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AN INVESTIGATION INTO THE EFFECT OF VARIOUS LEVELS OF SANITATION ON SURFACE WATER QUALITY IN A TYPICAL DEVELOPING COMMUNITY

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AN INVESTIGATION INTO THE EFFECT OF VARIOUS LEVELS OF SANITATION ON SURFACE WATER QUALITY IN A TYPICAL DEVELOPING COMMUNITY

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DECLARATION

I hereby certify that the work in this document is my own and has not been submitted for the purpose of obtaining a degree at any other institution.

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01/02/97

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SUMMARY

A growing need exists to assess the impact of urban and industrial development on the aquatic environment. Environmental strategies, which will result in an improvement of environmental quality without excessive cost, must be designed and implemented. In order to do this, it is important to identify sources of pollution, to quantify the possible pollutant load, and to identify such pollutants' pathways into the aquatic environment.

The primary objective of this study was to investigate the effect of various levels of sanitation on the quality of urban stormwater run-off. The Klein Modder River catchment, in the province of the Free State, South Africa, was selected as site for this study. Botshabelo is a large settlement in the catchment of the Klein Modder River. The city contains various types of developing urban profiles similar to those found elsewhere in developing urban areas in South Africa. The city has substantial shortcomings in sanitation that could lead to pollution of stormwater run-off.

The pollution impact of three sub-catchments of Botshabelo, where different levels of sanitation are being used, was investigated. The typical sanitation systems were waterborne sewage, bucket latrines and pit latrines. The pollution impact was evaluated by means of measured microbiological indicators, which are generally used to define the safety of surface water bodies for human contact. The flood peaks in each catchment were also calculated, and it was established that the hydrological variance, as a factor influencing the variability of the results, could be neglected. The conclusion reached was that the extent of pollution is clearly determined by the level of sanitation systems and the quality of the management of these systems.

OPSOMMING

'n Groeiende behoefte bestaan om die impak van stedelike en nywerheidsontwikkeling op die wateromgewing vas te stel. Omgewingsbeheermaatreëls, wat sal lei tot 'n verbetering van die omgewingskwaliteit sonder buitensporige koste, moet ontwerp en geïmplementeer word. Dit is dus belangrik om die bronne van besoedeling te identifiseer, die besoedelingslading te kwantifiseer en om die roete van sulke besoedelingstowwe na die wateromgewing te identifiseer.

Die primêre doelwit van die studie was om die effek van die verskillende vlakke van sanitasie op die kwaliteit van stedelike stormwater-afvloei te ondersoek. Die Klein Modderrivier-opvanggebied, in die Vrystaat, Suid-Afrika, is gekies as terrein vir hierdie studie. Botshabelo is 'n groot nedersetting in die opvanggebied van die Klein Modderrivier. Die stad bevat verskeie tipes ontwikkelende stedelike profiele wat soortgelyk is aan dié wat ook elders in Suid-Afrika aangetref word. Die stad het omvangryke tekortkominge ten opsigte van sanitasie wat kan lei tot besoedeling van stormwater-afvloei.

Drie sub-opvanggebiede van Botshabelo, met verskillende tipes sanitasiestelsels, is bestudeer om die besoedelingsimpak op die Klein Modderrivier te ondersoek. Die tipes sanitasiestelsels was onderskeidelik watergedraagde riolering, emmerstelsels en putlatrines. Die besoedelingsimpak is geëvalueer aan die hand van mikrobiologiese indikators, waardeur veral die veiligheid van die oppervlakwater vir menslike kontak, dan bepaal kan word. Die vloedspitse in elke opvanggebied is bereken, waar dit geblyk het dat hidrologiese variansie as 'n faktor om die wisselvalligheid van die resultate te beïnvloed, weggelaat kan word. Die gevolgtrekking wat gemaak is, is dat die omvang van besoedeling duidelik bepaal word deur die vlak van die sanitasiegeriewe en die kwaliteit van die bestuur van die stelsels.

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FOREWORD

"It may be said, with some justification, that the standard of sanitary science practised by a nation is an indication of its standard of living".

K.A. Murray (1987:1)

We are living in a wonderful world. A world, when after God had created it, He looked over all that He had made, and saw that it was excellent in every way (Gen 1:31). Sometimes we forget that God also made man: to master and care for this earth.

The earth, seen from space, is the blue planet, the planet of water. Most of this water is of little direct use to humans. The water that is most easily available to us - in rivers and lakes - amounts to about 0.26 % of all fresh water on this planet. Most of the world's population depend on these precious resources for their domestic, irrigation and industrial water.

Because fresh water is so important to life, people have always chosen - when they could - to live close to it. This is the main reason why so many of our lakes and rivers are now threatened by the danger of many forms of pollution and by ecological disturbances that threaten their future as useful resources.

Humans have been polluting their water supplies since civilisation began, but now, because there are many more of us using the same amount of water - and because our demands have increased - problems of scarcity and contamination are becoming severe.

Although reversing the damage done will itself be complicated and expensive, it is important to minimise further harm. Making more people aware of what is happening to their water supplies may be an effective way of slowing down water pollution. This can be done through research and the effective application of the results.

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1. INTRODUCTION

1.1 URBAN STORMWATER POLLUTION

> *"While great efforts are being made to treat 'formal' waste water, the stabilisation of polluted stormwater and other forms of surface water run-off are neglected, allowing water of poor quality to enter into natural environmental surface waters".*
>
> **(Jagals, 1994:1)**

Historically, major water pollution control activities were focused on the most obvious pollution source - waterborne sewage (Field and Turkeltaub, 1981:2). While secondary treatment of insanitary wastes is now a generally accepted minimum standard, this is not generally the case with stormwater run-off pollution. It therefore provides a rationale to consider stormwater run-off pollution and its inherent potential health hazards (Sheaffer *et al.*, 1982:253).

Recognition of the significance of stormwater-induced pollution has been slow. Only during the past twenty years, has it been recognised that stormwater run-off may be highly polluted (Field and Turkeltaub, 1981:2). Quereshi and Dutka (1979:979) reported that urban settlements contribute to pollution of aquatic environments. Many potential pollution sources, both point and non-point sources, are created by urban development (Wright *et al.*, 1993:2). A myriad of urban factors such as traffic, air pollution, construction activities, littering, animals, poor maintenance of drainage ways, residential and commercial site deficiencies, land uses and indiscriminate dumping practices are all contributing factors (Sheaffer *et al.*, 1982:255).

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Therefore a growing need exists to assess the impact of urban and industrial development on the aquatic environment. Environmental control strategies, that will result in demonstrable improvement in environmental quality without excessive cost, must be designed and implemented. In order to do this, it is important to **identify sources** of pollution, to **quantify** the possible **pollutant load**, and to **identify** such **pollutants' pathways** into the aquatic environment.

According to Wright *et al.* (1993:1), high-cost, low-density developed urban areas usually have a good infrastructure and pollution threats are mainly from point sources that can be monitored and controlled. Low-cost, high-density developing urban areas (Wright *et al.*, 1993:1) have a less sophisticated infrastructure with the result that pollution is more non-point/diffused and generally difficult to identify and control. Due to the fact that much of the present and future development in South Africa is of the "developing" type, there is a definite need to investigate stormwater contamination by these urban catchments, as well as its effect on receiving water bodies.

Developing urban areas consist mostly of formal and informal housing and other occupied structures usually around existing metropolitan areas. Most of these structures do not have in-house running water or ablution facilities (Wright *et al.*, 1993:16). Wong (1996:24) reported that, although identified as a priority in the government's Reconstruction and Development Programme (RDP), 12 million people in South Africa still do not have access to an adequate supply of clean water. In excess of 21 million people (roughly half of South Africa's population), are estimated to be without access to safe facilities for excreta disposal.

The population in many developing areas have varied forms of water sources. In the areas closer to the main metropolitan centres, inhabitants are generally supplied with public standpipe systems - in some areas providing water to as many as 200 households per standpipe (Department of Water Affairs and

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Forestry, 1994:2). This leads to a below-average usage of water per person, often resulting in poor sanitary practices. In fact, there seems to be a definite relation between the users of public standpipes and indiscriminate environmental defecation (Herbert, 1983:129). The lack of ablution facilities in these areas, therefore, leads to the use of the environment for daily latrine purposes. As a result of these circumstances, the surrounding land becomes a major pick-up for human faecal waste whenever it rains. Water leaving these urban catchments is thus a potential medium for the transportation of hazardous health-related pollutants such as bacteria and viruses.

1.2 PURPOSE OF THE STUDY

The primary objective of this study was to investigate the effect of the various levels of sanitation (on-site versus waterborne) on the quality of urban stormwater run-off; (1) to establish any possible relationships between the quality of such run-off and receiving water quality; and (2) to establish the level of contamination by such run-off on the receiving water quality with special emphasis on the risk for downstream consumers.

Assessing the impact and associated detrimental effects on receiving waters provide fundamental justification for improved levels of sanitation. This study also emphasises the value of sanitary education programmes as a priority among the objectives of health policies.

The upper Klein Modder River catchment was selected as a site for this study. Botshabelo is a large settlement in the catchment of the Klein Modder River in the Free State, South Africa (**Figure 1; Figure 2**). The city contains various types of developing urban profiles similar to what is found elsewhere in South Africa. The city has substantial shortcomings in sanitation that could lead to pollution of stormwater run-off.

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A study conducted by Jagals (1994) investigated the impact of surface run-off from Botshabelo on the microbiological quality of water in the Modder River. The Modder River is a major downstream source of potable water for the city of Bloemfontein, the capital of the province. The value of selected indicator micro-organisms for the assessment of faecal pollution of water was investigated in this study. Pollution profiles were drawn up of the Modder River catchment during the dry season, from stormwater run-off during general rain and immediately after thunderstorms. The data accumulated during this 1994 study were approached in different ways in an effort to establish the level of microbiological pollution contributed by the city of Botshabelo to the Modder River.

The results showed that the run-off from the developing settlement constituted a major source of pollution for the river catchment and may constitute an environmental health threat to downstream riparian consumers. However, this study by Jagals (1994) was a direct analysis of the effects of diffuse effluents from the urban catchment on the water quality of the Modder River. It did not address the specific contributions from the various urban areas in relation to the types of sanitation applied in each of these areas.

Therefore, the main objective of this study was to assess the effect of various levels of sanitation in Botshabelo on the quality of surface water and its direct impact on the receiving Klein Modder River - a tributary of the Modder River.

1.3 THE POTENTIAL THREAT OF SANITATION TO ENVIRONMENTAL HEALTH

Environmentalists recently raised questions on the safety of on-site sanitation. According to Wong (1996:24), on-site sanitation does not lend itself to use in developed areas where the close proximity thereof may cause pollution. Floods

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also cause problems in soakaway efficiency as well as backwash that builds up in latrines. On-site sanitation, although it might often be a cheaper option, is not necessarily the best way to address the sanitation problems in South Africa. In this study it will be shown that certain forms of sanitation may indeed be potentially more detrimental to environmental health than general perceptions may have it to be.

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2. LITERATURE REVIEW

2.1 COMPONENTS OF CATCHMENT RUN-OFF

Run-off represents the excess of precipitation over evapotranspiration losses after allowing for infiltration and surface detention (Ayoade, 1988:131; Wilson, 1982:102).

The four main components of catchment run-off are 1) channel precipitation; 2) overland flow; 3) interflow and 4) groundwater flow/base flow (Ayoade, 1988:131).

Channel precipitation is rain that falls directly onto the surfaces of rivers and lakes and immediately enters streamflow. The fact that water surfaces generally account for less than 5 % of a catchment (Ayoade, 1988:131) means that channel precipitation is usually not meaningful and is therefore seldom taken into account.

Overland flow is rainwater that flows over the ground surface as sheet flow and does not infiltrate the ground (Ayoade, 1988:131). Once overland flow reaches the stream channel it is called surface run-off (Wright *et al.*, 1993:11).

Interflow consists of rainwater that, after infiltrating into the soil surface, moves laterally through the upper soil horizon towards the stream channel. Interflow may either be as unsaturated flow in the upper soil region, or as shallow-perched saturated flow above the main ground level. Interflow routes vary a great deal. Subsurface textural change between horizons and the interface between weathered material and bedrock create channels for interflow and therefore also determine the rate of interflow. This implies that such interflow does not generally discharge directly into the stream channel,

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but may surface and move further as overland flow (Ayoade, 1988:132) and eventually as surface run-off (Wright *et al.*, 1993:11).

Groundwater flow consists of rainwater that percolates downwards into the earth (the unsaturated zone) to reach the underlying groundwater (the saturated zone). This flow may eventually reach the ground surface, but usually discharges directly into rivers and streams (Ayoade, 1988:132).

Stormwater run-off thus constitutes the sum total of channel precipitation, surface run-off and rapid interflow (Wright *et al.*, 1993:11).

2.2 RUN-OFF CYCLE

The cyclic movement of water from the atmosphere to the earth by precipitation, as well as the paths it follows to the stream/river channel, is referred to as the **run-off cycle** (Wright *et al.*, 1993:11). A simplified concept of this cycle in a natural catchment is shown in **Figure 4a**.

When this natural catchment is altered by events such as urbanisation, the natural hydrological processes are simplified/streamlined because various elements of these hydrological processes are bypassed/eliminated. These effects of urbanisation on the run-off cycle cause severe changes in the run-off cycle locally and may be summarised as follows:

- The infiltration capacity of the surface is changed.
- The natural drainage systems are modified through the construction of artificial drainage systems.
- Water sources, both surface and underground, are polluted.

(Ayoade, 1988:258)

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Urbanisation not only produces larger volumes of surface run-off, but concentrates the run-off more rapidly (Sheaffer *et al.*, 1982:101). Stephenson (1993:11), found that the greater the degree of urbanisation, the more the infiltration capacity is reduced, resulting in a larger percentage of the precipitation becoming overland flow and thus stormwater run-off. Consequently, urbanisation will greatly increase pollutant loads to receiving waters, not only because of increased surface run-off, but also because higher velocities enhance erosion, dislodgement and the entrainment of particulate pollutants (Simpson and Stone, 1988:231).

Even though several research projects have been undertaken to study the effects of urbanisation on run-off, the vast majority of these studies have concentrated on "developed" catchments with the result that little is known about developing urban catchments (Wright *et al.,* 1993:2). **Figure 4b** illustrates the run-off cycle in a developed urban catchment.

2.3 RUN-OFF QUALITY

Stormwater is not a pollutant (Wright *et al.*, 1993:12), though it may serve as a transportation medium for pollutants. Run-off from the streets, roofs, and other areas carries pollutants. If run-off is routed to receiving water bodies, pollutants will inevitably have to follow (Sheaffer *et al.*, 1982:255). This affects the quality of the urban stormwater run-off as well as of the receiving water. Another direct result is undesirable changes in the appearance of rivers and their hydrological amenities (Field, 1985:199). Furthermore, the urban lifestyle also contributes to the degradation of the quality of water in rivers as urban water courses are often used to carry domestic and industrial effluents (Field, 1985:200).

Reports indicate that microbiologically polluted surface run-off may be due to

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inadequate sanitation (Jagals, 1994:152). Polluted rivers lose their attractiveness and become smelly (anaerobic) and turbid with much of their aquatic life lost. Increased floods cause these rivers to become scoured or muddy stream channels, while trash deposited in stream- and riverbeds add to river disfigurement (Field, 1985:200). The results are that many urban rivers can no longer be used for recreational purposes like swimming, boating or fishing, and that the water from these rivers becomes increasingly difficult to treat for drinking and other domestic and industrial purposes.

2.3.1 Previous South African Studies

During the past thirty years many studies have been conducted world-wide to determine the quantitative and qualitative characteristics of stormwater discharges and their impact on receiving waters (Bradford, 1977:613; Geldreich *et al.,* 1968:1861; Olivieri *et al.*, 1977:78). The emphasis in these studies has been on the similarity between stormwater run-off and sewage and their inherent potential health hazards.

In recent years several studies on urban run-off pollution have been conducted in South Africa. The earlier studies were conducted on developed catchments and on stormwater run-off models. During the past five years, studies were generally more focused on low-cost, high-density developing urban catchments as the following will indicate:

- **Simpson (1986)** investigated a catchment within the municipal area of Pinetown, Kwa-Zulu Natal, South Africa, receiving mainly summer rainfall. It was a three-year study of pollution contained in stormwater run-off from a mixed 90 hectares (ha) residential-commercial-industrial land-use catchment. The sources of pollutants were divided into three main categories, 1) atmospheric fallout; 2) erosion of catchment materials and 3) materials

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from vehicles imported and deposited in the catchment. The wet and dry quality and quantity of pollutant atmospheric fallout and run-off were monitored. Measurements included suspended solids, soluble and insoluble forms of nitrogen and phosphorus, chemical oxygen demand and certain selected heavy metals. The microbiological quality of the stormwater run-off, however, was not investigated. Sanitation consisted of waterborne sewage with conventional waste water treatment.

- **Stephenson and Green (1988)** investigated two large residential areas in Johannesburg, South Africa. The first catchment represented a low density residential suburb with commercial and light industrial activity, as well as a solid waste disposal site. The second catchment represented a high density area with some commercial activity. Although these areas are also in the summer rainfall region, different rainfall patterns to that of the Pinetown catchment were reported. The microbiological quality of stormwater run-off was not investigated. Sanitation again consisted of waterborne sewage with conventional waste water treatment.

- **Kloppers (1989)** made a comparative study of the stormwater quality in two catchments, namely Three Anchor Bay and Mitchell's Plain, situated in the greater Cape Town metropolitan area, South Africa.

* The catchment of Three Anchor Bay is located within the municipal area of Cape Town and is within the winter rainfall region of South Africa. The catchment was considered a good example of an established residential catchment with medium population density and high road traffic.

* The catchment of Mitchell's Plain is approximately 20 km from Cape Town. This residential area generally comprised housing with a low-level socio-economic profile.

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Stormwater run-off in both areas was monitored during dry and wet weather conditions. Samples of baseflow were taken monthly and analysed for trace metals and total hydrocarbons. The microbiological quality of run-off was assessed in both catchments. Sanitation was not clearly described in this work.

- **Lord and Mackay (1991)** studied the impact of urban run-off on the water quality of the Swartkops Estuary. The Swartkops estuary is a major resource of the city of Port Elizabeth, South Africa, in terms of recreation and tourism. The Motherwell catchment forms part of the Swartkops Estuary. Motherwell is a new high-density residential development. An intensive field study was undertaken during September 1989 and December 1990, to investigate the quantity and quality of urban run-off from Motherwell via a main stormwater canal that drained into the estuary. The study concentrated on the possible microbiological pollution of the stormwater. Sanitation was not clearly described in this work

- **Wimberley (1992)** investigated the effect of the run-off from Alexandra Township (Johannesburg, RSA) on the water quality of the Jukskei River. The settlement in Alexandra had not, at the time of study, been provided with the necessary engineering services to effectively remove human waste. It was operating on a waste disposal system of bucket latrines that were reported to be serviced on a daily basis. A monitoring exercise was undertaken between August and December 1991 in order to quantify possible pollution, and the effect it has on the receiving waters of the Jukskei River. The microbiological quality of run-off was assessed in the catchments. The wet and dry profile was not clearly defined in this study.

- **Wright *et al.* (1993)** investigated the stormwater run-off from the Khayelitsha urban catchment in the False Bay area. Khayelitsha is situated

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centrally along the northern shoreline of False Bay some 25 km south-east of Cape Town. The catchment was entirely of a residential nature and contained organised squatter housing and formal housing. During the time of study most of Khayelitsha had waterborne sewage except one site where a bucket system was in use. The sewage system ran parallel with the stormwater system with two pump stations and one waste water treatment facility.

The main sampling programme consisted of both storm event sampling and the sampling of selected sites during specific weather conditions. Samples were analysed for trace metals, nutrients and microbiological indicator organisms.

- **Jagals (1994)** studied the effects of diffuse effluents from Botshabelo (Free State, South Africa) on the microbiological quality of water in the Modder River. The basic methodology used in this study was described in Chapter 1.

Summarising previous studies:

Most of the developing urban areas (low-cost, high-density) were mainly residential with little commercial or limited industrial activity. Coupled with the fact that it usually had less sophisticated infrastructure and poor sanitation, the major sources of pollutants were undoubtedly litter and faecal contamination from both human and domestic animals.

Urban run-off was reported capable of containing a wide range of pollutants often at high concentrations. By implication, stormwater is more polluted than treated sewage effluent. This is confirmed by Weatherby and Novak (1977:76) and by Qureshi and Dutka (1979:982) who have shown that microbiological stormwater run-off may be more contaminated than diluted raw sewage. The

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study done by Jagals (1994:150) has shown that urban stormwater outfalls contribute to far greater microbiological pollution than the effluent from the sewerage outfall works originating in the same urban area.

The developing type of urbanisation not only poses a health threat to the urban community within the catchment but also to downstream users. Water leaving such catchments was usually polluted from a microbiological perspective. International studies have further shown that the level of sanitation may have an influence on the quality of stormwater. However, this type of study is uncommon in South Africa.

2.4 RUN-OFF QUANTITY (YIELD)

Though several studies were conducted to determine the quantitative and qualitative characteristics of stormwater discharge, the relation between run-off yield and pollution remains controversial (Guillemin *et al.*, 1991:923). There are many conflicting views in literature on the modelling of run-off loads. Ellis *et al.* (1986:589), reported a study on run-off from a highway. They used stepwise linear regressions for the run-off yield and storm duration. With this, they were able to explain over 90 % of observed variance in pollutant loads. Bedient *et al.* (1978:1098) found, in an analysis of available stormwater data for several Houston area watersheds, that the direct linear relationships between pollutant loads and run-off yield were sufficient for correlation coefficients of about 0.9. Different parameters that can influence pollutant run-off loads, were investigated in the study by Simpson (1986:100). Stepwise linear regression was used to develop load equations and again run-off yield was identified as the most important determinant.

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2.4.1 Calculation of Yield

Calculating a hydrological yield from a catchment is best done through flow-related gauging at certain points in a catchment. However, due to constraints such as the security of equipment in developing areas, alternative methods were developed to simulate flow. Most of these methods have been tested repeatedly for the accurate prediction of run-off and are often used. If a suitable methodology is used, accurate simulations of run-off can be obtained without the need of gauging (Simpson, 1986:101).

Because numerous and varied models for predicting and/or determining run-off yield exist in literature, it was decided on the Rational Method for predicting run-off yield from the target catchments.

The Rational Method was one of the first techniques used to predict run-off. Even though its origin is uncertain, it first appeared in American literature in an article written in 1889 by Kuichling (Alexander, 1990:7.4). Some authors are of the opinion that the method had its origin in 1851 due to the work of the Irish engineer Mulvaney. In England the method is sometimes referred to as the Lloyd-Davis method due to the application of the method in sewage design calculations in 1906 (Lloyd-Davis, 1906:41).

The Rational Method is used in most engineering offices for predicting run-off. It has frequently come under criticism for its simplicity, but no other practical drainage design method has evolved to a greater level of general acceptance by the practising engineer. The Rational Method, if properly understood and applied, produces satisfactory results when calculating the run-off yield from smaller urban catchments (Sheaffer *et al.*, 1982:100).

The run-off yield from a catchment is firstly dependent on the amount of rainfall and secondly on the run-off pattern of the catchment. According to

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Ayoade (1988:153) the relationship between rainfall and run-off yield can be represented by a number of empirical and semi-empirical formulas of which the rational formula is an example.

The Rational Method is based on the rational formula:

$$Q = 0.256 * CIA \quad \textbf{metric}$$

Q = run-off yield (m^3 / s)
C = run-off coefficient (without dimension)
I = average rainfall rate on catchment (mm / h)
A = effective catchment (km^2)

(Rooseboom *et* al., 1993:2.20)

The run-off coefficient in the rational formula is an integrated value representing the various hydrological properties that determine the run-off pattern. The correct determination of the run-off coefficient (C) plays a vital role. An objective theoretical method for determining the value of C does not exist. The subjective theoretical elements of experience and engineering opinion are of great importance in the successful application of the method (Shaeffer *et al.*, 1982:100).

2.5 POLLUTION INDICATORS

It is obviously not practical to study all the numerous potential chemical compounds, physical water quality variables and various biological species in water. It was therefore decided that only one water quality criterion, namely microbiological indicators, will be investigated. This decision was supported by the following:

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- During the study done by Wright *et al.* (1993) where the stormwater run-off from a developing urban catchment was investigated, the major form of pollution was identified as microbiological in nature (Wright *et al.*,1993:58).

- The study done by Grobler *et al.* (1987) to assess the impact of a low-cost, high-density urban development (Botshabelo) on the water quality in the Modder River catchment did not include microbiological pollutants.

To determine the microbiological safety of water implicated for human contact would require the enumeration of many different species of pathogens, including species of bacteria, viruses and protozoan parasites. Because the detection of these pathogens entail complex, expensive and time-consuming procedures that render it impractical, it became practice to monitor microbiological water pollution on the basis of indicator organism levels, rather than the pathogens themselves (Jagals, 1994:16). Cabelli (1977:224) described the characteristics of an ideal faecal pollution indicator as:

- present in sufficient numbers to allow detection,
- easy to enumerate,
- present in a constant ratio as a pathogen,
- unable to multiply outside the intestines of humans and/or warm-blooded animals, and
- released into the environment solely in the faeces of humans and/or warm-blooded animals.

No single indicator is available that meets all the requirements for the ideal indicator. Most indicators used present some compromise of these properties (Department of Water Affairs and Forestry, 1993:12). Therefore, indicator data used in this study included various microbiological indicator organism groups and species such as faecal coliforms, faecal streptococci and coliphages.

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- **Faecal coliforms (FC)** represent a selected group of total coliform bacteria that are more specific for faecal pollution than the wider group of total coliforms (Grabow, 1986:159).
- **Faecal streptococci (FS)** are defined as those species of streptococci that are present in faeces in significant quantities (Clausen *et al.*, 1977:250). These organisms have a longer lifespan than faecal coliforms and can therefore be used to indicate faecal pollution for longer periods than faecal coliforms (Guillemin *et al.*, 1991:923).
- **Coliphages** (bacteriophages). Bacteriophages are viruses that infect bacteria. Phages that infect faecal bacteria can, therefore, be associated with faecal pollution (Grabow *et al.*, 1993:7). Somatic coliphages include a wide variety of phages that infect *E coli* and related species that are generally detected in large numbers in sewage polluted water. Phages may also indicate the possible presence of pathogenic human viruses in water.

Faecal coliforms and streptococci indicate water polluted by faeces which may contain entero-pathogenic bacterial species such as *Salmonella* and *Shigella*. The principal diseases caused by these species are dysentery, enteric fever and food poisoning. Cholera may also be implicated.

Coliphages are model viruses used to indicate the presence of entero-pathogenic human viruses such as *Rotavirus* and *Norwalk* which have the following clinical symptons: gastrointestinal syndrome, vomiting, watery diarrhea and abdominal cramps.

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3. RESEARCH METHODOLOGY

3.1 DESCRIPTION OF THE CATCHMENT

The Klein Modder River catchment is situated approximately 60 kilometres east of Bloemfontein, the capital of the Free State. The city of Botshabelo is a large settlement in this catchment. The Kgabanyane River and the Wildebees Spruit converge to form the non-perennial Klein Modder River that flows adjacent to it and then through the city of Botshabelo for about 8 kilometres. The Klein Modder River joins the Modder River approximately 10 kilometres downstream from Botshabelo (**Figure 1**; **Figure 2**). The Modder River is utilised as a major source of drinking water for the city of Bloemfontein downstream from this confluence.

3.1.1 Physical Parameters

3.1.1.1 Topography:

The catchment of the Klein Modder River is characterised by typical Eastern Free State topography. The eastern border of the catchment is formed by part of the Koranna Mountain range, with the highest mountain ridge being 1 745 m above sea level. Though numerous low ridges are present in the central and north-west of the area, the rest of the catchment mostly comprises gently rolling terrain, gradually sloping to the south-west at an average gradient of 1:190 (**Figure 2**).

3.1.1.2 Climate:

The study site was located within the summer rainfall zone of South Africa which is classified as a sub-humid, warm zone with annual water deficiency (Schulze, 1958:32). The mean annual precipitation varies between 500 mm

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and 600 mm (Rooseboom *et* al., 1993:2.27) and receives summer thunderstorms and soft rains in approximately equal quantities (Tyson, 1987:220). According to the Hydrological Research Unit (1981:185), the mean annual precipitation (M.A.P.) value for the period 1905 to 1976 was 533 mm.

A weather station at Thaba Nchu (approximately 15 km east of Botshabelo) was the closest comprehensive meteorological station to the study site. The rainfall from this station is summarised in **Appendix A1**, while the graph in **Figure 5** illustrates the seasonal trend. Air temperatures range from an average maximum of 30°C in January to an average minimum of 1°C in July. Daily temperatures range (for both summer and winter averages) some 15°C (Schulze, 1958:34; Tyson, 1987:220). Monthly pan-evaporation rates are highest in summer (December = 323 mm) and lowest in winter (July = 85 mm), with an annual average evaporation of approximately 1750 mm (Department of Water Affairs and Forestry, 1986:103).

3.1.1.3 Geology:

The catchment is situated on the Beaufort Series of the Karoo System. The regional geology consists of interbedded mudstone, siltstone and occasional sandstone that have been intruded by numerous narrow dolerite dykes and sills, presumably along old fault zones (Hartopp, 1979:57; Stone, 1985:38).

The mudstone and siltstone are predominantly greenish to beige or olive in colour and show varying degrees of weathering. This was particularly evident along exposed joints, fractures and bedding planes. The high mudstone and siltstone content in the soil is rapidly broken down to gravel, sand and clay when exposed to alternate wetting and drying (Stone, 1985:38). Dolerite sill-intrusions occur thoughout the area, predominantly as gently inclined or nearly horizontal sheets - often located as raised areas in the topography. Adjacent to the dolerite intrusions, the mudstone has been indurated/hardened by the

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molten dolerite, generally to a distance of one-third of the width of the dolerite intrusion (Hartopp, 1979:57). At several points along the Klein Modder River and a few of its smaller tributary streams, horizontal dolerite sills form the base of the river channel. These often act as small natural dams and trap pools of water at their upstream sides (Grobler *et al.*, 1987:10).

The predominant soil types found in the catchment were classed as transported (Stone, 1985:38). A relatively thin residual soil-cover overlies the siltstone and mudstone. The soil depth is reported to vary from 0.1 m to 1.0 m, usually averaging about 0.6 m (Hartopp, 1979:57; Stone, 1985:38). The soil profile consists of a shallow upper layer of blackish or dark-brown silty-clay overlying a slightly deeper layer of blackish or dark-brown silty-clay with occasional lime or ferricrete nodules. Beneath these two layers, the clays are usually dark yellow to olive in colour, mixed with weathered siltstone fragments and some sand (Stone, 1985:38). An average trial pit of the southern part of Botshabelo can be seen in **Figure 6** and is based on composite data extracted by Stone (1985:38).

3.1.1.4 Geohydrology:

The high clay content of the soils in the region results in very low permeability. Both the studies done by Hartopp (1979:57), and Stone (1985:38), indicated that typical permeability values for these soils vary between 4×10^{-4} cm/sec and 1×10^{-6} cm/sec. The permanent water table is usually located at a depth of 20m to 35m below ground level (Hartopp, 1979:57). Underground water supplies were classed as “sweet” and “hard” (Grobler *et al.*, 1987:12). This was confirmed by the presence of lime nodules in the upper clay horizons (Stone, 1985:38).

3.1.1.5 Vegetation:

The catchment contains three basic grassland vegetation types, namely:

- Type 48: Cymbopogon Themeda Veld

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- Type 49: Transitional Cymbopogon Themeda Veld
- Type 50: Dry Cymbopogon Themeda Veld

(Acocks, 1975:128).

Throughout the catchment, the grass species _Themeda_ _triandra_ is strongly dominant with varying numbers of other grass and short shrub species. Populations of _Euryops_ _empetrifolius_ and _Pentzia_ _globosa_ are common on the heavier clay soils. The riparian vegetation along the Klein Modder River is composed mainly of typical Karoo tree and shrub vegetation forms such as _Acacia_ _karoo_, _Olea_ _africana_. Small populations of the sedges _Cyperus_ *sp*. and _Schoenoplectus_ *sp*. are also found along the margins of pools in the Klein Modder River but are absent during the dry winter months (Grobler *et al.*, 1987:12).

Severe deterioration in the quality of the veld around the city of Botshabelo was evident. Large quantities of grass and sedge were removed with the result that wide areas of bare soil were exposed. Most of the woody species growing along the river channel and near the city were removed for firewood (Grobler *et al.*, 1987:12).

3.1.2 Description of Botshabelo

3.1.2.1 Location:

The city of Botshabelo is a large settlement in the catchment of the Klein Modder River. It is a typical low-cost, high-density urban development in South Africa. The city covers an area of approximately 12 400 ha and is located between the latitudes 29°10′ S and 29°25′ S, and longitudes the 26°35′ E and 26°48′ E (**Figure 1; Figure 2**).

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3.1.2.2 Urban development and population:

The city of Botshabelo was established in 1977 on empty veld south of the Bloemfontein-Thaba Nchu Road and within the first five years the settlement grew into a vast sprawling city with a population of about 200 000. At its peak in 1990 Botshabelo had 140 factories employing approximately 10 000 workers (Prisma, 1990:6).

In 1985 it was predicted that Botshabelo would have a population close to 1 million by 1995, but these predictions proved to be exaggerated (Zöllner, 1993:9). Over the last three years the Botshabelo population has stagnated and with the removal of decentralisation incentives, many factories closed down or relocated to the core cities, leading to large-scale retrenchments and rising unemployment (Zöllner, 1993:10). **Figure 7** shows the projected yearly population growth rate from 1979 to 2000. This figure indicates that population growth rates have declined from 8.52 % in 1988 to 1.74 % in 1991, and is expected to be 0.82 % in 2000.

The city was developed into 18 residential areas comprising designated blocks - each named with a letter of the alphabet (Zöllner, 1993:10). Despite the formal planning on which the development of the city was based, the dominance of sub-economical and various forms of other informal housing structures gave it an initial appearance of an informal settlement. The first areas to be developed were blocks A to E and H. Section H was developed as a higher income area, with larger plot sizes and fully reticulated services. It also has an advantageous location close to the industrial area, city centre and the very important Bloemfontein-Thaba Nchu road (Zöllner, 1993:11). Urbanised population lived in approximately 1 600 informal structures in areas amongst the formal housing zones (Jagals, 1994:9).

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A layout of the developed Botshabelo is given in **Figure 2.** The status of population and housing units per residential block in May 1992 is shown in **Table 1**.

Table 1: Population and housing units per residential block for Botshabelo during May 1992.

BLOCK	OCCUPIED STANDS	VACANT STANDS	HOUSING UNITS	BACKYARD SHACKS	TOTAL STRUCTURES	POPULATION
A	2 354	0	0	550	2 904	13 276
B	878	0	173	220	1 271	4 952
C	2 732	0	121	270	3 123	15 408
D	2 130	0	10	440	2 580	12 013
E	1 973	0	11	547	2 531	11 128
F	2 026	1 10	169	68	2 263	5 713
G	1 254	0	288	350	1 892	7 073
H	3 086	0	0	10	3 096	17 405
J	2 726	0	396	848	3 970	15 375
K	2 962	0	419	451	3 832	16 705
L	2 559	0	0	114	2 673	14 433
M	2 941	0	0	125	3 066	16 587
N	2 079	1 381	0	81	2 160	11 730
S	750	603	0	0	750	3 682
T	2 990	0	0	95	3 085	16 864
U	3 865	0	0	113	3 978	21 800
W	3 297	0	0	108	3 405	18 595
TOTAL	**40 602**	**2 994**	**1 587**	**4 390**	**46 579**	**222 739**

Status: May 1992

Compiled from Van Wyk & Louw (1993) and official Town Council figures (1993).

3.1.2.3 Sanitation:

A layout of the sanitation of the city of Botshabelo is shown in **Figure 3.** The various levels of sanitation of sub-catchments 5, 6 and 8 are illustrated in **Plates 1-3.**

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- **Waterborne systems** comprise about 4 % of sewage collection and disposal in the city. This includes the limited number of industries in the area. Waterborne sewage runs directly to the local treatment works in a well-developed main sewerage network. Sewage from another 1 % of the area, comprising shops, schools and other public services, is being collected in numerous underground conservancy tanks for removal by vacuum-operated tanker vehicles at required frequencies. These volumes of collected sewage are diluted and dumped on the sewerage network at specially equipped points (Jagals, 1994:12).

- Approximately 33 % of the houses are serviced by means of **bucket latrines** (a total of 13 700). Filled buckets are removed twice a week and emptied into specially equipped facilities in the waterborne sewerage system.
- A total of 26 500 **pit latrines** represents about 62 % of sewage disposal in the city. These latrines are generally seldom deeper than 1,5 m due to impenetrable geological substrata. Population per pit is also far greater than design capacity. These factors cause the pits to fill faster than originally intended. This results in people using the environment for latrine purposes.
- A lack of sanitation facilities for the informal housing areas of the urbanising population causes these people to use the environmental surroundings for daily latrine purposes.

3.1.3 Hydrological Network

3.1.3.1 Selection of Sub-catchments:

All available data on the Klein Modder River catchment were acquired from the relevant Government Departments and Project Engineers. The boundary of the Klein Modder River catchment was determined by the interpretation of a

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1:50 000 map with contour intervals, knowledge of the drainage network and by on-site inspections. The catchment was then divided into a number of sub-catchments based on natural features and logical drainage areas (**Figure 3**). Sub-catchments 5, 6 and 8 were chosen from the network to investigate the pollution load of urban stormwater run-off and the impact of this pollution on the receiving waters of the Klein Modder River. The sanitation levels varied in the 3 urban sub-catchments and consisted of 1) pit latrines; 2) bucket latrines and 3) waterborne systems. The various levels of sanitation in the sub-catchments are given in **Table 2** and are illustrated in **Plates 1-3**.

Table 2 : Sanitation levels of sub-catchments 5, 6 and 8.

Sub-catchment	**Pit latrines**	**Bucket latrines**	**Waterborne systems**
C5	6 800	400	NONE
C6	360	6 820	NONE
C8	NONE	2 000	1 500

Status: May 1992

Compiled from Zöllner (1993),Van Wyk en Louw (1993) and official Town Council figures (1993).

3.1.3.2 Run-off yield from selected sub-catchments:

The Rational Method was used in this study to determine the run-off yield (Chapter 2). Run-off yield is dependent on 1) the run-off pattern of the catchment as well as 2) the amount of rainfall.

- Run-off pattern: The run-off pattern is determined by various hydrological properties of the catchment such as size, slope and other characteristics of the basin. **Table 3** is a summary of the hydrological properties of the three sub-catchments. The areas of the sub-catchments were determined by planimeter and ranged in size from 5.56 to 8.1 km^2. The mainstream for each area was identified using aerial photographs, and the mainstream

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lengths were determined from the 1:50 000 map. The average slope was determined from the contour plan. Vegetation, permeability and landuse classification were determined by using aerial photographs, maps, and on-site inspections. Information gathered from previous studies in this area, as well as information received from the Town Council, was taken into account in compiling **Table 3**.

Table 3: Hydrological properties of sub-catchments 5, 6 and 8.

	SUB-CATCHMENT 5	**SUB-CATCHMENT 6**	**SUB-CATCHMENT 8**
EFFECTIVE AREA (km^2):	5.56	8.10	7.33
MAINSTREAM LENGTH (km):	2.8	4.5	4.2
MAP (mean annual precipitation):	600 mm	600 mm	600 mm
AREA DISTRIBUTION FACTOR:	(%)	(%)	(%)
Rural	50	40	40
Urban	50	60	60
RURAL:	(%)	(%)	(%)
Slope:			
Level areas (3-10 %)	100	90	80
Hilly areas (10-30 %)			8
Steep areas (.30 %)		10	12
Permeability:			
Permeable (sand)	10	10	10
Semi-permeable (clayey sand)	90	80	85
Impermeable (clay/rock)		10	5
Vegetation:			
Grass land	80	50	80
No vegetation	20	50	20
URBAN:	(%)	(%)	(%)
Landuse classification:			
Lawns, parks	30	30	25
Residential areas	55	55	45
Centre			20
Suburban	10	5	
Streets	5	10	10

Compiled from Zöllner (1993); Grobler *et al.* (1993); Stone (1985); Van Wyk & Louw (1993) and official Town Council figures (1993).

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- Amount of rainfall (Rainfall depth): Sampling of drainage basin points was done only when these areas were in flow. No special provision was made to sample at various flow times because the sampling points always filled up rapidly as soon as surface flow was carried. The sample taken was then considered to contain whatever pollutants the drainage basin would have. A series of these grab samples should then give an indication of the general components of the pollution. During the period of study, rainfall depths of 21 mm, 25 mm and 30 mm caused strong surface flow from the basins (**Appendix A3**). Therefore, to implement the model of the Rational Method, run-off yield for the sub-catchments was calculated for each of the above-mentioned rainfall depths.

The calculation procedure of the Rational Method is described in table form in **Appendix C1**. The calculations of run-off for sub-catchments 5, 6 and 8 were done using this table and were set out in detail in **Appendix C2**.

3.1.3.3 Rainfall Measurement:

Observations of rainfall were made at the sewage treatment works which is reasonably central to the geographical area of Botshabelo. Precipitation was measured in a fill-up VETSAK rain meter. The rate of fill-up was recorded while nearby drainage basins and sections of the Klein Modder River were observed for flow. Rainfall measured during the sampling period is given in **Appendix A3**.

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3.2 POLLUTION INDICATORS

The following microbiological indicator organism groups were used in this study:

3.2.1 Faecal coliforms

For the purpose of this study the faecal coliform ranges in the South African Water Quality Guidelines target ranges for Recreational Purposes (Department of Water Affairs and Forestry, 1993:62,66) were used and are shown in **Tables 4a & 4b**. Intermediate contact with the water of the Klein Modder River by residents of the city is common practice (clothes washing) while full contact (swimming) by children is frequently noticed in summer. Swimming and other recreational water activities may in future increase due to a dam which was recently built downstream from the city.

Table 4a: Guideline for faecal coliforms to be used for intermediate contact recreation.

Faecal coliform range (counts/100 ml)	EFFECTS
Target guideline range	
0 - 1000	Negligible health effects are indicated for intermediate contact with recreational water. If water contact is extensive and if full body immersion is likely to occur, the more stringent guidelines proposed for full contact recreation may be more appropriate. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a period of three months. Preferably this three month period should coincide with seasons to allow detection of seasonal variation in water quality.
1000 - 4000	It may be expected that limited contact with water of this quality is associated with a slight risk of gastrointestinal illness. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a three month period.
> 4000	Intermediate recreational contact with water can be expected to carry an increasing risk of gastro-intestinal illness as faecal coliform levels increase.

(Department of Water Affairs and Forestry, 1993)

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Table 4b: Guideline for faecal coliforms to be used for full contact recreation (swimming).

Faecal coliform range (counts/100 ml)	EFFECTS
Target guideline range	
0 - 150	Negligible risk of gastro-intestinal effects is expected. It should, however, be noted that while the presence of faecal indicators indicates a possible risk to health, the absence of indicators does not guarantee the absence of risk. The postulated range should not be exceeded by the geometric mean or median count over a period of three months. Whenever possible, this three month period should coincide with seasons to allow detection of seasonal variation in water quality.
150 - 600	A slight risk of gastro-intestinal illness is indicated at faecal coliform levels which occasionally fall in this range. The risk increases if geometric mean or median levels are consistently in this range. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a three month period.
600 - 2000	Noticeable gastro-intestinal health effects may be expected in the population of swimmers and bathers. Some health risk exists if single samples fall in this range, particularly if such events occur frequently.
> 2000	As the faecal coliform level increases above this limit, the risk of contracting gastrointestinal illness as a result of full contact recreation increases. The volume of water which needs to be ingested in order to cause adverse effects decreases as the faecal coliform density increases.

3.2.2 Faecal streptococci

Although no recreational target guidelines for fresh water exist at present, faecal streptococci are commonly used by analysts because of these organisms' relative higher resilience compared to faecal coliforms and can, therefore, be used to indicate faecal pollution for longer periods than faecal coliforms (Guillemin *et al.*, 1991:923).

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3.2.3 Coliphages

South African Water Quality Guidelines target ranges for Recreational Purposes (Department of Water Affairs and Forestry, 1993:72) were used and are shown in **Table 5.**

Table 5: Guideline for somatic coliphages to be used for full contact recreation (swimming).

Coliphage range (counts/100 ml)	EFFECTS
Target guideline range	
0 - 20	Negligible risks of sewage pollution and of enteric virus infection are indicated. It should be noted that, as for all indicators, the absence of the indicator does not necessarily guarantee the absence of indicated pathogens. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a period of three months. Preferably this three month period should coincide with seasons to allow detection of seasonal variation in water quality.
20 - 100	A slight risk of sewage pollution and of virus infection is indicated. The risk is increased if geometric mean or median levels frequently fall in this range but is probably minimal if only isolated instances are recorded. This range should not be exceeded by the geometric mean or median of fortnightly samples collected over a three month period.
> 100	Significant sewage pollution and health risks may be expected if geometric mean or median coliphage levels commonly exceed this limit. Risks increase as occurrences of high coliphage levels increase in frequency and extent.

3.3 SAMPLING DATA

Data for this study were extracted from a sampling programme conducted by Jagals (1994). The data obtained were, however, processed differently due to the different nature of the present objective.

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3.3.1 Selection of sampling points

From the above-mentioned sampling programme, 7 sampling points were selected for this study. The sampling points were as follows **(Figure 3)**:

- **UB:** upstream of Botshabelo to rule out any possible pollution effects from the settlement.
- **C5:** outside riverbed which represented the drainage of sub-catchment 5 (mainly pit latrine sanitation).
- **C6:** outside riverbed which represented the drainage of sub-catchment 6 (mainly bucket latrines).
- **C8:** outside riverbed which would represent the drainage of sub-catchment 8 (mainly waterborne systems).
- **KM1:** in the Klein Modder River downstream of sub-catchments 5 and 6.
- **KM2:** in the Klein Modder River downstream of sub-catchment 8.
- **DB:** downstream of the city. A flow of approximately 4 ML/day of chlorinated final effluent from the city sewerage treatment works provides a continual flow in the river at this point.

3.3.2 Sampling and analysis

The procedures for the collection, transport and analysis of samples from which the data for this present study were abstracted, were reported in the study of Jagals (1994:36-38) as well as described by Clesceri *et al.* (1992:9.53-9.73), and SABS (1984:1-15).

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3.3.3 Frequency of sampling

The European Community recommends a minimum fortnightly sampling frequency for water investigated for biological pollution (Jagals, 1994:36). This sampling frequency is considered sufficient in South Africa to define seasonal and long-term trends (Department of Water Affairs and Forestry, 1993). Because of the erratic weather and flow pattern in the study area as well as for economic reasons, the Klein Modder River was monitored at least twice a month during periods of no flow to establish a present time baseline status. Rainy periods of flow within the fortnightly pattern was sampled in lieu of dry weather sampling to fit into the allowed program of time and travel (Jagals, 1994:36).

3.3.4 Processing of data

The processing of data included 1) the interpretation of the data to meet the objective of this study; 2) determining the format in which the interpreted data would be represented/reported to illustrate the effect of various levels of sanitation on surface run-off.

The data, extracted from the assessment programme conducted by Jagals (1994), were processed as follows:

The geometrical mean of the microbiological indicators used in the study were determined for each of the three sub-catchments for the total sampling period (**Appendix B**). The monthly averages of the geometric mean were determined and are represented in table form and as graphs in this document.

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The data for the sampling points in the Klein Modder River were extracted and compiled in table form (**Appendix B**). From this information the minimum, maximum and geometric mean of the microbiological indicator organisms in the river were determined for dry weather, rainfall without surface run-off and rainfall that caused surface run-off. This information is represented in table form as well as by means of graphs in this document.

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4. RESULTS, INCLUDING COMPARISON TO WATER QUALITY GUIDELINES FOR RECREATIONAL PURPOSES

4.1 WATER QUANTITY AND QUALITY IN DIFFERENT SUB-CATCHMENTS

4.1.1 Run-off yield

The Rational Method, as discussed in Chapter 2, was used in this study to determine the stormwater run-off yield from the different sub-catchments under investigation. Rainfall depths of 21 mm, 25 mm and 30 mm were selected to represent rainfall depths for surface run-off carrying pollutant loads (Chapter 3).

The calculations of the run-off (Q) for sub-catchments 5, 6 and 8 were done in tables and are detailed in **Appendix C2**. **Table 6** is a summary of run-off calculated for the different sub-catchments.

Table 6: Values of rainfall depth (mm) and run-off (m^3/s) for sub-catchments 5, 6 and 8.

Rainfall depth (mm)	**Sub-catchment 5** **Q** (m^3/s)	**Sub-catchment 6** **Q** (m^3/s)	**Sub-catchment 8** **Q** (m^3/s)
21	4.10	5.64	5.72
25	4.88	6.72	6.81
30	5.86	8.06	8.17

Sub-catchment 5 was the smallest of the three sub-catchments, resulting in a lower run-off than sub-catchments 6 and 8. **Table 6** indicates that the run-off yield from the various catchments are relatively similar. From a hydrological point of view, pollutant loads from the sub-catchments should therefore be similar.

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4.1.2 Run-off quality

The different sanitation levels of sub-catchments 5, 6 and 8 are shown in **Table 2** (Chapter 3). Sub-catchments 5 and 6 have mainly on-site sanitation, pit and bucket latrines, while sub-catchment 8 has mainly waterborne sanitation. **Table 7** compares the mean levels of microbiological indicator organisms in surface run-off in these three sub-catchments.

Table 7: Geometric mean levels of microbiological indicator organisms in surface run-off in three sub-catchments.

DATE	FAECAL COLIFORMS			FAECAL STREPTOCOCCI			COLIPHAGES		
	C5	C6	C8	C5	C6	C8	C5	C6	C8
NOV 92	75 150	332 767	24 630	8 027	30 060	7 332	22 815	40 920	16 180
DEC 92	30 000	88 818	10 900	28 000	47 328	2 479	2 300	5 527	1 018
JAN 93	470 000	1 700 000	513 333	123 333	966 667	286 667	63 300	40 500	31 600
FEB. 93	125 000	2 226 667	85 500	53 332	299 500	11 600	17 950	36 650	7 750
MAR 93	840 000	1 485 000	340 000	313 333	440 000	230 000	53 000	188 500	9 160
AUG 93	103 000	130 667	1 933	30 667	80 667	347	5 300	33 300	100
Geo. Mean	117 200	298 000	36 000	31 700	52 900	2 800	10 900	22 000	4 000

Geometric mean organism counts per 100 ml for 9 grab samples during rainfall on sub-catchments.

- **Sub-catchment 5:**

  The mean values for faecal coliforms exceeded the recommended maximum safety limits (**Tables 4a & 4b**) for the quality of water for intermediate and full contact recreational use. The levels for faecal coliforms were comparable with levels found in raw sewage (Jagals, 1994:150). Faecal streptococci densities resembled the values for raw domestic sewage reported by Geldreich (1976:349). The mean values for somatic coliphages also exceeded the maximum safety limits recommended for the quality of water for full contact recreational use (**Table 5**).

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- **Sub-catchment 6:**

  Counts of indicators at this sampling point were the highest of all the basin (sub-catchment) sampling points. The mean value of faecal coliforms and the majority of individual counts, exceeded the South African Water Quality Guidelines, recommended limits for the quality of water for intermediate and full contact recreational use.

- **Sub-catchments 8:**

  Counts of all indicators were lower at this point than at the other basin sampling points. The mean value for faecal coliforms exceeded the recommended limits for the quality of water for intermediate and full contact recreational use (Department of Water Affairs and Forestry, 1993:62,66; **Tables 4a** and **4b**). Somatic coliphage values exceeded the limits for somatic coliphages in the proposed water quality guidelines referred to above (**Table 5**).

The results are illustrated in **Figures 9, 10** and **11**.

4.2 QUALITY OF RECEIVING WATER BODY

In **Table 8** the geometric mean levels of microbiological indicators in the riverbed are shown. There were no changes during dry weather and soft rainfall that caused no surface run-off. When surface run-off from the catchments did occur during heavier spells of rainfall, a rise in the levels of microbiological indicators in the riverbed was detected.

The results are illustrated in **Figures 12, 13** and **14**.

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Table 8: **Mean levels of microbiological indicator organisms per 100 ml sampled in the Klein Modder River during dry weather, rainfall with no surface run-off, and rainfall that caused surface run-off.**

POINT IN RIVERBED	DRY WEATHER	RAINFALL WITH NO SURFACE RUN-OFF	RAINFALL WITH SURFACE RUN-OFF
FAECAL COLIFORMS			
UB	320	880	8 030
KM1	580	1 310	73 620
KM2	450	4 130	76 680
DB	700	2 480	112 810
FAECAL STREPTOCOCCI			
UB	130	400	8 600
KM1	210	410	15 510
KM2	230	400	29 310
DB	230	500	26 790
COLIPHAGES			
UB	200	320	7 400
KM1	340	300	9 500
KM2	530	820	11 650
DB	270	320	12 180

- **Dry weather**

  The mean faecal coliform values at all the sampling points in the riverbed did not exceed 500 organisms per 100 ml, although peaks of up to 5 000 were obtained at the sampling point downstream of the city. Geldreich (1976:368) found faecal coliform densities in natural riverwater in ranges from 2 to 1400 organisms per 100 ml. According to the data used for this study, mean values for faecal streptococci never exceeded 300 organisms per 100 ml during dry weather (**Table 8**). Geldreich (1976:368) found densities of up to 440 per 100 ml in recreational water in the United States. Somatic coliphages were present during dry weather in the Klein Modder River and at all sampling points exceeded the target South African Water Quality Guideline ranges used for risk-free recreational purposes (**Table 5**).

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- **Rainfall with no surface run-off**

  The mean faecal coliform values increased to log 10^3, except at the sampling point upstream from the city (**Table 8**). These mean values exceeded the permitted conditions issued by the Department of Water Affairs and Forestry (1993:67) for admitting effluent into public water, for instance local authorities. A condition in such a permit limits the numbers of faecal coliforms in final effluents to 1000 organisms per 100 ml. The mean faecal streptococci values for all the sampling points in the riverbed increased during light rainfall but failed to enter the next log phase of 10^3. Peaks of 4 500 per 100 ml were tested at the sampling point upstream of Botshabelo. The mean values for somatic coliphages in water at all points exceeded the target guideline ranges (Department of Water Affairs and Forestry, 1993:72) used for risk-free recreational purposes (**Table 5**).

- **Rainfall with surface run-off**

  During heavy rainfall, when surface flow from the catchments contributed to river flow, the mean values for faecal coliforms in the Klein Modder River increased to log 10^4, except at sampling point UB, upstream from Botshabelo (**Table 8**). The mean values for faecal coliforms at all points in the riverbed exceeded safe risk limits in the target guidelines (**Table 4b**) proposed by the Department of Water Affairs and Forestry (1993:62) for the quality of water used for full contact recreation. These values also far exceeded the target guidelines for potable water proposed by the same department. The mean values for faecal streptococci also increased to log 10^4 at all sampling points during surface run-off, except at sampling point UB upstream from the city. The mean values for somatic coliphages in water at all points exceeded the target guideline ranges (Department of Water Affairs and Forestry, 1993:72) used for risk-free recreational purposes (**Table 5**).

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During heavy rainfall, surface flow from the catchments contributed to river flow. The mean, minimum and maximum levels of microbiological indicator organisms per 100 ml sampled in the Klein Modder River and sub-catchments 5, 6 and 8 during heavy rainfall are shown in **Table 9**.

Table 9: Geometric means and ranges of microbiological indicator organisms per 100 ml sampled in the Klein Modder River and sub-catchments 5, 6 and 8 during heavy rainfall.

SAMP. POINT INDICATOR	UB (River bed)	C5 (Catchment)	C6 (Catchment)	KM1 (River bed)	C8 (Catchment)	KM2 (River bed)	DB (River bed)
FC/100 ml	8 050 (870-51 300)	117 200 (15 300-840 000)	298 000 (15 300-4 400 000)	73 600 (26 000-540 000)	36 000 (1 900-510 000)	76 700 (21 000-730 000)	112 800 (31 000-840 000)
FS/100 ml	8 600 (3 300 - 26 300)	31 700 (753 - 310 000)	52 800 (1 080-970 000)	15 500 (1 200 - 65 300)	2 800 (350 - 290 000)	29 300 (2 300-413 300)	26 800 (6 200 - 59 000)
SC/100 ml	7 400 (6 100 - 9 000)	10 900 (910 - 63 000)	22 000 (2 660-189 000)	9 500 (4 800 - 18 600)	4 000 (100 - 31 600)	11 650 (3 100 - 44 000)	12 200 (3 800 - 39 000)

- **Faecal coliforms**

  The lowest mean value for faecal coliforms (8 050 per 100 ml) was obtained at sampling point UB. Following points in the Klein Modder River yielded far higher mean values, with peaks of 840 000 per 100 ml at sampling point DB (**Table 9**), resembling values tested for many raw sewage samples (Grabow *et al.*,1993:147). In the same study mean faecal coliform values of 44 200 per 100 ml with peak values of 210 000 per 100 ml were tested.

  Peak values for faecal coliforms of up to 4 400 000 per 100 ml were obtained from samples taken from the drainage basin (Sub-catchment 6) during stormflow (**Table 9**). This corresponds with reports by Geldreich (1976:367), who found faecal coliform densities of up to 350 000 per 100 ml in street gutters during flow following stormy weather. Densities in raw

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sewage tested by Geldreich ranged from 340 000 to 49 000 000 organisms per 100 ml.

- **Faecal streptococci**

  Faecal streptococci had a highest mean value of 29 300 organisms per 100 ml with a highest peak value of 413 300 organisms per 100 ml both at sampling point KM2 in the Klein Modder River (**Table 9**). Grabow *et al.* (1993:147) tested a mean faecal streptococci value of 10 300 per 100 ml with peak values of 57 000 per 100 ml in riverwater 500 m downstream from a discharging point for purified sewage effluent.

  Peak values for faecal streptococci of up to 970 000 per 100 ml were obtained from samples taken from the drainage basin at sub-catchment 6 during stormflow (**Table 9**). Geldreich (1976:368) found faecal streptococci in ranges of 64 000 to 4 500 000 organisms in raw waste water.

- **Somatic coliphages**

  The mean values for somatic coliphages in water at all sampling points exceeded the target guideline ranges (Department of Water Affairs and Forestry, 1993:72) used for risk-free recreational purposes (**Table 5**). Somatic coliphages peaked at 189 000 plaque forming units per 100 ml at sampling point C6 (**Table 9**).

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5. DISCUSSION

5.1 POLLUTANT LOADS

5.1.1 Levels of sanitation

The comparison of the three sub-catchments in relation to microbiological pollution indicated that the magnitude of contamination appears to depend more on the degree of infrastructure provided (various levels of sanitation) than land use changes. Because unequal run-off results in unequal pollutant loads (Chapter 2), the assumption can be made that equal run-off could result in equal pollutant loads. The wide discrepancy in the pollutant load values (**Table 7**) for the different sub-catchments, in spite of similar run-off values, indicates that the pollutant load vary due to other factors than the variation in run-off. Sub-catchment 6, which consists mainly of houses serviced by means of **bucket latrines**, was the heaviest polluted catchment. The mean value of faecal coliforms exceeded recommended limits for the quality of water for intermediate and full contact recreational use at all basin sampling points - the highest being tested at sampling point C6. Faecal streptococci densities, at all basin sampling points, resembled the values for raw domestic sewage reported by Geldreich (1976:368). Again, the mean value for streptococci was the highest at sampling point C6. While the mean values for somatic coliphages also exceeded the recommended limits for the quality of water for full contact recreational use (**Table 5**) at all sampling points, the highest counts (riverbed and basins) were tested at sampling point C6.

Reasons for this high level of microbiological pollution in sub-catchment 6 may be the following:

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The bucket system was introduced as an emergency measure to cope with land invasions and with the inhibitive cost of blasting pits in the rock in some areas. Buckets were to be collected twice per week and emptied at specially constructed vehicle-discharging points on existing sewer lines as a service arrangement in the area. However, the bucket system often failed during the time of the study conducted by Jagals (1994) due to industrial strike action or equipment failure. This resulted in very high levels of faecal pollution entering the Klein Modder River especially during rainfall events. The reason for this is the common occurrence during the periods of civil unrest of burying the contents from full buckets in shallow furrows. During periods of rainfall these contents were flushed out and overflowed into the river system. A two-week strike by sanitation workers on the bucket system during January 1993, is probably the main reason for the sharp increase in microbiological indicator organism levels (**Table 7**).

During the decade of its operation, the system has also been constantly hampered by a host of other difficulties:

- A shortage of equipment, notable trucks with vacuum tanker facilities.
- A shortage of personnel, particularly drivers.
- Problems with operation at the central bucket washing facility.

(Zöllner, 1993:24)

Possible institutionalised pollution could be taking place, possibly by municipal night soil removers indiscriminately dumping vacuum tanker contents in portions of the river in order to shorten their trips to the vehicle-discharging points (Jagals, 1994:137).

Even though the level of pollution in sub-catchment 5 (serviced by pit latrines) is lower than in sub-catchment 6, the microbiological indicator levels often

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approached the levels found in raw sewage (Jagals, 1994:149). Grobler *et al.* (1987:29) estimated that 90 % of the contents of pit latrines remains either in the pit or in its vicinity due to low soil permeability. Due to the presence of bedrock substrata, pit latrines in the area are dug very shallowly and essentially have to function as septic tanks. This implies that the overfilled pits have to be emptied on a regular basis (Zöllner, 1993:25). The local administration did not have sufficient personnel and equipment to cope with the number of requests for emptying the full latrines (Zöllner, 1993:25). In the low-lying areas stormwater entered pits and overflowed onto the flood plain areas and into the Klein Modder River.

The low permeability to water movement due to the high clay contents of the soils, as mentioned in Chapter 3, suggests that in the short term the pit latrines do not pose a significant eutrophication or groundwater pollution hazard (Grobler *et al.*, 1987:44), although Jagals (1994:137) suggested that the continual presence of faecal pollution in seeping water during the dry season may be leaching from pit latrines.

Although still significantly high, the lower level of pollution from the higher income area (sub-catchment 8) serviced mainly by **waterborne systems** is evident.

During a survey done by Grobler *et al.* (1987:18-20) - the majority of respondents who did not have any form of sanitation (mainly influxing squatters) indicated that they use open areas for daily latrine purposes. In general, the survey indicated that 44 % of the respondents had children under the age of 5 years. However, despite the fact that most of the respondents who had been living in Botshabelo for a considerable period of time have some form of sanitation, all but one of the respondents indicated that their children under 5 years of age, defecated directly on the ground. This is mainly due to cultural and other behaviour towards "modern-day" sanitation. The lower level

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of pollution found in sub-catchment 8 also confirms the general view that waterborne sewerage systems are more suitable from an environmental and services perspective.

5.1.2 First flush effect

One of the drawbacks of this study was the inability to establish any initial flushing of pollutant loads due to the fact that flow measurement was not monitored.

The period of study fell in a time during which South Africa experienced one of the most serious droughts ever. The period for sampling was one full year, to be able to have all four seasons represented and to have ample rainy spells to monitor surface run-off. Even so, more dry weather samples were generally taken due to an exceptionally dry summer, and additional sampling had to be done whenever it rained enough to create surface run-off.

It is generally assumed that contaminants accumulate in the ground during dry periods (Guillemin *et al.*, 1991:923; Simpson, 1986:122). Ellis *et al.* (1986:590) claims that 30 to 60 % of the total pollutant load may be expected to be discharged by 30 % of the water volume. In the study by Wimberley (1992:23) most of the run-off events were characterised by both a first flush effect and a reduced dilution effect for the constituents analysed. However, the contaminants referred to in the above-mentioned studies are predominantly biochemical by nature. Jagals (1994:135) indicated that pathogenic enteric micro-organisms have a limited lifespan outside the human gut, especially in adverse circumstances such as high temperatures, and intense sunlight. Therefore micro-organism species such as those which were used in the 1994 study, do not indicate accumulated pollution.

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However, exceptionally high pollutant loads were recorded from surface flow at the basin sample points in the present study. This may possibly indicate the magnitude of daily fresh deposition of faecal material in the areas with limited sanitation. In the area with waterborne sanitation, leaking sewers - observed especially during rainfall events - may contribute to the presence of these indicator organisms. In the absence of constant flow monitoring during rainfall, as well as the die-off profile of the standard indicator organisms, the first flush phenomenon could not be investigated during this study - or the study of Jagals (1994). Further investigation into the first flush effect of pollutant loads from the sub-catchments will, however, be required to confirm this statement.

5.1.3 Reduction of pollutant loads

The pollution load originating from Botshabelo is essentially the result of over-population of the area and the use of inadequate sewage disposal systems by a large percentage of the population. The problem is therefore social and political as well as engineering by nature. Intervention can only be effective if a combination of both social and engineering measures are implemented.

An engineering solution to the pollution problem is to reduce the possibility of faecal deposition on land and the consequent discharge of faecal pollutants into the stormwater system. This would involve extending and upgrading of the waterborne sanitation system to incorporate the areas of informal settlement. As this involves much time and costs, it can only be regarded as a long-term solution. As a short-term solution, upgrading of the present facilities to provide, inter alia, bigger capacities for vacuum tankers and more regular uninterrupted service runs, is essential.

As a social solution, health education remains a priority. It should be aimed at the application of simple hygiene in individual and family life, with greater

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responsibility of the community in maintaining the cleanliness of surface areas. Young children should be enabled to use the available facilities. Sanitary education courses, as part of a primary health care programme, are essential elements in eliminating pollution risk factors.

5.2 IMPACT OF POLLUTED RUN-OFF ON RECEIVING WATER BODY

All surface run-off inevitably ends in a receiving water body such as a river or lake and eventually the ocean (**Figure 4a**). Under natural conditions these water bodies are, in the long term, able to absorb the fluctuations in run-off volumes and quality i.e. a natural balance is maintained. Human activities, however, are inclined to amplify the fluctuations and place unrealistic demands on a receiving water body's assimilation capacity. The effect of stormwater run-off on receiving water can either be a short-term shockload impact or a long-term accumulation impact (Wright *et al.*, 1993:43).

An immediate effect of stormwater run-off is microbiological pollution which may pose a health risk and restrict water resource use, recreational use and fishing use of the receiving water (Wright *et al.*, 1993:25). Pollutants that have a long-term impact can cause depletion of the oxygen supply or they can become available through resuspension, resulting in the disruption of the ecosystem.

In **Table 7** the mean levels of microbiological indicators in the Klein Modder River are shown. There are no remarkable changes during dry weather and rainfall that causes no surface run-off. When surface run-off from the catchments does occur during heavier spells of rainfall, there is a significant rise in the levels of microbiological indicators in the riverbed. These contributions evidently originate from the Botshabelo catchments.

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The mean faecal coliform values at all the sampling points in the Klein Modder River did not exceed 500 organisms per 100 ml during dry weather. The mean values increased to log 10^3, except at the sampling point upstream from the city during light showers. During heavy rainfall, when surface flow from the catchments contributed to riverflow, the mean values for faecal coliforms in the Klein Modder River increased to log 10^4, except at sampling point UB, upstream from Botshabelo. The mean values for faecal coliforms during heavy rainfall at all sampling points exceeded safe risk limits given in the target guidelines (**Table 4b**) proposed by the Department of Water Affairs and Forestry (1993:62) for the quality of water used for full contact recreation. These values also far exceeded the target guidelines for potable water proposed by the same Department.

Mean values for faecal streptococci never exceeded 300 organisms per 100 ml during dry weather. The values increased during light showers, but failed to enter the next log phase of 10^3. During heavy rainfall the mean values for faecal streptococci increased to log 10^4 at all sampling points, except at sampling point UB, upstream from the city.

The values for faecal coliforms and faecal streptococci clearly indicate faecal pollution of the Klein Modder River. It is evident that the densities of both faecal coliforms and faecal streptococci rapidly increased after heavy rainfall, that caused run-off, thus suggesting that these contributions originated from the city of Botshabelo. The lower mean values at sampling point UB, taken upstream from the city to rule out any possible pollution effects from the city, confirmed this view. According to Jagals (1994:151), the microbiological pollution found at this sampling point (UB) can be contributed to faecal pollution predominantly of animal origin.

The mean values for somatic coliphages in water at all points exceeded the target guideline ranges used for risk-free recreational purposes (**Table 5**) during

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all weather conditions, but increased from log 10^2 to log 10^4 after heavy rainfall causing run-off (**Table 8**). As discussed in section 4.1.3, coliphages are generally detected in large numbers in sewage polluted water. As no waterborne sewerage system exists in the greater part of Botshabelo, pollution is generally from faeces deposited on land.

Water in the Klein Modder River generally exceeded the limits recommended by South African guidelines for faecal pollution in water used for recreational or drinking purposes (Department of Water Affairs and Forestry, 1993:67). This implies that the river generally constituted a risk of infection to people, primarily children, who used the water for domestic purposes, including bathing.

The results of this study corroborate the findings reported by previous investigators and demonstrate the existence of potential health hazards in stormwater discharges. The results also show the seriousness of urban stormwater run-off as a major factor in non-point source pollution of receiving waters.

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6. COMPARISON WITH PREVIOUS STUDIES

Several urban stormwater studies undertaken in South Africa have investigated urban run-off pollution (Chapter 2). Unfortunately no standard set of water quality variables have been measured in these studies. Furthermore, pollution loads and their impacts are often site-specific and it is therefore difficult to compare the quality and loads from different catchments. Variability in geological strata, climate and nature of urban development all caused variance in stormwater quality measured in these studies.

Descriptions of those studies conducted in South Africa which have investigated microbiological pollution, are given below. The characteristics of the catchments used in the studies have been summarised to provide a background for comparison purposes.

6.1 DEMOGRAPHIC DETAILS

- **Three Anchor Bay and Mitchell's Plain** (Kloppers, 1989).

  The catchment of Three Anchor Bay is 152 ha with an average population density of 56 persons / ha. The area is in the winter rainfall region and the mean annual rainfall is 518 mm. An established residential area of medium population density and high traffic loadings cover the catchment. Stormwater from the catchment is drained by a reticulation system which is separate from the sewer system, and is discharged into Table Bay.

  The catchment of Mitchell's Plain is 1375 ha and the estimated population density of the area is 59 persons / ha. The mean annual rainfall of the area is 616 mm of which 80 % falls in winter. The area is zoned as residential and comprises almost entirely of low-lying houses. Impervious areas

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constitute 46 % of the total catchment. The catchment is drained by a separate stormwater system and run-off is discharged directly into False Bay.

- **Motherwell** (Lord and Mackay, 1991)

  The Motherwell catchment forms part of the Swartkops Estuary. The estuary is about 14 km long with wide supratidal and intertidal flats. Motherwell is a new high-density residential development. The Motherwell canal carries stormwater from Motherwell directly to the estuary. Included in this report are the results from sampling programmes done from August to October 1988 and from September 1989 to December 1990.

- **Khayelitsha** (Wright *et al.*, 1993)

  Khayelitsha is a high-density settlement on the northern shores of False Bay and by 1990 had an "official" population of 320 000. The area is in the winter rainfall region and on average 97 rain days are experienced per annum, with an annual average of 508 mm. The catchment is of an entirely residential nature and contains organised squatter housing with minimal services, serviced sites and formal housing. Most of Khayelitsha has waterborne sanitation. The catchment may be divided into a number of sub-catchments with a dual stormwater drainage system down the centre of the catchment.

- **Botshabelo**

  The city of Botshabelo covers an area of approximately 12 400 ha with a total population of 222 800. The area is in the summer rainfall region and the mean annual rainfall is 600 mm. Sub-economical and various forms of informal housing structures are dominant in the catchment. The sanitation of the catchment consists mainly of pit latrines and bucket latrines.

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Waterborne systems comprise about 4 % of sewage collection and disposal in the city.

6.2 COMPARATIVE DISCUSSION

The Botshabelo study differed from most other South African studies in that the main emphasis was on the quality of stormwater run-off from sub-catchments with various types of sanitation levels. Sampling was not only restricted to the total stormwater run-off leaving the catchment. Several sampling points in the Klein Modder River, as well as outside the riverbed, were included to determine the impact of the run-off from the different sub-catchments on the receiving water body.

Most of the other studies investigated a number of water quality variables, while the Botshabelo study investigated only the microbiological quality of stormwater run-off. Where the other studies experienced mainly winter rainfall, this study was conducted in the summer rainfall zone (mainly convectional rainfall).

Table 10 is a summary of the microbiological stormwater quality in the different areas as compared to Botshabelo. **Figure 8** shows the site location of the other South African studies.

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The results of three of the studies (Khayelitsha, Mitchell's Plain and Motherwell) are relatively similar. However, the stormwater run-off from Three Anchor Bay yielded faecal coliform counts of 260 000 per 100 ml (**Table 10**) and in the Klein Modder River downstream from Botshabelo the value was more than 840 000 per 100 ml (maximum level). As Three Anchor Bay is a

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highly developed urban catchment, it was expected to have less faecal contamination. The reason for the pollution was probably due to a high percentage of impervious cover in the catchment and a consequential large build-up of pollutants on the catchment surface. Most of these pollutants will be washed from the catchment surface during storm run-off events and be transported through the stormwater drainage system to the receiving water course.

Stormwater run-off from the Mitchell's Plain catchment was monitored during both dry and wet weather conditions. Samples of baseflow were taken monthly and analysed in the same way as samples from Three Anchor Bay. Unfortunately only one run-off event from Mitchell's Plain was sampled. However, the Mithell's Plain catchment is similar to Khayelitsha even though Mitchell's Plain was at a further stage of development than Khayelitsha (a higher population density and relatively more impervious areas). Both catchments consisted of a high percentage of pervious surfaces and thus a lack of overland flow. The catchments form part of the extensive Cape Flats Plain comprising geological recent sand cover that results in high soil infiltration. The topography of the area also contributes to high soil infiltration, being generally flat with vegetated sand dunes. Due to the lack of overland flow and high soil infiltration, many pollutants can be filtered out in the sands. The sandy nature of the area thus ensures that not all of the pollution finds its way into the final stormwater run-off, giving a fairly uniform poor quality run-off throughout the year (irrespective of whether it is a baseflow or stormflow condition).

Water samples from the Motherwell catchment were collected on 22 days between 9 August and 20 October 1988. The results showed that soon after the commencement of development in Motherwell, a continual flow of polluted

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run-off was reaching the Swartkops estuary. The run-off showed high levels of faecal bacteria and was nutrient-enriched. Viruses had also been positively identified as present in the run-off. The data from the 1989 to 1990 sampling programme showed clear differences between run-off quality in wet and dry weather. In most cases, the dry weather flow exceeded the General Effluent Standard in all determinants, while the wet weather flow quality was usually acceptable in terms of this standard. Dry weather flow could be traced back to blockages of the sewerage system, often due to vandalism. Much refuse and litter were dumped in the canal and this added to pollutant loads. The results from Motherwell are similar to the formal housing of Khayelitsha and suggest a certain degree of uniformity within the coastal zone.

Table 10: Comparison of mean microbiological indicator organism levels in stormwater from Botshabelo and other South African sites.

Determinant	Botshabelo (max levels)	Khayelitsha	Mitchell's plain	Three Anchor Bay	Motherwell
Faecal coliforms per 100 ml	112 800 (840 000)	34 000	41 000	260 000	54 000
Faecal streptococci per 100 ml	26 800 (59 000)	6 100	2 500	23 000	37 000
Coliphages as pfu's per 100 ml	12 200 (39 000)	20 000	1 300	2 000	4 000

Mean, as well as maximum levels of microbiological indicators, per 100 ml, from the Botshabelo catchment were tested at sampling point DB downstream of the city.

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7. CONCLUSIONS AND RECOMMENDATIONS

The main objective of the study was to assess the effect of various levels of sanitation installed in the city of Botshabelo on surface water quality and its impact on the receiving water, namely the Klein Modder River. The city of Botshabelo contains all the features typical of urbanisation taking place in South Africa. The discrepancy between various types of development within the same city borders is evident and not conducive to a sound environmental engineering ethic.

Conclusions drawn from the study:

- Surface run-off originating in the urban catchment is polluted throughout the year, especially after storm events.
- Stormwater run-off from Botshabelo yielded faecal coliform counts of more than 4 000 000 per 100 ml in the drainage basins and more than 840 000 per 100 ml in the Klein Modder River, which is equivalent to that of many raw sewage effluents.
- The microbiological quality of water in the Klein Modder River generally exceeded the safety limits recommended by the South African Water Quality Guidelines for water used for recreational or drinking purposes. This implies that the river constituted a risk of infection to people who used the water for domestic purposes, including bathing.
- The high population density, poor living conditions and a general lack of environmental awareness ensure ongoing pollution far in excess of that experienced in more developed type of urban catchments.
- In areas of formal housing with waterborne systems, the pollutant loads are greatly reduced. The lower level of pollution confirms the general view that waterborne sewerage systems are more suitable from an environmental and services perspective.

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- In areas that consist mainly of houses serviced by means of bucket latrines, the pollution was the heaviest. Very high levels of faecal pollution occurred in the Klein Modder River during rainfall events, especially if the bucket system fails due to industrial strike action or equipment failure.
- Even though the level of pollution in the areas serviced by pit latrines is lower than in areas serviced by means of bucket latrines, the microbiological indicator levels often approached the levels found in raw sewage.

The foregoing conclusions reflect achievement of the original objectives of the study. The effect of various levels of sanitation on the quality of urban stormwater run-off is evident from the results. The relationship between the quality of such run-off and receiving water quality, as well as the level of contamination by such run-off, has been clearly established.

Though fundamental justification for improved infrastructure and levels of sanitation has been provided in this study, a great responsibility still lies with the consumer to eliminate some of the risk factors through health education.

The developing type of urbanisation, with its informal housing and sanitation systems, is very much part of South Africa and will continue to play a role in this country for many years to come. It is thus necessary for continued research in these catchments, as engineering solutions from developed catchments are not always applicable to developing urban areas. Future research may include:

- A protection policy for the management of receiving water bodies of polluted surface run-off.
- Groundwater contamination as a result of the developing type of urbanisation, especially where poor geological conditions for pit latrines occur.

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APPENDICES

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APPENDIX A1

RAINFALL DATA: THABA NCHU MUNICIPALITY

EXPLANATION OF HEADINGS

Ave	Average rainfall for the month
St Dev	Standard deviation from the normal s = SQRT (SUM(X*X)/n - (AVE(x)*AVE(x)))
N Day	Average number of rain days per month
Num Mon	Number of months used in calculation
Max R Day	Maximum rainfall that occurred over a 24-hour period (08:00 - 08:00)
Max R Date	Date maximum rainfall occurred
1.0 - 900.0	Average number of raindays in range inclusive

DATA USED FOR AVERAGE CALCULATIONS ARE NOT USED IF:

1. There are more than five consecutive days of accumulation.
2. If data for certain days in the month are unavailable.
3. If the accumulation period occurred at the end of the month.

DATA USED FOR FREQUENCY CALCULATIONS ARE NOT USED IF:

1. Accumulation occurred in the month.
2. If data for certain days in the month are unavailable.

THABA NHCU - MUN. **climn 0262613 O** **LAT:2913**
1923 - 1995 **HEIGHT: 1524 m** **LON: 2651**

Mon	Ave	St Dev	N Day	Num Mon	1.0 5.0	5.1 10.0	10.1 20.0	20.1 50.0	50.1 100.0	100.1 900.0	Max R Day	Max R Date
Jan	87.6	59.4	7.3	66	2.1	1.9	1.7	1.1	0.2	0.0	77.5	66/01/20
Feb	92.8	61.2	7.5	63	2.4	1.9	1.8	0.9	0.2	0.0	83.0	77/02/05
Mrc	87.0	54.3	6.8	66	2.1	1.5	1.5	1.4	0.1	0.0	95.3	48/03/12
Apr	60.1	45.7	4.8	67	1.5	1.2	1.2	0.8	0.1	0.0	67.0	82/04/10
May	22.1	22.9	2.6	67	1.1	0.6	0.6	0.2	0.0	0.0	60.2	43/05/13
Jun	11.3	15.9	1.3	69	0.7	0.3	0.3	0.1	0.0	0.0	47.0	61/06/03
Jul	9.8	15.2	1.0	68	0.4	0.3	0.3	0.0	0.0	0.0	34.0	65/07/17
Aug	10.8	17.7	1.2	69	0.4	0.3	0.2	0.1	0.0	0.0	34.3	39/08/15
Sep	20.5	34.5	1.7	70	0.7	0.4	0.4	0.2	0.0	0.0	50.5	77/09/25
Oct	53.4	41.0	4.4	68	1.4	1.1	1.0	0.6	0.1	0.0	84.0	93/10/03
Nov	78.3	53.1	6.2	67	1.9	1.4	1.6	1.1	0.1	0.0	70.0	64/11/04
Dec	70.1	39.5	5.6	64	1.5	1.4	1.6	1.0	0.0	0.0	87.0	58/12/28
YR	**603.8**		**50.4**		**16.1**	**12.2**	**12.3**	**7.5**	**0.9**	**0.0**		

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APPENDIX A2

RAINFALL DATA: BOTSHABELO

EXPLANATION OF HEADINGS

Ave	Average rainfall for the month
St Dev	Standard deviation from the normal s = SQRT (SUM(X*X)/n - (AVE(x)*AVE(x)))
N Day	Average number of rain days per month
Num Mon	Number of months used in calculation
Max R Day	Maximum rainfall that occurred over a 24-hour period (08:00 - 08:00)
Max R Date	Date maximum rainfall occurred
1.0 - 900.0	Average number of raindays in range inclusive

DATA USED FOR AVERAGE CALCULATIONS ARE NOT USED IF:

1. There are more than five consecutive days of accumulation.
2. If data for certain days in the month are unavailable.
3. If the accumulation period occurred at the end of the month.

DATA USED FOR FREQUENCY CALCULATIONS ARE NOT USED IF:

1. Accumulation occurred in the month.
2. If data for certain days in the month are unavailable.

BOTSHABELO **climn 0264022 X** **LAT:2922**
1936 - 1989 **HEIGHT: 1646 m** **LON: 2731**

Mon	Ave	St Dev	N Day	Num Mon	1.0 5.0	5.1 10.0	10.1 20.0	20.1 50.0	50.1 100.0	100.1 900.0	Max R Day	Max R Date
Jan	121.7	69.3	11.0	51	3.9	2.1	2.0	1.7	0.1	0.0	149.4	42/01/16
Feb	110.8	60.1	11.1	50	4.1	2.2	2.1	1.4	0.2	0.0	87.5	55/02/09
Mrc	100.4	59.9	10.2	51	3.6	2.1	1.7	1.3	0.2	0.0	84.3	46/03/21
Apr	72.9	52.3	7.6	50	2.6	1.5	1.4	1.0	0.1	0.0	77.5	48/04/14
May	34.7	31.8	4.6	51	2.1	0.9	0.7	0.4	0.0	0.0	49.5	68/05/17
Jun	12.5	15.4	2.0	48	0.7	0.4	0.3	0.1	0.0	0.0	38.5	61/06/04
Jul	15.5	20.8	2.3	49	0.9	0.5	0.3	0.2	0.0	0.0	36.1	43/07/04
Aug	21.3	30.0	2.4	51	0.7	0.5	0.5	0.3	0.0	0.0	36.0	87/08/15
Sep	31.5	35.5	4.0	49	1.5	0.8	0.7	0.3	0.1	0.0	57.7	43/09/01
Oct	77.5	51.8	7.6	50	2.3	1.4	1.8	0.9	0.1	0.0	92.2	43/10/12
Nov	99.3	55.0	9.3	52	3.2	1.7	1.8	1.4	0.1	0.0	64.3	40/11/08
Dec	104.0	56.9	9.6	51	3.1	2.0	2.2	1.2	0.2	0.0	132.5	61/12/17
YR	**801.9**		**82.7**		**28.8**	**16.0**	**15.5**	**10.3**	**1.0**	**0.0**		

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APPENDIX A3

RAINFALL DATA: SAMPLING PERIOD

SAMPLING DATE	DAILY RAINFALL (mm)	SURFACE RUN-OFF
17/08/92	10	None
01/09/92	15	None
13/10/92	18	None
02/11/92	18	Reasonable flow
10/11/92	55	Strong flow
23/11/92	8	None
14/12/92	16	None
28/12/92	17	Slight
12/02/93	25	Srong flow
22/01/93	30	Strong flow
07/02/93 - 22/02/93	70.7	Strong flow (22/02/93)
01/03/93	10	Slight flow
04/03/93	25	Strong flow
08/03/93	18	Slight flow
16/03/93	10	None
30/03/93	10	None
13/04/93	9	Slight flow
27/04/93	2	None
11/08/93	21	Strong flow

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APPENDIX B

BOTSHABELO STORMWATER QUALITY

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Sub-catchments 5,6 and 8

MICROBIOLOGICAL INDICATOR ORGANISM: Faecal coliforms

FC	**C5**		**C6**		**C8**	
DATE		LOG		LOG		LOG
01/11/92	135000	5.13	130000	5.114	45300	4.656
10/11/92	23000		853000	5.931	33000	
23/11/92	15300	4.185	15300	4.183	3960	3.598
14/12/92	30000	4.477	88818	4.949	10900	4.038
22/01/93	470000	5.672	1700000	6.23	513333	5.710
02/02/93	86667	4.938	86667	4.938	31000	4.491
12/02/93	163333	5.213	4366667	6.640	140000	5.146
04/03/93	840000	5.924	1485000	6.172	340000	5.531
11/08/93	103000	5.013	130667	5.116	1933	3.286
GMEAN	**117200**	**5.069**	**298000**	**5.474**	**36000**	**4.556**

MICROBIOLOGICAL INDICATOR ORGANISM: Faecal streptococci

FS	**C5**		**C6**		**C8**	
DATE		LOG		LOG		LOG
01/11/92	15 300	4.185	9 100	3.959	14 300	4.155
10/11/92	22000		80000	4.903	44000	
23/11/92	753	2.877	1080	3.033	363	2.56
14/12/92	28000	4.447	47328	4.675	2479	3.394
22/01/93	123333	5.091	966667	5.985	286667	5.457
02/02/93	40333	4.606	45667	4.66	11600	4.064
12/02/93	66330	4.822	553333	5.743	180000	
04/03/93	313333	5.496	440000	4.643	230000	5.362
11/08/93	30667	4.487	80667	4.907	347	2.54
GMEAN	**31700**	**4.501**	**52900**	**4.723**	**2800**	**3.442**

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Sub-catchments 5,6 and 8

MICROBIOLOGICAL INDICATOR ORGANISM: Somatic coliphages

SC	**C5**		**C6**		**C8**	
DATE		LOG		LOG		LOG
01/11/92	42 000	4.623	29 300	4.467	31 000	4.491
10/11/92	1600		8960	3.952	5900	
23/11/92	3630	3.56	2660	3.425	1360	3.134
14/12/92	2300	3.362	5527	3.743	1018	3.008
22/01/93	63300	4.801	40500	4.607	31600	4.5
02/02/93	900	2.954	51000	4.708	4500	3.653
12/02/93	35000	4.544	22300	4.348	11000	4.041
04/03/93	53000	4.724	188500	5.275	9160	3.962
11/08/93	5300	3.724	33300	4.522	100	2
GMEAN	**10900**	**4.037**	**22000**	**4.343**	**4000**	**3.599**

MONTHLY AVERAGES: Microbiological indicator organisms in sub-catchments 5, 6 and 8

	FAECAL COLIFORMS			**FAECAL STREPTOCOCCI**			**COLIPHAGES**		
DATE	**C5**	**C6**	**C8**	**C5**	**C6**	**C8**	**C5**	**C6**	**C8**
01/11/92	135000	130000	45300	15 300	9 100	14 300	42 000	29 300	31 000
10/11/92	23000	853000	33000	22000	80000	44000	1600	8960	5900
23/11/92	15300	15300	3960	753	1080	363	3630	2660	1360
NOV92	**75150**	**332767**	**24630**	**8027**	**30060**	**7332**	**22815**	**40920**	**16180**
14/12/92	30000	88818	10900	28000	47328	2479	2300	5527	1018
DEC92	**30000**	**88818**	**10900**	**28000**	**47328**	**2479**	**2300**	**5527**	**1018**
22/01/93	470000	1700000	513333	123333	966667	286667	63300	40500	31600
JAN93	**470000**	**1700000**	**513333**	**123333**	**966667**	**286667**	**63300**	**40500**	**31600**
02/02/93	86667	86667	31000	40333	45667	11600	900	51000	4500
12/02/93	163333	4366667	140000	66330	553333	180000	35000	22300	11000
FEB93	**125000**	**2226667**	**85500**	**53332**	**299500**	**11600**	**17950**	**36650**	**7750**
04/03/93	840000	1485000	340000	313333	440000	230000	53000	188500	9160
MRC93	**840000**	**1485000**	**340000**	**313333**	**440000**	**230000**	**53000**	**188500**	**9160**
11/08/93	103000	130667	1933	30667	80667	347	5300	33300	100
AUG93	**103000**	**130667**	**1933**	**30667**	**80667**	**347**	**5300**	**33300**	**100**
GMEAN	**117200**	**298000**	**36000**	**31700**	**52900**	**2800**	**10900**	**22000**	**4000**

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Klein Modder River: UB, KM1, KM2 and DB

MICROBIOLOGICAL INDICATOR ORGANISM: Faecal coliforms

FC	**UB**		**KM1**		**KM2**		**DB**	
DATE	VALUE	LOG	VALUE	LOG	VALUE	LOG	VALUE	LOG
17/08/92			10	1			350	2.544
24/08/92			14	1.146			1460	3.164
01/09/92			730	2.863			5800	3.763
14/09/92			1275	3.106			562	2.75
22/09/92							23	1.362
28/09/92			226	2.354			2200	3.342
06/10/92			126	2.1			630	2.799
13/10/92	450	2.653	2430	3.386	3660	3.563	2800	3.447
27/10/92	117	2.068	380	2.58	109	2.037	166	2.22
02/11/92	4700	3.672	6560	3.817	4331	3.637	263	2.42
10/11/92	10500	4.021	26000	4.415	29600	4.471	55300	4.743
16/11/92	1560	3.193	4130	3.616	636	2.803	3200	3.505
23/11/92	613	2.787	1400	3.146	6230	3.794	3700	3.568
07/12/92	930	2.968	290	2.462	266	2.425	593	2.773
14/12/92	8850	3.947	3055	3.485	10500	4.021	10150	4.006
21/12/92	4767	3.678	183	2.262			330	2.519
28/12/92	3833	3.584	1667	3.222	3733	3.572	5600	3.748
04/01/93	853	2.931	320	2.505			4900	3.69
22/01/93	8866	3.948	536667	5.730	726667	5.861	836667	5.923
02/02/93	3033	3.482	3200	3.505	4700	3.672	4100	3.613
08/02/93	200	2.301	247	2.393	313	2.496	387	2.589
15/02/93	2433	3.386	3467	3.540			5000	3.699
22/02/93	51333	4.71	72667	4.861				
01/03/93	410	2.613	853	2.931			1833	3.263
08/03/93	330	2.519	2500	3.398	5600	3.748	8467	3.928
16/03/93	290	2.462	2300	3.362	2300	3.362	1967	3.294
30/03/93	727	2.862	3067	3.487	1800	3.255	2500	3.398
13/04/93	227	2.356	2033	3.308	3900	3.591	2300	3.362
27/04/93	147	2.167	1667	3.222	3000	3.477	817	2.912
07/05/93	227	2.356	1700	3.23	1900	3.279	1233	3.091
22/05/93	143	2.156	1400	3.146	2133	3.329	483	2.684
09/06/93	40	1.602	2007	3.303	67	1.826	187	2.272
22/06/93	2	0.301	323	2.509	15	1.176	183	2.262
11/08/93	870	2.940	29000	4.462	21000	4.322	31000	4.491

	DRY WEATHER
▨	RAINFALL WITHOUT SURFACE RUN-OFF
▨	RAINFALL WITH SURFACE RUN-OFF

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Klein Modder River: UB, KM1, KM2 and DB

MICROBIOLOGICAL INDICATOR ORGANISM: Faecal coliforms

FC	UB		KM1		KM2		DB	
DATE	VALUE	LOG	VALUE	LOG	VALUE	LOG	VALUE	LOG
17/08/92			10	1			350	2.544
24/08/92			14	1.146			1460	3.164
01/09/92			730	2.863			5800	3.763
14/09/92			1275	3.106			562	2.75
22/09/92							23	1.362
28/09/92			226	2.354			2200	3.342
06/10/92			126	2.1			630	2.799
13/10/92	450	2.653	2430	3.386	3660	3.563	2800	3.447
27/10/92	117	2.068	380	2.58	109	2.037	166	2.22
02/11/92	4700	3.672	6560	3.817	4331	3.637	263	2.42
10/11/92	10500	4.021	26000	4.415	29600	4.471	55300	4.743
16/11/92	1560	3.193	4130	3.616	636	2.803	3200	3.505
23/11/92	613	2.787	1400	3.146	6230	3.794	3700	3.568
07/12/92	930	2.968	290	2.462	266	2.425	593	2.773
14/12/92	8850	3.947	3055	3.485	10500	4.021	10150	4.006
21/12/92	4767	3.678	183	2.262			330	2.519
28/12/92	3833	3.584	1667	3.222	3733	3.572	5600	3.748
04/01/93	853	2.931	320	2.505			4900	3.69
22/01/93	8866	3.948	536667	5.730	726667	5.861	836667	5.923
02/02/93	3033	3.482	3200	3.505	4700	3.672	4100	3.613
08/02/93	200	2.301	247	2.393	313	2.496	387	2.589
15/02/93	2433	3.386	3467	3.540			5000	3.699
22/02/93	51333	4.71	72667	4.861				
01/03/93	410	2.613	853	2.931			1833	3.263
08/03/93	330	2.519	2500	3.398	5600	3.748	8467	3.928
16/03/93	290	2.462	2300	3.362	2300	3.362	1967	3.294
30/03/93	727	2.862	3067	3.487	1800	3.255	2500	3.398
13/04/93	227	2.356	2033	3.308	3900	3.591	2300	3.362
27/04/93	147	2.167	1667	3.222	3000	3.477	817	2.912
07/05/93	227	2.356	1700	3.23	1900	3.279	1233	3.091
22/05/93	143	2.156	1400	3.146	2133	3.329	483	2.684
09/06/93	40	1.602	2007	3.303	67	1.826	187	2.272
22/06/93	2	0.301	323	2.509	15	1.176	183	2.262
11/08/93	870	2.940	29000	4.462	21000	4.322	31000	4.491

	DRY WEATHER
░	RAINFALL WITHOUT SURFACE RUN-OFF
▒	RAINFALL WITH SURFACE RUN-OFF

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Klein Modder River: UB, KM1, KM2 and DB

MICROBIOLOGICAL INDICATOR ORGANISM: Faecal streptococci

FS	**UB**		**KM1**		**KM2**		**DB**	
DATE	VALUE	LOG	VALUE	LOG	VALUE	LOG	VALUE	LOG
17/08/92			15	1.176			265	2.423
24/08/92			24	1.38			270	2.431
01/09/92			200	2.301			2560	3.408
14/09/92			200	2.301			82	1.914
22/09/92							46	1.663
28/09/92			163	2.212			290	2.462
06/10/92			138	2.14			450	2.653
13/10/92	939	2.973	1860	3.27	450	2.653	816	2.912
27/10/92	115	2.061	91	1.959	41	1.613	36	1.556
02/11/92	4500	3.653	2060	3.314				
10/11/92	7300	3.863	27600	4.441	26000	4.415	53000	4.724
16/11/92	1530	3.185	5560	3.745	350	2.544	283	2.452
23/11/92	480	2.681	310	2.490	490	2.690	340	2.531
07/12/92	106	2.025	196	2.292	490	2.690	60	1.778
14/12/92	486	2.687	246	2.391	406	2.609	373	2.572
21/12/92	147	2.167	123	2.090			487	2.688
28/12/92	310	2.491	473	2.675	240	2.380	620	2.792
04/01/93	127	2.104	186	2.270			840	2.924
22/01/93	8533	3.931	65333	4.815	413333	5.616	58667	4.768
02/02/93	3167	3.501	1733	3.239	2633	3.42	2200	3.342
08/02/93	143	2.155	33	1.519	293	2.467	347	2.393
15/02/93	2000	3.301	177	2.248			4033	3.606
22/02/93	26333	4.421	27333	4.437				
01/03/93	197	2.294	400	2.602			183	2.262
08/03/93	210	2.322	293	2.467	503	2.702	670	2.826
16/03/93	110	2.041	203	2.307	243	2.386	233	2.367
30/03/93	280	2.447	1400	3.146	1667	3.222	403	2.605
13/04/93	247	2.393	1700	3.230	157	2.196	963	2.984
27/04/93	467	2.669	1433	3.156	450	2.653	123	2.090
07/05/93	210	2.322	513	2.710	123	2.090	103	2.013
22/05/93	20	1.301	127	2.104	87	1.940	187	2.272
09/06/93	320	2.505	180	2.255	57	1.756	153	2.185
22/06/93	8	0.903	67	1.826	0		150	2.176
11/08/93	3333	3.523	1172	3.069	2344	3.37	6200	3.792

	DRY WEATHER
░	RAINFALL WITHOUT SURFACE RUN-OFF
▒	RAINFALL WITH SURFACE RUN-OFF

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Klein Modder River: UB, KM1, KM2 and DB

MICROBIOLOGICAL INDICATOR ORGANISM: Somatic coliphages

SC	**UB**		**KM1**		**KM2**		**DB**	
DATE	VALUE	LOG	VALUE	LOG	VALUE	LOG	VALUE	LOG
17/08/92			0				1	0
24/08/92			0				100	2
01/09/92			129	2.111			830	2.919
14/09/92			738	2.868			60	1.778
22/09/92							100	2
28/09/92			0				100	2
06/10/92			60	1.778			1060	3.025
13/10/92	830	2.919	500	2.699	3700	3.568	700	2.845
27/10/92	0		0		0		30	1.477
02/11/92	0		30	1.477			30	1.477
10/11/92	9000	3.954	4830	3.684	3120	3.494	3800	3.580
16/11/92	530	2.724	1130	3.053	730	2.863	360	2.556
23/11/92	1060	3.025	2360	3.373	1100	3.041	800	2.903
07/12/92	0		0		0		0	
14/12/92	60	1.778	0		150	2.176	0	
21/12/92								
28/12/92								
04/01/93	30	1.477	30	1.477			30	1.477
22/01/93			18600	4.27	43600	4.639	39000	4.591
02/02/93	30	1.477	0		1700	3.230	5630	3.751
08/02/93	400	2.602	0		60	1.778	160	2.204
15/02/93	660	2.820	1960	3.292			1653	4.218
22/02/93	6100	3.785						
01/03/93	230	2.362	30	1.477			200	2.301
08/03/93	130	2.114	600	2.778	760	2.881	660	2.820
16/03/93	0		160	2.204	360	2.556	100	2
30/03/93	0		1230	3.090	900	2.954	130	2.114
13/04/93	633	2.801	1200	3.079	1633	3.213	1300	3.114
27/04/93	700	2.845	1200	3.079	1967	3.294	1033	3.014
07/05/93	367	2.565	1100	3.041	1133	3.054	1133	3.054
22/05/93	533	2.727	100	2	667	2.824	267	2.427
09/06/93	30	1.477	160	2.204	100	2	60	1.778
22/06/93	0		0		0		160	2.204
11/08/93								

□	DRY WEATHER
░	RAINFALL WITHOUT SURFACE RUN-OFF
▒	RAINFALL WITH SURFACE RUN-OFF

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Klein Modder River: UB, KM1, KM2 and DB

Minimum, maximum and geometric mean of microbiological indicator organisms in river

DRY WEATHER

	FAECAL COLIFORMS				FAECAL STREPTOCOCCI				COLIPHAGES			
DATE	**UB**	**KM1**	**KM2**	**DB**	**UB**	**KM1**	**KM2**	**DB**	**UB**	**KM1**	**KM2**	**DB**
24/08/92		14		1460		24		270				100
14/09/92		1275		562		200		82		738		60
22/09/92				23				46				100
28/09/92		226		2200		163		290		60		100
06/10/92		126		630		138		450				1060
27/10/92	117	380	109	166	115	91	41	36		1130		30
16/11/92	1560	4130	636	3200	1530	5560	350	283	530		730	360
07/12/92	930	290	266	593	106	196	490	60				
21/12/92	4767	183		330	147	123		487		30		
04/01/93	853	320		4900	127	186		840	30			30
02/02/93	3033	3200	4700	4100	3167	1733	2633	2200	30		1700	5630
08/02/93	200	247	313	387	143	33	293	347	400	1960	60	160
15/02/93	2433	3467		5000	2000	177		4033	660	1300		1653
27/04/93	147	1667	3000	817	467	1433	450	123	700	1200	1967	1033
07/05/93	227	1700	1900	1233	210	513	123	103	367	1100	1133	1133
22/05/93	143	1400	2133	483	20	127	87	187	533	100	667	267
09/06/93	40	2007	67	187	320	180	57	153	30	160	100	60
22/06/93	2	323	15	183	8	67		150				160
Nu	13	17	10	18	13	17	9	18	9	9	7	16
Min	2	14	15	23	8	24	41	36	30	60	60	30
Max	4767	4130	4700	5000	3167	5560	2633	4033	700	1960	1967	5630
GM	320	580	450	700	130	210	225	230	200	340	525	270

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BOTSHABELO STORMWATER QUALITY

SAMPLING STATIONS: Klein Modder River: UB, KM1, KM2 and DB

Minimum, maximum and geometric mean of microbiological indicator organisms in river

RAINFALL WITHOUT SURFACE RUN-OFF

DATE	FAECAL COLIFORMS				FAECAL STREPTOCOCCI				COLIPHAGES			
	UB	**KM1**	**KM2**	**DB**	**UB**	**KM1**	**KM2**	**DB**	**UB**	**KM1**	**KM2**	**DB**
17/08/92		10		350		15		265				
01/09/92		730		5800		200		2560		129		830
13/10/92	450	2430	3660	2800	939	1860	450	816	830	500	3700	700
02/11/92	4700	6560		263	4500	2060				30		30
23/11/92	613	1400	4331	3700	480	310	490	340	1060	2360	1100	800
14/12/92	8850	3060	6230	10150	486	246	406	373	60		150	
28/12/92	3833	1667	10500	5600	310	473	240	620				
01/03/93	410	853	3733	1833	197	400		183	230	30		200
08/03/93	330	2500	5600	8467	210	293	503	670	130	600	760	660
16/03/93	290	2300	2300	1967	110	203	243	233		160	360	100
30/03/93	727	3067	1800	2500	280	1400	1667	403		1230	900	130
13/04/93	227	2033	3900	2300	247	1700	157	963	633	1200	1633	1300
Nu	10	12	9	12	10	12	8	11	6	9	7	9
Min	227	10	1800	263	110	15	157	183	60	30	150	30
Max	8850	6560	10500	10150	4500	2060	1667	2560	1060	2360	3700	1300
GM	880	1310	4130	2480	400	411	402	500	316	300	820	320

RAINFALL WITH SURFACE RUN-OFF

DATE	FAECAL COLIFORMS				FAECAL STREPTOCOCCI				COLIPHAGES			
	UB	**KM1**	**KM2**	**DB**	**UB**	**KM1**	**KM2**	**DB**	**UB**	**KM1**	**KM2**	**DB**
10/11/92	10500	26000	29600	55300	7300	27600	26000	53000	9000	4830	3120	3800
22/01/93	8866	536667	726667	836667	8533	65333	413333	58667		18600	43600	39000
22/02/93	51333	72667			26333	27333			6100			
11/08/93	870	29000	21000	31000	3333	1172	2344	6200				
Nu	4	4	3	3	4	4	3	3	2	3	2	2
Min	870	26000	21000	31000	3333	1172	2344	6200	6100	4830	3120	3800
Max	51333	536667	726667	836667	26333	65333	413333	58667	9000	18600	43600	39000
GM	8030	73620	76680	112810	8600	15510	29310	26790	7400	9500	11650	12180

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APPENDIX C

C1 RATIONAL METHOD

- compiled from Rooseboom *et al.* (1986), Shaeffer *et al.* (1982)

C2 PEAK DISCHARGES: Sub-catchment 5, 6 and 8

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APPENDIX C1

RATIONAL METHOD

•compiled from Rooseboom *et al.* (1986), Shaeffer *et al.* (1982)

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Area distribution factor (α+β+γ=1):		
Rural (α) =	Urban (β) =	Lakes (γ) =

RURAL: Surface slope			Mean Annual Precipitation (mm)			Cs
Classification	Slope	Decimal	< 600	600 - 900	> 900	
Marshes, pans	<3%		0.01	0.03	0.05	
Level areas	3-10%		0.06	0.08	0.11	
Hilly areas	10-30%		0.12	0.16	0.20	
Steep areas	>30%		0.22	0.26	0.30	
	Total:	1.00			**Total:**	

RURAL: Permeability			Mean Annual Precipitation (mm)			Cp
Classification		Decimal	< 600	600 - 900	> 900	
Very permeable	(coarse sand)		0.03	0.04	0.05	
Permeable	(sand)		0.06	0.08	0.10	
Semi-permeable	(clayey sand)		0.12	0.16	0.20	
Impermeable	(clay / rock)		0.21	0.26	0.30	
	Total:	1.00			**Total:**	

RURAL: Vegetation		Mean Annual Precipitation (mm)			Cv
Classification	Decimal	< 600	600 - 900	> 900	
Dense bush, plantation		0.03	0.04	0.05	
Light bush, farm lands		0.07	0.11	0.15	
Grass land		0.17	0.21	0.25	
No vegetation		0.26	0.28	0.30	
Total:	1.00			**Total:**	

Cs + Cp + C v = **C1:**

URBAN: Landuse classification		Decimal	Factor	**C2**
Lawns, parks	Sandy, level (<2%)		0.05-0.10	
	Sandy, steep (>7%)		0.15-0.20	
	Heavy soil, level (<2%)		0.13-0.17	
	Heavy soil, steep (>7%)		0.25-0.35	
Residential areas	Houses		0.30-0.50	
	Flats		0.50-0.70	
Industrial areas	Light		0.70-0.95	
	Heavy		0.50-0.80	
Business areas	Centre		0.60-0.90	
	Suburban		0.50-0.70	
Streets			0.70-0.95	
Maximum flood			1.00	
	Total:	1.00	**Total:**	

LAKES (If lake contributes to run-off C3 = 1) **C3:**

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OFF COEFFICIENT (dimensionless) **C:**
[α*C1 + β*C2 + γ*C3]

Main stream length (km) =			L
Height of most remote part above outlet (m) =			H
Height of 0.10*Length (m) =		Height of 0.85*Length (m) =	
Slope of catchment (m/m) = S = [H/1000L]			S
Mean slope (m/m) = $Sm = [H_{0.85L} - H_{0.10L}] / 1000*0.75L$			Sm
Roughness coefficient =			r
Recommended values: Sparse grass = 0.3	Clean compacted soil = 0.1 Moderate grass = 0.4	Paved areas = 0.02 Dense grass = 0.8	
Time of concentration: surface flow (hour) = $Tc(surface) = 0.604*(r.L/S^{0.5})^{0.467}$			Tc (surface)
Time of concentration: canal flow (hour) = $Tc(canal) = (0.87.L^2/1000.Sm)^{0.385}$			Tc (canal)
Total time of concentration (hour) = Tc = Tc(surface) + Tc(canal)			Tc

Recurrence period (year) =	
Rainfall region (Summer / Winter / Year round) =	
Mean annual precipitation (mm) =	
Rainfall depth (mm) =	

AVERAGE RAINFALL INTENSITY (mm/h) **I:**
[Rainfall depth / Tc]

EFFECTIVE AREA OF CATCHMENT (km^2) **A:**

Recurrence period (year):	2	5	10	20	50	100
Adjustment factor:	0.75	0.80	0.85	0.90	0.95	1.00

PEAK DISCHARGE (m^3/s) **Q:**
[Q = 0.256*CIA*Adjustment factor]

RATIONAL METHOD	
Description of catchment:	Notes:
Date:	

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APPENDIX C2

PEAK DISCHARGES: Sub-catchment 5, 6 and 8

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Area distribution factor ($\alpha+\beta+\gamma=1$):		
Rural (α) = *0.5*	Urban (β) = *0.5*	Lakes (γ) = *0*

RURAL: Surface slope			Mean Annual Precipitation (mm)			Cs
Classification	Slope	Decimal	< 600	600 - 900	> 900	
Marshes, pans	<3%		0.01	0.03	0.05	
Level areas	3-10%	*1.00*	0.06	0.08	0.11	*0.06*
Hilly areas	10-30%		0.12	0.16	0.20	
Steep areas	>30%		0.22	0.26	0.30	
	Total:	1.00			**Total:**	*0.06*

RURAL: Permeability		Mean Annual Precipitation (mm)			Cp
Classification	Decimal	< 600	600 - 900	> 900	
Very permeable (coarse sand)		0.03	0.04	0.05	
Permeable (sand)	*0.1*	0.06	0.08	0.10	*0.006*
Semi-permeable (clayey sand)	*0.9*	0.12	0.16	0.20	*0.108*
Impermeable (clay / rock)		0.21	0.26	0.30	
Total:	1.00			**Total:**	*0.114*

RURAL: Vegetation		Mean Annual Precipitation (mm)			Cv
Classification	Decimal	< 600	600 - 900	> 900	
Dense bush, plantation		0.03	0.04	0.05	
Light bush, farm lands		0.07	0.11	0.15	
Grass land	*0.8*	0.17	0.21	0.25	*0.136*
No vegetation	*0.2*	0.26	0.28	0.30	*0.052*
Total:	1.00			**Total:**	*0.188*

Cs + Cp + C v = **C1:** *0.362*

URBAN: Landuse classification		Decimal	Factor		C2
Lawns, parks	Sandy, level (<2%)	*0.30*	0.05-0.10	*0.10*	*0.03*
	Sandy, steep (>7%)		0.15-0.20		
	Heavy soil, level (<2%)		0.13-0.17		
	Heavy soil, steep (>7%)		0.25-0.35		
Residential areas	Houses	*0.55*	0.30-0.50	*0.50*	*0.275*
	Flats		0.50-0.70		
Industrial areas	Light		0.70-0.95		
	Heavy		0.50-0.80		
Business areas	Centre		0.60-0.90		
	Suburban	*0.10*	0.50-0.70	*0.70*	*0.07*
Streets		*0.05*	0.70-0.95	*0.70*	*0.035*
Maximum flood			1.00		
	Total:	1.00		**Total:**	*0.410*

LAKES (If lake contributes to run-off C3 = 1) **C3:** *0*

OFF COEFFICIENT (dimensionless) **C:** *0.386*
[α*C1 + β*C2 + γ*C3]

Main stream length (km) =		*2.8*	L
Height of most remote part above outlet (m)		*50*	H
Height of 0.10*Length (m) = *1395*	Height of 0.85*Length (m) =	*1430*	
Slope of catchment (m/m) = $S = [H/1000L]$		*0.018*	S
Mean slope (m/m) = $Sm = [H_{0.85L} - H_{0.10L}] / 1000*0.75L$		*0.018*	Sm
Roughness coefficient =		*0.3*	r

Recommended values: Clean compacted soil = 0.1 Paved areas = 0.02
Sparse grass = 0.3 Moderate grass = 0.4 Dense grass = 0.8

Time of concentration: surface flow (hour) = $Tc(surface) = 0.604*(r.L/S^{0.5})^{0.467}$	*1.423*	Tc (surface)
Time of concentration: canal flow (hour) = $Tc(canal) = (0.87.L^2/1000.Sm)^{0.385}$	*0.688*	Tc (canal)
Total time of concentration (hour) = $Tc = Tc(surface) + Tc(canal)$	*2.111*	Tc

Recurrence period (year) =	/
Rainfall region (Summer / Winter / Year round) =	/
Mean annual precipitation (mm) =	/
Rainfall depth (mm) =	*21*

AVERAGE RAINFALL INTENSITY (mm/h) **I:** *9.95*
[Rainfall depth / Tc]

EFFECTIVE AREA OF CATCHMENT (km^2) **A:** *5.56*

Recurrence period (year):	2	5	10	20	50	100
Adjustment factor:	0.75	0.80	0.85	0.90	0.95	1.00

PEAK DISCHARGE (m^3/s) **Q:** 4.10
[Q = 0.256*CIA*Adjustment factor]

RATIONAL METHOD

Description of catchment: ***Sub-catchment 5***	Notes:
Date: *December 1995*	

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Area distribution factor ($\alpha+\beta+\gamma=1$):		
Rural (α) = *0.4*	Urban (β) = *0.6*	Lakes (γ) = *0*

RURAL: Surface slope			Mean Annual Precipitation (mm)			Cs
Classification	Slope	Decimal	< 600	600 - 900	> 900	
Marshes, pans	<3%		0.01	0.03	0.05	
Level areas	3-10%	*0.90*	0.06	0.08	0.11	*0.054*
Hilly areas	10-30%		0.12	0.16	0.20	
Steep areas	>30%	*0.10*	0.22	0.26	0.30	*0.022*
	Total:	1.00			**Total:**	*0.076*

RURAL: Permeability			Mean Annual Precipitation (mm)			Cp
Classification		Decimal	< 600	600 - 900	> 900	
Very permeable	(coarse sand)		0.03	0.04	0.05	
Permeable	(sand)	*0.10*	0.06	0.08	0.10	*0.006*
Semi-permeable	(clayey sand)	*0.80*	0.12	0.16	0.20	*0.096*
Impermeable	(clay / rock)	*0.10*	0.21	0.26	0.30	*0.021*
	Total:	1.00			**Total:**	*0.123*

RURAL: Vegetation	Decimal	Mean Annual Precipitation (mm)			Cv
Classification	Decimal	< 600	600 - 900	> 900	
Dense bush, plantation		0.03	0.04	0.05	
Light bush, farm lands		0.07	0.11	0.15	
Grass land	*0.50*	0.17	0.21	0.25	*0.085*
No vegetation	*0.50*	0.26	0.28	0.30	*0.130*
Total:	1.00			**Total:**	*0.215*

Cs + Cp + C v = **C1:** *0.414*

URBAN: Landuse classification		Decimal	Factor		C2
Lawns, parks	Sandy, level (<2%)	*0.30*	0.05-0.10	*0.10*	*0.03*
	Sandy, steep (>7%)		0.15-0.20		
	Heavy soil, level (<2%)		0.13-0.17		
	Heavy soil, steep (>7%)		0.25-0.35		
Residential areas	Houses	*0.55*	0.30-0.50	*0.50*	*0.275*
	Flats		0.50-0.70		
Industrial areas	Light		0.70-0.95		
	Heavy		0.50-0.80		
Business areas	Centre		0.60-0.90		
	Suburban	*0.05*	0.50-0.70	*0.70*	*0.035*
Streets		*0.10*	0.70-0.95	*0.70*	*0.035*
Maximum flood			1.00		
	Total:	1.00		**Total:**	*0.415*

LAKES (If lake contributes to run-off C3 = 1) **C3:** *0*

RUN-OFF COEFFICIENT (dimensionless) **C:** *0.412*
[α*C1 + β*C2 + γ*C3]

Main stream length (km) =		*4.5*	L
Height of most remote part above outlet (m)		*215*	H
Height of 0.10*Length (m) = *1385*		Height of 0.85*Length (m) =	*1460*
Slope of catchment (m/m) = S = [H/1000L]		*0.048*	S
Mean slope (m/m) = Sm = [$H_{0.85L}$ - $H_{0.10L}$] / 1000*0.75L		*0.019*	Sm
Roughness coefficient =		*0.3*	r
Recommended values: Sparse grass = 0.3	Clean compacted soil = 0.1 Moderate grass = 0.4	Paved areas = 0.02 Dense grass = 0.8	
Time of concentration: surface flow (hour) = Tc(surface) = 0.604*$(r.L/S^{0.5})^{0.467}$		*1.412*	Tc (surface)
Time of concentration: canal flow (hour) = Tc(canal) = $(0.87.L^2/1000.Sm)^{0.385}$		*0.971*	Tc (canal)
Total time of concentration (hour) = Tc = Tc(surface) + Tc(canal)		*2.383*	Tc

Recurrence period (year) =	/
Rainfall region (Summer / Winter / Year round) =	/
Mean annual precipitation (mm) =	/
Rainfall depth (mm) =	*21*

AVERAGE RAINFALL INTENSITY (mm/h) **I:** 8.81
[Rainfall depth / Tc]

EFFECTIVE AREA OF CATCHMENT (km^2) **A:** *8.10*

Recurrence period (year):	2	5	10	20	50	100
Adjustment factor:	0.75	0.80	0.85	0.90	0.95	1.00

PEAK DISCHARGE (m^3/s) **Q:** 5.65
[Q = 0.256*CIA*Adjustment factor]

RATIONAL METHOD	
Description of catchment: ***Sub-catchment 6***	Notes:
Date: ***December 1995***	

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Area distribution factor (α+β+γ=1):		
Rural (α) = 0.4	Urban (β) = 0.6	Lakes (γ) = 0

RURAL: Surface slope			Mean Annual Precipitation (mm)			Cs
Classification	Slope	Decimal	< 600	600 - 900	> 900	
Marshes, pans	<3%		0.01	0.03	0.05	
Level areas	3-10%	0.80	0.06	0.08	0.11	0.048
Hilly areas	10-30%	0.08	0.12	0.16	0.20	0.010
Steep areas	>30%	0.12	0.22	0.26	0.30	0.026
	Total:	1.00			**Total:**	0.084

RURAL: Permeability		Mean Annual Precipitation (mm)			Cp
Classification	Decimal	< 600	600 - 900	> 900	
Very permeable (coarse sand)		0.03	0.04	0.05	
Permeable (sand)	0.10	0.06	0.08	0.10	0.006
Semi-permeable (clayey sand)	0.85	0.12	0.16	0.20	0.102
Impermeable (clay / rock)	0.05	0.21	0.26	0.30	0.011
Total:	1.00			**Total:**	0.119

RURAL: Vegetation		Mean Annual Precipitation (mm)			Cv
Classification	Decimal	< 600	600 - 900	> 900	
Dense bush, plantation		0.03	0.04	0.05	
Light bush, farm lands		0.07	0.11	0.15	
Grass land	0.80	0.17	0.21	0.25	0.136
No vegetation	0.20	0.26	0.28	0.30	0.052
Total:	1.00			**Total:**	0.188

Cs + Cp + C v = **C1:** 0.391

URBAN: Landuse classification		Decimal	Factor		C2
Lawns, parks	Sandy, level (<2%)	0.25	0.05-0.10	0.10	0.025
	Sandy, steep (>7%)		0.15-0.20		
	Heavy soil, level (<2%)		0.13-0.17		
	Heavy soil, steep (>7%)		0.25-0.35		
Residential areas	Houses	0.45	0.30-0.50	0.50	0.225
	Flats		0.50-0.70		
Industrial areas	Light		0.70-0.95		
	Heavy		0.50-0.80		
Business areas	Centre	0.20	0.60-0.90	0.90	0.180
	Suburban		0.50-0.70		
Streets		0.10	0.70-0.95	0.90	0.090
Maximum flood			1.00		
	Total:	1.00		**Total:**	0.520

LAKES (If lake contributes to run-off C3 = 1) **C3:** 0

RUN-OFF COEFFICIENT (dimensionless) **C:** 0.468
[α*C1 + β*C2 + γ*C3]

Main stream length (km) =		4.2	L
Height of most remote part above outlet (m)		162	H
Height of 0.10*Length (m) = 1390	Height of 0.85*Length (m) =	1440	
Slope of catchment (m/m) = $S = [H/1000L]$		0.032	S
Mean slope (m/m) = $Sm = [H_{0.85L} - H_{0.10L}] / 1000*0.75L$		0.016	Sm
Roughness coefficient =		0.3	r

Recommended values: Clean compacted soil = 0.1 Paved areas = 0.02
Sparse grass = 0.3 Moderate grass = 0.4 Dense grass = 0.8

Time of concentration: surface flow (hour) = $Tc(surface) = 0.604*(r.L/S^{0.5})^{0.467}$	1.435	Tc (surface)
Time of concentration: canal flow (hour) = $Tc(canal) = (0.87.L^2/1000.Sm)^{0.385}$	0.984	Tc (canal)
Total time of concentration (hour) = Tc = Tc(surface) + Tc(canal)	2.419	Tc

Recurrence period (year) =	/
Rainfall region (Summer / Winter / Year round) =	/
Mean annual precipitation (mm) =	/
Rainfall depth (mm) =	21

AVERAGE RAINFALL INTENSITY (mm/h) **I:** 8.68
[Rainfall depth / Tc]

EFFECTIVE AREA OF CATCHMENT (km^2) **A:** 7.33

Recurrence period (year):	2	5	10	20	50	100
Adjustment factor:	0.75	0.80	0.85	0.90	0.95	1.00

PEAK DISCHARGE (m^3/s) **Q:** 5.72
[Q = 0.256*CIA*Adjustment factor]

RATIONAL METHOD	
Description of catchment: Sub-catchment 8	Notes:
Date: December 1995	

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PLATES

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Sub-catchment 5

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Sub-catchment 6

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Sub-catchment 8

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FIGURES

TECHNIKON
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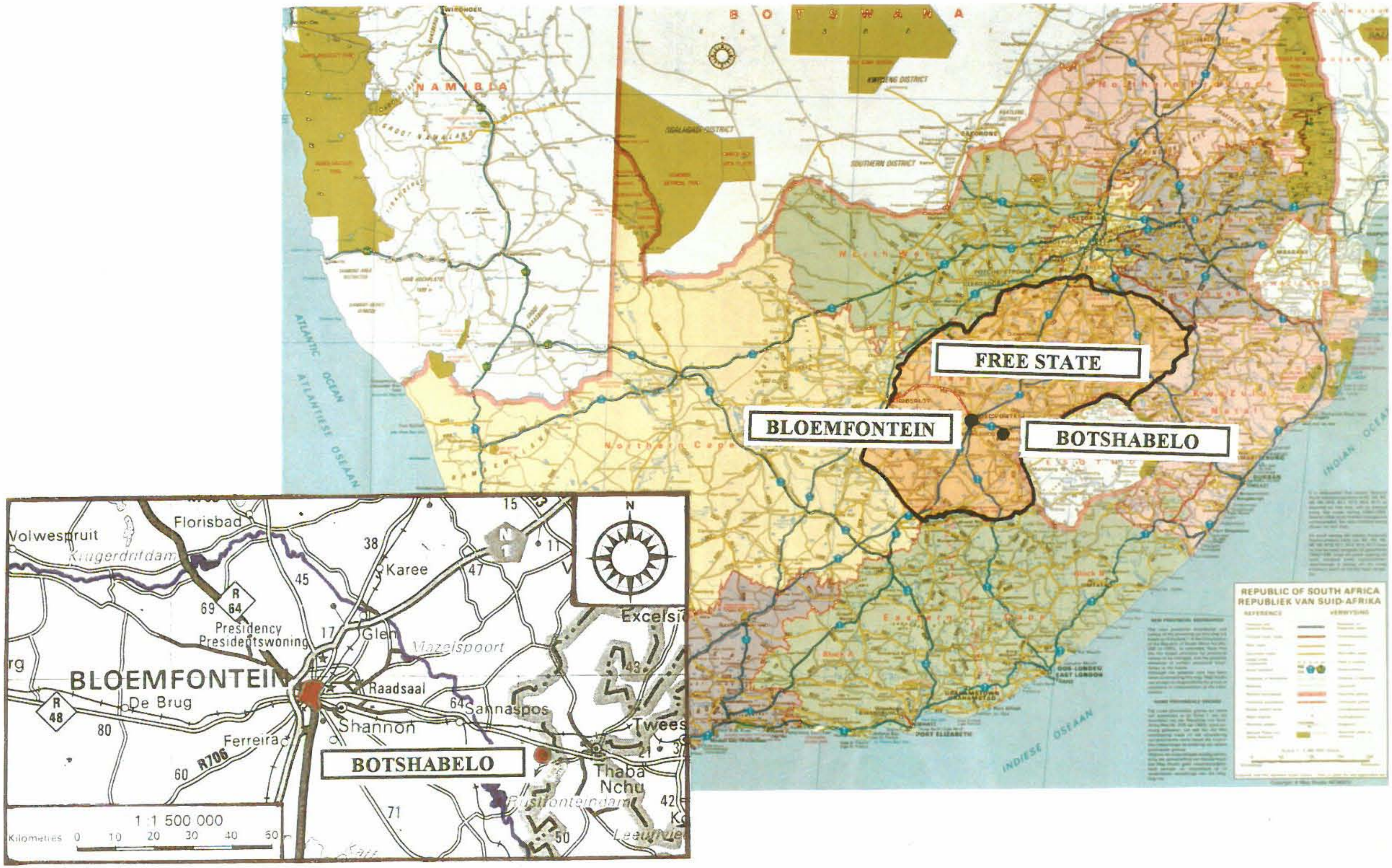

Figure 1: Locality plan.

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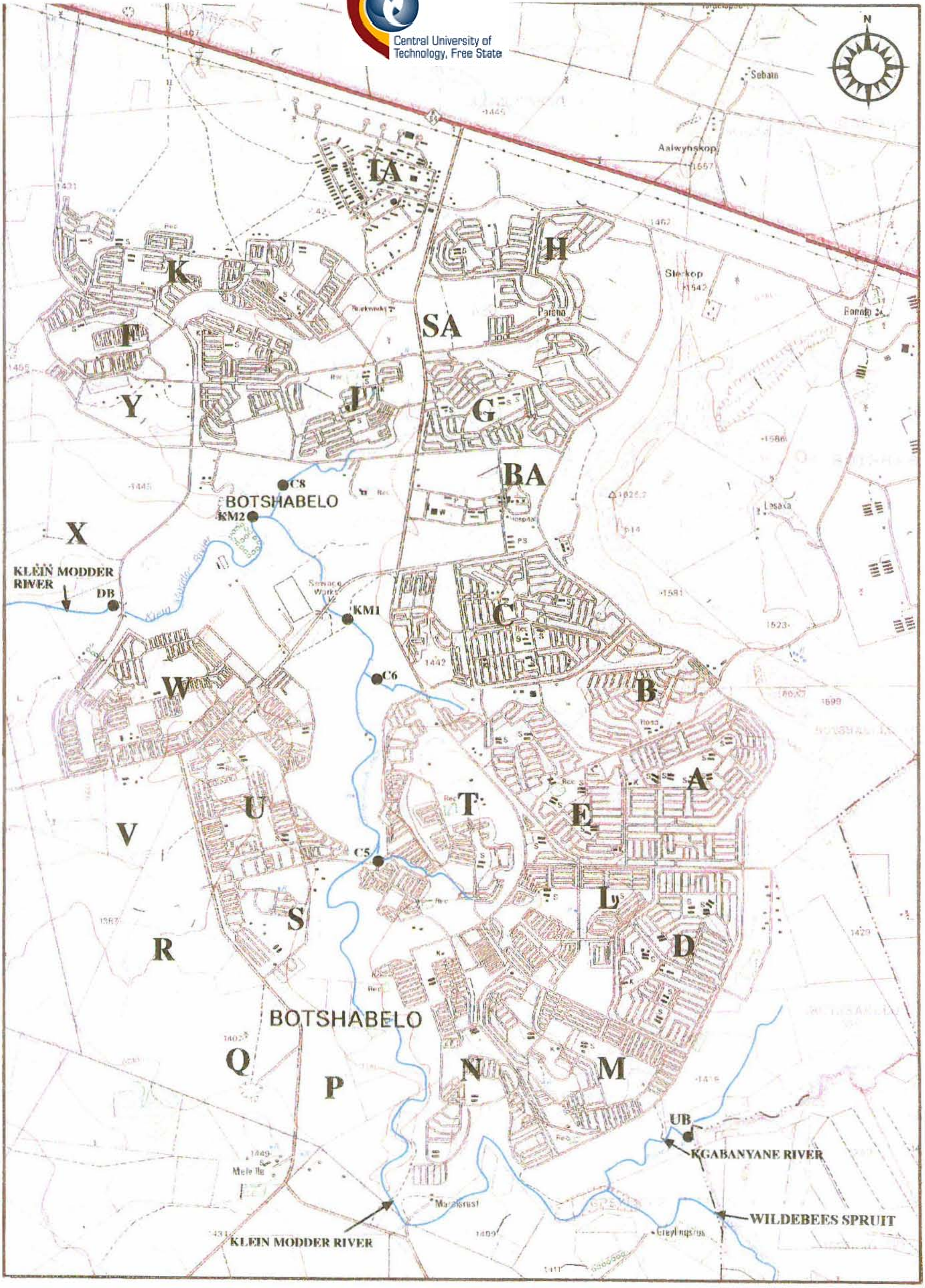

Figure 2: Topography and layout of developed Botshabelo.

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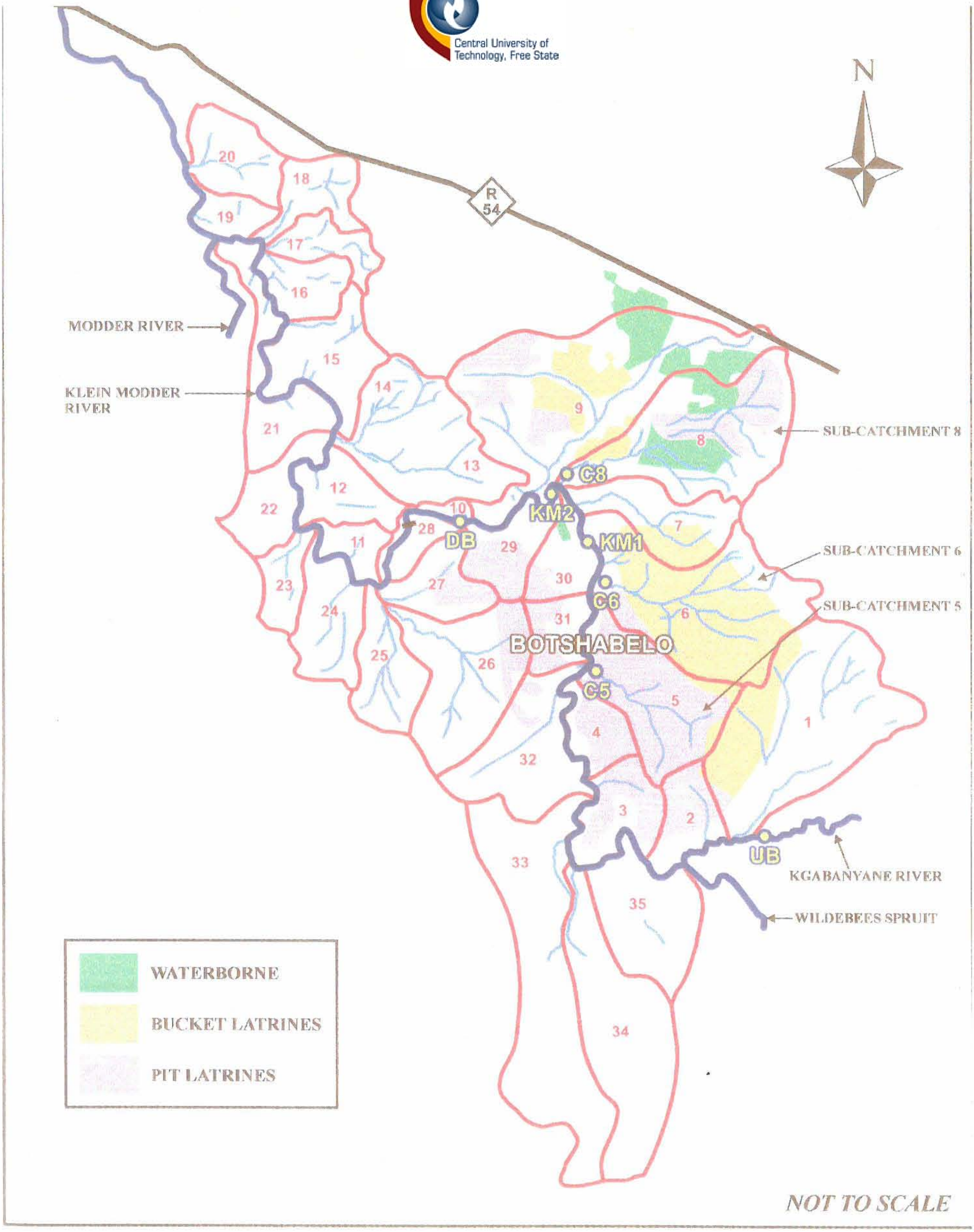

Figure 3: Hydrological network and layout of Botshabelo sanitation system.

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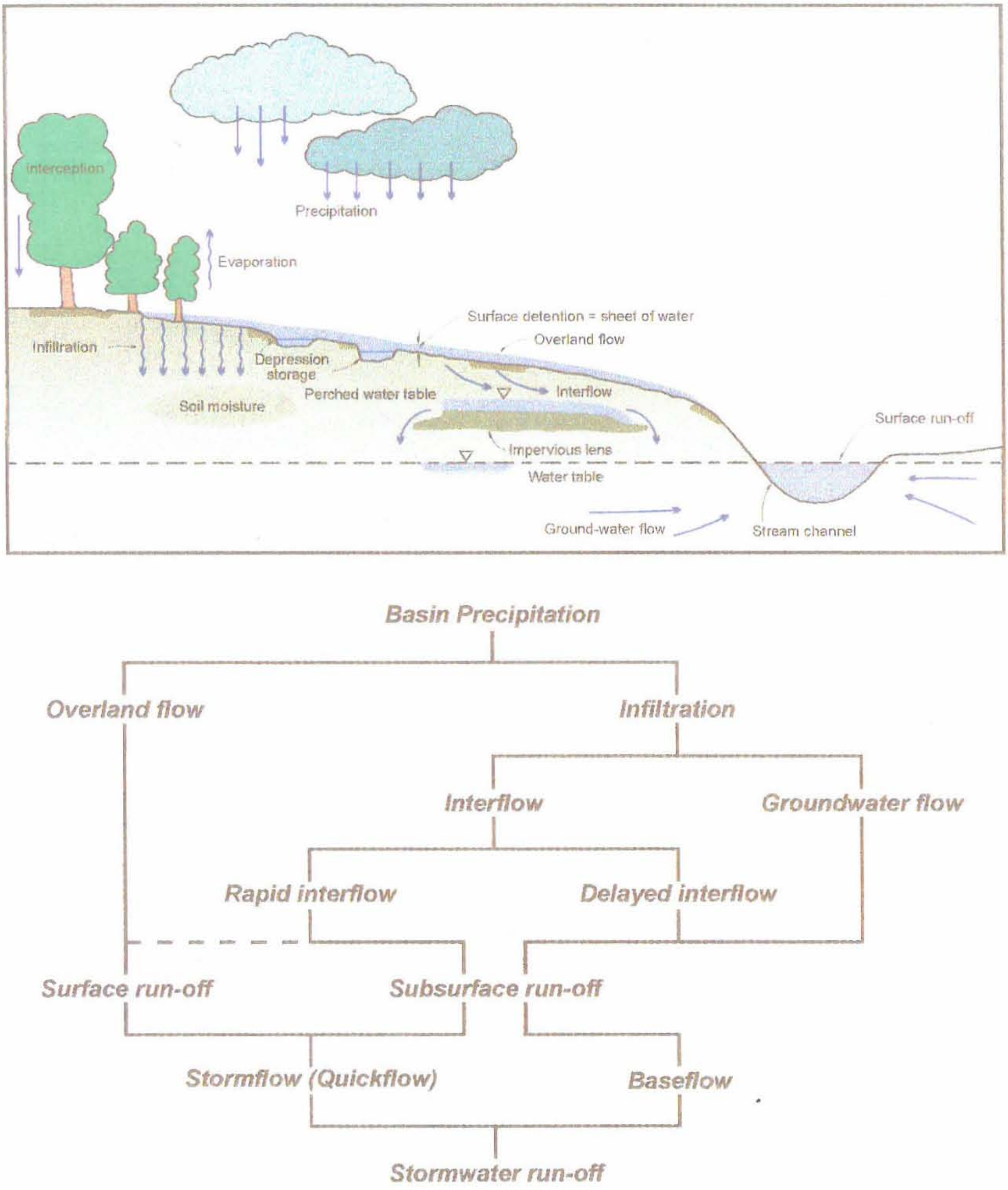

Figure 4a: Run-off in a natural catchment.

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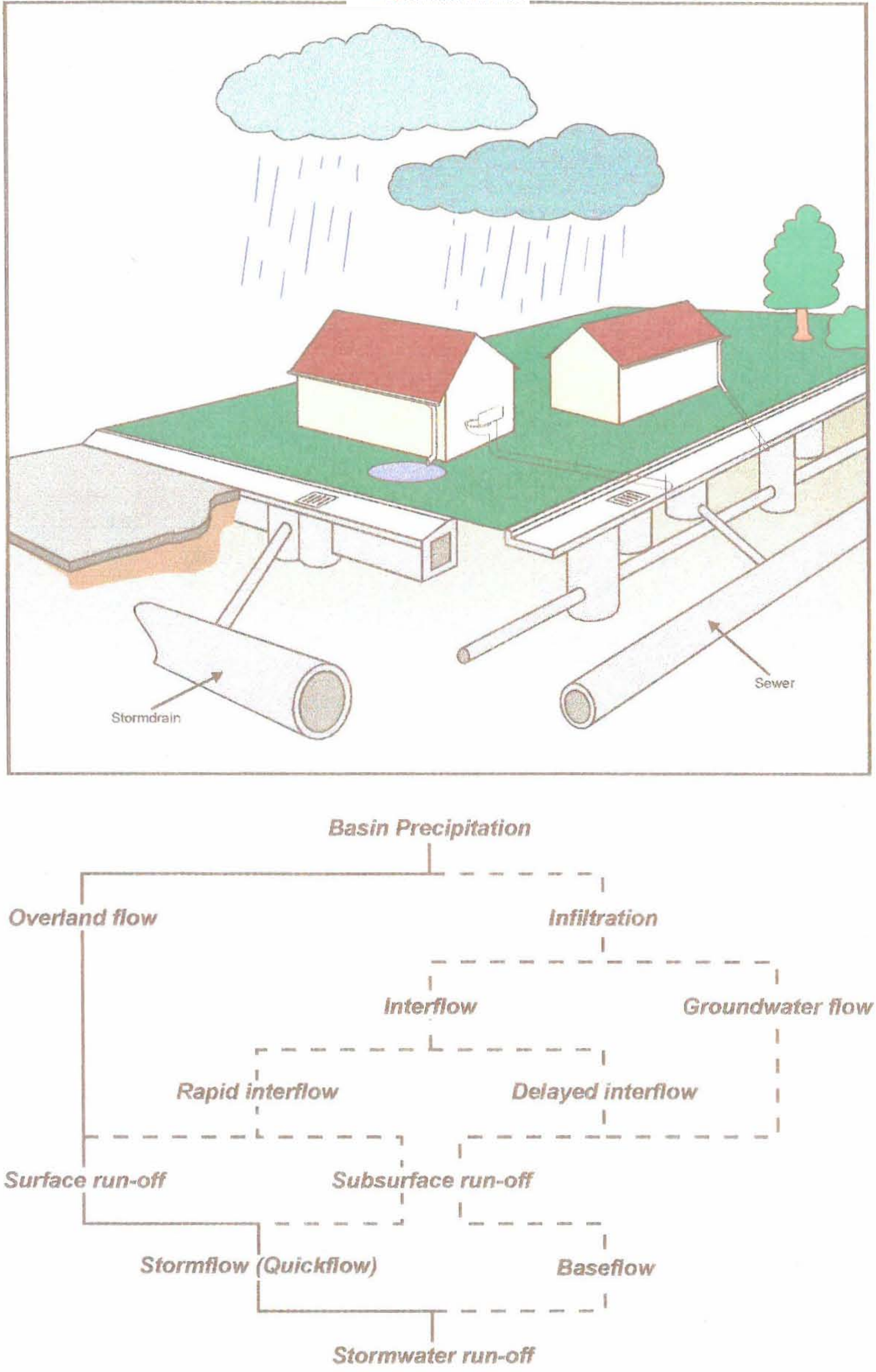

Figure 4b: Run-off cycle in a Developed urban catchment.

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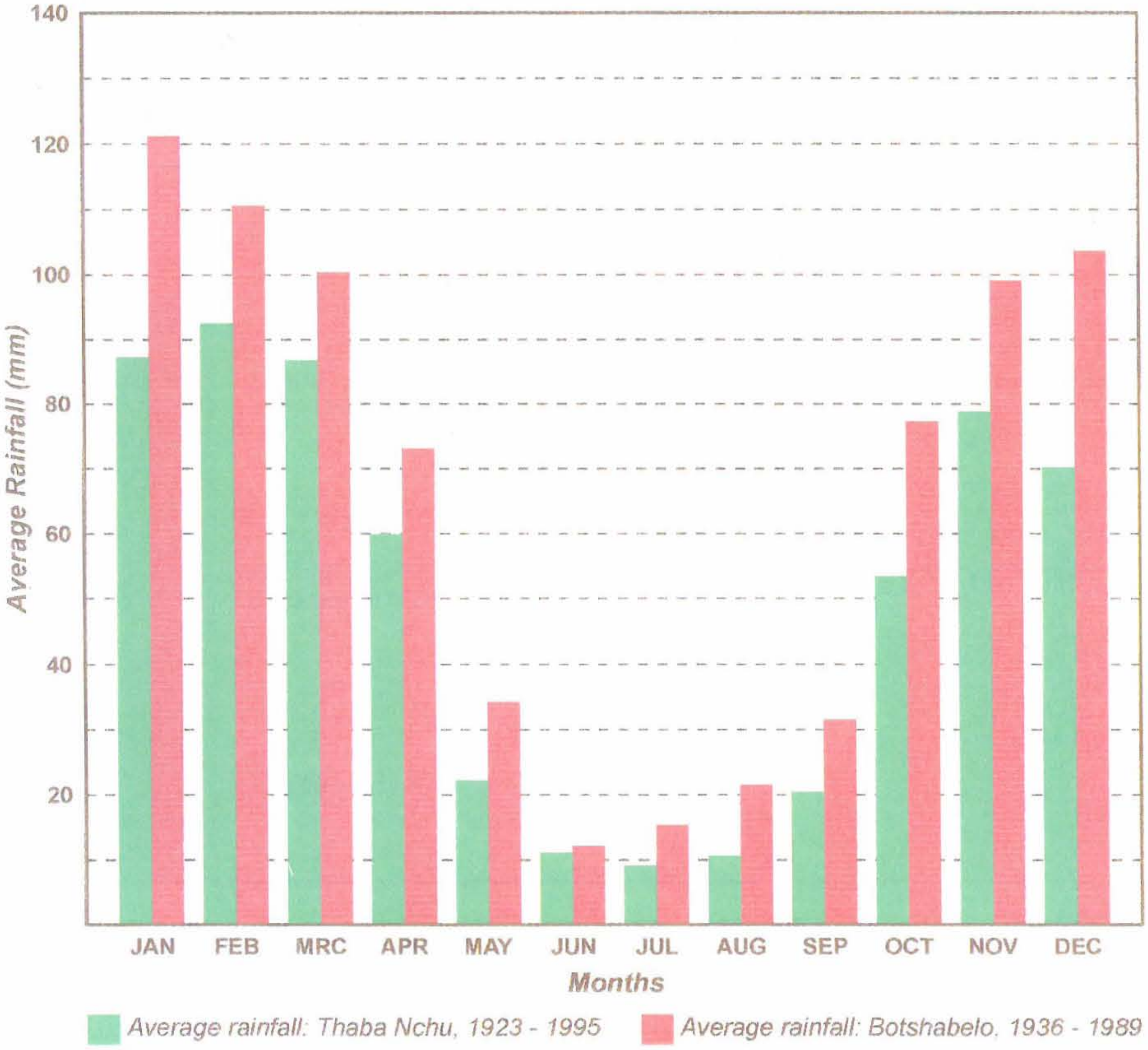

Figure 5: Monthly rainfall trend of study area.

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Figure 6: Diagram of an average soil profile of Southern Botshabelo.

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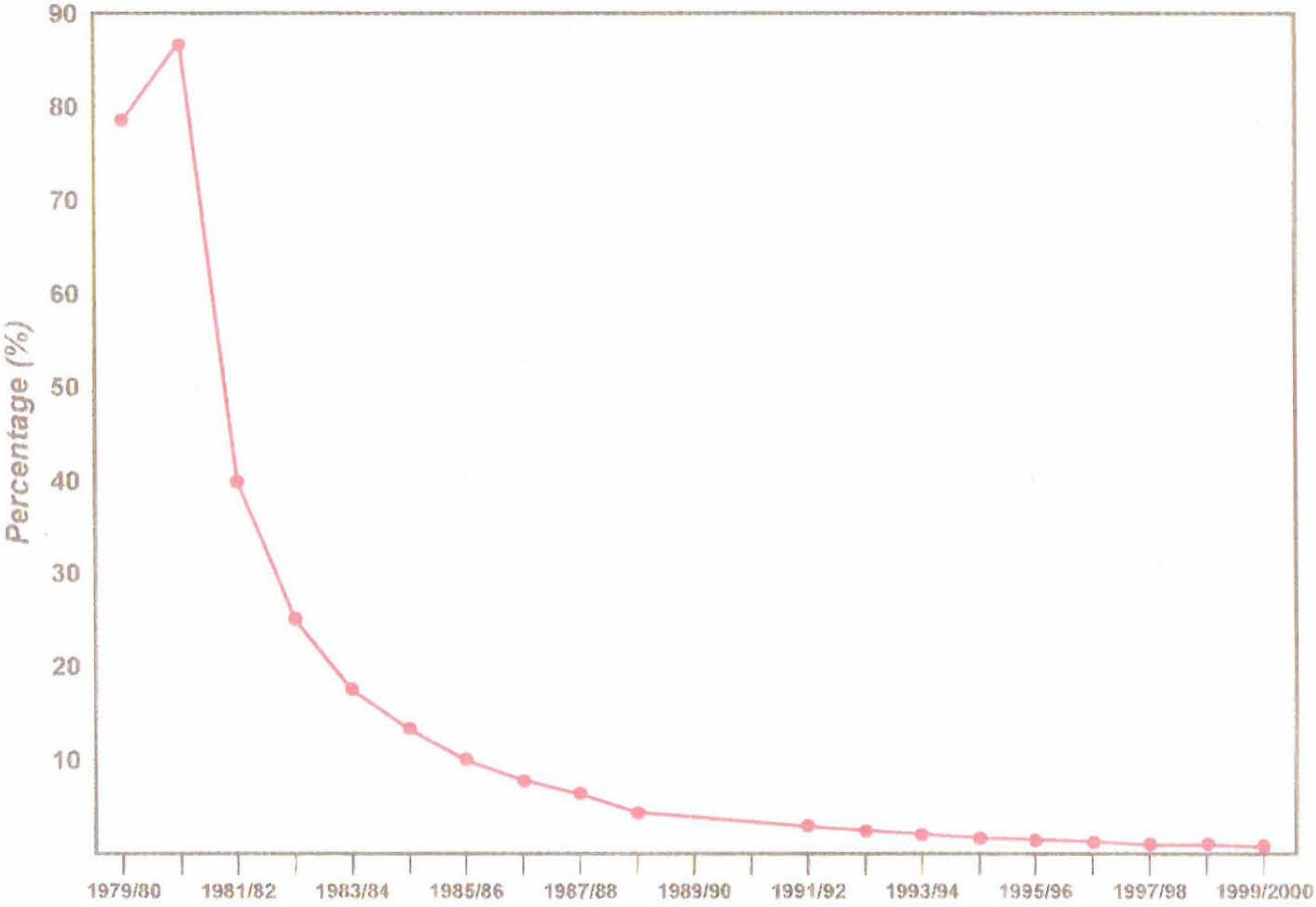

Figure 7: Yearly population growth rate, Botshabelo 1979 - 2000.

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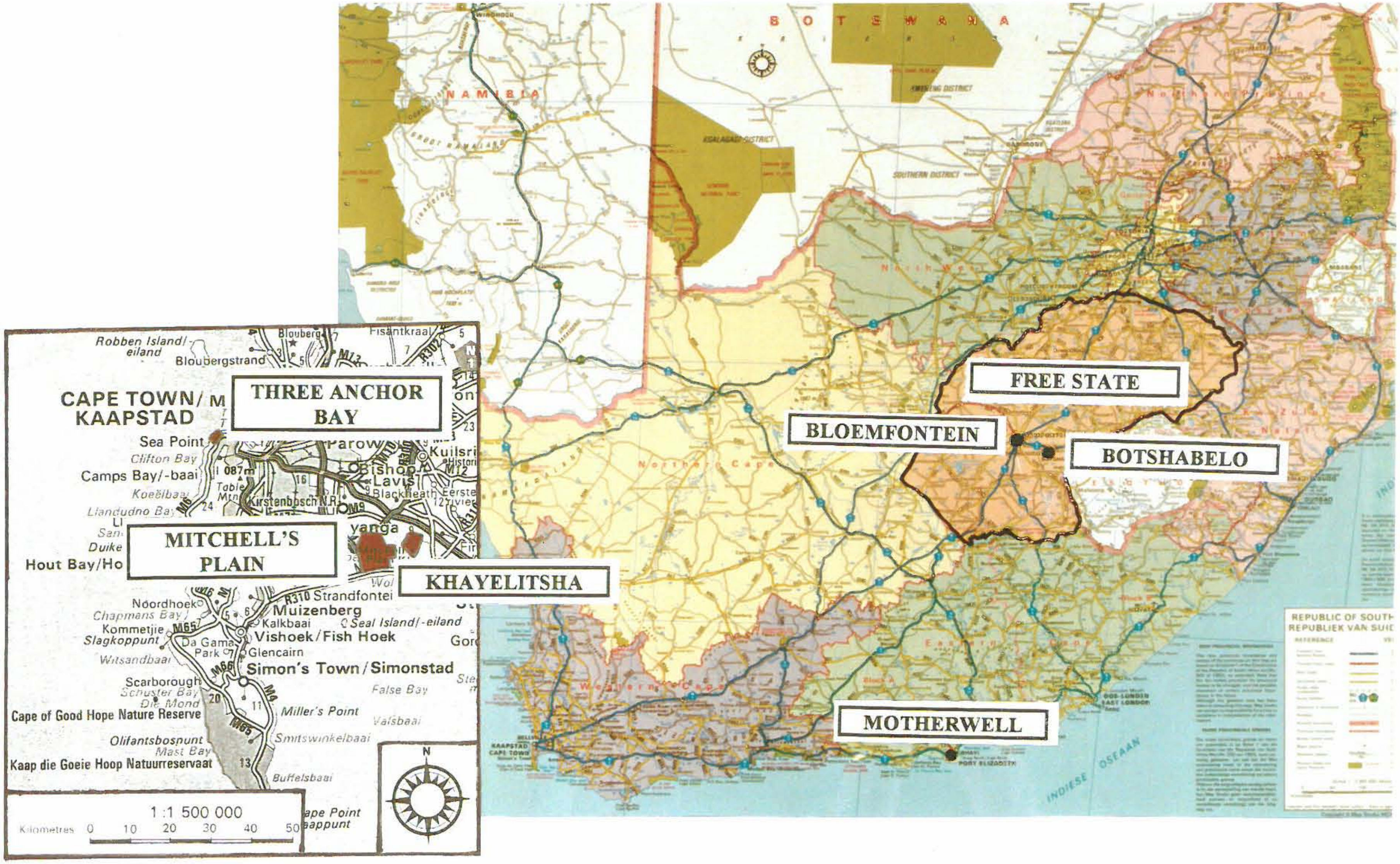

Figure 8: Location of other South African study sites.

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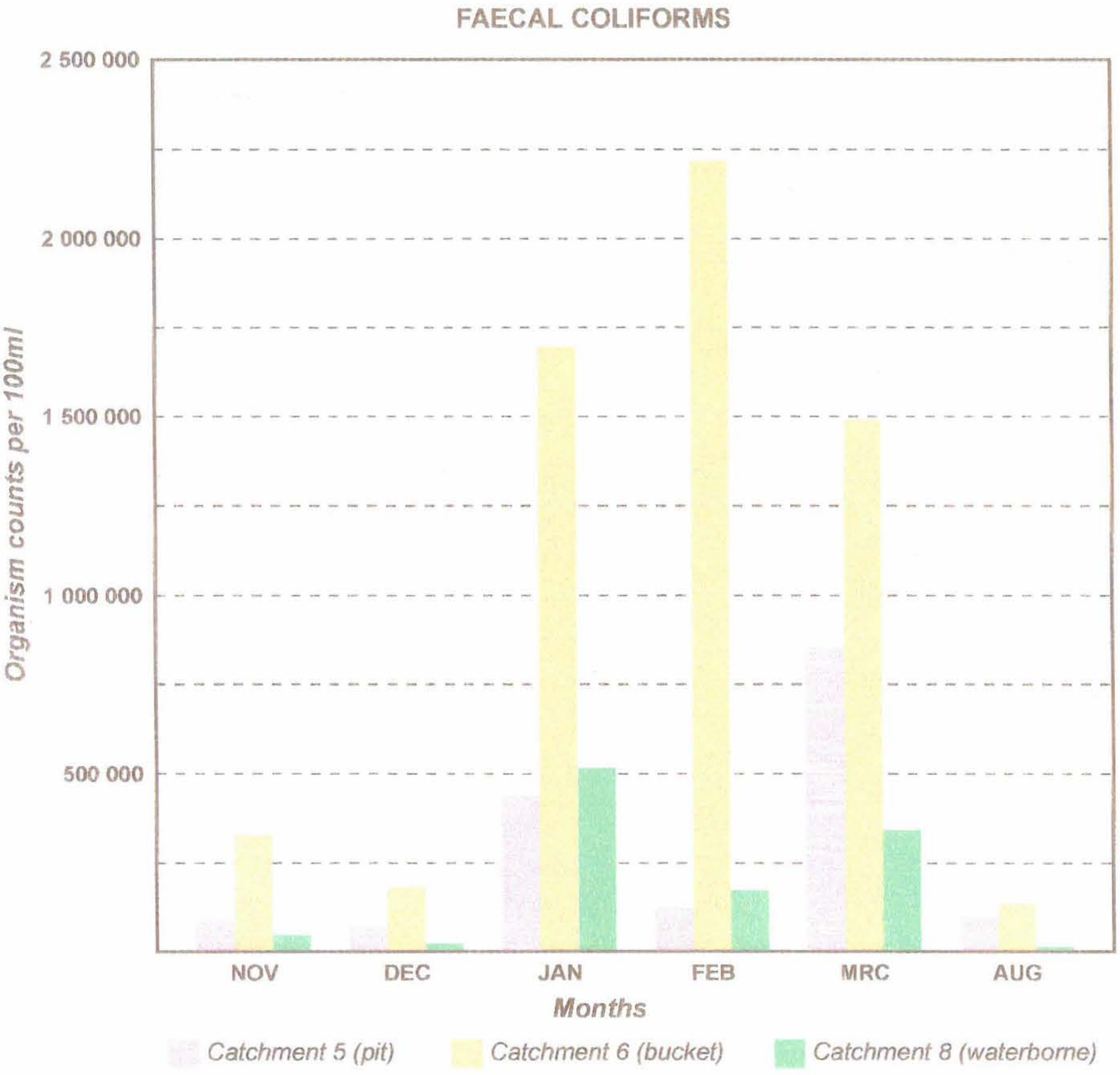

Figure 9: Mean levels of faecal coliforms in stormwater run-off in three sub-catchments.

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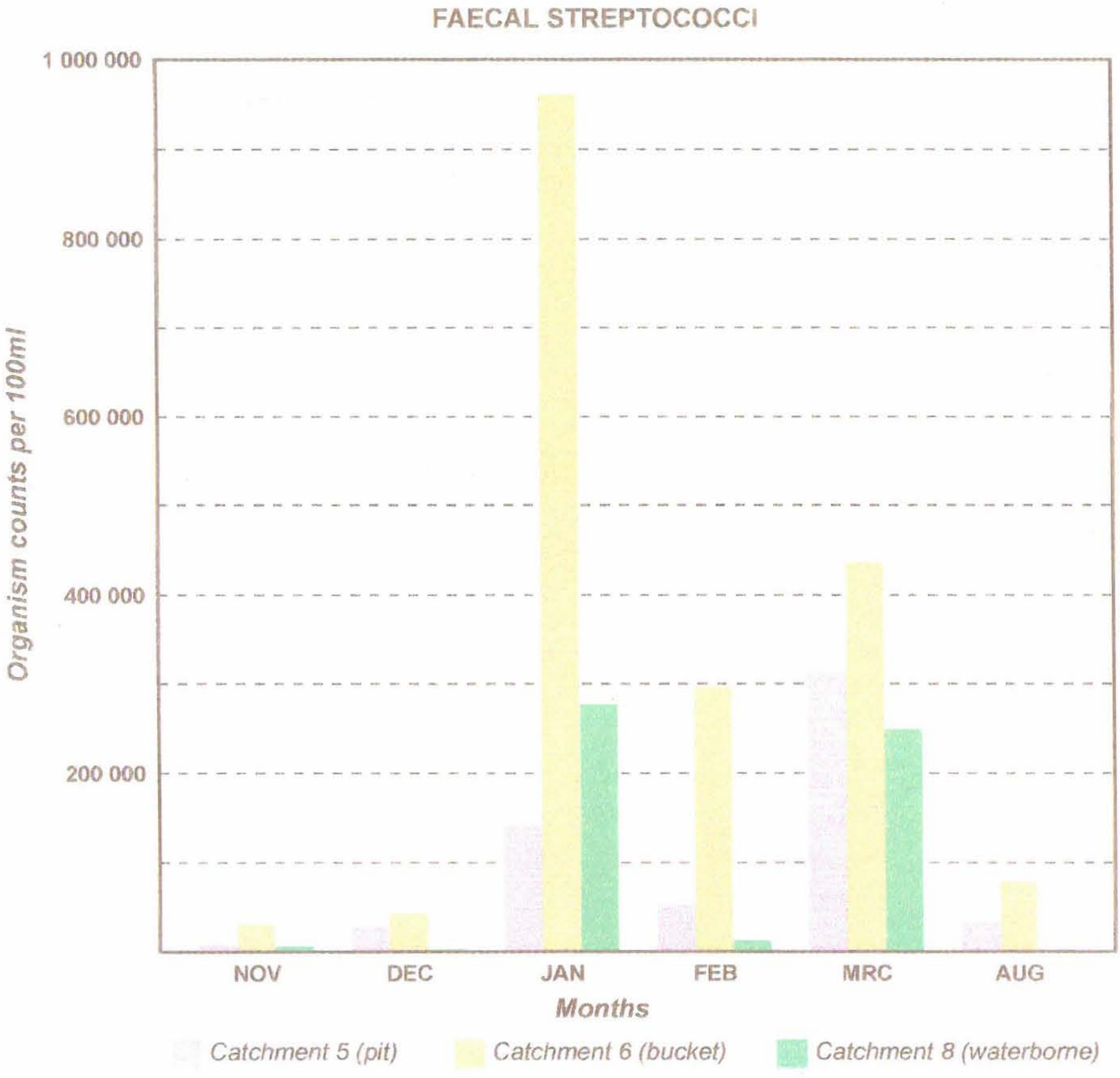

Figure 10: Mean levels of faecal streptococci in stormwater run-off in three sub-catchments.

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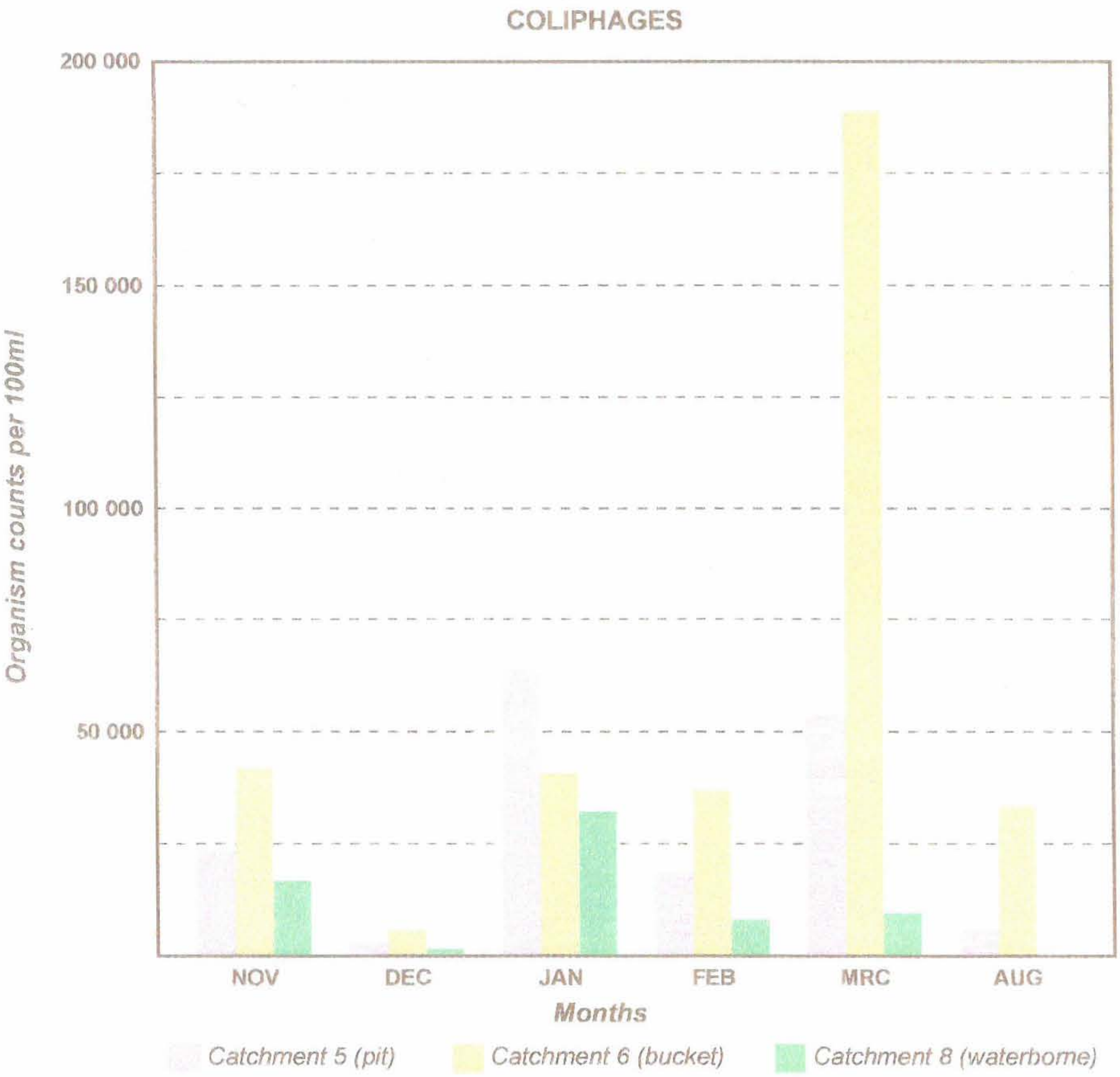

Figure 11: Mean levels of coliphages in stormwater run-off in three sub-catchments.

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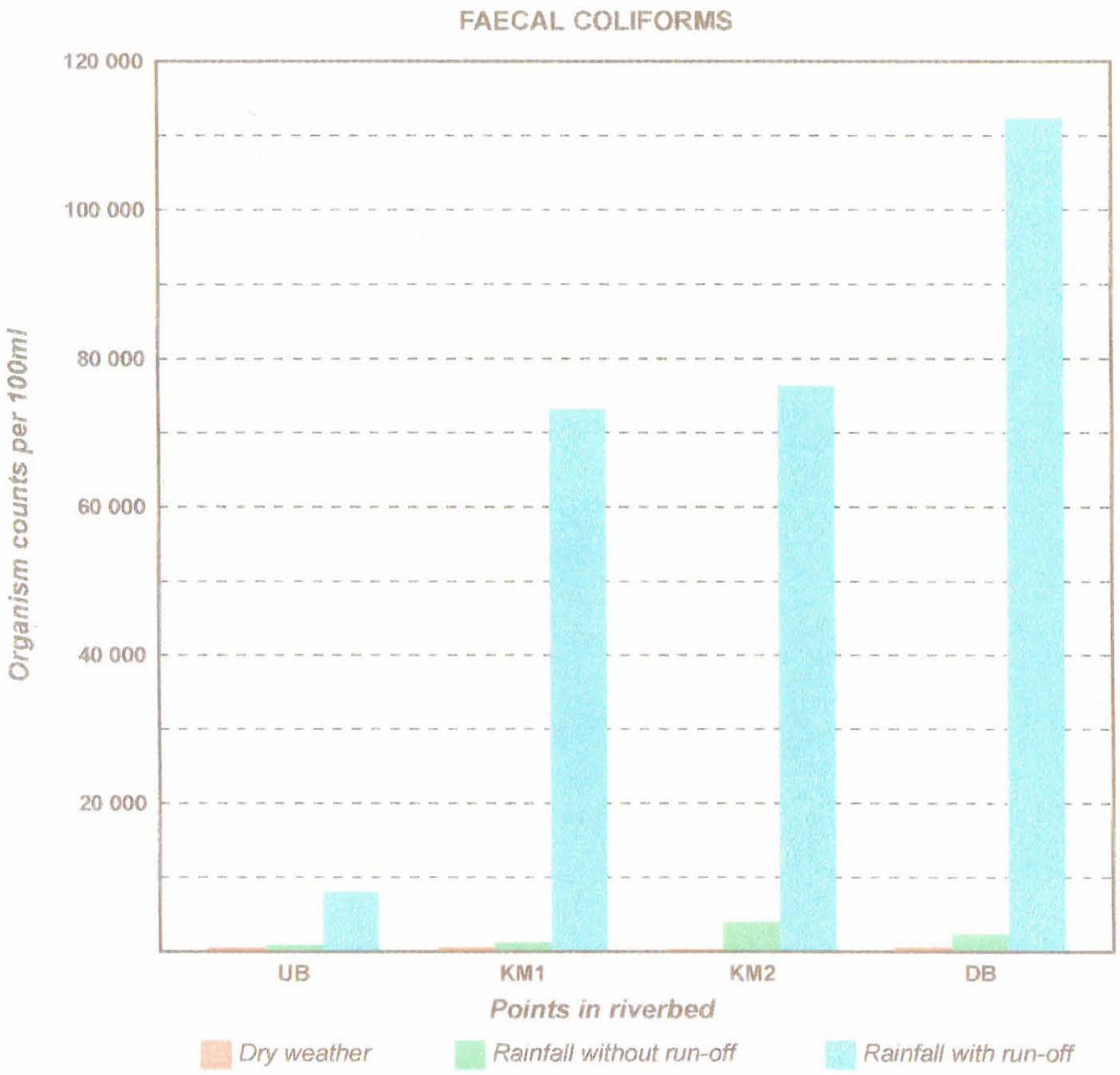

Figure 12: Mean levels of faecal coliforms in the Klein Modder River.

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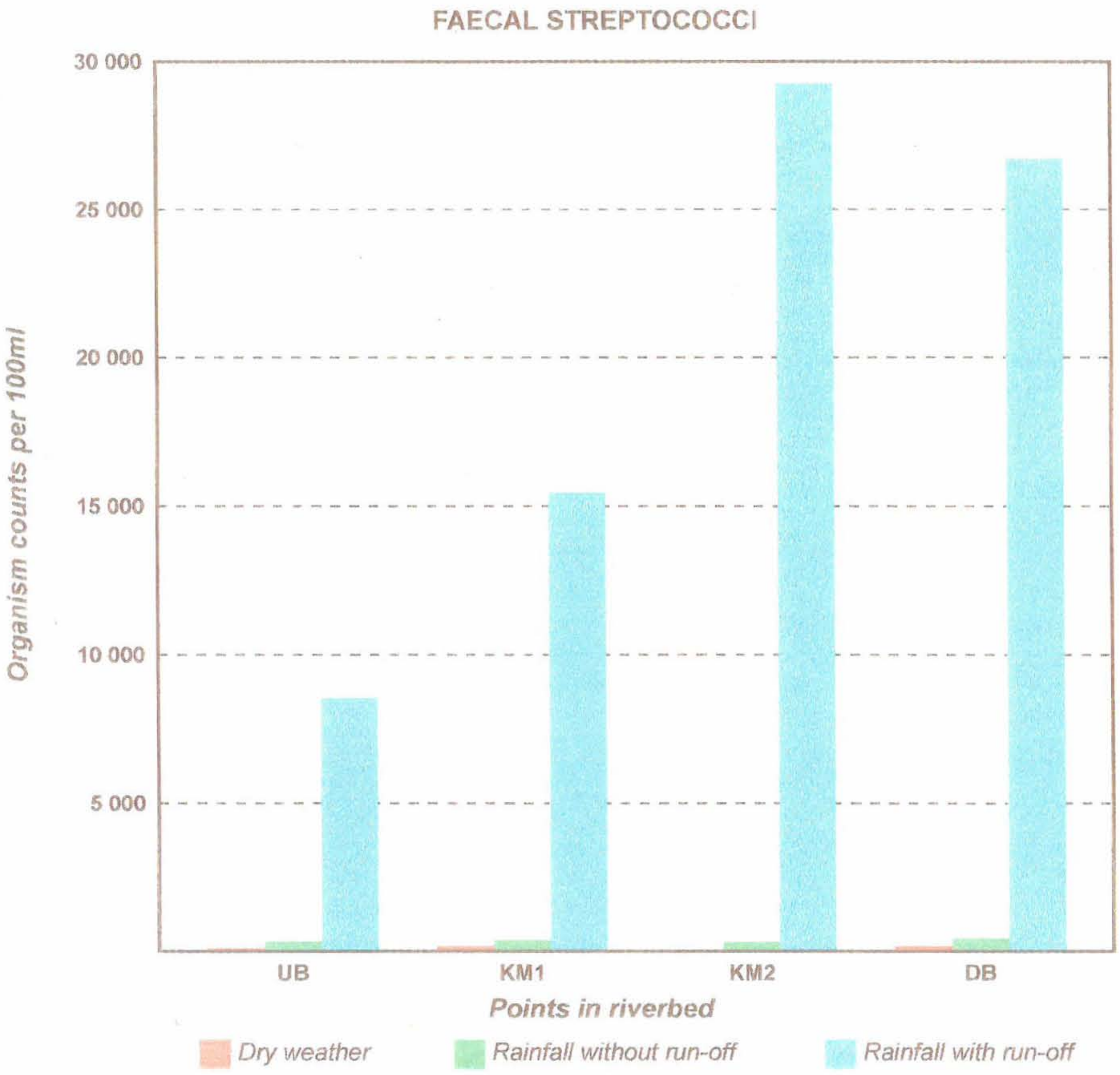

Figure 13: Mean levels of faecal streptococci in the Klein Modder River.

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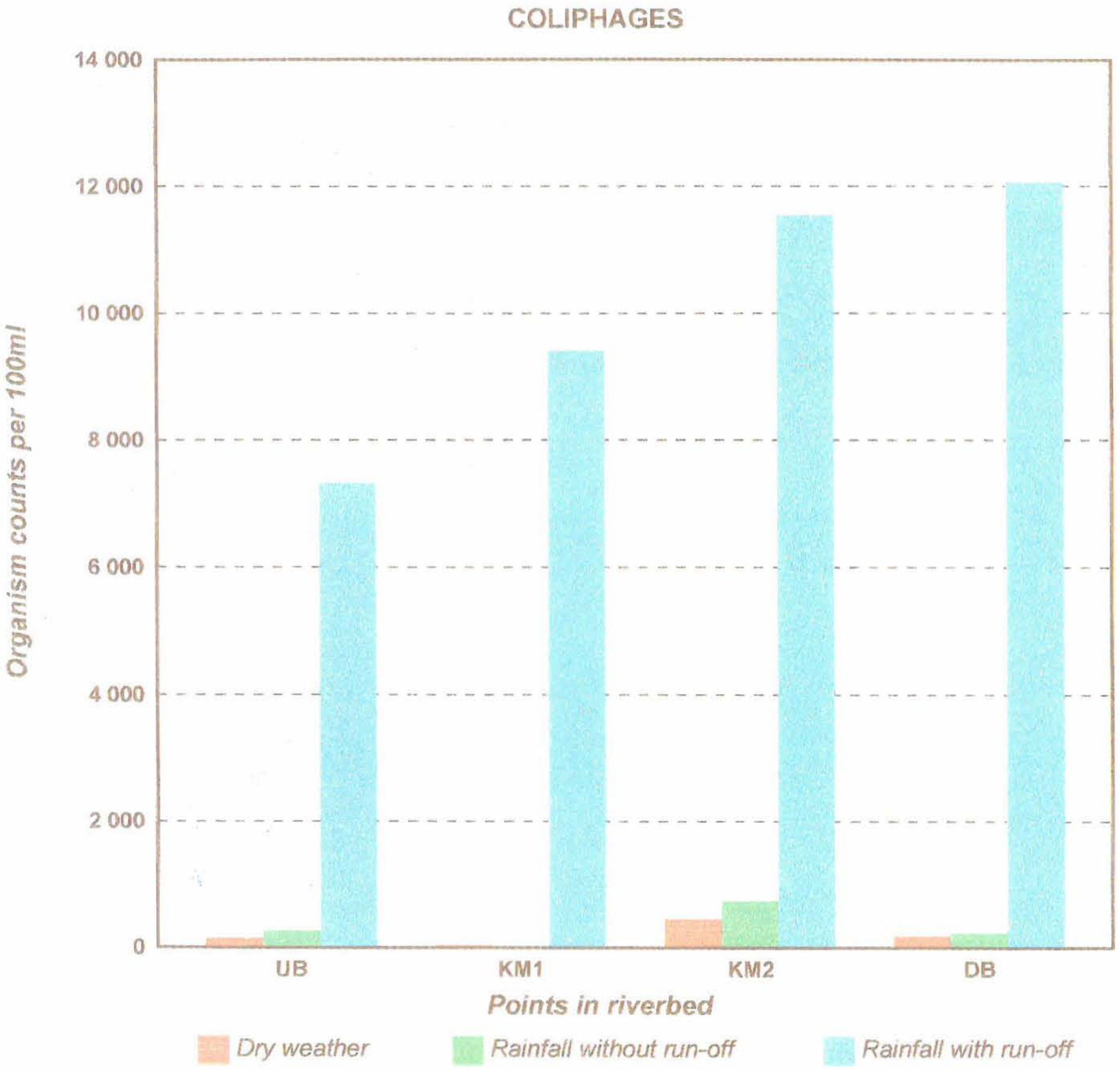

Figure 14: Mean levels of coliphages in the Klein Modder River.

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