achieve 80% of the benefits.

In the report prepared by J.L. Barnard "Urban Stormwater Runoff on the Quality of Water Resources in South Africa", several scenarios for combatting stormwater pollution were briefly discussed. Unfortunately, conditions vary from one location to the next so that it is almost impossible to standardise on a system. One would thus need to look at general rules and guidelines for treatment which could be expanded and then applied to every situation.

For this study area, pollution control strategies will be necessary for the following land users:

- Informal settlements - lack of structured facilities
- Formal and informal housing - structured facilities
- Industrial sites

7.3 Informal Settlements, Lack of Structured Facilities

Most informal settlements in South Africa, as illustrated by Ivory Park, are the result of the urgent need for housing. This resulted in lack of planning, proper infrastructure and control measures to combat stormwater runoffs, solid waste disposal and sewage disposal and treatment.

The provision of control facilities in existing settlements are more difficult to implement than in new areas where the facilities can form part of the overall town planning scheme. The implementation of control facilities are, therefore, site-specific.

- **Gross pollutant traps**

  The surface water runoff from Ivory Park discharges directly into the Kaalspruit. The roads are not contoured and are in need of repair due to erosion from stormwater runoff. To provide first flush holding facilities and pollutant traps for all stormwater drains might not be a feasible proposition although it would result in a more efficient system.

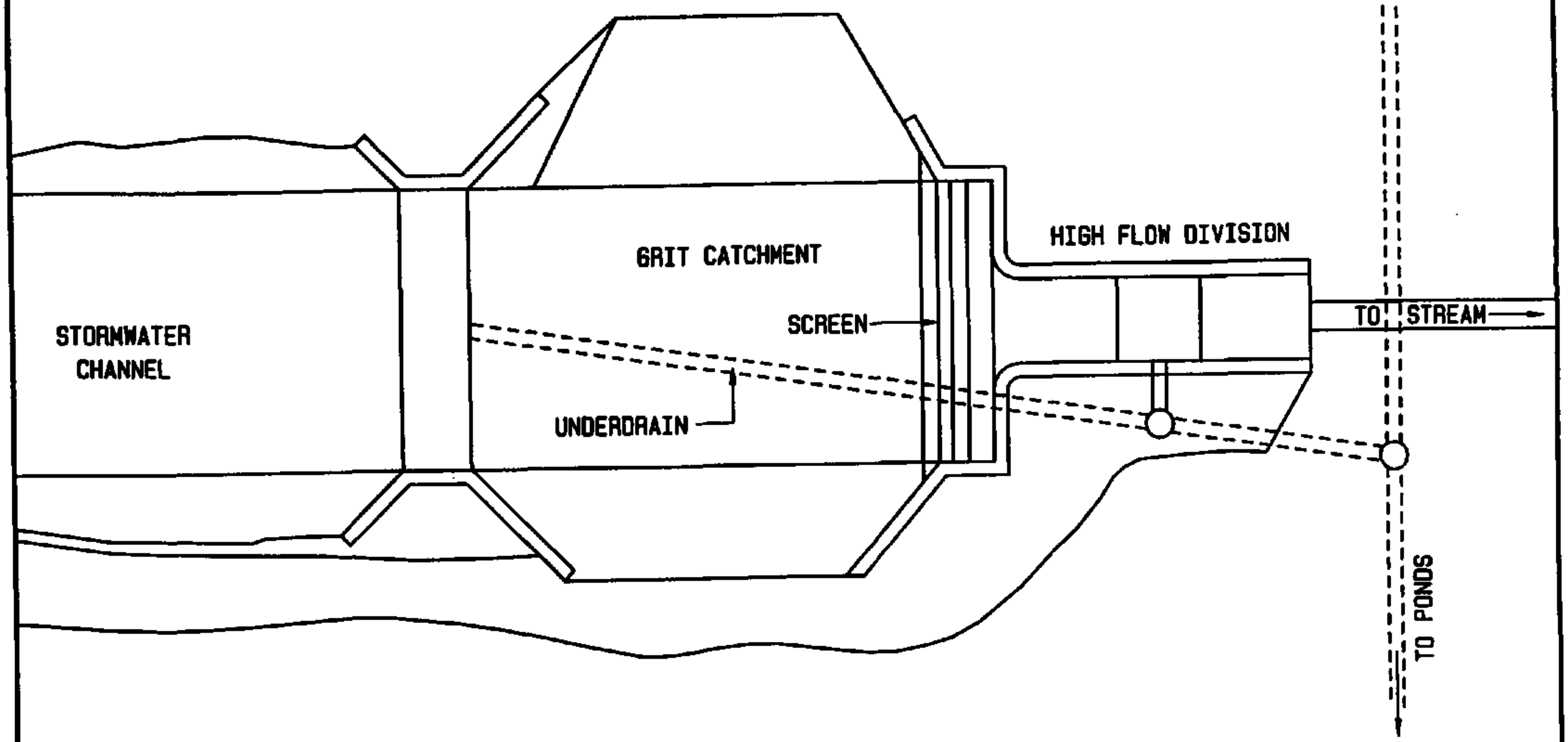
  Figure 7.1 illustrates a system of drains and pollution traps which could be implemented in new and existing settlements. The gross pollutant traps will consist of screen and grit traps with an overflow to the river. The first flush after a storm is retained in the trap and the clean water is bypassed to the river, stormwater drain or retention ponds, as shown in **Figure 7.2.**

Provision should be made for the regular cleaning of the grit trap using local labour. The trap should also be designed so that machine cleaning is possible. The silt and grit will contain some organic matter, 10 - 20% by weight, as observed at Centurion Lake. Due to the large content of silt, it is recommended that the grit be stacked so as to encourage semi-aerobic stabilisation. The dry silt can be used as fill material on sports fields, roads and scour holes, thus eliminating standing water which may become septic and cause health hazards.

In the same way, the screens will need cleaning and the screenings should be taken to the local dump site. The size of the silt and grit removal basin will need to take into account the size of the catchment and other hydrological requirements. The success of low cost systems depend primarily on maintenance.

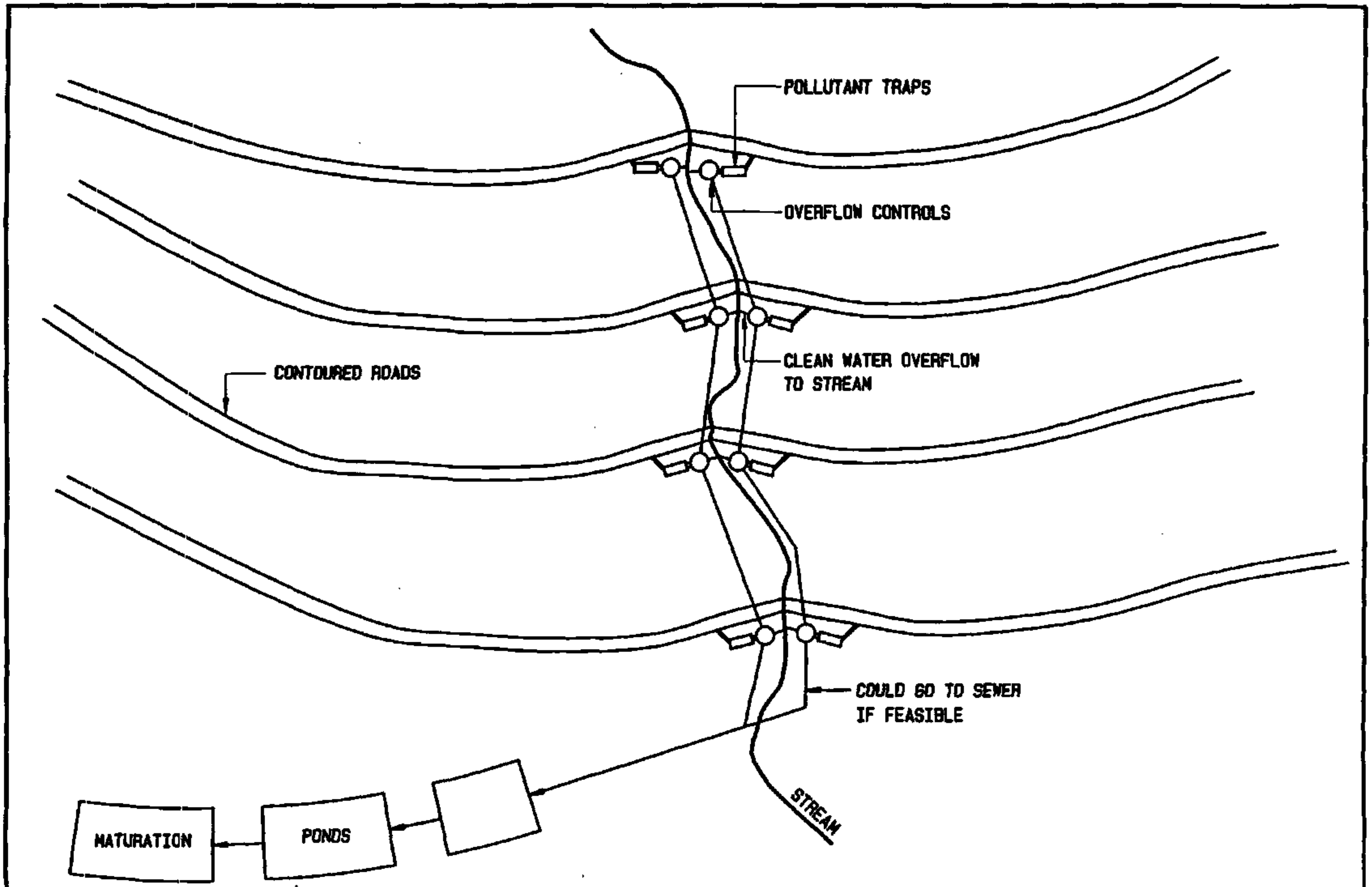
The system could further be improved by structural measures to relieve the worst areas, until waterborne sanitation systems can be afforded. Even at this stage, pollution of stormwater will not disappear and the first flush should be captured before discharging to the river.

Small in-stream settling ponds with screening at the inlet can also serve as gross pollutant traps ahead of a secondary treatment stage. This system could be implemented in existing settlements. The problem with in-stream settling ponds is that flooding of low lying areas might occur during storms due to uncontrolled settlements in the flood plain.



SIMPLE GRIT TRAP AND BASE FLOW CATCHMENT

FIG.7.1



WMB PROPOSED STORMWATER MANAGEMENT SYSTEM FOR INFORMAL SETTLEMENTS FIG. 7.2

- **In-stream Detention Ponds**

  The informal development along the banks of the Kaalspruit is within the 50 year flood plain and any restriction within the stream will cause major flooding upstream of the weir. In this case, it is recommended to rather allow the polluted water to flow to a more suitable location for treatment.

  Due to the permanent base flow emanating from the area under consideration, a wet detention pond with a permanent pool of water will be appropriate. It will have aesthetic advantages as the debris and sediment will be covered by water. Maintenance of the system is of the utmost importance and a bypass should be provided so that the ponds can be cleaned.

  Both gross and minor pollutant traps and detention ponds will not improve the bacteriological water quality as the retention time is too short. To improve the water quality during base flows, the construction of a wetland downstream of the detention pond will be necessary. This will artificially increase the retention time and exposure to sunlight.

- **Wetlands**

  Wetlands can help to regulate and maintain the hydrology of our nation's rivers, dams and streams by storing and slowly releasing stormwater. They help maintain the quality of water. One of the major functions is the removal of suspended solids from water travelling through the wetlands. Flow velocity of the water is decreased as its movement changes from channel flow to sheet flow in the wetland. The decrease in velocity and the presence of vegetation promotes the fallout of suspended particles. The separation of sediment can result in the removal of nutrients and toxins as these substances are taken up by plants in the wetland.

  Many rivers in the PWV area have natural wetlands and the discharge of pre-treated water from gross pollutant traps will ensure that the capacity of these wetlands will not be overloaded. In many areas serving informal housing, existing wetlands may be improved as a low cost treatment system. They are useful in protecting receiving water quality and even for the treatment of first flush effluent as the first stage in formal treatment. The latter is only recommended if gross pollutant traps are installed ahead of the wetland to protect it against silting-up and the accumulation of debris and trash.

The use of "swales" or diversion weirs to feed semi-contaminated flows at a controlled rate into the wetland system should be considered. In this case, the polluted base flow in the Kaalspruit can be diverted into a wetland at a controlled site. The retention pond will function as a gross pollutant trap and raise the water level so that the polluted water can flow onto the original floodplain. Wetlands can be constructed here to improve the water quality in terms of COD, ammonia, Faecal Coliform and suspended solids. The retention time should be in the order of 5 days, but this depends on the background water quality, the degree of purification required and the availability of space.

The constructed wetland consists of one or more "cells" in series or parallel. Multiple cells improve the effectiveness of the system and provide flexibility for operating and maintaining the system. These cells contain wetland plants and microscopic organisms that utilise both aerobic and anaerobic processes. Potential pollutants are trapped in the wetland and transformed into basic elements and plant biomass.

Wetlands add topographic expression, vegetative patterns and wildlife to the landscape. They provide open space and aesthetic value to urban and non-urban areas as well as opportunity for fishing, bird watching, hiking and sightseeing. These wetlands, if properly planned and designed, can be self-sufficient by creating income from recreational and educational facilities.

- **Stormwater Retention Ponds**

The construction of a series of retention and maturation ponds at a low point in the catchment so that all the surface runoff can be captured during the storms could also be considered as shown in **Figure 7.2.** The pond system will enhance the environment and attract birds and other water animals. Depending on the size of the ponds, water can be recycled for irrigation purposes in parks, sports fields etc. Contaminated base flow can also be treated in the pond system. Due to the polluted first flush and the presence of silt during storms, it is necessary to provide gross pollutant traps ahead of the ponds. All overflows from the pond system will discharge into the nearest river. This water will be relatively "clean" and further polishing in a wetland is always recommended to improve the receiving water quality.

7.4 Formal Housing - Structural Facilities

Tembisa and Rabie Ridge have been provided with structured facilities such as tar roads and waterborne sanitation. However, diffused pollution from surface runoff in these areas require measures for combatting pollution as mentioned in Section 7.2.

In this case, end-of-pipe treatment is the norm as the unit export load is less. While fewer pollutant traps may be required, the number cannot be reduced drastically as this will make the system less efficient.

One of the major problems associated with areas that have waterborne sanitation and sewers is that main outfall sewers are deliberately blocked at manholes with bricks, steel pieces, car tyres, wood etc. resulting in overflows directly to the river. This situation cannot occur in settlements without waterborne sanitation.

The main priority is the sealing of manhole covers on the larger diameter sewers. The ideal system would require covers that could not be easily destroyed or removed except by a mechanical lifting device. Merely bolting the manhole covers in place will only lead to vandalism. Heavy concrete covers should suffice. Such measures will hopefully stop the dumping of garbage in the sewers and limit the incidence of sewer blockages and overflows. These measures have already been successfully implemented in Tembisa at a cost of R300 per manhole. The total amount spent is R100 000.00. Smaller diameter sewers may not need such drastic treatment since dumping in these will lead to local blockages which serve as a deterrent. **However, it is clear that the authorities should move away from cast iron covers in order to protect the environment.**

This polluted water will eventually contribute to the base flow in the river. At Tembisa, a small diversion weir has been constructed to divert the base flow back to the sewer line. Due to the lack of funds for the maintenance and unblocking of sewer lines these services are usually only rendered weeks after the Local Authority has been informed. This is an unacceptable situation, as money spent on controlling pollution, could rather be channelled towards pollution prevention at source. The cost of the diversion weir was R160 000.00.

The Reconstruction and Development Program (RDP) proposed by the Government will aid in addressing the problems observed in urban townships and rural settlements.

According to the RDP, as a minimum all housing must provide protection from the weather, be of a durable structure and provide reasonable living space and privacy. A house must include sanitary facilities, stormwater drainage and must have convenient access to clean water.

The RDP's short-term aim is to provide every person with adequate facilities for health. This can be achieved by establishing a national water and sanitation programme. The aim is to provide all households with a clean, safe water supply of 20-30 litres per capita per day (ℓcp) within 200 metres, an adequate/safe sanitation facility per site and a refuse removal system to all urban households.

The RDP's long-term goal is to provide every South African with accessible water and sanitation.

Solid waste pollution is a major problem in these areas and contributes to the diffused pollution during base and storm flows.

7.5 Industrial Sites and Industrial Townships

The gross pollution presently experienced from industrial sites is inexcusable, since mechanisms for control already exist in Article 23 of the Water Act of 1956. The strict enforcement by local authorities is required. In spite of the normal requirements that all industrial activities that pollute stormwater should be covered and connected to the sewer system, polluted water finds its way into the stormwater system. Apart from accidental and non-accidental cross connections between sewer and storm sewer, the possibility exists that spills and overflows that cannot be handled by the sewers may foul the stormwater. This has happened at even modern facilities, where, according to the design, it should not be possible. In some instances, dust from the manufacturing process may cover roofs, parking lots and open spaces. First flush facilities should be installed at all industrial sites where pollution is possible. They should be retro-fitted to all industrial plants where pollution of stormwater is evident. The first flush tanks should not have a drain to the stormwater system but should be fitted with pumps, which automatically pump the tank out after a suitable delay. The contents should be pumped to the sewer through a metering device. If not, a percentage should be added to the water consumption figures for stormwater treatment. The first flush facility may take many forms depending on the on-site conditions. A typical unit is shown in **Figure 7.3.**

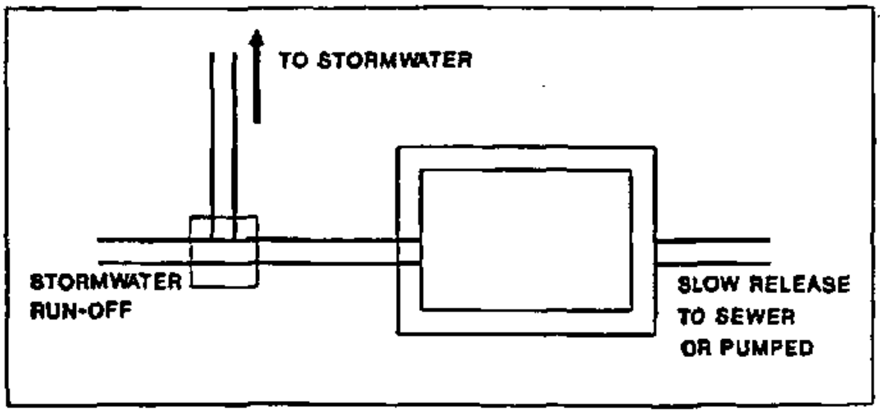


Figure 7.3 First Flush Holding Tank

All industrial process units and pipes carrying liquids with a high pollution potential should be containerised in order to catch any spills caused by accidental breakages. In addition, a special catch basin should be inserted in the storm sewer to prevent such a spillage even reaching the first flush tank.

In spite of all these precautions, storm sewers from industrial townships should be provided with first flush holding facilities in order to check for illegal discharges and to guard against groundwater pollution.

At larger industrial sites, it may be necessary to install more than one first flush tank in order to minimise the volume of polluted water. Each facility will have to be individually assessed.

7.6 Costs of Control Measures

The costs of control measures are site-specific and the selection thereof depends on the topography, infrastructure, flow, pollution load, general geology, geohydrology and services (roads, water, sewers). All these factors contribute towards the cost and it is, therefore, difficult to prioritise the control measure until a detailed study and survey is conducted. This study should recommend long term remediation measures on a cost/benefit basis. Several control measures and recommendations for pollution control measures have either been completed or are in progress for the Hennops Valley. Specific solutions mentioned in the report and their associated costs and benefits are presented in **Table 7.1.**

TABLE 7.1: SPECIFIC SOLUTIONS FOR POLLUTION CONTROL MEASURES IN THE HENNOPS VALLEY

Description of Control Measures		Estimated Cost	Benefit
1.	***Informal Settlements***		
	Gross Pollutant traps	R10 000	Pre-treatment of first flush run-off. Solid waste, silt, grit and organic matter removal.
	In-stream settling ponds	R50 000	Same as above but containment of larger flows.
	Stormwater retention ponds	R150 000/ha	Treatment of contaminated run-off. Effluent can be used for irrigation purposes.
	In-stream detention ponds	R100 000/pond	Aesthetic advantages as all debris and sediment are covered with water. Removal of gross pollutants during base and storm flows.
	Wetlands	R80 000/ha	Improvement of water quality in river by at least 50%. Establishment of recreational and educational facilities.
	Garbage removal		Prevention of contaminated leachate discharge during storm flows.
	Tarred Roads	R65/m^2	Prevention of erosion.
	Water-borne sanitation	R1 800/household	Prevention of sub-surface pollution.
2.	**Formal Housing**		
	Heavy concrete covers	R300/cover	Prevents vandalism and deliberate pipe blockages.
	Diversion weirs	R160 000/weir	Raw sewage is diverted into outfall sewer.
	Garbage Removal		Prevention of contaminated leachate discharge during storm flows.
	Maintenance of sewer systems		Prevention of pipe blockages and polluted overflows to streets and rivers.
3.	**Industrial Sites**		
	First flush holding tanks	R10 000	Pre-treatment of first flush run-off. Solid waste, grit, oils and organic matter removal at source. Overflow to stormwater drain.
	Holding ponds	R50 000/pond	Same as above but containment of total flow.
	Wetland	R80 000/ha	Treatment of stormwater. 1 ha of wetland can treat 1,2 Mℓ /d of polluted water. Organic pollution reduction by ± 50%.

7.7 Abatement Strategies

7.7.1 Introduction

Traditional point source control relies on the collection of waste water and its treatment at the pipe end of the system. In-house waste water reduction and pollution prevention at industrial premises are not strictly enforced by the Local Authorities. An industrial concern is usually not concerned with management of the effluent, as these are considered unproductive activities. For this reason, control of both point and non-point source pollution requires urgent attention as part of an integrated approach towards the management of a watershed.

When dealing with diffuse sources the term 'management' is used instead of treatment and removal. In the USA, Best Management Practices (BMP) commonly imply nonstructural or low structural, typically on-site measures that are effective in controlling diffuse pollution.

Application and selection of BMP's should be based on the following:

- type of land use activity.
- physical condition of the watershed.
- pollutants to be treated.
- site-specific conditions.

It is not possible to control all sources of diffuse pollution. BMP's must be assigned, in priority order, to the most polluted sources and/or priority watersheds where point source controls will not achieve receiving water quality objectives.

As a general rule, the cost of both point and non-point source pollution control is inversely proportional to the extent of pollutant dilution by the runoff. Thus control costs increase with the distance runoff travels from the source to the point of disposal and treatment.

7.7.2 Best Management Practices

Management practices to control non-point pollution can be divided into four categories:

- Source control measures.

- Hydrological modification of the drainage area.

- Modification of conveyance systems and reduction of the delivery of pollutants from the source area to the receiving water body.

- Storage and treatment.

7.7.2.1 Source Control Measures

These measures are designed to reduce the source emission of potential pollutants and prevent them from leaving the surface area. Such controls should include:

- Control of atmospheric deposition from stacks or from vehicles.

- A ban on the use of harmful substances such as DDT, PCB's and organochlorine pesticides which threaten the entire ecosystem.

- Litter and refuse control as well as the limitation on excessive disposal of sewage, sludges and septic tank outflows into soils.

- Erosion control practices to reduce erosion rates and subsequent soil and pollutant losses within acceptable limits are necessary. These should be compatible with receiving water quality objectives.

7.7.2.2 Hydrological Modification

These modifications will reduce pollutant loads by changing the so-called "fast conveyance" storm and combined sewer systems. This can be done by incorporating storage and infiltration facilities and by reducing impervious areas to permeable drainage areas wherever possible and economically achievable.

7.7.2.3 Reduction of Delivery

Certain measures maximise the attenuation process of pollutants between the source area and the receiving water bodies and improve the water quality. An example is the installation of vegetated buffer strips between the source area and the receiving water body in agricultural areas.

7.7.2.4 Storage and Treatment

These practices are the most expensive end-of-pipe control measures. Due to the high variability and intermittent nature of diffuse pollution loads, storage is required to reduce the required capacity of the subsequent treatment units.

Less expensive and more natural storage and treatment systems include, for example, artificial wetlands. New developments include enhanced storage-wetland pond systems developed in Maryland and Washington DC, french drain system as developed for a residential site on Lacamas Lake (Washington), sand and sand-peat filters, flow balancing storage units developed in Sweden, infiltration storage manholes and catchbasins developed in Japan (Novotny, 1994).

8. SUMMARY AND CONCLUSIONS

The Hennops River Valley catchment extends from Chloorkop/Tembisa in the south to the Centurion Lake in the North. This catchment encompasses a variety of land users, such as formal and informal housing, industries, point sources and agriculture. All the features of a typical South African catchment are represented here.

The objectives of the study were to assess the magnitude of non-point source pollution from various land users, to identify pollution sources and provide site-specific and general pollution abatement strategies based on the 80/20 approach.

The following conclusions may be drawn from the study:

- Point source and non-point source runoff originating in the of the Hennops River Valley catchment is polluted throughout the year. The pollution is predominantly of a microbiological nature with correspondingly high concentrations of nutrients and organics.

- The quality of the stormwater at the beginning of the rainy season is worse than the background base flow quality and the subsequent storm events during the season. These results indicate that the first flush effect is a seasonal rather than a storm event occurrence. The quality of the runoff can be expected to be at its worst after the first storm event.

- The pollution load emanating from this catchment is similar to the load observed in similar studies conducted in South Africa. The type of land use activity and the physical condition of the watershed are key parameters causing different stormwater qualities between catchments and sub-catchments.

- The major source of pollution is litter and faecal contaminants which are the result of deliberate pipe blockages in Tembisa, the high population density and poor living conditions in Ivory Park. The accumulation of solid waste, inadequate maintenance of sewers and a general lack of environmental awareness ensures ongoing pollution generation.

- In this study, it has been found that the pollution load emanating from the Tembisa formal housing and serviced stands is considerably higher than from informal and unserviced stands. The provision of waterborne sanitation, as in the serviced site sub-catchment B, does not necessarily reduce the pollution problem.

- The point source contribution from the Olifantsfontein Waste water Treatment Works dilutes the highly polluted base flow in the river.

- The contribution from the Industrial sub-catchment D is insignificant and its impact on the receiving water cannot be determined due to the high base flow in the river.

- Centurion Lake functions as a pollution reduction facility during base flow conditions. Its main function is suspended solids removal and bacteriological reduction. The Lake contains 50% silt which can be largely attributed to the soil runoff from urban development in the of the catchment i.e. Ivory Park and Tembisa.

- Microbiologically, the concentration in base flow and stormwater runoff is unacceptable in the Lake. Direct contact recreation should, therefore, not take place in the Lake.

- The water quality in the river is unfit for use when compared to the selected water quality guidelines of the various water user groups (Domestic, Contact Recreation, Industry, Irrigation - Class I, Livestock and Aquatic Life).

9. RECOMMENDATIONS

9.1 Background

The results of this study further confirm the presence of severe diffused pollution occurring as a result of runoff from formal and informal settlements. The results are in agreement with other studies undertaken to quantify the effects of urban runoff on the water quality of a receiving water body in South Africa.

Although this study as well as others have encountered complications in the monitoring exercise, resulting in inadequate data in some areas, an improvement in the accuracy of the results through continuous monitoring will serve no purpose at this stage. In most cases the problem pollutants have been identified. The stage has now been reached where technical solutions for NPS pollution must be implemented based on the 80/20 approach, where 80% of the pollution load is eliminated at 20% of the total cost.

The approach to solving NPS pollution is different from the traditional "point" source abatement. In most cases the diffused pollution loads are transient, highly variable, hydrological phenomena that are related to the use (or misuse) of land and the activities taking place on the land.

The solutions to NPS pollution are known as Best Management Practices (BMP's) and can be divided into four categories:

- Source control measures.
- Hydrological modification of the drainage area.
- Modification of conveyance system.
- Storage and treatment.

BMP's must be assigned, in priority order, to the most polluted sources. This is not always possible, especially in South African settlements where rapid uncontrolled urbanisation has taken place and where politicisation has resulted in the collapse of services and infrastructure. BMP's are site-specific and the possible short term and long term solutions to the water quality problem in the Hennops Valley will be addressed in the following section.

9.2 Short-term Pollution Control Measures for Catchment

Due to the immediate base flow pollution problem in the upper reaches of the Hennops River Valley, several emergency measures have already been implemented. These measures are to provide heavy duty manhole covers in Tembisa and to divert sewer overflows at source back into the main outfall sewer.

The construction of a detention pond, diversion weir and wetland at monitoring point 5 is currently being investigated by Wates, Meiring & Barnard for the Town Council of Verwoerdburg. This would serve as a pollution control facility for the base flow from these settlements, but which will also enhance the environment and provide a sanctuary for wildlife. A nature reserve will be established and will incorporate an environmental education centre and bird park. The purpose of the detention pond is to retain most of the litter, garbage and sediment prior to diverting it to a series of wetlands to be constructed on the original flood plain of the river. This control facility will improve water quality in terms of bacteriological counts, suspended solids, COD and ammonia during base flow situations occuring throughout the year. However, during storm events, the wetland will be flooded. By providing a detention pond and by flooding the wetland, the velocity of flow will be reduced considerably, thus retaining some of the sediment and litter. These measures will result in a pollution load reduction of more than 50%.

The base flow from the Industrial area, Clayville, although only a minor pollution contributor, will also be diverted through the wetland.

Maintenance of the system is of the utmost importance and a bypass will be provided so that the ponds can be cleaned.

9.3 Long Term Pollution Control Measures

9.3.1 Formal and Informal Settlements

Source control measures should be implemented and should be part of the RDP's long term goal. The management practices include:

- litter and refuse removal.
- halting or reducing the discharge of sewage into the stormwater system.
- maintaining sewers.

- providing erosion control measures.
- installing berms and vegetated buffer strips.
- involving the community by making them participants.
- educational programmes related to health and the protection of the environment.
- providing gross pollutant traps ahead of ponds.
- providing stormwater retention ponds.
- providing adequate stormwater drainage.
- providing waterborne sanitation or suitable on-site treatment facilities to all households.
- maintaining septic tanks and aqua privies.

These measures will aid in controlling NPS pollution from the settlements and thus improve the water quality in the receiving water. The provision of control facilities in existing settlements is more difficult to implement than in new developments, where these measures can form part of the overall town planning scheme. As a general rule, control costs increase with the distance runoff travels from the source to the point of treatment. It is therefore essential, without exception, that source control should be a priority in combating pollution from developed areas.

9.3.2 Industrial Sites and Industrial Townships

First flush facilities should be installed at all industrial sites where pollution is possible and should be retrofitted to all industrial sites where pollution of stormwater is evident. These tanks can be connected to the stormwater system, but the contents should be pumped out into the sewer for further treatment. The disposal of the contents, including settled matter, depends on the nature and composition of the waste water. Oils, heavy metals as well as organic and inorganic toxins should be removed by a private Contractor for treatment and disposal at a centralised dedicated treatment plant.

At larger industrial sites it may be necessary to install more than one flush tank and these can be followed by a wetland if sufficient land is available. The outflow from the wetland can be used for irrigation parks and gardens and for cleaning and washing purposes.

Source control measures are essential and much more cost effective than pipe-end treatment. In the short term, the stormwater and base flow originating from Clayville will be treated in the proposed wetland at **monitoring point 5**. In the long term, it will still be necessary to implement source control. Good housekeeping within factories and the recycling of treated waste water can improve the quality and quantity of runoff.

Unfortunately, industries are reluctant to implement environmental awareness programs and control measures to ensure that the impact on the environment is minimised. This can mainly be attributed to the lack of enforcement of Standards by local authorities, as well as designed by industry. The industries should rather become a partner in solving the country's deteriorating water quality problems.

It is critical that industries also develop a stormwater pollution prevention plan with emphasis on employee education and training.

9.3.3 Agricultural Activities

Agricultural non-point sources are a major contributor to both surface and groundwater contamination. In agricultural areas, the largest contributors to these surface and groundwater pollution problems are considered to be inefficient nutrient management, high level of soil erosion and runoff as well as excessive pesticide use. In the Hennops River Valley, agricultural activities along the river are on a very small scale and no negative impact has been observed on the receiving water quality.

Many tools and technologies, such as terracing, conservation tillage, filter strips (vegetative buffer) and sediment trapping structures may be needed to achieve a local area's water quality goals. Determining the mix of tools that is most efficient in improving water quality will depend on both the physical characteristics of the watershed as well as the behavioural characteristics of the farmers.

The effectiveness of filter strips as a water quality tool is widely accepted as the most efficient control measure in flat areas and least effective in hilly areas.

9.4 Future Research

Future research should focus on Integrated Watershed Management. Abatement strategies should form part of plan. This will include many different disciplines including:

- land use planning (water supply and sanitation)

- flood control
- development
- stormwater management.

Furthermore, it will be necessary to investigate and study the occurrence of diseases in the catchment as a consequence of using polluted water. The direct medical costs and indirect related costs such as loss of man-hours and productivity should be assessed and compared to the cost of control measures, waterborne sanitation and a potable water supply. A more comprehensive and detailed cost/benefit analysis of control measures can then be formulated.

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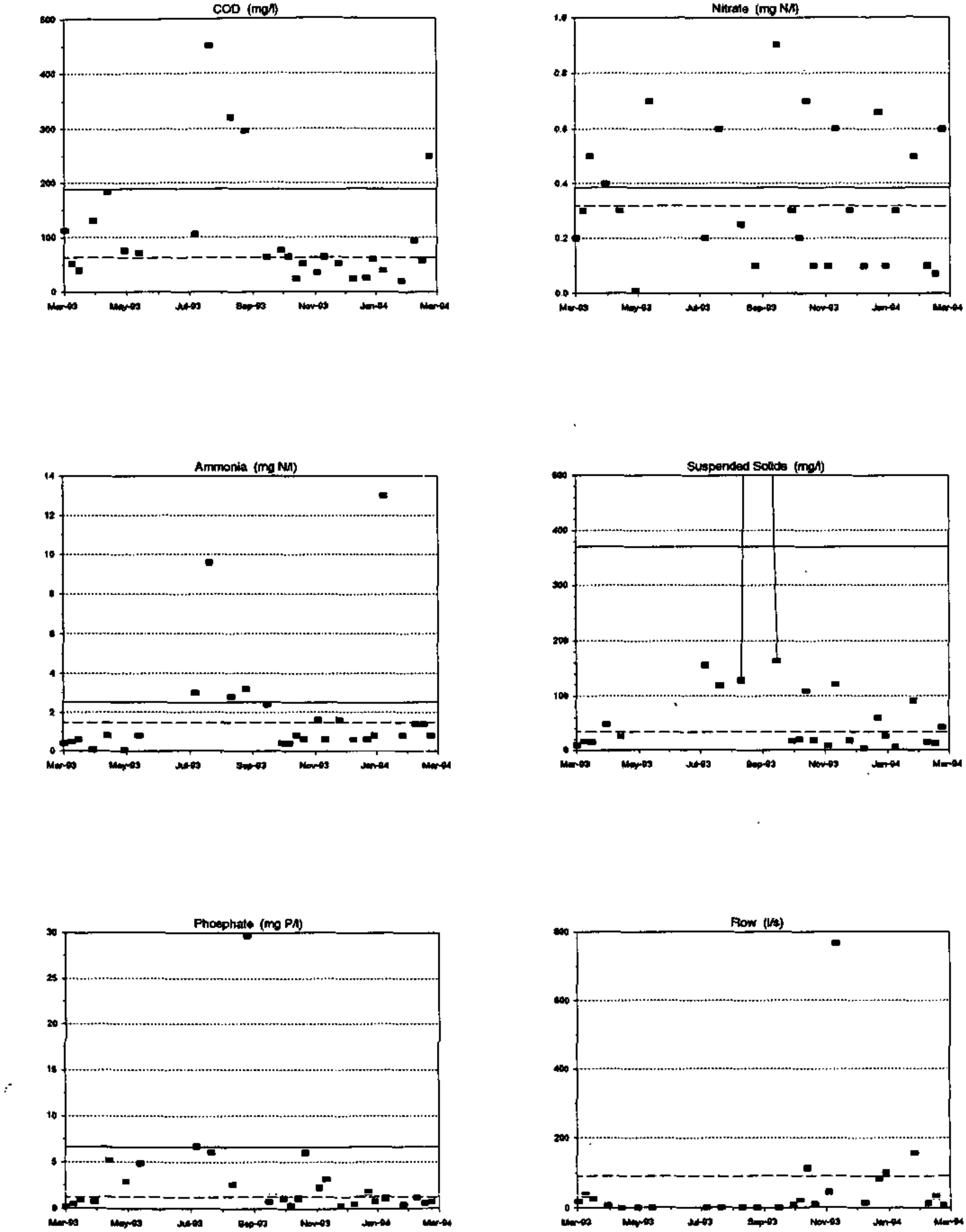
APPENDIX A



2629-210

Figure 6.10 : Time series plots and average summer and winter values at monitoring point 6

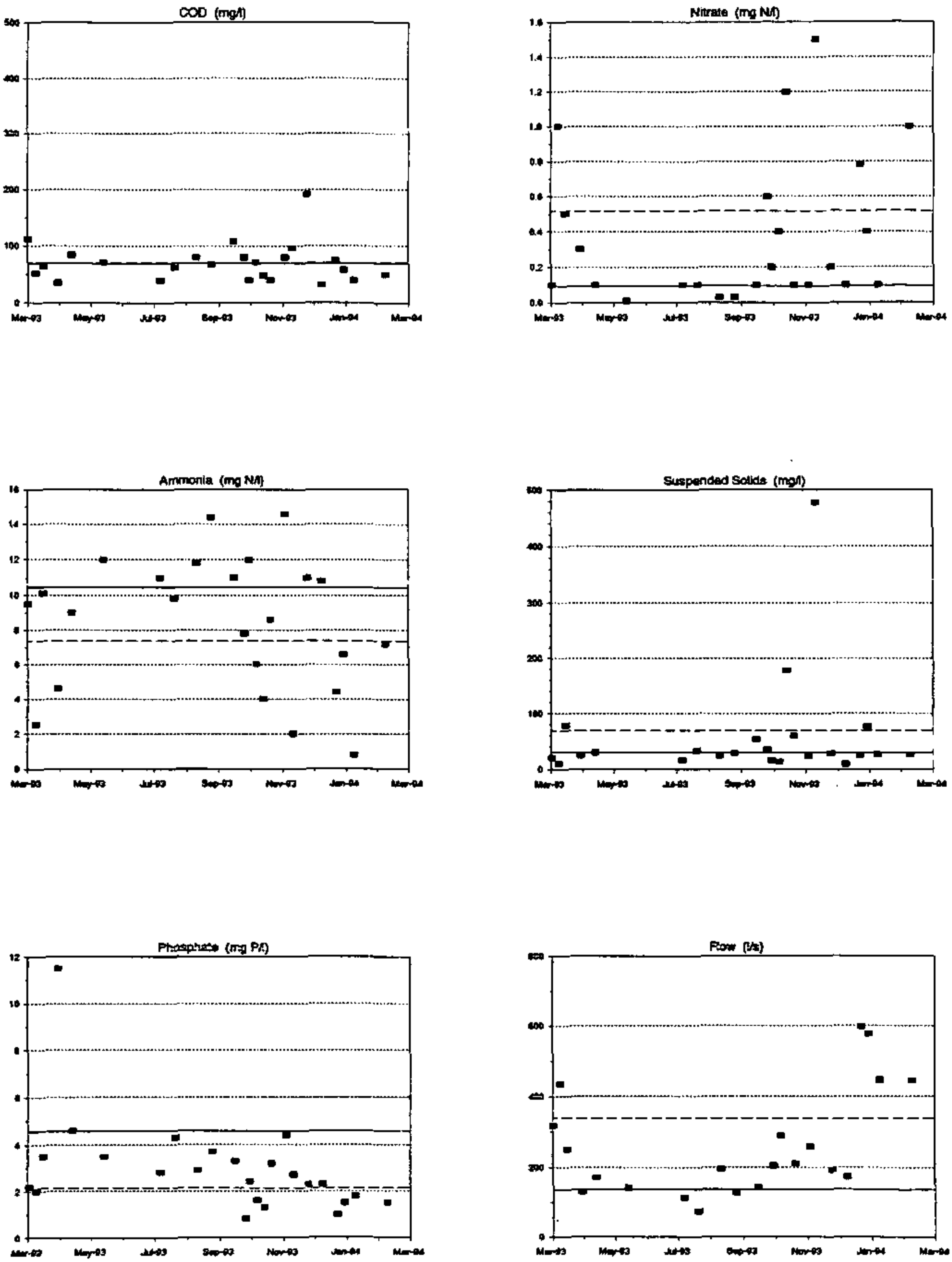


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Figure 6.11 : Time series plots and average summer and winter values at monitoring point 7

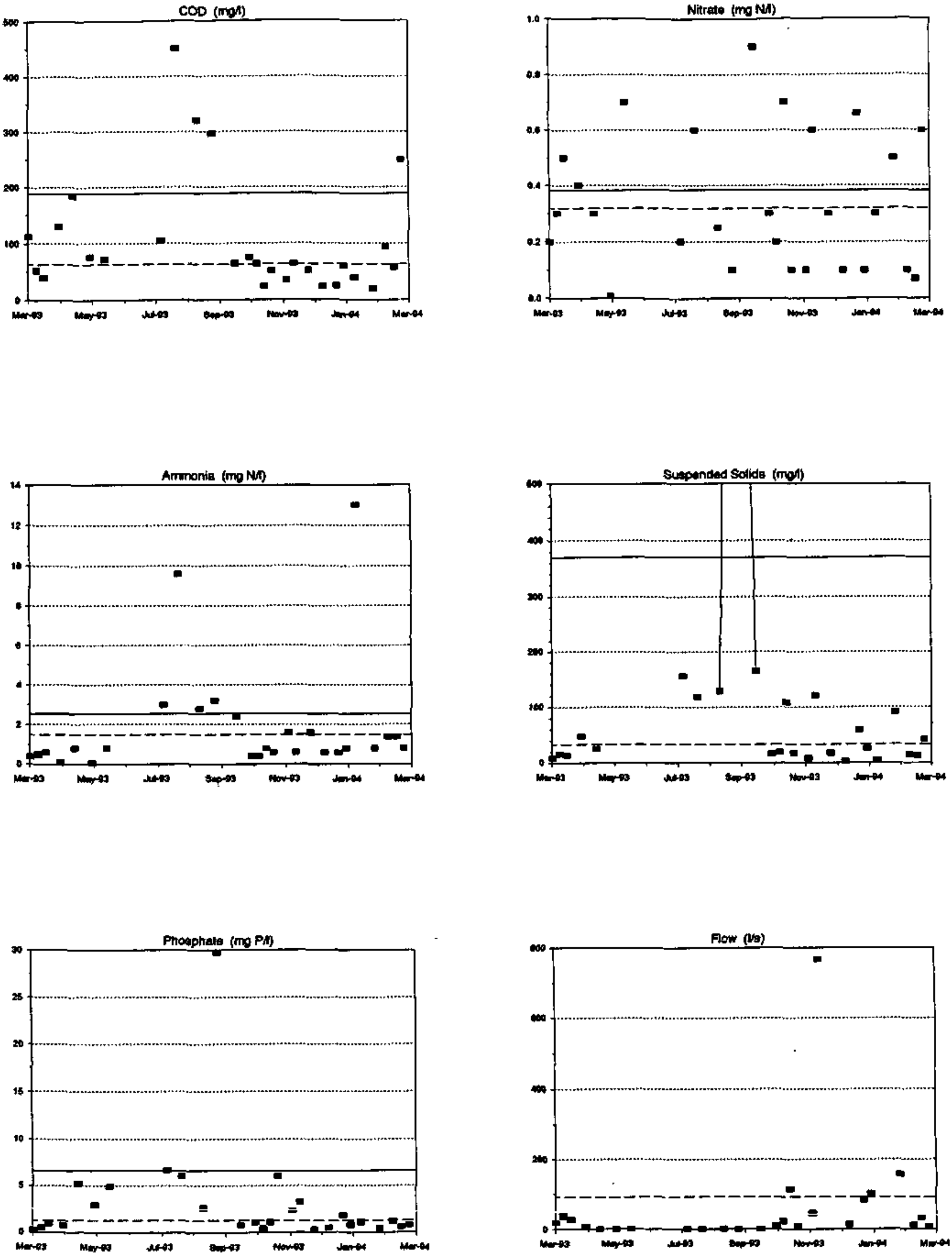

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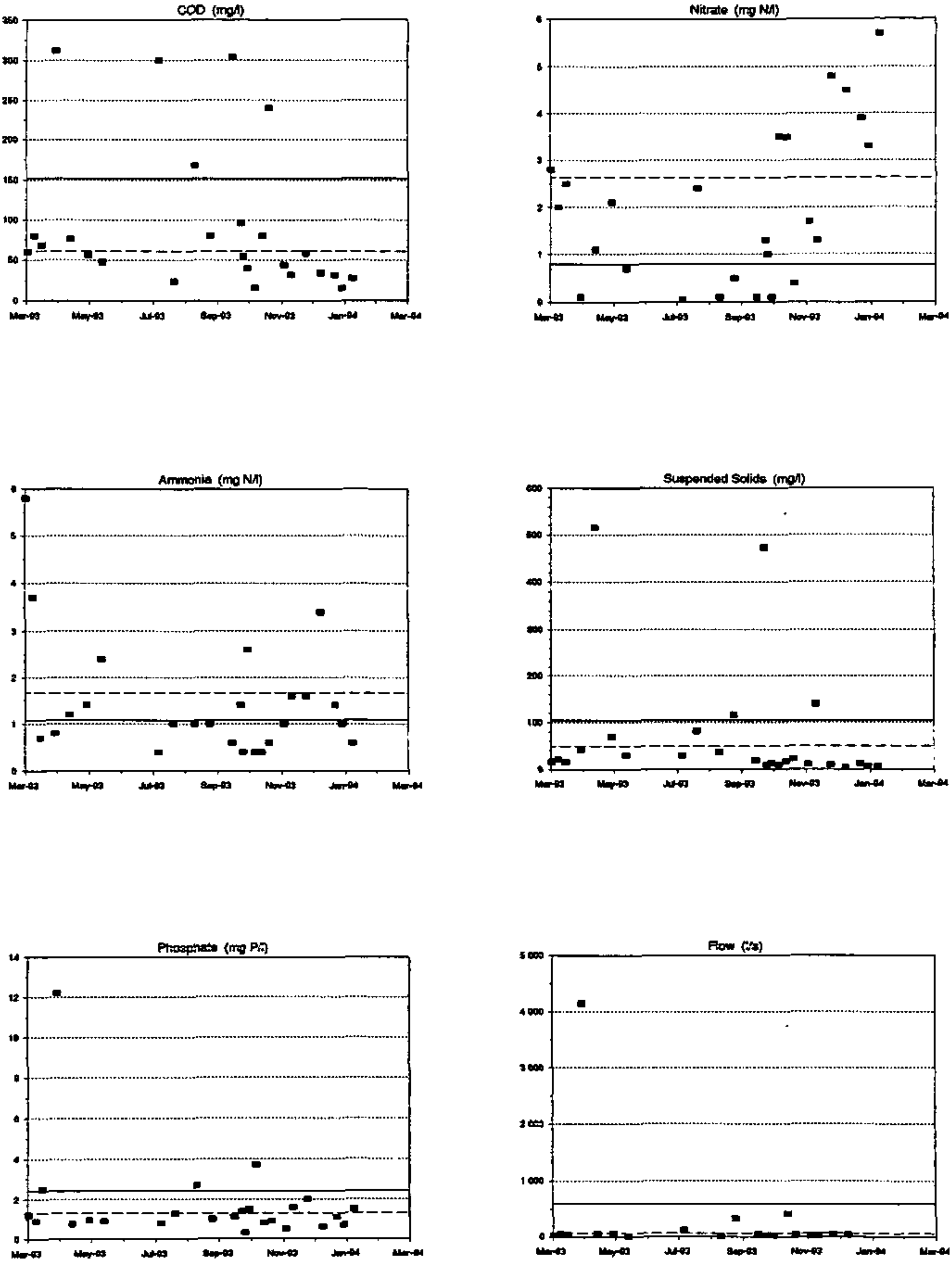
Figure 6.12 : Time series plots and average summer and winter values at monitoring point 5



2629-214

Figure 6.13 : Time series plots and average summer and winter values at monitoring point 2

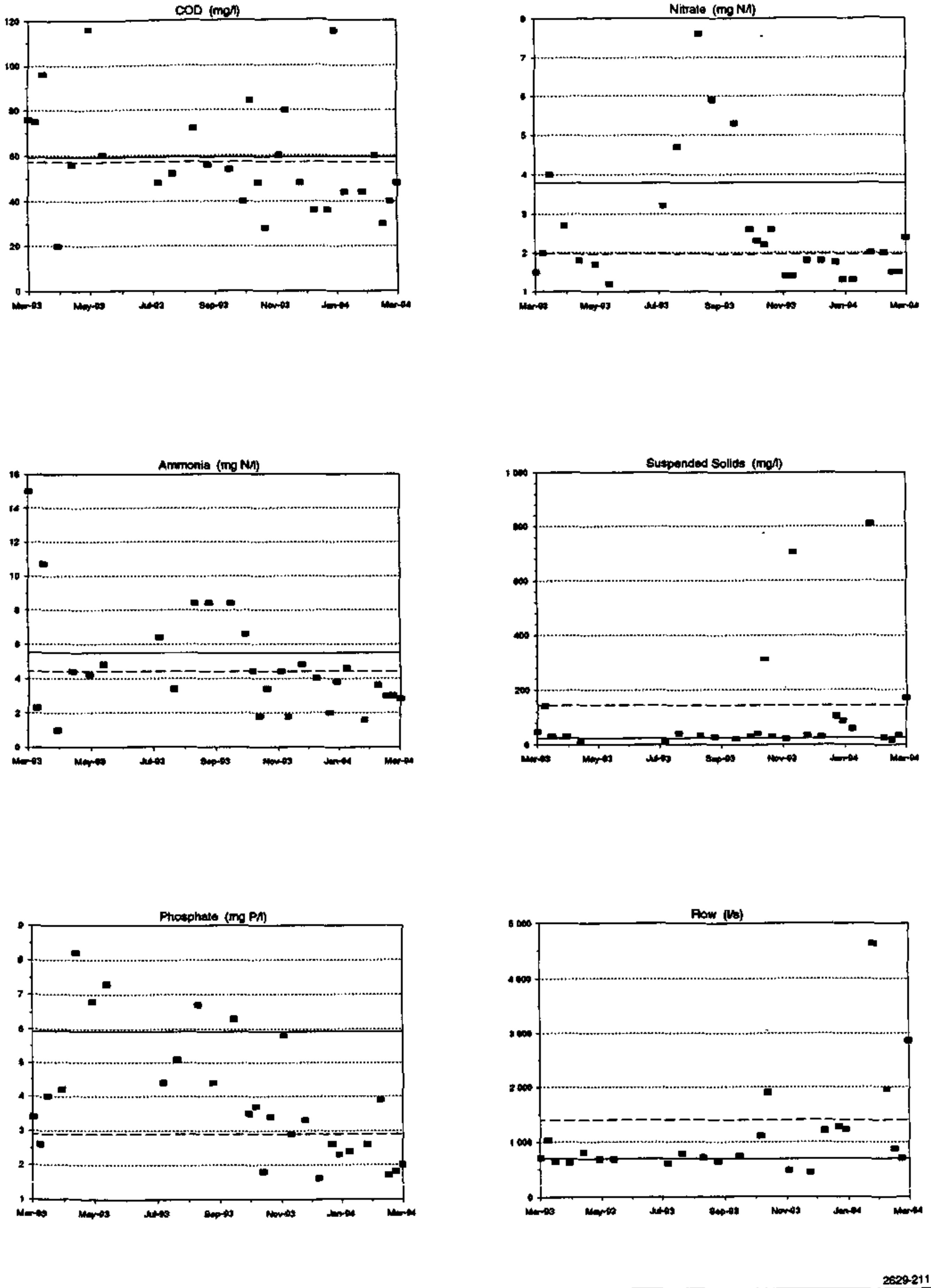


Figure 6.14 : Time series plots and average summer and winter values at monitoring point 3

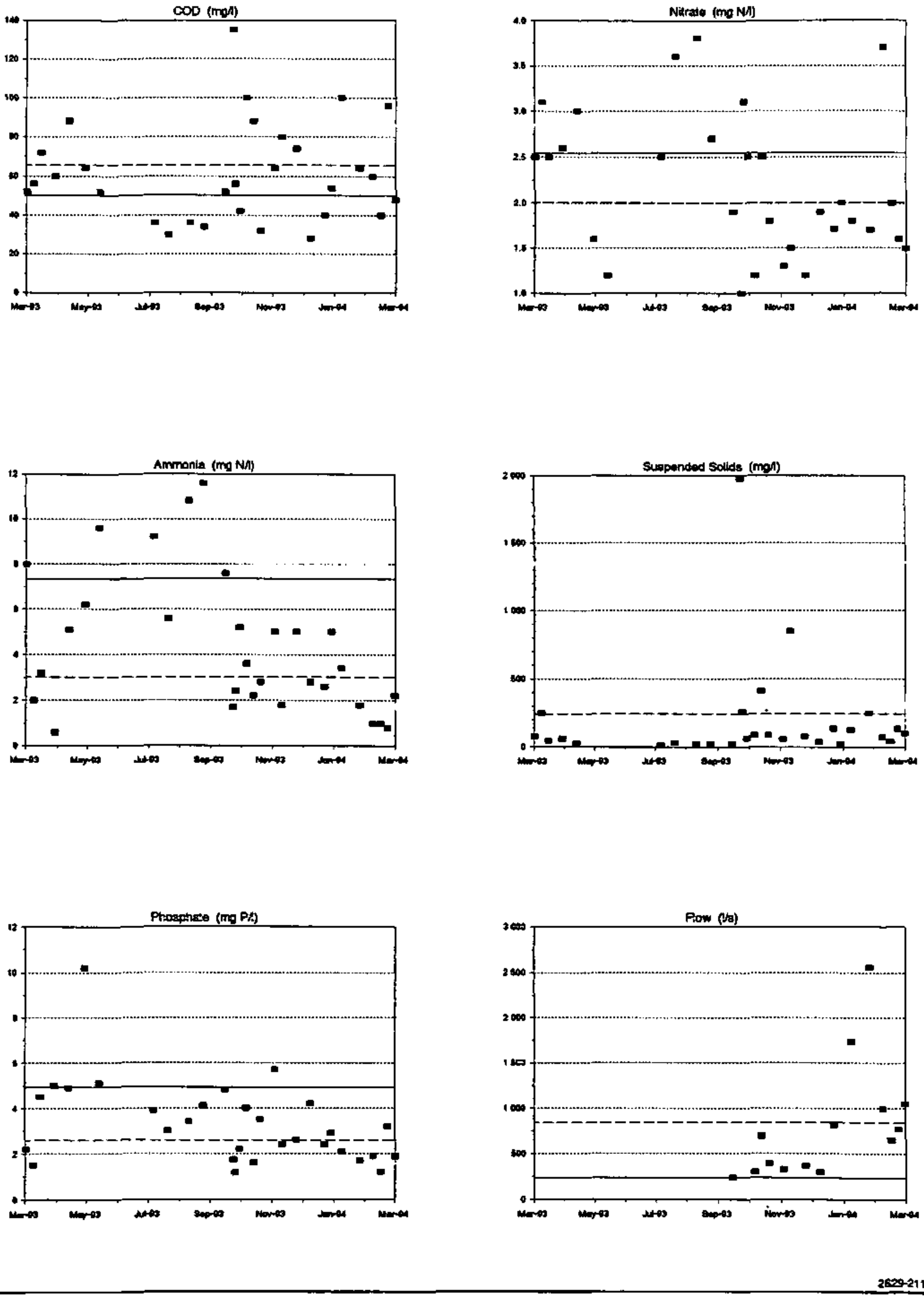
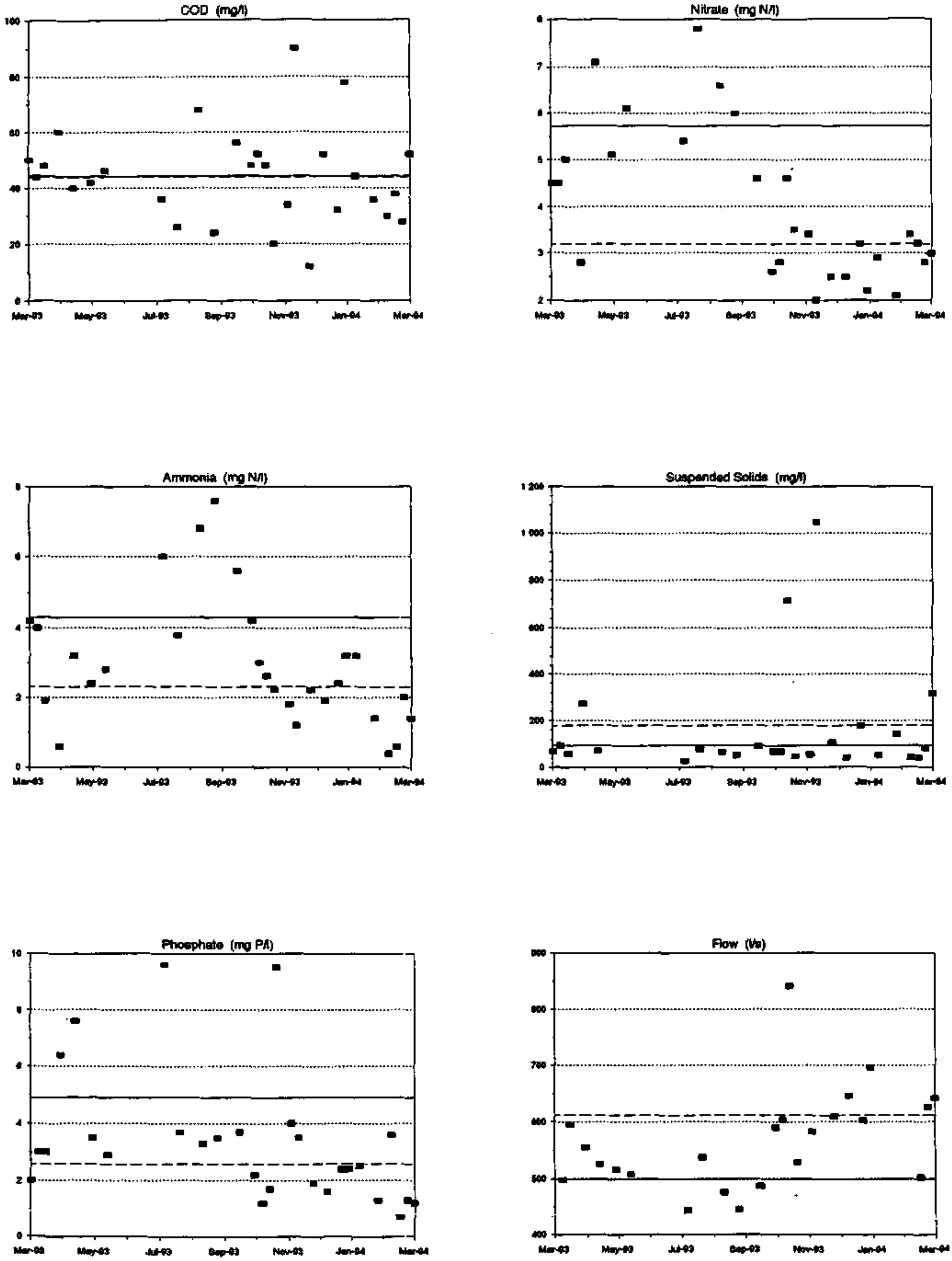


Figure 6.15 : Time series plots and average summer and winter values at monitoring point 11



2629-211

Figure 6.16 : Time series plots and average summer and winter values at monitoring point 15

2629-200

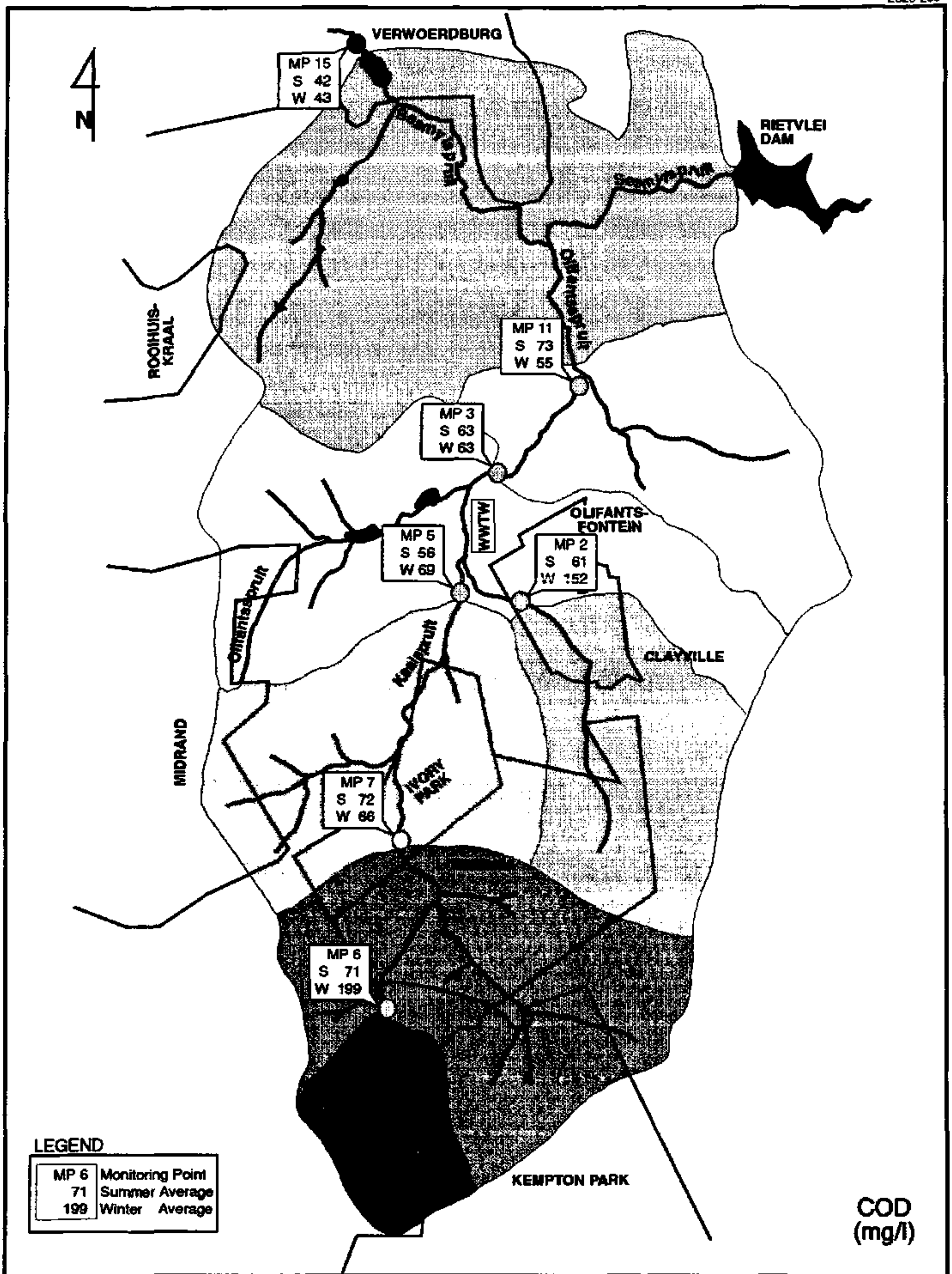


FIGURE 6.17 : SUMMER AND WINTER COD (mg/l) AVERAGES FOR SELECTED MONITORING POINTS

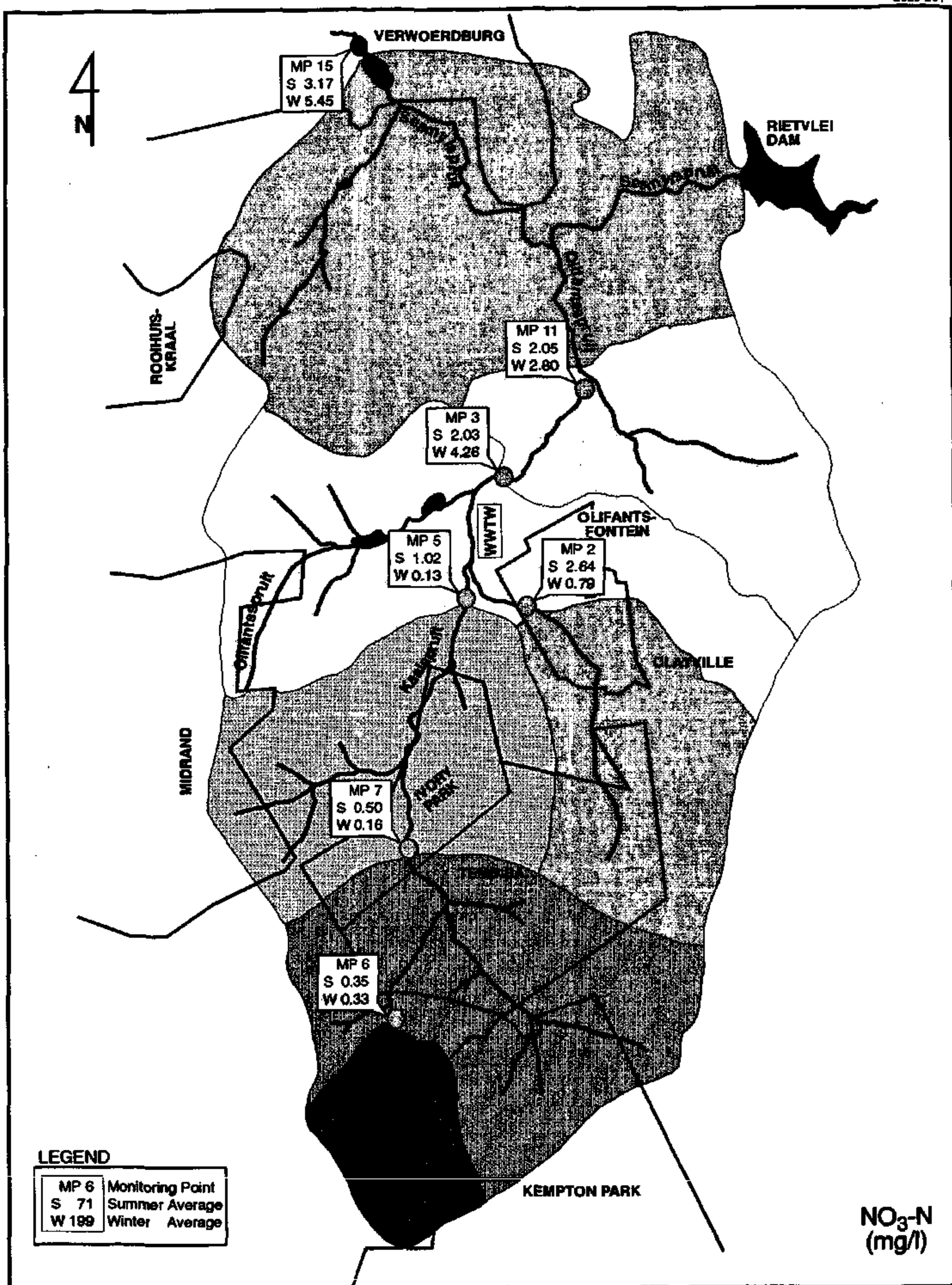
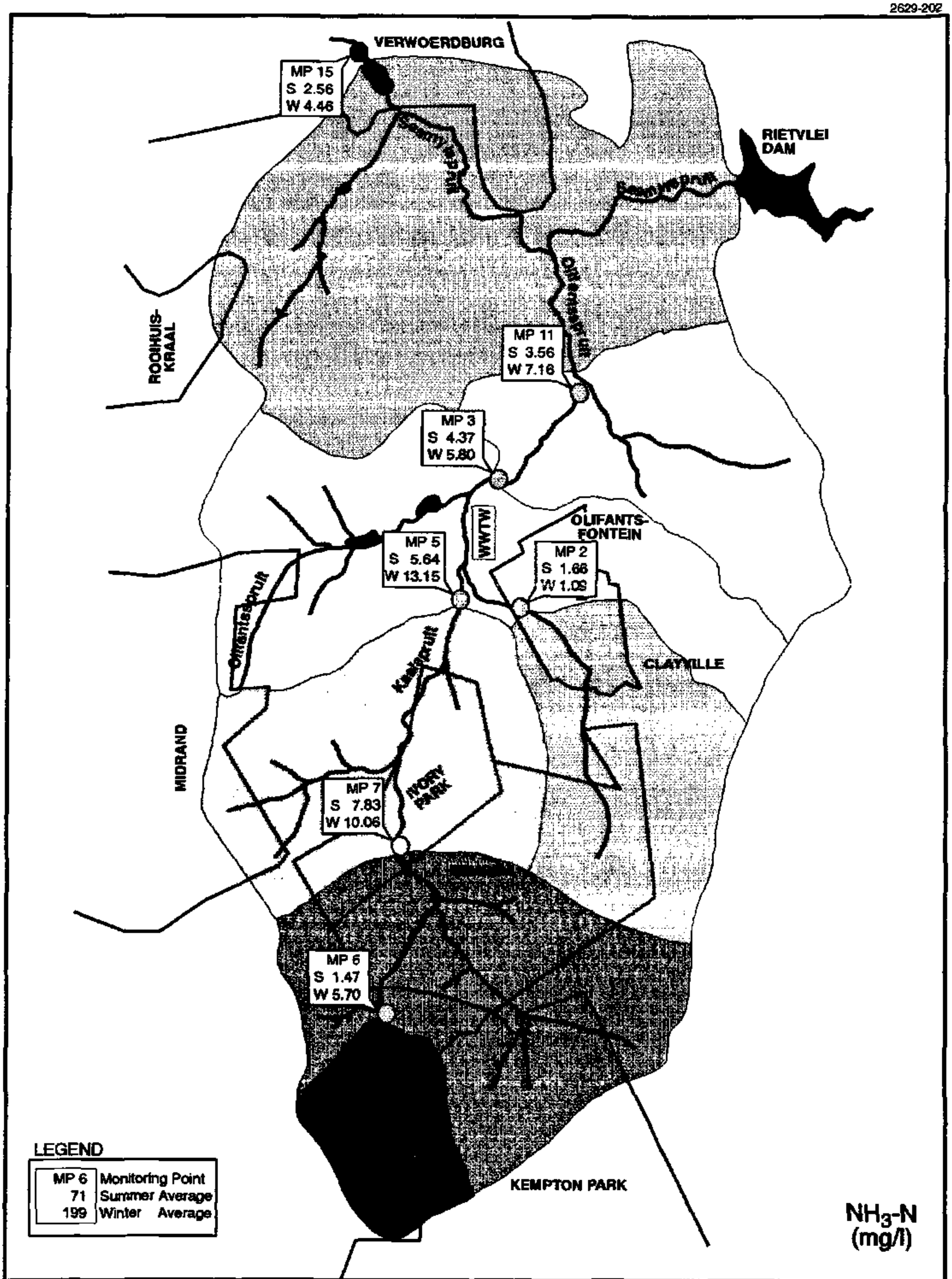


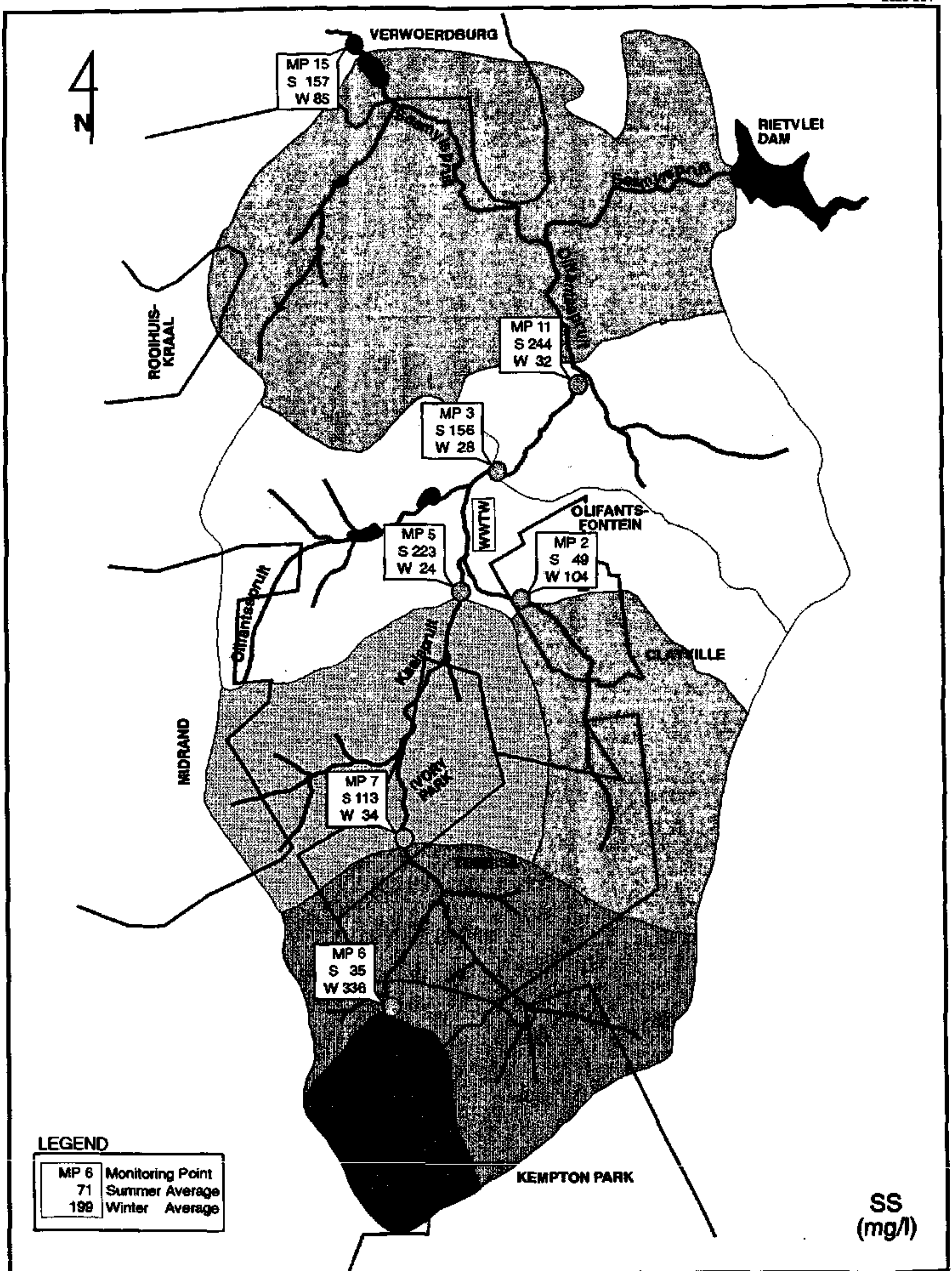
FIGURE 6.18 : SUMMER AND WINTER NO_3 (mg/l) AVERAGES FOR SELECTED MONITORING POINTS

2629-202



WMB

FIGURE 6.19 : SUMMER AND WINTER NH_3 (mg/l) AVERAGES FOR SELECTED MONITORING POINTS



WMB

FIGURE 6.20 : SUMMER AND WINTER SS (mg/l) AVERAGES FOR SELECTED MONITORING POINTS

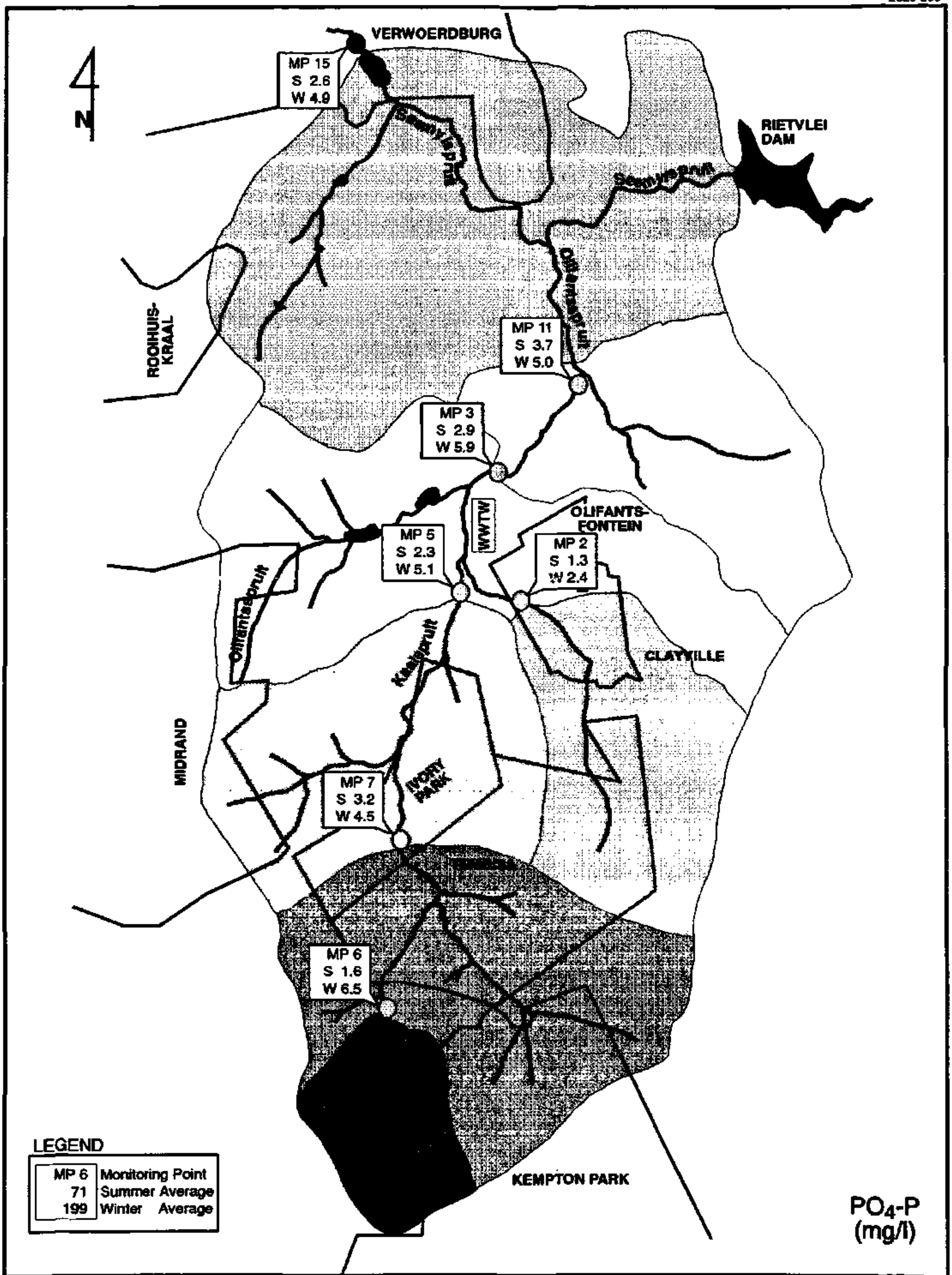


FIGURE 6.21 : SUMMER AND WINTER PO_4 (mg/l) AVERAGES FOR SELECTED MONITORING POINTS

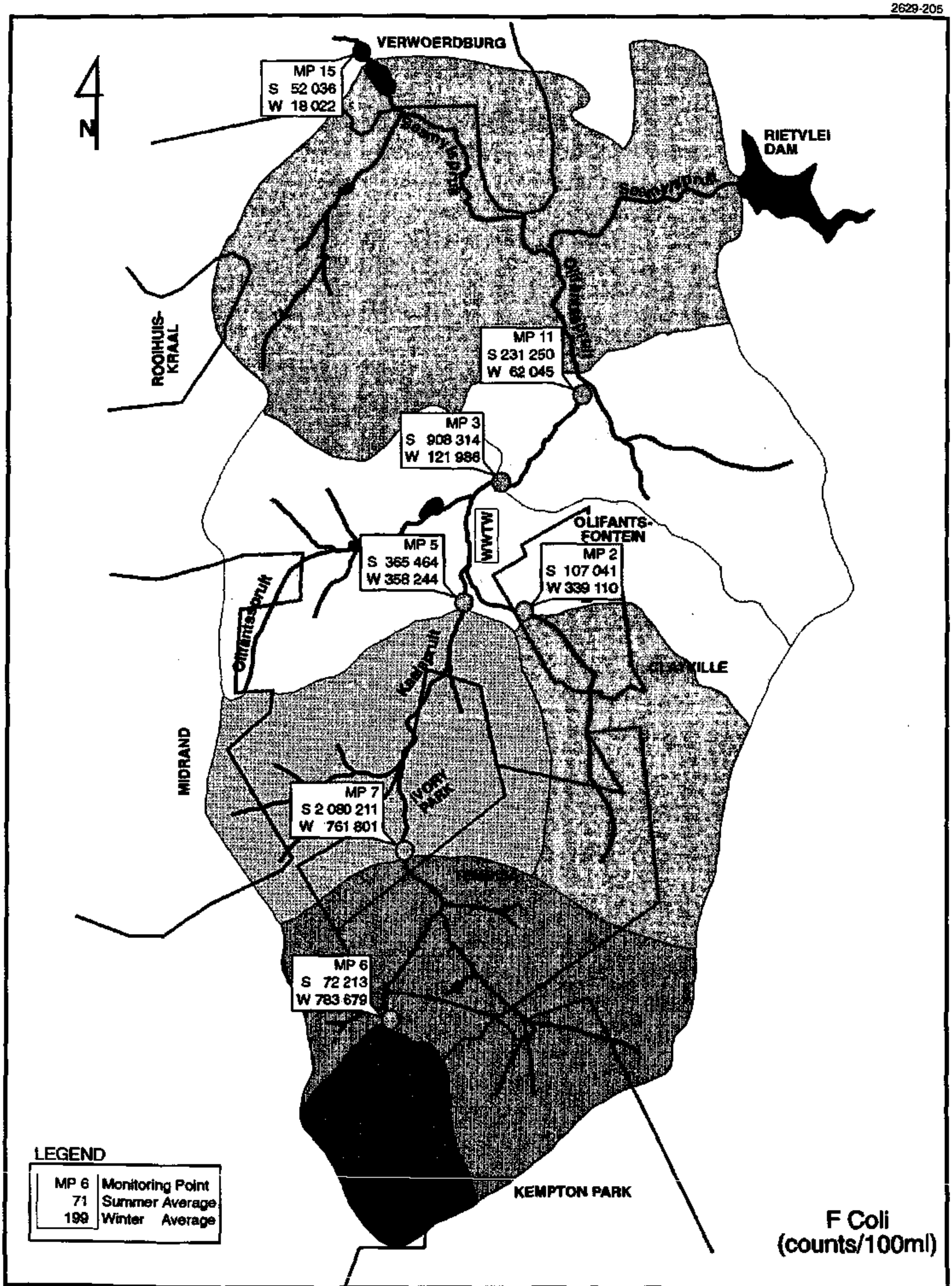


FIGURE 6.22 : SUMMER AND WINTER F Coli (counts/100ml) AVERAGES FOR SELECTED MONITORING POINTS