A SITUATION ANALYSIS OF WATER QUALITY IN THE CATCHMENT OF THE BUFFALO RIVER, EASTERN CAPE, WITH SPECIAL EMPHASIS ON THE IMPACTS OF LOW COST, HIGH-DENSITY URBAN DEVELOPMENT ON WATER QUALITY

VOLUME 2
(APPENDICES)

FINAL REPORT

to the

Water Research Commission

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EXECUTIVE SUMMARY

1. Introduction and aims of the project

The Buffalo River provides water and a conduit for effluent disposal in one of the most populous areas on the East coast of southern Africa. The catchment supports a rapidly-growing population of 311 000 people, in which King William's Town, Zwelitsha, Mdantsane and East London are the main towns, and they are all supplied with water from the river. The management of the river is complicated by the political division of the catchment between Ciskei and South Africa (figure 1.1), but a joint agreement makes provision for the formation of a Permanent Water Commission for coordinating the management of the river's resources.

The river rises in the Amatole Mountains and flows South-East for 125 km to the sea at East London (figure 1.1). It can be divided into three reaches: The upper reaches to King William's Town, comprising the mountain stream in montane forest down to Maden Dam, and the foothill zone flowing through agricultural land downstream of Rooikrans Dam; the middle reaches, comprising the urban/industrial complex of King William's Town/Zwelitsha to Laing Dam, and an area of agricultural land downstream of Laing; and the lower reaches downstream of Bridle Drift Dam, comprising coastal forest and the estuary, which forms East London's harbour.

The four dams mentioned above provide the main water storage in the river. Maden Dam supplies King William's Town, Rooikrans Dam mainly supplies Zwelitsha, Laing Dam supplies Zwelitsha, and Bridle Drift Dam supplies Mdantsane and East London.

For many years there has been concern about the water quality, particularly in the middle and lower reaches of the river. Laing Dam is situated downstream of King William's Town and Zwelitsha, and receives treated domestic and industrial effluent, and the immediate catchment of Bridle Drift Dam is dominated by Mdantsane, from which four small tributaries carry domestic effluents into the dam. Major water quality concerns are the levels of salinity in the middle reaches, eutrophication in Laing and Bridle Drift Dams, and faecal contamination in Bridle Drift Dam as a result of broken sewers in Mdantsane. In particular, excess nutrients have caused nuisance algal blooms (*Microcystis aeruginosa*) in both dams. The Department of Water Affairs and Forestry (DWAF), implemented a Special Effluent Phosphate Standard of 1 mg/l in 1980, with the aim of reducing nutrients and therefore preventing algal blooms. However, this policy alone has not yet proved successful.

DWAF have recently changed their approach from pollution control to water quality management in order to achieve Receiving Water Quality Objectives (RWQO) (see figure 1.2). This study has been one of the first in the country aimed at providing information from which DWAF can set

RWQO's on a whole catchment scale.

The main aims of this project were therefore to carry out a situation analysis of water quality in the Buffalo River using existing data; to define water quality guidelines for different users; to design a water quality monitoring system; and to make management recommendations to reduce the impacts of pollution in the river. A second set of aims was to assess the effects of diffuse runoff from different types of townships in the catchment on the water quality of the river, and to derive a phosphate budget for the catchment, in order to identify the major sources of input.

2. The physical system

The Buffalo River consists of a mountain reach zone, characterised by steep, turbulent, clear water in shallow, narrow channels, followed by a foothill zone extending for the rest of the river, which is a series of riffle-pool sequences, with the riffles becoming less frequent and the pools more extensive as the river gets larger.

The catchment can be divided into three climatic zones (figure 2.2):

i) The high (1500 - 2000 mm) rainfall mountainous upper catchment
ii) The lower (500 - 625 mm) rainfall middle reaches to Bridle Drift Dam, including the major urban areas other than East London.
iii) The coastal (700 - 800 mm) rainfall zone, consisting mainly of the estuary.

Mean annual rainfall over the whole catchment is 736 mm, but the upper zone provides 40% of the runoff for the whole catchment. There are distinct seasonal differences in rainfall, summer rainfall being approximately double that for winter. Evaporation rates are 160 - 170 mm per month in December and January, reducing to 70 mm during June and July.

Most of the catchment is underlain by sedimentary rocks of the Lower Beaufort Series of the Karoo System with dolerite outcrops. Soils are a grey sandy loam derived from the Beaufort sediments and red and black clays from the dolerite. The average sediment yield in the catchment is 150 t/Km^2/annum (ranging from 1000 in the upper to 150 in the lower catchment, and totalling 66 x 10^4 t/annum). The consequence of the marine sedimentary rocks is that rain falling on the catchment rapidly picks up dissolved salts which contribute 65% of the salinity in the river.

The natural vegetation consists of five main types: False Macchia (Fynbos) at the top of the Amatole Mountains; Afro-montane forest on the slopes of the mountains; False Thornveld of the eastern province in the middle catchment; Valley Bushveld in the immediate river valley; and Coastal Forest and Thornveld in the lower reaches. There is now little of the natural vegetation remaining except in the upper catchment, and in the protected coastal forests.

The mainstream of the Buffalo River flows permanently in the upper reaches above Maden Dam, but, below the Dam, it is reduced to pools during droughts. Releases from Rooikrans Dam through the Pirie Trout Farm ensure that the river flows in the reaches immediately below the dam, but the river is often reduced to a trickle by the time it reaches King William's Town. Return flows from industry and STW's ensure the flow into Laing Dam, but there is no compensation flow released downstream of Laing. Water is released from Bridle Drift Dam to the Umzaniana Weir (7 Km downstream), below which treated sewage effluent from Mdantsane enters the river and makes up most of the base flow. Median flows in all parts of the river are less than one cubic metre per second (cumec) (table 2.1).

Natural water quality in the upper reaches has been little changed by development. Salinity is generally less than 20 mS/m, pH varies from 6.1 to 7.4, and median phosphate concentrations are less than 0.1 mg/l. in the middle reaches it is possible to predict what the natural water quality would have been in the absence of urban and industrial development: A salinity of 50 - 60 mS/m during the dry season and 30 - 35 during the wet season. Phosphate concentrations would have been less than 0.3 mg/l, and the pH would have been between 7.5 and 8.0 for most of the time.

3. Water users and requirements

Water supplies in the catchment are mainly derived from the four dams, but some of the supply to Mdantsane is met by Nahoon Dam in the neighbouring catchment. In the near future it will be possible to augment the supply with water from the Wriggleswade Dam on the Kubusi River via the Amatole inter-basin transfer scheme.

Primary users of raw water from the Buffalo River are the King William's Town (47 000 kl/month) and East London (80 000 kl/month) municipalities, Ciskei Public Works (607 000 kl/month) and Da Gama Textiles (3 660 kl/month) (figure 3.1). These users supply all the other secondary users in the catchment (listed in table 3.2).

Two methods were used to assess the water quality requirements in the Buffalo River: All users were interrogated as to their requirements by means of questionnaires, visits, and/or telephone calls, and their responses were categorised in terms of ideal, acceptable, tolerable, and unacceptable limits. The most stringent of these requirements are summarised for each reach of the river in tables 3.3 to 3.5. The second method was to use the DWAF General Water Quality Guidelines, which have been developed for each type of water use. These methods were not suitable for the definition of environmental water quality requirements, and there is not yet an accepted method for developing these. An empirical method was therefore developed, using the presence and absence of common invertebrate species to identify sites in the river which are polluted beyond the tolerances of significant proportions of the community. The ninetieth percentile of key water quality variables at these sites was defined as the tolerance limits for environmental purposes. In the middle and lower reaches of the river, salinity tolerances were estimated at 77 mS/m, and phosphate tolerances at 0.38 mg/l.

Future predictions for the catchment are that the population may increase to 6 or 700 000, that there will be a 4% annual growth in intractable industrial effluent, which could rise to 11 800 kl/day, and 119 000 kl/day of domestic effluent, with the largest increases in the Mdantsane/Potsdam area. Only moderate increases in saline effluent were foreseen for the middle reaches, but this prediction may change in the light of Da Gama Textiles' decision to move their East London operation to Zwelitsha. Very little growth is foreseen in the agricultural sector, but there may be an increase in the use of fertilisers as farming methods are upgraded.

4. Effluent producers

The major sources of return flow to the river are as follows:

i) From King William's Town via the STW or industrial irrigation schemes.
ii) From Zwelitsha via the STW and industrial irrigation schemes.
iii) Waste water from Mdantsane accidentally reaching Bridle Drift Dam from broken sewers.
iv) A small amount of irrigation return flow from the upper/middle catchment.

(Those organisations which produce effluent are listed in table 4.1. and the effluent discharge points are indicated in figure 3.1)
Three rubbish dumps situated on or near to the river banks (figure 3.1) are suspected of producing polluted seepage during local rainfall events, but at present there are no data to verify this.

All effluent producers in the Buffalo River catchment are required to comply with the general effluent standard and the special 1 mg/l phosphate standard. Two industries in the catchment use irrigation schemes to dispose of their effluent - King Tanning, a leather tannery, and Da Gama Textiles. The effect of run-off from these irrigation schemes during local rainfall events has yet to be measured, but it has been estimated that up to 88% of the salt load entering the river, other than from natural sources, is derived from these two industries.

5. The water quality situation in the Buffalo River

The major water quality problems in the Buffalo River are concentrated in the reaches between King William's Town and the inflow to Laing Dam, and in Bridle Drift Dam. Figure 5.1 shows the salinity concentrations down the river, with the highest levels (up to 5130 mg/l of TDS, or 765 mS/m) at site 18, the inflow to Laing Dam. Phosphate concentrations (figure 5.2) show similar spatial trends, reaching maximum concentrations of 15 mg/l downstream of King William's Town and at the inflows of the small tributaries into Bridle Drift Dam. Faecal bacterial counts (figure 5.3) in Bridle Drift Dam also reach unacceptably high levels (up to 15 000 cells per 100 ml) at the tributary inflows, indicating the presence of raw sewage. Samples taken in the middle reaches during 1991/92 contained much lower counts, only once exceeding the general recreational standard of 2000 cells per 100 ml (figure 5.4).

Fears have been expressed, particularly during the early 1980's, that salinity was increasing over time, particularly in Laing Dam. While it is true that salinity and nutrient levels in Laing Dam did increase from very low levels immediately after the dam was built, figure 5.5 shows that there is no discernable long-term increase in TDS in the river, but that temporary increases do occur during droughts, and the river is then flushed out, or reset, by floods. The same temporal trends are apparent for phosphate concentrations (figure 5.6) for which there are also no long-term trends in the main river. For faecal bacteria there is less data with which to discern trends, but concentrations in Bridle Drift Dam have certainly increased since the 1960's, when some initial samples were taken.

According to the results of 45 year simulations of salinity loads entering the river, the catchment runoff during wet periods contributed 65% of the load into Laing Dam, while point sources (industries and STW's) contributed 35% (figure 5.8). For Bridle Drift, the catchment contributed 45% of the salt load, point sources (spills from Mdantsane) contributed 25%, and overflow from Laing Dam contributed the remaining 30% (figure 5.9). A similar exercise to quantify total phosphate loads indicated that diffuse runoff from urban catchments dominates the loads during wet periods, but that point sources provide the majority of the load during dry periods. Of the load entering Laing Dam, urban runoff contributed 62% and point sources 30%. The contribution of the non-urban catchment is 8% (figures 5.10 and 5.11). In Bridle Drift the relative contributions were 73% from urban runoff, 19% as overflow from Laing Dam, 8% from point sources, and only 0.13% from the non-urban catchment (figures 5.12 and 5.13).

The spatial and temporal distributions of all measured water quality variables are compared with user requirements and DWAF guidelines in Tables 5.1 to 5.26 and figures 5.14 to 5.65. Few of the variables remain within the no impact/ideal limits at all times, but many are within acceptable limits for most of the time. Salinity remains within acceptable limits except at the inflow to Laing Dam, and phosphate (as ortho-phosphate) is above the 1 mg/l special standard for most of the time at the inflow to Laing Dam. Median concentrations of calcium, chlorides, total alkalinity, and turbidity all exceed tolerable limits in the middle reaches of the river, but in the upper and lower reaches, median concentrations of all variables remained within acceptable limits.

6. Variables of concern

Variables of concern are those aspects of water quality whose concentrations actually or potentially exceed user requirements or DWAF guidelines in the river. We have defined two types of variable of concern: Main variables of concern, about which users have expressed concern and which have been identified in previous studies as causing water quality problems. For the Buffalo River these are salinity, nutrients, and faecal bacteria. The second type of variable of concern includes those about which no particular fears have been expressed, but which exceed the user requirements/DWAF guidelines at some time in some part of the river. These variables have been compared with user requirements/DWAF guidelines at the "no impact/ideal" and at the "major impact/unacceptable" levels.

At the no impact level, all variables are of concern in the Buffalo River, since all at some time/place exceed the most stringent requirements. Those for which there are no or insufficient data must also be of concern until proven otherwise. Table 6.1A lists those variables in different parts of the river which exceed the major impact limits. Table 6.1B lists the variables for which there is either no data, or for which no requirements or guidelines have been defined. Calcium, total nitrogen, magnesium, and sulphate were always within acceptable limits at the major impact level, and are therefore not of concern unless they increase. There are other variables, and particularly heavy metals, for which there are insufficient data to evaluate, and for which the priority is to collect samples so that their status can be evaluated.

7. Assimilative capacity

The assimilative capacity of a water body is its ability to absorb pollutants without detriment to the recognised users. Within one water body, there are different assimilative capacities for each user, for each variable, for each level of impact, and for each season. For this project assimilative capacities have been defined for each variable for which there are data and user requirements/guidelines available, in terms of the most stringent user requirements, at two levels of impact (no impact/ideal and major impact/unacceptable), for summer and winter, in the upper, middle, and lower zones of the river. The assimilative capacities have been calculated as the difference between the highest monthly ninety-fifth percentile in each season subtracted from the relevant user requirement/guideline. Obviously, if the ninety-fifth percentile concentration is higher than the requirement/guideline, there is no available assimilative capacity.

Table 7.1 lists available assimilative capacities for each variable in terms of the major impact limits, and table 7.2 in terms of no impact limits. There is considerable available assimilative capacity for many variables at the major impact level, especially in the upper and lower reaches, but very little at the no impact level, except in the upper reaches of the river.

8. Importance of low-cost, high-density housing on water quality.

One of the main aims of the project was to assess the effects of runoff from different kinds of townships in different climatic areas. Since all the main urban areas are situated in the middle and lower parts of the catchment, where the climate is homogeneous, this was not possible, but five different townships were investigated to assess water use, waste disposal, and demographics, in order to build a picture of the effects of diffuse runoff to the river. Three hundred interviews were conducted in these townships, and the results were modelled using phosphorus as the currency, to investigate the relative contributions of different components to the loads entering the river. The townships were Zwelitsha, Mdantsane, Ilitha, Needs Camp (a resettlement camp), and Mlakalaka (a traditional village). Eight different house types were described, from elite houses to squatter shacks.

The results indicated that 56% of the households had waterborne sanitation, 28% used pit latrines, 6% had bucket systems, and 9% had no access to any kind of formal sanitation. Stand-pipes in the road provided water for 38% of the households, 30% had outside taps on the property, and 24% had taps in their houses. Three-quarters of the households used 100 to 150 l of water per day. Rubbish collection was a universal problem, with many of the households having no collection system, and those that did complaining that collection was very irregular and unsatisfactory. As a result, much of the rubbish is disposed of on the catchment, and is washed off into the river during rains. The traditional villages kept many more livestock than the urban areas, and therefore produced 2.5 times as much phosphate per person onto the catchment. Multiple use of different fuels was common, but the most popular fuel was paraffin (used by 80% of households), while 35% had electricity, 29% used wood, and 15% used gas.

Figure 8.1 shows the population distribution in the catchment, ranging from 10 people per km^2 in the upper catchment to over 1000 people per km^2 in the township areas. Table 8.1 summarises the phosphorus loads which are deposited onto the catchment by different townships, and the proportions which reach the river. Larger towns obviously produce more than smaller ones, but the production per 1000 persons is much greater in the rural villages, primarily as a result of the large number of livestock kept. The proportion of available phosphorus reaching the river is also very variable, and is largest in towns which have least waterborne sewage disposal, so that more waste is deposited on the catchment. Figure 8.2 summarises the catchment-wide simulation of phosphorus loads.

9. The water quality monitoring system

The main requirement for the Buffalo river is to monitor variables of concern at all key points in the river. It is also very important to be able to monitor discharge, since the volume of water in the catchment is a major determinant of water quality. Also important are nutrients, turbidity and water temperature, since they affect the growth of undesirable algal scums.

Suitable monitoring points would be:

- In Maden Dam
- In Rooikrans Dam
- Upstream of the Buffalo/Mgqakwebe confluence (as a reference point)
- Between King Williams Town and Zwelitsha
- In the Malakalaka stream at Zwelitsha sewage works
- Downstream of Zwelitsha, before the Buffalo River flows into Laing Dam
- On the Yellowwoods River, downstream of Bisho
- At Laing Dam wall
- At the inflow of the Buffalo river into Bridle Drift Dam
- At Bridle Drift Dam wall
- At the downstream ends of each of the main tributaries flowing out of Mdantsane into Bridle Drift (the Shangani, Sitotona, Tindelli and Umdanzani streams).

At each point, salinity turbidity, temperature, phosphates, nitrates, nitrites, ammonium and faecal coliform bacteria should be measured weekly. Heavy metals should be measured at six monthly intervals at all sites. This would be the routine monitoring system, designed to give early warnings of adverse conditions in the river. Ideally, all water quality monitoring should be the responsibility of a single authority. Table 9.1 lists the different authorities currently monitoring discharge and water quality.

For discharge there should ideally be continuous monitoring of all major tributaries, as well as upstream of all four dams on the main stream. The main areas and variable not at present being adequately monitored are: Discharge into Bridle Drift Dam; faecal bacteria in the middle reaches; seepage from the three rubbish dumps in the middle reaches; discharge from the four Mdantsane tributaries; and compliance monitoring of effluents at all STW's, King Tanning and Da Gama Textiles.

10. Potential water quality management options

10.1 The upper reaches (upstream of Maden Dam):

In the upper reaches there are at present no water quality problems. However, since 40 % of the runoff is generated in this area of the catchment, the protection of this vital supply of high quality water is essential. The management options for this section of the catchment are to continue to protect the area as a recreation and conservation zone, with limited and controlled commercial forestry, and more effective policing of the recreational use of Maden Dam.

10.2 The upper/middle reaches (to King William's Town):

This is an area of agriculture and rural settlement. At present the water quality is acceptable, although there are elevated nutrient levels, probably as a result of irrigation return flows carrying fertiliser. As for the upper catchment, the problems are potential rather than actual, and the management option should be to control the development of agriculture and the use of fertilisers, and to implement the Guide Plan (1993) recommendations for the rational development of urban areas with adequate facilities in the catchment.

10.3 The middle reaches (to Laing Dam):

The following management options are available for the middle reaches of the river:

- Upgrade all the existing sewage treatment works, and ensure stricter compliance to the 1 mg/l P effluent standard.
  These measures are already in progress, and the King William's Town STW now generally conforms to the Standard. The Zwelitsha STW has also been upgraded, and has conformed to the Standard since October 1992.
- Extension of the existing Cyril Lord pipeline to Berlin or King William's Town. The idea of the pipeline extension would be to dispose of intractable effluents out to sea, rather than treating them and returning them to the river. However, unless some agreement is reached on financing a pipeline, it seems very unlikely that these plans will progress.
- Monitor and remove or seal rubbish dumps in the catchment.
  There are three rubbish dumps in the middle reaches of the river which give cause for concern because of the possibility that pollutants leach into the river during local rainfall.
- Upgrade the squatter section in Zwelitsha. A small squatter section of Zwelitsha is situated near the banks of the river, without adequate water supplies or sanitation. The inhabitants use the river directly, causing unquantified local pollution. The priority here is to provide facilities, and this is apparently being done.
- Retain *Eichhornia* (water hyacinth) growth in the inflow to Laing Dam, so that it can serve as a nutrient sieve. This would be a controversial option, since water hyacinth is a proclaimed noxious weed.
- Use water from Wriggleswade Dam on the Kubusi River to improve conditions in the Yellowwoods River and to dilute saline water in Laing Dam. The disadvantage would be that the quality of the transferred water would deteriorate both in the Yellowwoods River and in Laing Dam.

10.4 The middle/lower reaches (from Laing Dam to downstream of Bridle Drift Dam):

The following management options are available for the middle/lower reaches :

- Control and mend the breakages in the sewer and reticulation systems in Mdantsane.
- Divert low flows from the four streams in Mdantsane to the sewage works.
- The damage to sewage pipes in Mdantsane appears to be deliberate. If it is the consequence of casual vandalism rather than conscious sabotage, then an information and education programme might help to enlighten people as to the consequences of their actions, offering a measure of prevention rather than cure for these problems.

11. Conclusions

Water quality problems in the Buffalo River are ultimately a consequence of over-population and over-development in a relatively small catchment with inadequate water resources. These problems are compounded by the political division of the catchment between Ciskei and South Africa, naturally high salinity levels derived from the catchment geology, and the position of the two largest dams immediately downstream of large townships. The political division may soon be a thing of the past, but the population growth, naturally high salinity, and position of the dams, are all likely to be persistent and intractable problems. The potential for managing water quality in the river has to be viewed within the context of these problems.

Major water users:

Water users have been defined in terms of primary users, who abstract water directly from the river, and secondary users, who are supplied with treated water, normally by their local municipality. It is principally the primary users who are concerned with the quality of raw river water, and these are the municipalities of King William's Town and East London, Ciskei Public Works, and Da Gama Textiles (chapter 3).

Spatial water quality trends:

There are two sections of the river where the deterioration in water quality gives most cause for concern (see figures 5.1 and 5.2): the section between King William's Town and the inflow to Laing Dam, where urban and industrial effluent cause increases in salinity and nutrients; and Bridle Drift Dam, where urban runoff and leakage of sewage effluent from Mdantsane result in periodic algal blooms and unacceptably high concentrations of faecal bacteria.

The role of Laing Dam in diluting saline effluent and as a sink for nutrients is very important.

Temporal water quality trends:

Despite fears expressed during the 1980's, there do not appear to be any discernable long-term increases in either nutrient levels or salinity levels in the main river (see figures 5.5 and 5.6).

Future Developments:

The main node of future development will be West of the Buffalo River between King William's Town and East London. Growth in population and in industry will lead to increased intractable industrial and sewage effluents, as well as urban runoff (chapter 3.3).

Variables of concern:

Two levels of variables of concern were designated: Main variables of concern (salinity, nutrient enrichment, and faecal contamination) are those which the water users and previous studies have identified as causing water quality problems in the river. Other variables of concern are those about which no specific complaints have been made, but which exceed the user requirements/DWAF guidelines for the river. All the variables measured in the Buffalo River fell into this category. For some variables, such as heavy metals, there is insufficient information to assess their status as variables of concern.

Sources of pollution:

Natural background salinity from the local geology contributes 65% of the dissolved salt load entering Laing Dam, and Da Gama Textiles contributes a further 21%. The main phosphate loads entering Laing Dam originate from urban run-off during high rainfall events, but effluents from the STW's are the main contributors for 70% of the time, during low flows (see figure 5.10 and 5.11).

In Bridle Drift Dam, natural background sources contribute 45% of the salt load, with a further 30% originating from Laing Dam overflows. Most of the phosphate entering Bridle Drift Dam is derived from urban runoff and overflows from Laing Dam during periods of high rainfall. However, during dry periods (for 35% of the time), the phosphate inputs are dominated by low flows from the Mdantsane tributaries (designated as point sources in figures 5.12 and 5.13).

Although the above point sources contribute only a small fraction of the phosphate load entering the dam, they constitute the fraction which is most influential in promoting the algal blooms which are the main cause of concern in Bridle Drift Dam.

Effects of low-cost, high-density housing:

In the middle reaches, diffuse urban runoff contributes 62% of the total phosphorus load reaching the river, and in the lower reaches, 73%. This compares with the point sources, which respectively contribute 30% and 8% of the loads. It was not possible to investigate the differential effects of townships in different climatic zones (see aims 6 and 7 of the terms of reference), since all the major townships are situated in the middle/lower catchment where the climate is relatively homogeneous. There were, however, major differences in the amount of nutrient produced per 1000 people in different types of township, and this was largely related to the numbers of animals kept.

An assessment of the RWQO approach:

RWQO's are set in terms of concentrations for each variable from which acceptable waste loads can be calculated. While this may be a reasonable approach for conservative elements such as the major ions which contribute most to total salinity, it is not suitable for predicting the effects of nutrients, which cause secondary problems such as algal blooms. The algal blooms are not simply a consequence of nutrient loads, but are in fact a consequence of a suite of conditions, including light penetration, temperature, stratification, and levels of turbulence in the water, as well as the availability of nutrients. In the case of Bridle Drift Dam, the influent phosphate loads and resulting concentrations are a very poor indication of the likelihood of algal blooms. A clear understanding of the physical and biological processes in the dam are a prerequisite for predicting the conditions which lead to algal blooms.

12. RECOMMENDATIONS

N.B. One of the results of this investigation has been to stimulate activity to improve water quality in the Buffalo River. A number of the recommendations listed below (and specifically those in section 12.1) are being planned or executed already (R. Kahn and A. Lucas, pers. comm.).

Improvements to the infrastructure in the catchment

Upgrade all the existing sewage treatment works in the Buffalo River catchment to comply with the 1 mg/l P effluent standard.

Upgrade the water supplies and sanitary facilities in the squatter section in Zwelitsha, so as to reduce the inhabitants' direct dependence on raw river water, and to reduce their contribution to the local pollution in the river.

Control and mend the breakages in the sewer and reticulation systems in Mdantsane which are resulting in partially treated or untreated sewage flowing down the Mdantsane tributaries into Bridle Drift Dam, and in the loss of treated water from the reticulation system.

Intercept low flows from the four streams in Mdantsane by means of weirs at the downstream ends, and divert the water to the sewage works, in order to prevent spillages from Mdantsane entering Bridle Drift Dam.

Water Management

Use water from Wriggleswade Dam to improve conditions in the Yellowwoods River and to dilute saline water in Laing Dam. (N.B. This recommendation is dependent on an analysis of the volume required to affect salinity in Laing Dam, an analysis of the effects of inflows on nutrient processes at the inflow to Laing Dam, and a cost benefit analysis of alternative uses and pathways for the Wriggleswade water).

Monitoring

Monitor the three rubbish dumps situated next to the river, so as to measure the effect of leachates on water quality during local rainfall events, and remove or seal them if they prove to be contributing significantly to water quality deterioration.

Determine the impact on the river of runoff from the Textile and Tannery irrigated effluent during local rainfall events.

Install a flow gauging weir and associated water chemistry sampling site upstream of the inflow to Bridle Drift Dam, in order to calibrate the hydrological model for assessing loads flowing into the reservoir.

Information and education

In cooperation with the residents' associations of Mdantsane organise information days to inform the local people of the consequences and financial implications caused by vandalism to their sewage and reticulation system.

TERMS OF REFERENCE

The primary aims of this investigation were two-fold:

- To undertake a detailed situation analysis of water quality in the Buffalo River catchment, eastern Cape, and
- To quantify the impacts of low-cost, high-density housing developments on water quality in the catchment.

To achieve these primary aims, the following secondary aims were addressed:

1. Identify the major users of water from the Buffalo River and their water quality requirements.
2. Define water quality guidelines and criteria for the different water users in the Buffalo River catchment.
3. Assess the present water quality in the Buffalo River catchment and define the water quality variables of concern.
4. Identify and quantify the sources of pollution, including both point and non-point sources.
5. Provide the Department of Water Affairs and Forestry with information on the existing water quality situation from which they will determine the assimilative capacity of the catchment for the water quality variables of concern.
6. Identify low-cost, high-density urban developments in different climatic zones which have an impact on water quality in the Buffalo River, with particular emphasis on the eutrophication of downstream impoundments.
7. Evaluate the temporal and spatial distribution of phosphorous loads from these urban developments and their effects on water quality in downstream impoundments.
8. Quantify and compare the impacts of both point and non-point source phosphorous loads.
10. Assess the present water quality monitoring programmes and data sources in the Buffalo River catchment. Design a water quality monitoring system that will enable the Department of Water Affairs to manage water quality in the Buffalo River catchment.
11. Recommend possible management actions to ameliorate or reduce the impacts of water quality problems in the catchment.

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CONTENTS

APPENDIX A

LITERATURE REVIEW

by

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1. TOPOGRAPHY AND DRAINAGE

The Buffalo River catchment is situated in the Border Region of the Eastern Cape of South Africa and reaches the sea at East London (32°02'S : 27°45'E) as a fourth order stream. The Buffalo River is a warm, turbid, polluted, alkaline system (O'Keeffe *et al*, 1990), with four man-made impoundments along the river.

The catchment originates in the afforested, high rainfall area of the Pirie Mountains near Stutterheim and Keiskammahoek at an altitude of 1300 m (Palmer and O'Keeffe, 1989a). The river runs in a south-easterly direction, passing through King William's Town, Zwelitsha and Mdantsane. After a distance of almost 125 km it discharges into the sea at East London, the only river port in South Africa. The catchment covers an area of 1276 km², 70% of which falls under the jurisdiction of the Ciskei Government (figure 1).

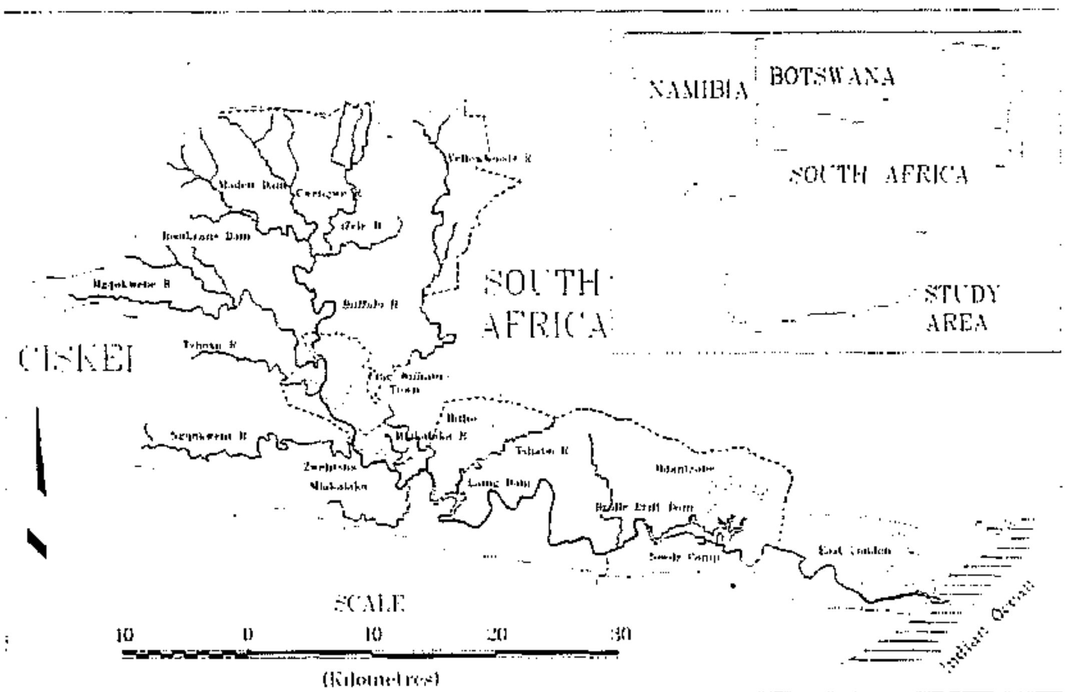

Figure 1. The Buffalo River catchment showing the Ciskei/South Africa borders.

The upper Buffalo River catchment area is characterised by its high altitude and steep gradient, which reduces along its length. The upper reaches of the Buffalo River catchment range in altitude between 900 m and 250 m (Board, 1962). The important tributaries, the Yellowwoods, Izeli, Cwencwe and Green Rivers are all in the more exposed upper area and

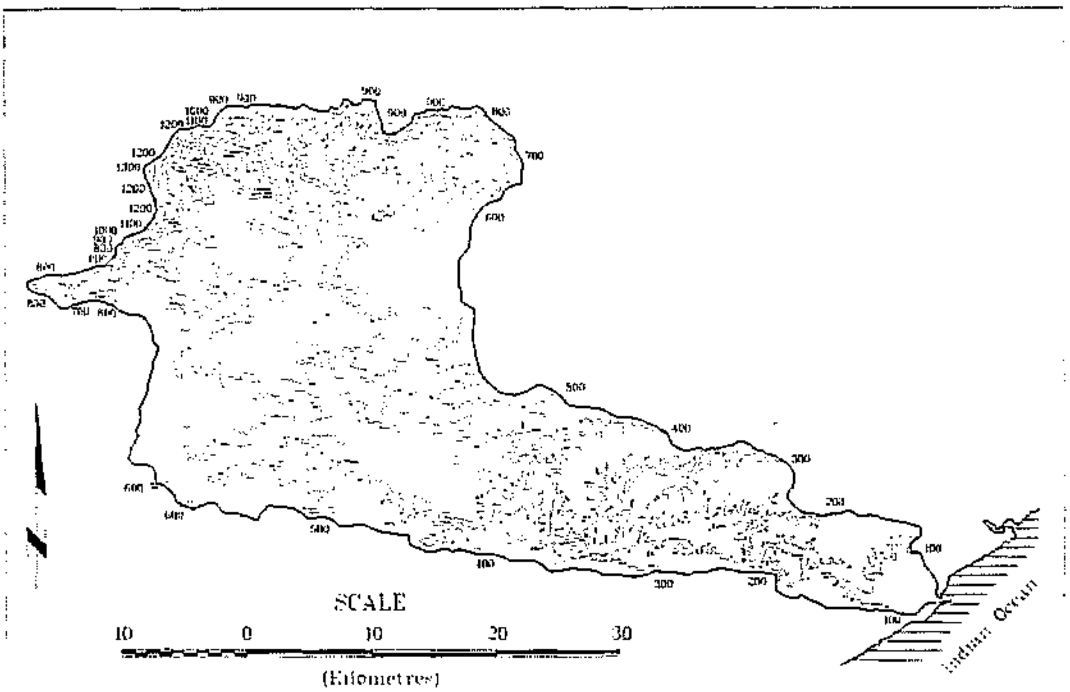

Figure 2. The Buffalo River catchment showing the change in altitude from the upper reaches to the lower reaches of the river.

middle reaches of the catchment. The valleys towards the coast are deeply incised below the level of the coastal plain. The lower coastal belt, which lies between the coast and an altitude of about 250 m, is approximately 10 km in width. Close to the sea the catchment becomes very narrow and the river runs in a gorge, the tributaries are short and have steep gradients. A tidal effect reaches 10 km upstream (Mountain, 1945; 1974, Ninham Shand and Partners, 1976) (figure 2).

2. CLIMATE

High evaporation and low, variable rainfall are typical of the catchment (Hart, 1982). Rainfall ranges from a mean annual value of 930-2000 mm in the upper reaches to an average of 450-640 mm in the middle reaches (King William's Town), and 762-900 mm in the lower reaches (East London) (Thornton *et al*, 1967; Stone, 1982; Schwab *et al*, 1988). Rainfall maxima occur from spring to autumn, and precipitation is usually in the form of short storms (Watling *et al*, 1985). The Buffalo River drains some 1 300 km^2 of summer rainfall in a semi-arid/temperate transition region of South Africa (Hughes and Görgens, 1982). During 1899 the Buffalo River was completely dry (Tankard, 1990)

3. REGIONAL GEOLOGY

The region is not well endowed with mineral wealth (Thornton *et al*, 1967). The geology of the catchment consists predominantly of sedimentary rocks of the Lower Beaufort Series (Adelaide Subgroup) of the Karoo System (Mountain, 1945, 1974; Thornton *et al*, 1967; Hiller and Stavrakis, 1980; Hart, 1982; Stone, 1982; Weaver, 1982) with a few dolerite outcrops (Stone,1982). In places the slopes are almost vertical forming bare rock cliffs up to 120 m in height. Below the cliffs the surface is strewn with large dolerite and sandstone boulders (Ninham, Shand and Partners, 1976). A feature of the middle plateau is the occurrence of hills formed partly of marine deposits and indicating relatively recent geological submergence beneath the sea.

4. SOILS

Mountain (1945, 1962, 1974), Bader (1962), Stone (1982) and Weaver (1982) have reviewed the soils and sediment production within the catchment. The Beaufort sandstones weather to produce a grey sandy loam with an average clay content of 23%, which may be largely impermeable, reducing the potential for infiltration and soil moisture storage. The dolerite outcrops weather to form two different types of soil :

- red dolerite clays with a clay content of 55% and high porosity,
- black clays with a clay content of 38% and a lower porosity than the red clays (Stone, 1982).

Middleton *et al* (1981) reported that the catchment has a sediment yield of 150 t/km^2/annum. Weaver (1982) based on Rooseboom and Coetzee (1975) found the sediment production to be 1000 t/km^2/annum in the upper catchment, 500 t/km^2/annum in part of the middle plateau and 150 t/km^2/annum only in coastal belt of the catchment. The total annual sediment yield according to the sediment map is estimated at $66*10^4$tons (Weaver, 1982).

5. VEGETATION AND LAND USE

The extent to which changing landuse alters the characteristics of run-off from catchments is a crucial environmental factor affecting dams and reservoirs (Whitmore and Reid, 1975). Acocks (1975), Trollope and Coetzee (1978) and Daniel (1982) maintain that human activity has accelerated the Karoo invasion to the east, and Acocks (1975) predicted that this invasion would stretch to the east of Peddie by the year 2050. Downing (1978) mentions that the rate of encroachment of Karoo vegetation is 2,4 km per year rather than the slower rate of 0,44 km per year derived by Acocks (1975), and is due to agricultural activity. Acocks (1975) stated that in spite of this Karoo invasion the principle Veld Types will remain as bushveld, forest and scrubland in the Buffalo River catchment. Daniel (1981) stressed the need for better planning in agricultural development. Only 10% of the area under agriculture is allocated to pineapple farming, the remaining 90% is pastoral (Watling *et al*, 1985). The steeper slopes in the upper and lower catchment reaches are heavily forested, covering an area of approximately 140km^2.

Irrigation covers an area of 8,5 km^2 (Middleton *et al*, 1981). Urban areas occupy only 9% of the total catchment with forestry and agriculture occupying a further 75% (Watling *et al*, 1985).

The coastal belt has coastal forest and thornveld vegetation, while the middle plateau is mainly covered by valley bushveld (Mountain, 1974). Over time the natural vegetation has been replaced by scrub and grassland, due to the removal of forest for agricultural purposes.

6. INDUSTRIAL AND POPULATION GROWTH

Hart (1982) anticipated industrial growth due to stimulated efforts of the government in the East London area and the independence of Ciskei. The slow rate of economic growth is aggravated by rural-urban migration, the high rate of population increase amongst blacks and the resettlement policies (Daniel, 1982).

The Buffalo River catchment was inhabited by some 200 000 people during 1967 (Thornton *et al*, 1967), and the majority of these people lived in or near King William's Town and East London. Daniel (1981) found a population increase of 27% in the Ciskei from 1975-1980. According to Watling *et al* (1985) and Pike (1989) approximately 0.5 million people now reside in the catchment, of which 57% live in the urban areas. This shows a population increase of more than 100% since 1966. The average population density in the catchment was 400 per km^2 during the study by Hart (1982). This high population density gave rise to high overall water demands. Hart (1982) foresaw an increase in the catchment utilisation due to industrial development in the East London area by the Government. According to Smit (1979), Mdantsane is one of the biggest homeland towns and one with a rapid population growth and serious squatter problems.

7 PHYSICAL/CHEMICAL AND BIOLOGICAL CHARACTERISTICS

7.1 Hydrological characteristics

Selected hydrological characteristics of the four impoundments in the river are presented in Table 1.

Board (1962) reports that the Buffalo River usually has perennial flow although periods of no river discharge during droughts (1945 and 1949 as well as 1899 (Tankard, 1990)) occurred. This suggests very limited groundwater storage (Stone, 1982).

Any comprehensive assessment of the state and potential of the surface water resources of the Karoo Biome would have to account for changes in runoff patterns and volumes, as well as research on possible changes or dynamic equilibrium that may have accelerated during the past few decades (Görgens and Hughes, 1982). Runoff is very sensitive to changes in the hydrological processes preceding it. A relatively small change in a major factor such as the amount of water retained in a catchment, induced by changes in land management, has proportionately a much greater effect on a smaller factor such as runoff (Whitmore, 1967). The implications of reduced vegetation cover due to increasing population pressures, and any depression in the economy to the hydrological cycle and the production of sediment have not been quantified for the catchment (Hart, 1982). Thornton *et al* (1967) noted the lack in Buffalo River flow data for determining the correlation of runoff due to irrigation and the mineralisation within the river.

7.2 Temperature characteristics

Both Laing and Bridle Drift Dams are warm monomictic impoundments with turnover during April-June (1978) (Tow, 1980a, 1980b).

Impoundments cause alterations to the temperature characteristics of the receiving river. Laing Dam with surface-releases had a slight dampening effect on downstream river temperatures, while the bottom-releases of Bridle Drift Dam caused reductions of up to 16°C in river temperatures downstream (Palmer and O'Keeffe, 1989a).

7.3 Mineralisation

Total dissolved solids (mg/l) levels can usually not economically be removed or reduced, once added to water, so minerals represent a permanent form of degradation.

Farming activities were restricted to pastoral agriculture during 1966-1967 and fertilisers were not widely used (Reed and Thornton, 1969). However, salinity was then already regarded as one of the major problems in the catchment. The major input of mineralisation (± 61%) originates from natural geological sources, while ±27% came from industrial origins (textile and tannery) and only 12% from human output (Reed and Thornton, 1969).

Geological formations result in deterioration of the water quality upstream of King William's Town. Downstream of King William's Town effluent irrigation is the main cause of the increase in mineral content of the water. The Isana Stream, which drains the tannery effluent is the main source of salt (Thornton *et al*, 1967).

The total dissoved solids (TDS) content of Laing Dam is high and appears to be increasing to unacceptable levels according to Ninham Shand and Partners (1982). Since 1978 the TDS content of water in Laing Dam has risen from aproximately 150 mg/l to over 600 mg/l by the end of 1982. This is in excess of the maximum desirable limit of 500 mg/l accepted for potable supplies (Bruton and Gess, 1988; Pike, 1989).

7.4 Eutrophication

Phosphorus is an essential element for all life. In aquatic ecosystems it is often the growth or yield limiting nutrient (Wiechers and Heynicke, 1986). Selkirk and Hart (1984) found that the available phosphate in the sediments of Rooikrans Dam was extremely low and in Laing Dam very high. Toerien and Tow (1976) suggested that Laing Dam (like virtually every other lake and reservoir in the world) acts as a phosphorus trap; this finding was confirmed by O'Keeffe (1989) and O'Keeffe *et al* (1990). The dam would thus be expected to respond slowly to decreased external phosphorous loading. Laing Dam was found to be nitrogen limited and Bridle Drift Dam was phosphate limited, with few available phosphates in the sediment. High inflows from Laing Dam with their high phosphate concentrations should be controlled (Toerien and Tow, 1976).

If the 1 mg/l phosphorous effluent standard had been applied since 1985 at all point sources in the catchment, the phosphorus content in the Buffalo River might have changed to the predictions of Grobler and Silberbauer (1984) as seen in Table 3.

Laing Dam is potentially eutrophic due to total phosphate concentrations of higher than 50 μg/l which might cause algal growth problems (Thornton *et al*, 1967; Reed and Thornton 1969; Tow, 1980a, 1980b; Walmsley and Butty, 1980a; Selkirk and Hart, 1984; Schwab *et al* 1988). High turbidity (Hart, 1982; Van Ginkel and Theron, 1987; Schwab *et al*, 1988)

Table 1: Selected hydrological characteristics of the four major impoundments in the Buffalo River catchment (FSL - full supply level; MAP - mean annual precipitation; MAR - mean annual run-off) (Ninham Shand and Partners, 1976; Tow, 1980a, 1980b, 1981; Balzer, 1985; Palmer and O'Keeffe, 1989a; DWA, 1990a, 1990b)

Hydrological characteristics	MADEN	ROOIKRANTZ	LAING	BRIDLE DRIFT
Distance from the sea(km)	137	134	65	24
Year of completion	1910	1953/1969	1951/1977	1968/1984
Altitude (m)	525	518	310	109
Catchment area (km^2)	31	48	913	1176
FSL capacity (*10^6m^3)	0.32	4.91	20.87	101.70
FSL area (ha)		75.7	204	746
FSL mean depth (m)			10.4	12.3
FSL max depth (m)			37.5	40.9
MAP (mm)			695	
MAR (*10^6m^3)	8	11	51	114
Inflowing rivers	Buffalo	Buffalo	Buffalo Yellowwoods Tsaba	Buffalo Shangani Sitotona Tindelli Umdanzani
Sediment loads	0.5	0.5	0.2	0.2
Areas served	KWT	KWT	KWT Zwelitsha Mount Coke Ndevane Berlin Ilitha Phakamisa Bisho	East London Mdantsane Potsdam

inhibits the algal growth in Laing and Bridle Drift Dams. This indicates the self-purification potential for the Buffalo River water quality (Thornton *et al*, 1967; Selkirk and Hart, 1984; Palmer and O'Keeffe, 1990). The algal biomass is nevertheless excessive (Ninham Shand and Partners, 1982) in spite of this 'natural' environmental control mechanism. The electrical conductivity in the system, especially in Bridle Drift Dam, must not be allowed to increase as it will have an increasing effect on the flocculation potential and thus increase in water transparency (Selkirk and Hart, 1984), with the threat of increasing algal blooms. Ninham Shand and Partners (1982) noted that the uncontrolled discharge of sewage and industrial effluent which is only partially treated causes major problems in the water quality, both upstream and in Laing Dam. Selkirk and Hart (1984) doubted whether the Amatola Scheme (Directorate of Water Affairs, 1981) would have a lasting effect on the water quality of Laing Dam and downstream Buffalo River, because of possible turbulence and diluting effects it might have on the system. Sewage and industrial effluent have been identified as the major point source contributors to phosphorus loads in the fresh water environment in South Africa (Taylor *et al*, 1984).

Water quality is determined by a variety of chemical, physical, aesthetic and biological attributes (Kempster, Hattingh and Van Vliet, 1980; Pike, 1989). The first study on the water quality of the Buffalo River was done by Thornton *et al* (1967) during 1961 - 1963. At this time Mdantsane was not yet developed, nor was Bridle Drift Dam. Reed and Thornton (1969) studied the system in 1966 -1967 shortly after the completion of the Bridle Drift Water Scheme. According to Hart (1982) the water quality is degraded from a naturally elevated baseline condition (Thornton *et al*, 1967, Reed and Thornton, 1969) as a result of industrial, domestic and agricultural effluent, but the relative contributions to mineralisation and eutrophication are not known. Selkirk and Hart (1984) investigated the sensitivity of the major impoundments in the Buffalo River catchment to eutrophication. The minima and maxima of different water quality indices for which the catchment has been analysed, particularly in Laing and Bridle Drift Dams and the inflowing Buffalo River, are presented in Table 2.

Thornton *et al* (1967) found that deterioration of the water quality downstream of King William's Town was mainly due to human activity and that the Buffalo River could not assimilate the pollution entering Laing Dam.

The Buffalo River estuary was found to be contaminated with a wide variety of toxic substances in the form of metal levels. These levels were much higher than in other estuaries in South Africa (Watling *et al*, 1985).

7.5 Biology

In the early studies the faunal composition of the Buffalo River gave no indication of deterioration in water quality during 1961 - 1963 (Thornton *et al*, 1967). Jackson (1982) compiled a list of fish occurring in the catchment and briefly described each species (Anon, 1953, Harrison, 1952, 1954, 1963; Hey, 1944; Jubb, 1967; Place, 1955; Skead, 1955, 1958, 1959; Skelton, 1977; Trewavas, 1981 and Welcomme, 1981). There are 13 endemic and 7 introduced fish species. The trout (*Salmo gairdneri*) fish population is used mainly for angling. According to Jackson (1982) gillnet catches on Laing Dam suggest that of commercial fishing by the local population would be feasible, although this practice does not occur. Fish kills in the middle reaches of the river, due to pollution, were noted by Jackson (1982).

Selkirk and Hart (1984) seriously questioned the chlorophyll results of Tow (1979, 1980a, 1980b, 1981) as their chlorophyll data was 20 times higher and the nutrient levels were lower than in 1975 - 1978. Toerien and Tow (1976) mentioned that algal blooms have been observed in Laing and Bridle Drift Dams and a hyacinth infestation in Bridle Drift Dam was successfully eradicated.

7.6 Bacteriology

A few tributaries of the Buffalo River have been examined bacteriologically by Thornton *et al* (1967) and heavy faecal contamination was found in the Ncabanga Stream. No further bacteriological studies were undertaken prior to the East London Municipality's monitoring programme that started in 1987.

7.7 Water agreements

An agreement between the Governments of the Republics of the Ciskei and South Africa concerning the utilisation of water resources of common interest and the management of communal water works, was signed on November 20, 1981 according to the Helsinki Rules. Table 4 summarises the water allocations as they were during the study of Ninham Shand and Partners (1982). This agreement did not refer to irrigation rights nor to the quantity of water to be used for this purpose. Provision was made for the later incorporation of such an option. Stoffberg (1985) note that due to reservations regarding water reclamation (Meiring *et al.*, 1983) it has been decided to implement the Amatola Scheme (Directorate of Water Affairs, 1981) which will bring in additional water from the Kubusi River.

Water use in East London and Mdantsane was approximately $27*10^6$ m^3/annum (Meiring *et al*, 1983). The water allocations from dams in the catchment during the study of Ninham Shand and Partners (1982) are shown in Table 4.

Table 2 : Compiled minimum and maximum concentrations of different water quality indices found in the two major impoundments in the Buffalo River catchment during previous studies (Tow, 1979, 1980a, 1980b, 1981, NIWR, 1980, Walmsley and Bruwer, 1980, Van Ginkel and Theron, 1987) (ND = not detected).

Variable	Laing Dam				Bridle Drift Dam			
	Buffalo River		Dam station top		Buffalo River		Dam station top	
	Min	Max	Min	Max	Min	Max	Min	Max
Na (mg/l)	8	417	33	82	23	159	49	70
K (mg/l)	1.9	8.2			2.8	21.7	4.6	8.9
Ca (mg/l)	8	47			9.3	42.2	11.1	20.9
Mg (mg/l)	3	36			6.7	44.0	10.7	19.0
SO_4 (mg/l)	21	128			6.8	39.9	11.1	25.8
Cl (mg/l)	35.2	324	40	102	36	280	44	86
Si (mg/l)	4.9	9.7			6.6	7.9		
EC (*mS/m*)	32	194	21	62	12	111	26	45
Alk (mg/l)	64	249			21	170	57	86
TN (mg/l)	0.44	9.55	0.30	5.31	0.06	7.88	ND	3.42
Diss N (mg/l)	ND	8.44	0.03	4.16	ND	6.81	ND	1.33
NH_4-N (mg/l)	ND	4.52	ND	1.21	ND	6.08	ND	0.27
NO_3-N (mg/l)	0.94	5.74	0.66	2.61	ND	6.08	0.18	2.88
NO_2-N (mg/l)	ND	0.45	ND	0.02	ND	0.08	ND	0.05
TP (mg/l)	0.081	6.36	0.40	2.56	0.072	3.28	0.20	9.28
T diss P(mg/l)	0.033	5.80	0.24	0.93	0.05	1.20	0.13	0.88
PO_4-P (mg/l)	0.08	3.30	0.06	0.31	0.009	0.32	0.02	0.38
Temp (°C)	10.9	26.6	12.8	26.9	10.4	26.6	12.1	26.8
DO			6.4	9.5	0.1	8.1	5.5	11.5
Turbidity (NTU)	3	120	19	122	5	1100	42	160
pH	7.1	9.0	7.1	8.1	7.0	8.5	7.1	8.1
Suspended solids (mg/l)	3	257	5	90	9	2276	8	85

Chl a (µg/l)			ND	2.22			ND	39.56
Secchi depth(m)			0.04	0.45			0.05	1.00

Table 3 : Prediction for the total phosphorus content in the Buffalo River catchment (Grobler and Silberbauer, 1984) with the implementation of the 1 mg/l phosphate special effluent standard.

Years of prediction	1981	1985	1995	2000
Total Phosphorous tonnes P.a^{-1}	29	6	9	11

Table 4: The water apportionment from existing dams on the Buffalo River (From Ninham Shand and Partners, 1982)

Dam	R.S.A.	Ciskei	Total net assured yield
	million cubic metres per annum		
Maden	0.75	-	0.75
Rooikrans	2.65	2.15	4.80
Laing	10.92	4.18	15.10
Bridle Drift	15.90	8.40	24.30
Total	30.22	14.73	44.95

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APPENDIX B

SAMPLING AND ANALYSIS METHODS

by

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CONTENTS

1. INTRODUCTION

This section summarises all the sampling and analysis methods that were used during the course of the project.

2 SAMPLING AND ANALYSIS METHODS

2.1 Physical/Chemical and Biological data

2.1.1 *Hydrological data and modelling approach*

Total annual flow data were measured by continuous flow meters at the Department of Water Affairs and Forestry (DWAF) gauging weirs and the rainfall data were supplied by the Weather Bureau. In both cases use was made of the CCWR network to collect the data.

2.1.2 *Basic modelling methodology*

Given the quantity and quality of the available data, it was decided that a monthly time-step modelling approach would be the most appropriate and that the most suitable model to use would be the widely known Pitman model. All the basic information required to set the model up for the different parts of the region was available. In addition, initial estimates of the model parameter values were available from the relevant volume of the Water Resources of South Africa (Middleton *et al*, 1981).

To simulate the conditions in the major dams of the system, a version of the RESSIM simulation program developed at the Institute for Water Research, Rhodes University (Hughes, 1992) was used. Both of these models were contained within an integrated software package that allowed several different types of model to be operated within the same environment.

The total Buffalo River catchment was divided up into 38 relatively homogeneous sub-catchments on the basis of the available information on land use and climate characteristics as well as the position of the streamflow gauging stations and the location of the major abstraction or return flow points. The distribution of these sub-areas is illustrated in Appendix G.

The initial simulation exercise involved a progessive calibration of Pitman's rainfall-runoff model, starting in the upstream areas and gradually working down to the outlet at R2H002.

Part of this process also involved simulating the historical conditions in the major reservoirs. The starting points for parameter value estimation were always the regional values specified by Middleton *et al* (1981). As the calibration exercise progressed downstream, more and more sub-areas became involved where observed data were not available for calibration purposes. In these cases the parameters values were transferred from similar sub-areas already calibrated, but accounting for any major differences in land use or water consumption. This calibration exercise was based on the 10 years of data obtained from 1964 to 1973.

Once an acceptable parameter set was derived for all the sub-areas a common period of 46 years (1930 to 1975) was used to simulate a typical flow regime that may be considered applicable to the current day situation. This means that any parameters of the rainfall-runoff and reservoir water balance models that relate to water consumption, or other historically dynamic conditions, were fixed to reflect present day situations. Thus, the simulated time-series of flow may be considered representative, but cannot be compared with historical flow records.

2.2 Chemical data

The Hydrological Research Institute, Department of Water Affairs and Forestry (HRI - DWAF); East London Municipality (ELM) and the South African Bureau of Standards (SABS - for Pollution Control (PC)) measured electrical conductivity and ortho-phosphate concentrations at bi-weekly (HRI - DWAF, ELM) and monthly (PC) intervals. All available data from these monitoring programmes were combined for the different sites to give a more complete set and longer time series of data.

Statistical Analysis: Annual median, minimum and maximum concentrations were calculated for all variables in the Buffalo River (Appendix D).

2.3 Biological data

Water samples for bacteriological analysis had been collected bi-weekly by ELM since 1989 in the four inflowing streams from Mdantsane township into Bridle Drift Reservoir, as well as at a site near the dam wall. These samples were analysed for *E. coli* using the Most Probable Number (MPN) technique (SABS). Results were expressed as MPN/100ml.

Statistical Analysis: The geometrical mean, minimum value and maximum value were determined for the bacteriological counts in the Buffalo River and the four inflowing streams (from Mdantsane) into the Bridle Drift Reservoir as well as a site at the dam wall. The geometrical mean is used to describe random variables that vary over several orders of magnitude, such as coliform counts (Sanders *et al*, 1983). The geometric mean of a set of *n* numbers is given by the *n*th root of their product (Freund, 1974) namely :

$$\sqrt[n]{x_1 . x_2 .. x_n}$$

Time exceedance graphs were drawn for ranked data for all sites to determine the percentage of time that bacteriological counts exceeded the recommended recreational criteria (Kempster *et al*, 1980). The seasonal data trends were calculated by using all data from September to February as summer data and March to August as winter data.

2.4 Demographic data

The demographic data was collected by using questionnaires (See Appendix F). This data was then analysed to determine the phosphate budgets for the five townships where the demographic study was conducted.

2.5 Phosphorus budget

The method used to calculated phosphate exports from these townships are also discussed in Appendix H. The contribution by sanitation, soaps/detergents, coal, wood, animal wastes and food wastes were condensed into flow diagrams to show the path of phosphorus in each township.

The data from the demographic study (Appendix F) were used to determine the phosphorus budgets for the five townships that were studied. To determine the phosphorus budgets for each township the following calculations were used :

Median values were determined from the questionnaire data for each of the variables as shown in tables 1 - 5. The number of different types of houses were then counted for each township.

2.5.1 *Sanitation*

The total phosphate input from sanitation was determined in metric ton/annum as the sum of phosphate input from each type of house by the following equation :

$$(((N1xP_a)xP_{out})+((N1xP_b)xP_{out})+((N1xP_c)xP_{out}))/1000 \times 365$$

N1	=	Number of houses in township of a specific house type
P_a	=	Mean number of children under 5 years
P_b	=	Mean number of persons between 6 and 15 years
P_c	=	Mean number of persons over 16 years
P_{out}	=	Phosphate output for specific age groups in g/day
		< 5 years - 0.818
		6 - 15 years - 1.343
		> 16 years - 1.685 From (Documenta Geigy, 1962)

The questionnaire (Appendix F) determined the number of people that work out of the townships and it was found that the majority of those who do, are outwith the township for 50% of the day. The corresponding phosphate value was deducted from the total phosphorus production of the township. Numbers of chamber pots were used to determine the amount of urine that did not go into the sewer system but rather was thrown out onto the ground every morning.

The total phosphate production collected by sanitation facilities was calculated as the total phosphorus production minus that of people working out of town and minus the chamber pot production.

2.5.2 *Soaps/detergents*

Washing powders and detergents are required by law (SABS Standard 892, 1976) to contain at least 6.7% phosphorus (as P, by mass). In practice, these compounds contain between 20 and 24% P_2O_5, (approximately 22% P_2O_5 on average, by mass (Dunstan, 1987: pers. comm.), which is equivalent to 9.8 % (by mass) phosphorus as P.

The mean amount of soap/detergents used in each type of house was calculated for every township. These values were multiplied by the number of houses of each house type. The phosphate proportion of 9.8% was used to determine the total P input from soaps/detergents in each township.

2.5.3 *Coal ash*

Coal has an average ash content of 13.5% (by mass), which, in turn, has an average phosphorus content of 0.53% (by mass, of the ash), (Kruger, 1987: pers. comm.). Here it is important to note that during combustion, approximately 50% of the phosphorus in coal is transformed together with silicates into a form of slag or glass that renders the phosphorus unavailable (Kruger, 1987: pers. comm.).

To determine the coal ash phosphorus contribution, the input from every type of house was determined by the sum of the mean amount of coal used per house type multiplied by the total number of each house type in the township.

2.5.4 *Wood ash*

Dry firewood has an average ash content of 1.0% (by mass), with an average phosphorus content of 0.5% (by mass, of the ash) in the ash (Hose, 1987: pers. comm.).

The questionnaire (Appendix F) determined the amount of wood that was used seasonally in kg/season. From this the annual usage of wood was determined and the phosphorus input was calculated from the wood ash.

2.5.5 *Animal wastes*

The total number of different animals per house type was determined by the Demographic Survey (Appendix F). The total animal waste phosphate production was determined as tonnes/annum by the sum of the productions from each animal species. To determine the production from each species, the following formula was used:

$$\Sigma(H_T \times N_A) \times TP/1000$$

where H_T = house type

N_A = number of animals per house type

TP = total phosphate production per animal (kg/animal/annum)

The values used as total phosphate production per animal type can be seen in Table 1.

Table 1. The median values for all of the variables for each house type which were important in the determination of the phosphorus budget components for Ilitha.

ILITHA (60)	Improved municipal (10)	Typical municipal (30)	Backyard shacks (20)
No of people/household	4.7	5.3	4.9
No of adults (15 yrs- over)/household	2.20	3.33	2.85
No. of children (6-15 yrs)/household	1.9	1.4	1.5
No. of children (up to 5 yrs)/household	0.60	0.63	0.70
Waterborne toilets (%)	80	96.67	10
Pit latrines (%)	0	3.33	0
Bucket systems (%)	10	0	90
No toilet facilities (%)	10	0	0
Amount of soap powder (g/week)	405	358.6	380
Amount of water used (litre/day)	95	108.3	102
Disposal of water on ground (%)	35.14	21.70	81.0
Disposal of water in sewer system (%)	64.86	78.3	19.0
Refuse production (kg/week)	0	13.1	3.7
Food and vegetable waste (kg/week)	1.9	2.4	2
Compost used per season (kg/year)	15	27.5	9.17
Cattle (No.)/household	.4	0	0.15
Goats (No.)/household	-	0.33	-
Poultry (No.)/household	0.67	0.67	1.00
Pigs (No.)/household	0.2	0.56	0.30
Donkeys (No.)/household	-	-	-
Dogs (No.)/household	0.2	0.56	0.30
Cats (No.)/household	-	-	-
Wood (kg/week/winter)	3	2.5	-
Wood (kg/week/summer)	2	2.0	-
Coal (kg/winter)	-	-	-
Coal (kg/summer)	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-

Table 2. The median values for all of the variables for each house type which were important in the determination of the phosphorus budget components for Mdantsane township.

MDANTSANE (30)	Elite (10)	Improved municipal (2)	Typical municipal (16)	Squatters (0) (Extrapolated from Zwelitsha)	Backyard shacks (2) (Extrapolated from Zwelitsha)
No of people/household	5.1	4.0	6.31	4.03	3.47
No of adults (15 yrs- over)/household	3.2	3.0	4.31	2.53	2.30
No. of children (6-15 yrs)/household	1.4	1.0	0.75	0.90	0.73
No. of children (up to 5 yrs)/household	0.5	0.0	1.31	0.87	0.43
Waterborne toilets (%)	100	100	100	0	100
Pit latrines (%)	0	0	0	13.3	0
Bucket systems (%)	0	0	0	0	0
No toilet facilities (%)	0	0	0	86.7	0
Amount of soap powder (g/week)	470	375	339.06	333.3	348.3
Amount of water used (litre/day)	190	150	143.75	86.67	83.33
Disposal of water on ground (%)	0	0	6	100	33.02
Disposal of water in sewer system (%)	100	100	94	0	66.98
Refuse production (kg/week)	2.4	2.5	2.69	3.93	3.53
Food and vegetable waste (kg/week)	1.8	2.0	1.56	1.6	1.67
Compost used per season (kg/year)	0.75	3.75	7.66	7.5	15
Cattle (No.)/household	-	-	-	-	-
Goats (No.)/household	-	-	-	-	-
Poultry (No.)/household	-	-	1.87	-	0.67
Pigs (No.)/household	-	-	-	-	-
Donkeys (No.)/household	-	-	-	-	-
Dogs (No.)/household	0.4	0	0.31	0.2	0.2
Cats (No.)/household	-	-	-	-	-
Wood (kg/week/winter)	0.1	0.5	0.38	1.93	0.3
Wood (kg/week/summer)	0.1	0.5	0.31	1.53	0.27
Coal (kg/winter)	-	-	-	-	-
Coal (kg/summer)	-	-	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-	-	-

Table 3. The median values for all of the variables for each house type which were important in the determination of the phosphorus budget components for Zwelitsha township.

ZWELITSHA (130)	Elite (10)	Improved municipal (30)	Typical municipal (30)	Squatters (30)	Backyard shacks (30)
No of people/household	4.7	6.83	6.2	4.03	3.47
No of adults (15 yrs- over)/household	3.5	4.63	4.17	2.53	2.30
No. of children (6-15 yrs)/household	1.0	1.53	1.80	0.90	0.73
No. of children (up to 5 yrs)/household	0.2	0.63	0.73	0.87	0.43
Waterborne toilets (%)	100	100	100	0	100
Pit latrines (%)	0	0	0	13.3	0
Bucket systems (%)	0	0	0	0	0
No toilet facilities (%)	0	0	0	86.7	0
Amount of soap powder (g/week)	660	571.67	447.5	333.3	348.3
Amount of water used (litre/day)	170	114.83	115	86.67	83.33
Disposal of water on ground (%)	6.06	26.72	29.57	100	33.02
Disposal of water in sewer system (%)	93.94	73.28	70.43	0	66.98
Refuse production (kg/week)	4.9	5.8	1.47	3.93	3.53
Food and vegetable waste (kg/week)	3.1	2.1	2.03	1.6	1.67
Compost used per season (kg/year)	4.17	4.5	16.39	7.5	15.0
Cattle (No.)/household	-	-	-	-	-
Goats (No.)/household	-	-	-	-	-
Poultry (No.)/household	-	1.33	1.67	-	0.67
Pigs (No.)/household	-	-	-	-	-
Donkeys (No.)/household	0.2	-	-	-	-
Dogs (No.)/household	0.3	1.03	0.7	0.2	0.2
Cats (No.)/household	-	-	0.17	-	-
Wood (kg/week/winter)	-	0.33	0.4	1.93	0.3
Wood (kg/week/summer)	-	0.3	0.3	1.53	0.27
Coal (kg/winter)	0.1	0.07	0	-	-
Coal (kg/summer)	0.1	0.03	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-	-	-

Table 4. The median values for all of the variables for each house type which were important in the determination of the phosphorus budget components for Mlakalaka township.

MLAKALAKA (40)	Elite Village (6)	Typical Village (16)	Humble village (16)	Backyard shacks (2) (Extrapolated from Zwelitsha)
No of people/household	5.5	5.0	5.88	3.47
No of adults (15 yrs- over)/household	3.83	3.44	3.75	2.30
No. of children (6-15 yrs)/household	1.0	1.19	1.63	0.73
No. of children (up to 5 yrs)/household	.033	0.19	0.75	0.43
Waterborne toilets (%)	0	0	0	0
Pit latrines (%)	100	100	100	50
Bucket systems (%)	0	0	0	0
No toilet facilities (%)	0	0	0	50
Amount of soap powder (g/week)	658.33	432.81	425	348.3
Amount of water used (litre/day)	116.67	106.25	88.13	83.33
Disposal of water on ground (%)	100	100	100	100
Disposal of water in sewer system (%)	0	0	0	0
Refuse production (kg/week)	2.67	3.25	2.94	3.53
Food and vegetable waste (kg/week)	2.0	1.5	1.63	1.67
Compost used per season (kg/year)	1.67	10.0	7.34	15.0
Cattle (No.)/household	2.67	1.31	1.75	-
Goats (No.)/household	-	1.25	1.88	-
Poultry (No.)/household	6.67	5.63	9.38	0.67
Pigs (No.)/household	2.33	0.94	0.56	-
Donkeys (No.)/household	-	0.50	-	-
Dogs (No.)/household	1.17	0.69	0.94	0.2
Cats (No.)/household	-	-	-	-
Wood (kg/week/winter)	0.33	2.0	3.75	0.3
Wood (kg/week/summer)	0.33	1.31	3.06	0.27
Coal (kg/winter)	-	-	-	-
Coal (kg/summer)	-	-	-	-
Manure (bags/winter/household)//(kg/winter) (1Bag = 20kg)	-	-	2.31//46.25	-
Manure (bags/summer/household)//(kg/summer)	-	-	1.56//31.25	-

Table 5. The median values for all of the variables for each house type which were important in the determination of the phosphorus budget components for Needs camp township.

NEEDS CAMP (40)	Typical municipal (0) (Extrapolated from Mlakalaka)	Squatters (40)	Backyard shacks (0) (Extrapolated from Zwelitsha)
No of people/household	5.0	6.05	3.47
No of adults (15 yrs- over)/household	3.44	3.43	2.30
No. of children (6-15 yrs)/household	1.19	2.00	0.73
No. of children (up to 5 yrs)/household	0.19	0.83	0.43
Waterborne toilets (%)	0	0	100
Pit latrines (%)	100	100	0
Bucket systems (%)	0	0	0
No toilet facilities (%)	0	0	0
Amount of soap powder (g/week)	432.81	413.13	348.3
Amount of water used (litre/day)	106.25	96.9	83.33
Disposal of water on ground (%)	100	100	33.02
Disposal of water in sewer system (%)	0	0	66.98
Refuse production (kg/week)	3.25	3.08	3.53
Food and vegetable waste (kg/week)	1.5	1.35	1.67
Compost used per season (kg/year)	10.0	4.72	15.0
Cattle (No.)/household	1.31	0.37	-
Goats (No.)/household	1.25	0.75	-
Poultry (No.)/household	5.63	6.50	0.67
Pigs (No.)/household	0.94	0.88	-
Donkeys (No.)/household	0.50	-	-
Dogs (No.)/household	0.69	0.35	0.2
Cats (No.)/household	-	0.08	-
Wood (kg/week/winter)	2.0	6.43	0.3
Wood (kg/week/summer)	1.31	5.28	0.27
Coal (kg/winter)	-	-	-
Coal (kg/summer)	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-

Table 6. The total phosphorus production per animal that was used in the determination of the total annual phosphorus input from the animals in the catchment

Animal type	TP production (kg/animal/annum)
Cattle	6.57
Goats	1.53
Poultry	0.39
Pigs	5.48
Donkeys	6.21

2.5.6 *Compost*
The amount of compost used by the people of the townships was determined for different types of houses. This usage was determined as kg/year. The total amount of compost used per township was determined by the following formula:

$$\Sigma(H_T \text{ x } C_U) \text{ x } (6.57 \text{ x } 0.7)/558/1000$$

H_T = house type
C_U = compost usage per house type (kg/year)

The 6.57 value (kg/animal/year) was derived from the phosphorus output of cattle and the 0.7 value account for the fact that only 70% of the phosphorus output is derived from manure, which is used as compost. The value of 558 is a correction factor as it is the total dry matter produced by an animal per year as (kg/animal/year).

2.6 Phosphate export modelling
A deterministic nutrient export model is undergoing development (Hughes and Van Ginkel, 1992) at the Rhodes IWR. This model is a semi-distributed, daily time-step model that links an SCS (Soil Conservation Service of the United States) type runoff generation algorithm with a storage depletion nutrient mass balance function. The daily inputs of phosphorus are estimated from the socio-economic surveys according to the methods outlined in Grobler *et al* (1987) and the proportion of the amount in storage at any one time that is washed off is determined using a non-linear relationship with runoff. The major problem with the utilisation of this model is estimation of the shape of the non-linear relationship in the absence of any field data to define the nature of the processes involved, or against which the model could be calibrated. The results generated from applying such a model must therefore be treated with caution until such time that they can be confirmed. However, given the lack of real data, the same is true of any estimation technique applied to this problem.

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3.2 Personal communications

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Mr F.R. Hose. Chief Researcher, National Institute for Timber Research, C.S.I.R.

Dr R.A. Kruger. Co-ordinator, F.R.D. Waste Management Programme, C.S.I.R.

APPENDIX C

WATER USERS AND WATER QUALITY CRITERIA

by

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CONTENTS

1. INTRODUCTION

The water users in the Buffalo River catchment can be divided into the five major water user groups identified by the Department of Water Affairs, namely: domestic, industrial, agricultural, environmental and recreational. There are no mining activities in the Buffalo River catchment.

In the Buffalo River catchment all the major users (as supplied by Mr A Lucas - Water Quality: Eastern Cape) were contacted to determine their water quality and quantity requirements. As the majority of the users use municipal water, the main users are East London and King William's Town municipalities and the Department of Public Works (Government of Ciskei), where applicable (figure 1). The only industry that uses water from the river is Da Gama Textiles. King Tanning is a secondary user, as it uses purified water which is supplied by King William's Town. Both these companies are situated in the middle reaches of the Buffalo River upstream of Laing Dam and discharge effluent onto irrigation lands. The conservation and agricultural sectors were contacted and supplied the water quality requirements which were considered to be important in their sectors.

The Buffalo River catchment used to fall under the jurisdiction of both Ciskei and the Republic of South Africa (figure 2), but this situation changed in 1994. The division of users in Ciskei and South African is therefore no longer applicable, but for the purposes of this report users and effluent producers are still divided under Ciskei and South Africa.

2. GENERAL WATER QUALITY FITNESS FOR USE

The Department of Water Affairs and Forestry is in the process of determining the fitness for use graphs for all variables in the freshwater systems of South Africa. These graphs are being used in the water quality management process of South African water resources. Figures 3 to 13 show the fitness for use curves as determined by the DWAF. These curves are used here to determine the general fitness for use of the Buffalo River water in terms of water quality.

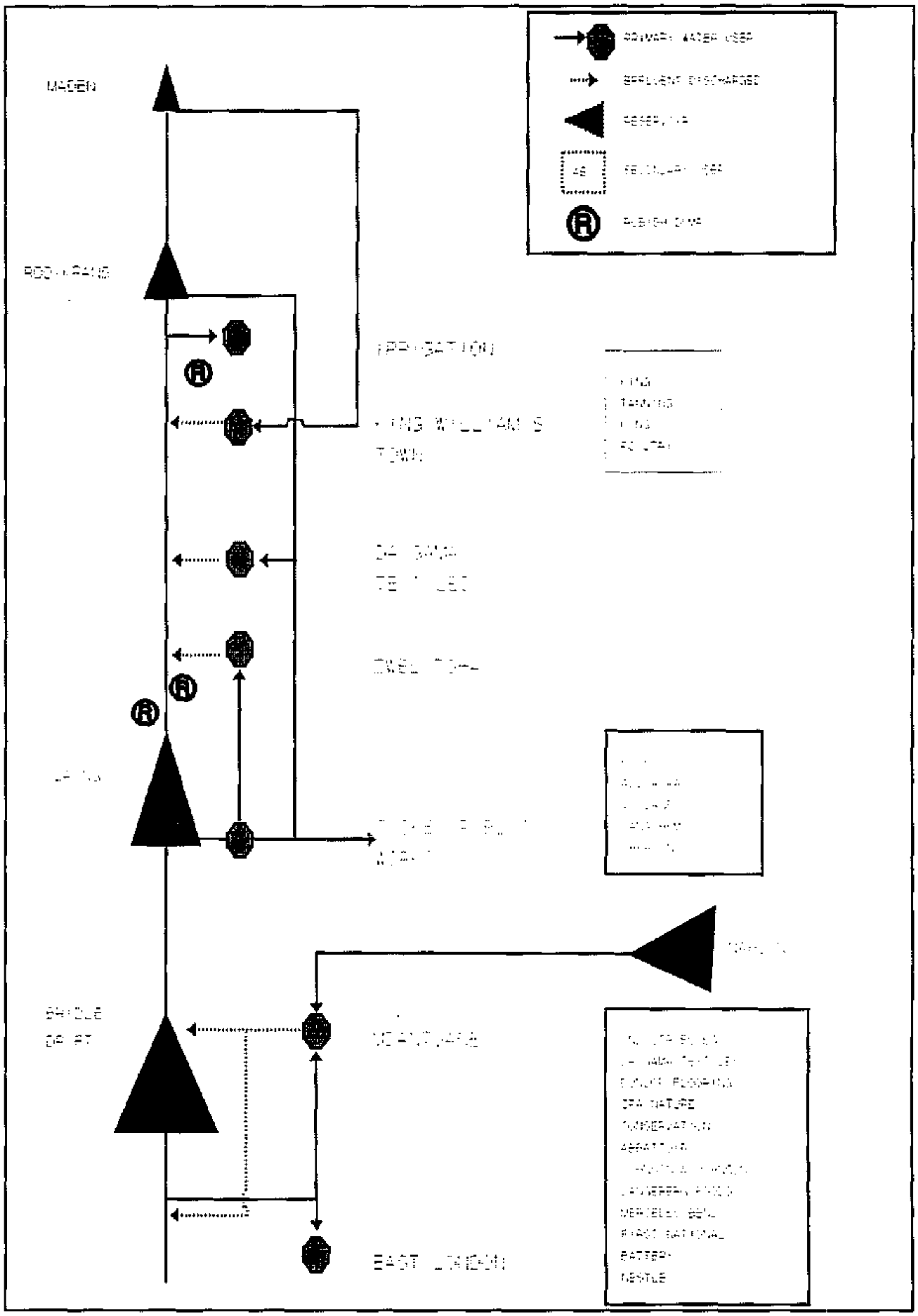

Figure 1. A flow diagram, showing the draw-off points of the primary users, and some of the secondary users in the Buffalo River system. The effluent producers are also indicated.

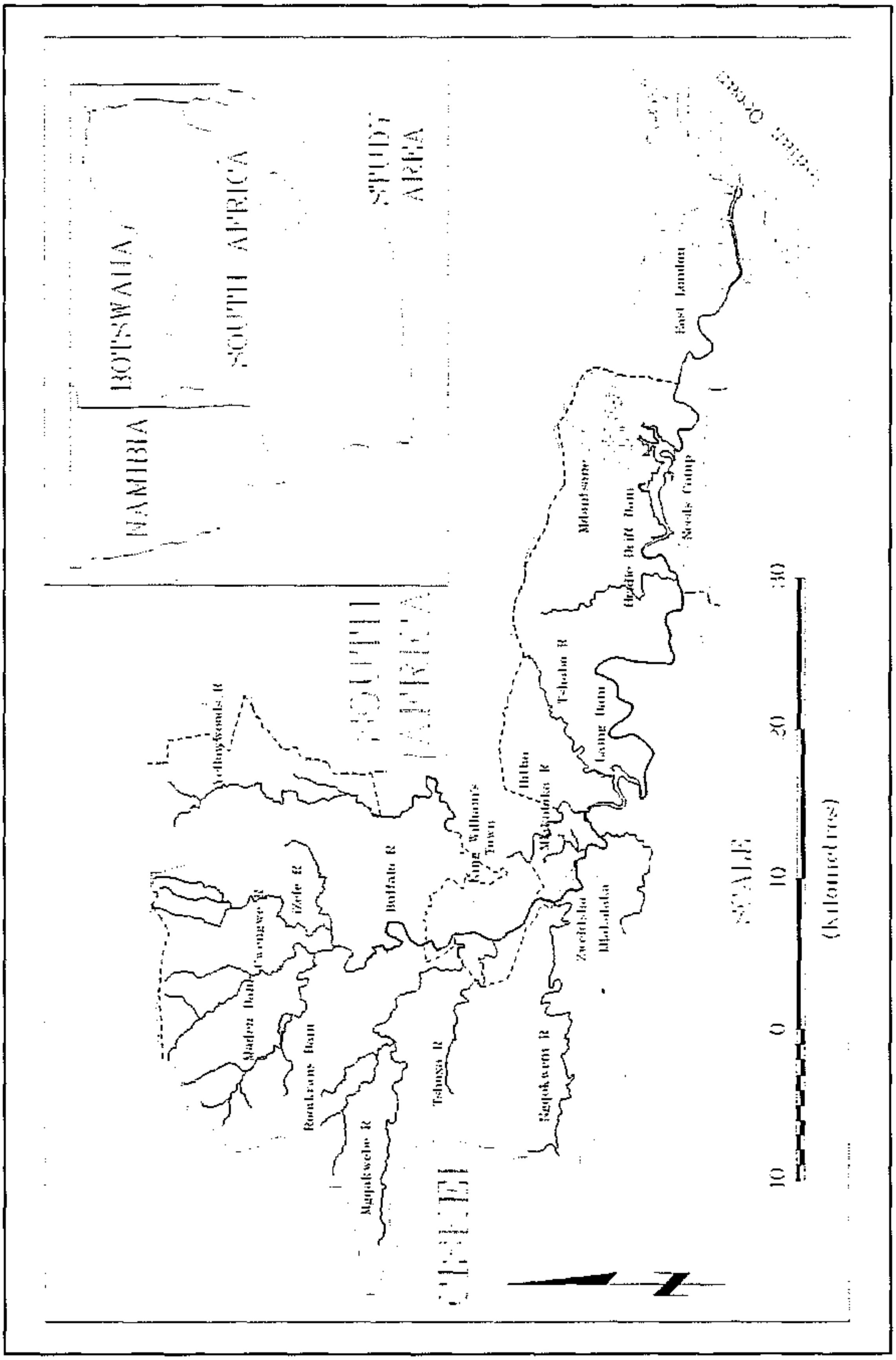

Figure 2. The Buffalo River cathment showing where its position in South Africa, the South African and Ciskei borders and the main rivers.

Table 1. The water users in the Buffalo River catchment divided under South African and Ciskei users and effluent producers. Primary users are indicated in bold. * indicates effluent producers that irrigate their effluent onto farming land in the catchment.

Users		Effluent producers	
RSA	**Ciskei**	**RSA**	**Ciskei**
East London	**Ciskei Public Works**	Breidbach	Bisho STW
King William's Town	Municipalities :	King William's Town (STW)	Da Gama Textiles
Amatola Regional Services Council	Bisho Municipality	King Poultry Farm cc.	Ilitha STW
Border combing	Frankfort Township	Chicken abattoir *	Mount Coke Hospital STW
Consolidated textiles	Ilitha Township	King Tanning Company *	Potsdam and Mdantsane STW
Da Gama Textile company	Mdantsane Township	Da Gama Textiles *	Proglove
Distillers Corp.	Phakamisa Township		Zwelitsha STW
Dunlop Flooring	Potsdam Township		Zwelitsha abattoir
Formalchem	Qongota Township		
Johnson & Johnson	Zwelitsha Township		
Kilimanjaro Bottling	Phakamisa		
King Tanning Company	Berlin		
Langeberg Co-operative	King William's Town (occasionally)		
Mercedes Benz of SA	Rural areas :		
Nature Conservation, Forestry	Kwalini		
Nature Conservation	Bonke		
Nestle	Tyutyu Resettlement		
Raylite Bataries(First National Batteries?)	Jongumsovbomvu Military Base		
Sanachem	Zinyoka		
South African Abattoir corporation	Skobeni		
South African Breweries	Mlakalaka		
Steiner services	Ndevana		
Tek Industrials	Tshabo		
Agriculture - irrigation	Mncotsho		
Recreation	Ciskei Technicon/Potsdam		
	Tembeni		
	Frankfort		
	Industrial :		
	Da Gama Textiles		
	Funiwe School		
	Kei Brick		
	Khambusho Youth Training Centre		
	Mount Coke Hospital		
	Thembelihle School for the Blind		
	Zwelitsha Abbattoir		
	Agriculture - irrigation		
	Recreation		

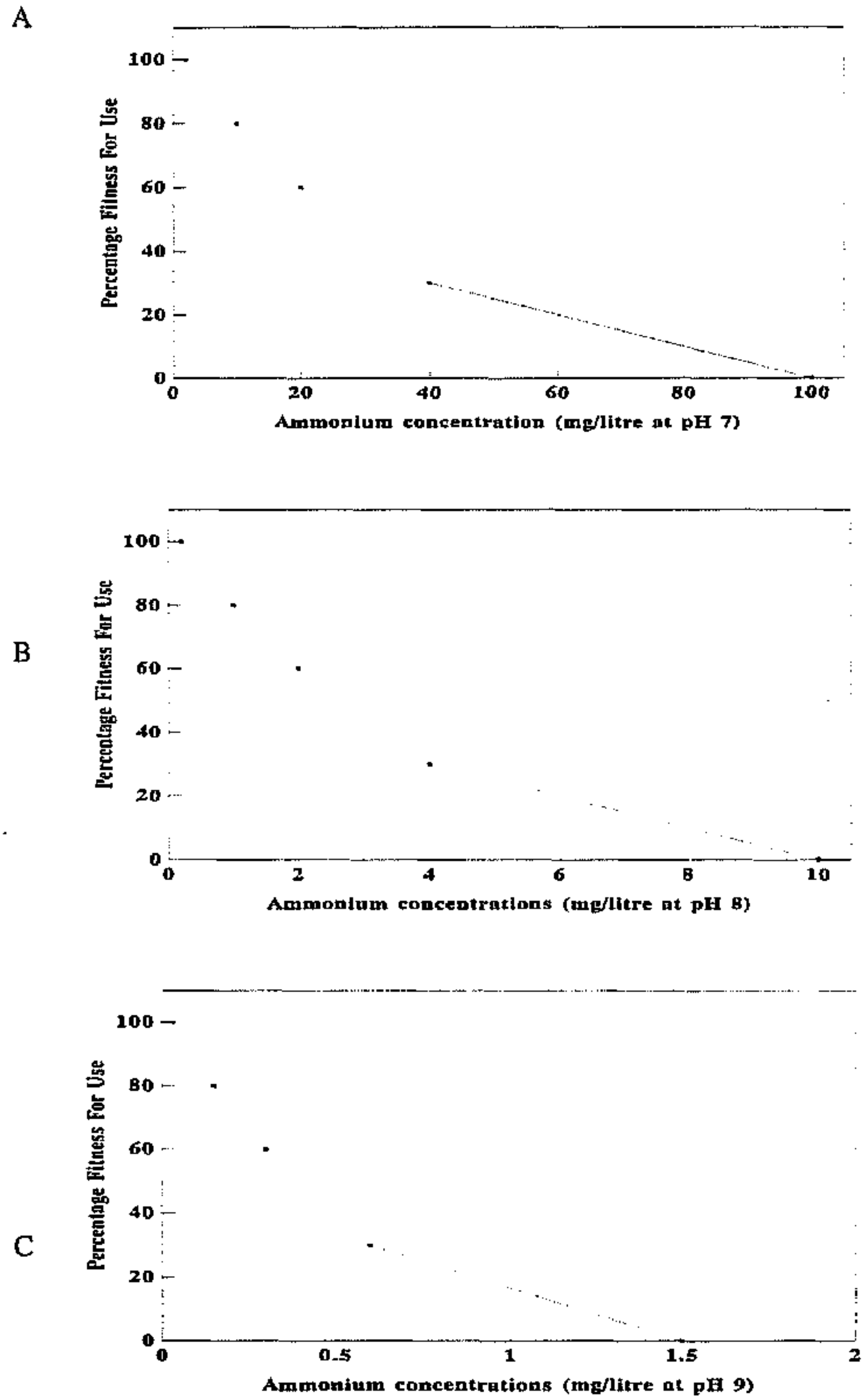

Figure 3. The fitness for use graphs for NH_4 at A (pH 7), B (pH 8) and C (pH 9), as determined by the Department of Water Affairs and Forestry.

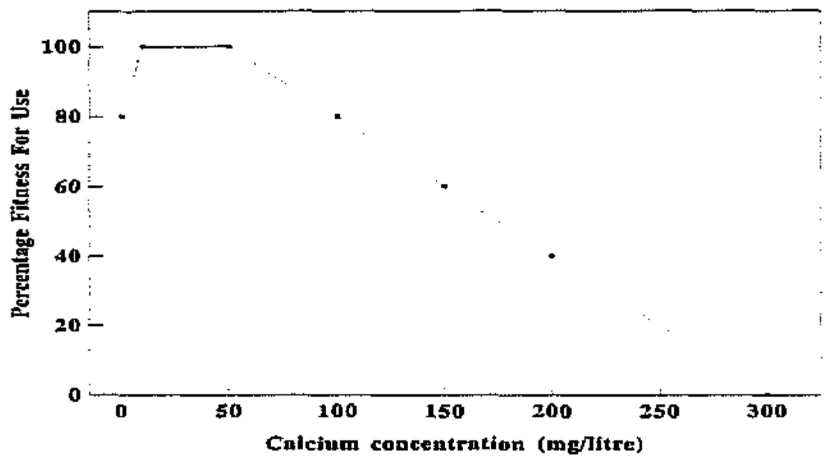

Figure 4. The fitness for use graph for calcium concentrations in river water as determined by the Department of Water Affairs and Forestry.

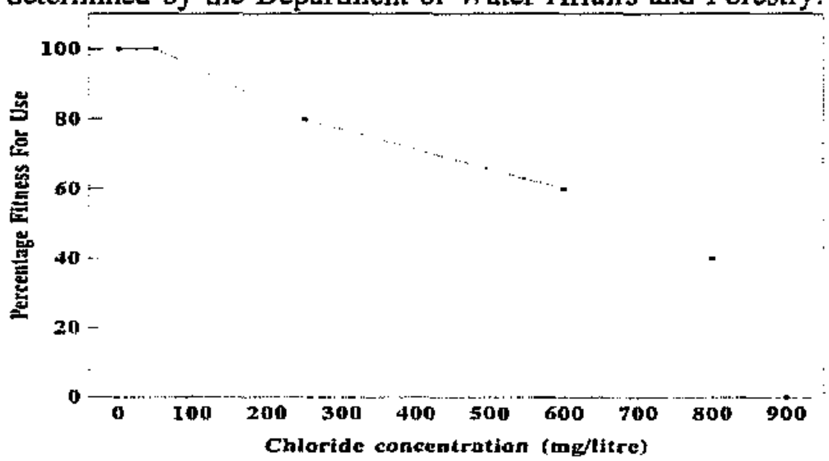

Figure 5. The fitness for use graph for chloride concentrations in river water as determined by the Department of Water Affairs and Forestry.

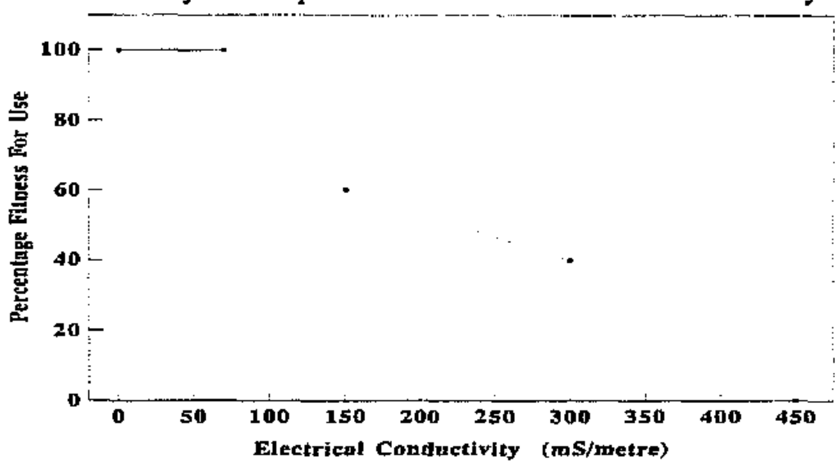

Figure 6. The fitness for use graph for electrical conductivity values in river water as determined by the Department of Water Affairs and Forestry.

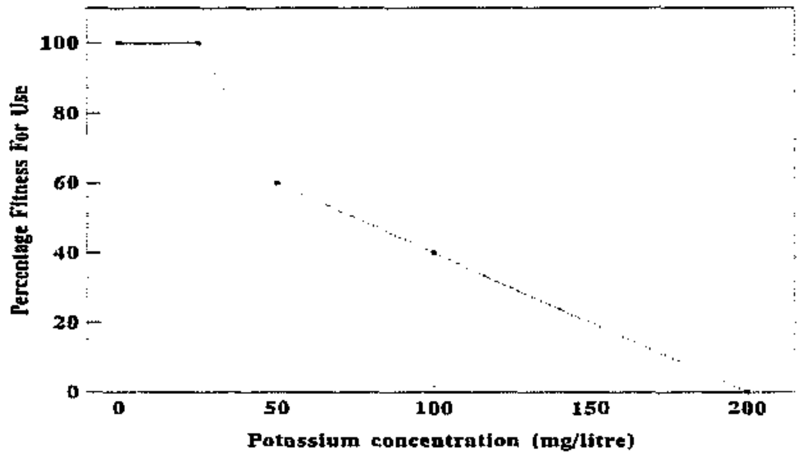

Figure 7. The fitness for use graph for potassium concentrations in river water as determined by the Department of Water Affairs and Forestry.

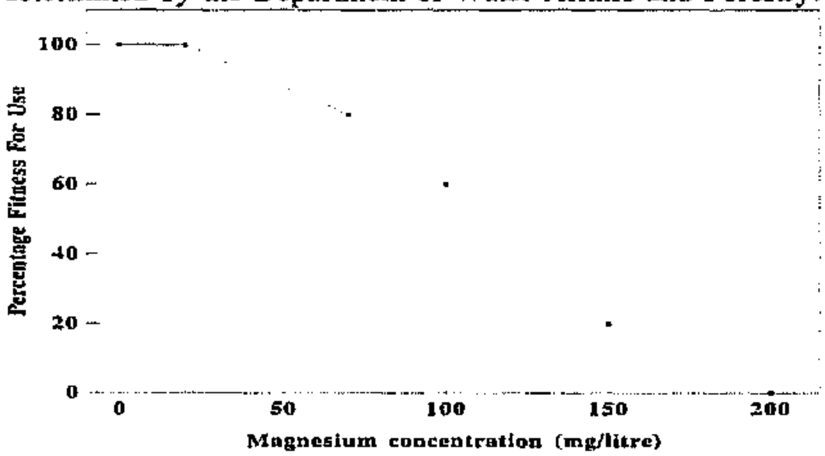

Figure 8. The fitness for use graph for magnesium concentrations in river water as determined by the Department of Water Affairs and Forestry.

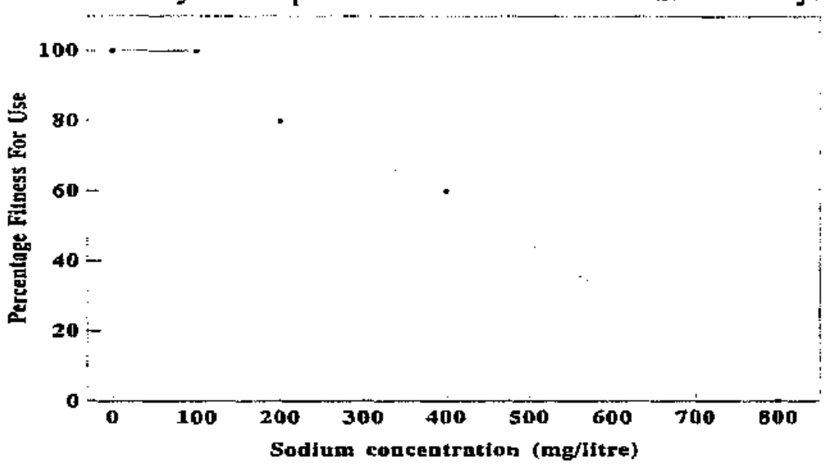

Figure 9. The fitness for use graph for sodium concentrations in river water as determined by the Department of Water Affairs and Forestry.

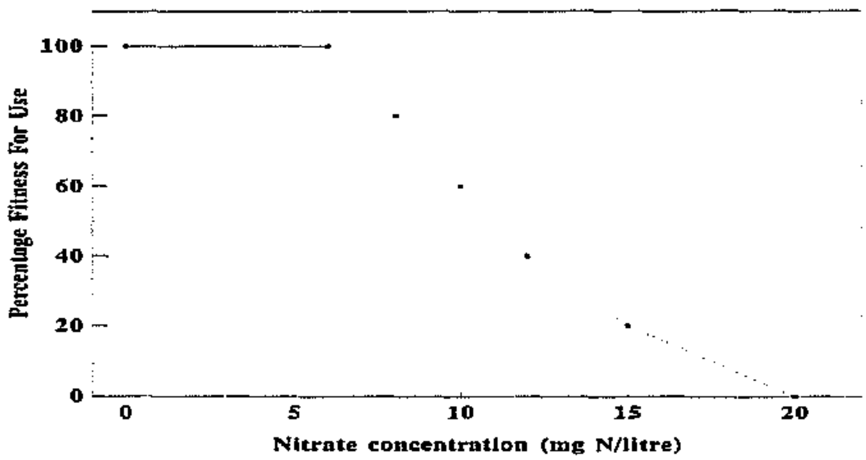

Figure 10. The fitness for use graph for nitrate concentrations in river water as determined by the Department of Water Affairs and Forestry.

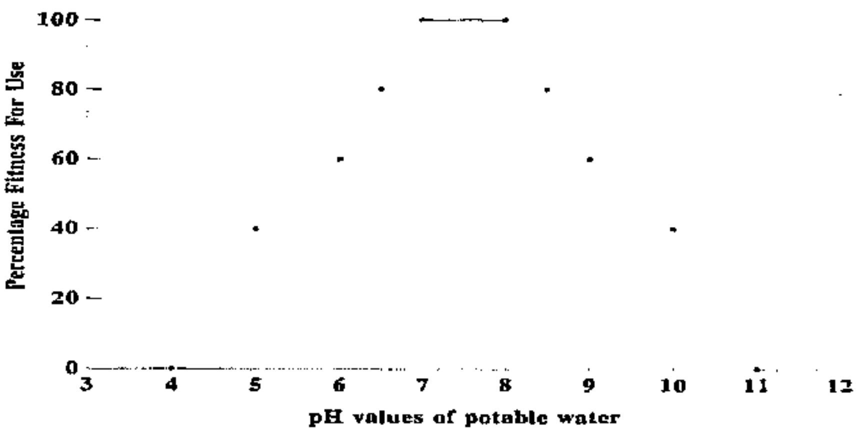

Figure 11. The fitness for use graph for pH values in potable water as determined by the Department of Water Affairs and Forestry.

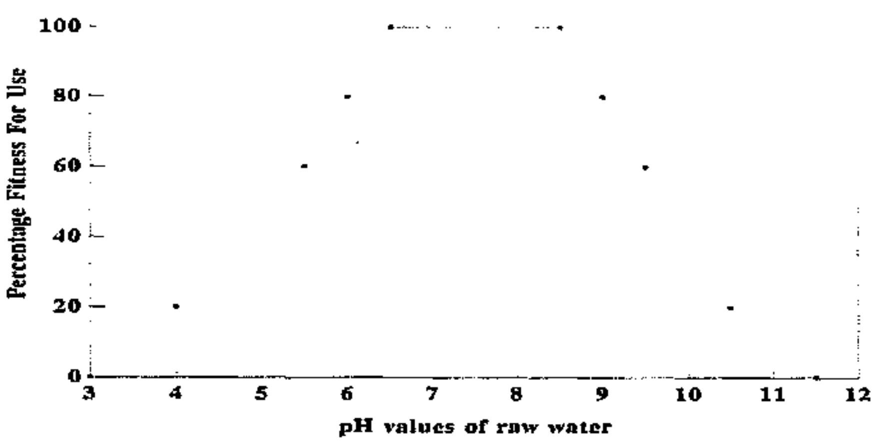

Figure 12. The fitness for use graph for pH values in raw river water as determined by the Department of Water Affairs and Forestry.

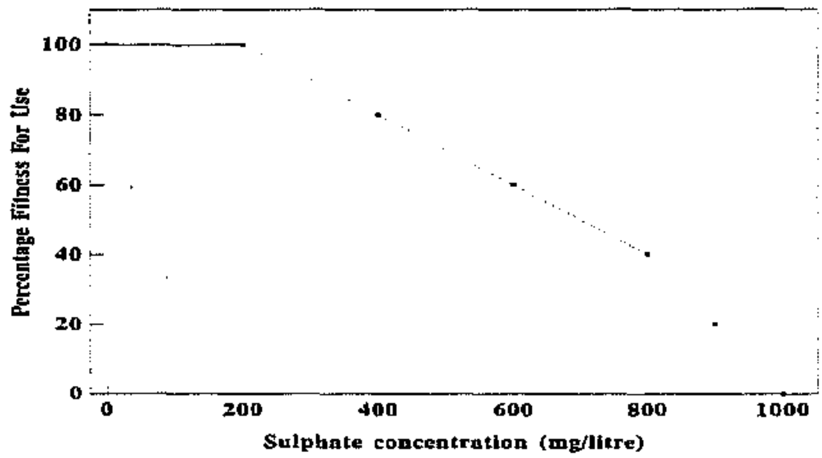

Figure 13. The fitness for use graph for sulphate concentrations in river water as determined by the Department of Water Affairs and Forestry.

3. WATER QUANTITY REQUIREMENTS

According to the Department of Water Affairs (1986), there are 53.3 million m^3/year water available in the Buffalo River catchment. All users were contacted to determine their water quality requirements and needs. Table 2 shows the quantities of water used per month, where the supplies originate, whether they supply to any secondary users and whether any treatment is involved, as well as water quality at discharge points.

East London and Ciskei Public Works (Mdantsane and Potsdam) use the greatest quantities of water and Mdantsane's water are supplemented from Nahoon Dam (figure 1). These two users, together with King William's Town, supply all secondary users of water.

The water quantity requirements are still met by available water sources in the Buffalo River catchment and the water transfer from the Kubusi River will supply future development needs (Meiring *et al*, 1987).

Table 2. The users in the Buffalo River showing their water quantity requirements, their importance in the Buffalo River catchment as secondary suppliers and possible pollution effects they might have on the system.

Variable Industry	Water used per month/ capasity(STW)	Water supply	Users	Water usage	Water treatment	Amount water discharged per month	Monitoring programmes	Water quality at discharge
Da Gama Textiles (EL)	± 45 200 kl	Nahoon Dam	No	Fabric processing	Yes	14 933,7 kl	Yes	pH 10-10.5
Distillers Corp.								
Dunlop Flooring	33 000 kl	Municipal	No	Boiler, cooling, etc	Yes, Oxygen digestion with chemical plant	± 17 000 kl	No	-
EL Municipality		Municipal	Yes	Municipal supply	Yes		Yes	SABS
Johnson & Johnson	±11 214 kl	Municipal	No	Process + human consumption	Yes, Aeration + activated sludge	±7 214 kl	No	DWA
King Tanning KWT	2109 kl	Municipal	No	Leather processing	Yes Flood irrigation	± 1900 kl	No	-
KWT Municipality	±47 000 kl	Maden Rooikrantz Laing	Yes	Urban + Industrial	Yes	±47 000kl	No	pH 8.5 Cl 0.4 Turb 1.0 NTU
Langeberg Coop.	±315 000	Municipal	No	Processing	Solids removed Lime-dosed	±236 250 (not measured)	Yes	pH 6 - 12
Mercedes Benz	± 18 000 kl	Municipal	No	Domestic electrocoating, etc.	Yes, In house	± 12 000 kl	No	-
Nestle	50 000 kl	Municipal	No	Cleaning	Yes Fat separation	±37 825 kl	Yes	Sugar content Permanganate Soluble solids - 5000ppm
First national batteries	2 615 kl	Municipal	No	Process + production	Yes, Neutralization	2 613 kl	Yes	pH 6-12 Lead <5mg/l
Sanachem	30 000 - 60000 kl	Municipal	No	Agricultural chemicals	Yes	Sea output	Yes	pH 7-8
East London Abattoir corp.	±6000 kl	Municipal	No	Drinking Slaugtering	No	± 5500 kl	No	SABS
Tek Industrials	30.000	Municipal	No	Rinsing during electroplating	No	30.000 kl	No	pH 5.5

Variable / Industry	Water used per month/ capasity(STW)	Water supply	Users	Water usage	Water treatment	Amount water discharged per month	Monitoring programmes	Water quality at discharge
Bisho STW	27 750 kl	Bisho, Police College, Military base & Bisho hospital	Yellowwoods	Sewage treatment	Yes, oxidation ponds & irrigation (not used at the moment)			
Ilitha STW	64 800 kl	Ilitha	No	sewage treatment	Yes, building new plant		Yes, regional lab	
Mdantsane STW	700 000 kl	Mdantsane & Potsdam	Buffalo below EL extraction weir	sewage treatment	Yes, biol. filter & evaporation ponds		Yes, Regional lab	
Potsdam	280 000 kl	Potsdam	Mdantsane STW	Sewage treatment	Yes, biol. filter → Mdantsane evap. ponds		Yes	
Zwelitsha STW		Zwelitsha, Phakamisa	Buffalo	Sewage treatment	Yes, Biol. filtration & maturation ponds		Yes, Regional lab	
Da Gama (KWT)		Rooikrantz Dam	Mlakalaka	Fabric processing	Yes Evaporation ponds		Yes Regional lab	
Kei brick		Laing Dam	No	Processing	Yes, septic tanks			
Mount Coke STW	6 000 kl	Mount Coke hospital		Sewage treatment	Yes			
Zwelitsha abattoir		Laing Dam	Zwelitsha STW	Washing blood and intestines	Yes, irrigation and Zwelitsha STW			
Southern Combing Co.		Sandile scheme	Mgqakwebe River	Processing	Yes, oxidation ponds, effluent into Buffalo			
Bony bird farms Ciskei		Bridle Drift Nahoon	Mdantsane STW		Yes, pretreatment anfd into Mdantsane STW			
Proglove Enterprises		Laing Dam	No		Yes, ponds - evaporation and seepage			

Table 2. (continued)

NA = Not applicable

4. WATER QUALITY REQUIREMENTS

Questionnaires were issued to determine whether the water quality requirements of all possible users were ideal, acceptable, tolerable or unacceptable. The user requirements were then used to determine upper, middle and lower reach user criteria, which are shown in tables 3 to 5.

4.1 Variables of concern

The main "variables of concern" were identified by the users and the research team as the minerilisation (expressed as total dissolved solids (TDS)), nutrient enrichment (measured as ortho-phosphate in mg/l) and faecal coliforms (MPN/100ml). Mineralisation was measured as electrical conductivity (EC) since it is a measure of dissolved material in the water. The EC values were converted to total dissolved solids by a conversion factor of $\pm$ 6.5 - each site had a specific conversion factor according to actual EC and TDS data. Phosphorus appeared to be the main limiting nutrient for algal growth in the Buffalo River (Selkirk and Hart, 1984) and is therefore the variable that may be used to manage eutrophication in our scarce water resources. Faecal coliform bacterial numbers, particularly in Bridle Drift Dam, have been a major cause of concern for East London Municipality in recent years.

4.1 Domestic water quality requirements

Standard water quality criteria have been applied to water quality for domestic use for some time. All municipalities should comply to these standards and therefore have water purification works.

The South African Bureau of Standards (SABS) standard for domestic use is well documented and will not be discussed any further in this report.

4.2 Industrial water quality requirements

Kempster *et al* (1980) has drawn up a summarised report on water quality criteria in which the necessary user requirements for different industrial uses are discussed. In the Buffalo river the industrial users are textiles only because all other industries use municipal water, which should comply to the SABS standards.

Table 3. The most stringent concentrations as indicated by the users in the Upper Buffalo River catchment. The variable concentrations are divided under ideal, acceptable, tolerable and unacceptable - the minimum values for each catogory were used.

VARIABLE	CONCENTRATION			
	Ideal	Acceptable	Tolerable	Unacceptable
Alkalinity (mg/l)	-	-	-	-
Calcium (mg/l)				>1000
Chloride (mg/l)	40			>400
EC (mS/m)	<70	150	300	>450
Hardness, total ($CaCO_3$) (mg/l)	-	-	-	-
Magnesium (mg/l)				>300
pH	7.5		8.7	<4.5;>9
Ortho Phosphate (mg/l)				>0.38
Total Phosphate (mg/l)	-	-	-	-
Potassium (mg/l)			<50	>50
Silica (mg/l)			<50	>50
Sodium (mg/l)	<100	200	400	>800
Sulphate (mg/l)	500		<1000	>1000
Zinc (mg/l)	0.3			>0.1
Human faecal bacteria (cells/100ml)	-	-	-	-
NO_2 + NO_3	-	-	-	-
Taste and odour	-	-	-	-
Colour (Hazen units)	-	-	-	-
Turbidity (NTU)	-	-	-	>82
Temperature				>24.3°C
Suspended solids	-	-	-	-
Total solids	-	-	-	-

Table 4. The most stringent concentrations as indicated by the users in the Middle Buffalo River catchment. The variable concentrations are divided under ideal, acceptable, tolerable and unacceptable - the minimum values for each catogory were used.

VARIABLE	CONCENTRATION			
	Ideal	Acceptable	Tolerable	Unacceptable
Alkalinity (mg/l)	30	50	70-80	>100
Calcium (mg/l)	<10	<15	15-20	>25
Chloride (mg/l)	<50	<100	<200	>200
EC (mS/m)	20	<100	<200	>200
Hardness, total ($CaCO_3$) (mg/l)	<50	<100	<200	>200
Magnesium (mg/l)	<10	<25	<50	>50
pH	7.0	7.5	8.0 - 8.5	<7.0;>8.5
Ortho Phosphate (mg/l)	-	-	-	-
Total Phosphate (mg/l)	0.1-1.0	20	<45	>55
Potassium (mg/l)	10	20	30	>40
Silica (mg/l)	0	6	<8	>10
Sodium (mg/l)	41	<200	<300	>400
Sulphate (mg/l)	50	200	<400	>400
Zinc (mg/l)	0.1	1	2	>5
Human faecal bacteria (cells/100ml)	0	0	0	>0
$NO_2 + NO_3$	-	-	-	-
Taste and odour	-	-	-	-
Colour (Hazen units)	0	<10	<20	>20
Turbidity		<5		
Suspended solids		<5		
Total solids		<800		>1000

Table 5. The most stringent concentrations as indicated by the users in the Lower Buffalo River catchment. The variable concentrations are divided under ideal, acceptable, tolerable and unacceptable - the minimum values for each catogory were used.

VARIABLE	CONCENTRATION			
	Ideal	Acceptable	Tolerable	Unacceptable
Alkalinity (mg/l)	30	50	50-100	>100
Calcium (mg/l)	<10	10	<20	>20
Chloride (mg/l)	0.25	50 - 100	100 - 150	>150
EC (mS/m)	<25	<50	<70	>70
Hardness, total ($CaCO_3$) (mg/l)	<10	50 - 100	50 -150	>150
Magnesium (mg/l)	<5	<15	<20	>20
pH	6.8	7.5	7.0 - 8.5	<7.0; >8.5
Ortho Phosphate (mg/l)	0	<0.05	<0.1	>0.1
Total Phosphate (mg/l)	<0.05	<0.07	<0.1	>0.1
Potassium (mg/l)	<5	<7	<10	>10
Silica (mg/l)	0	3	5	>5
Sodium (mg/l)	<50	50	<100	>100
Sulphate (mg/l)	0	20	<50	>50
Zinc (mg/l)	0	<0.5	<1.0	>5
Human faecal bacteria (cells/100ml)	0	0	0	>0
$NO_2 + NO_3$	<1	<2	<5	>0
Taste and odour	None	None	None	Any
Colour (Hazen units)	-	-	-	-
Turbidity	-	-	-	-
Suspended solids	-	-	-	-
Total solids	-	-	-	-

4.3 Agricultural water quality requirements

The water quality criteria for farming vary amongst agricultural enterprises since crop tolerances to specific conditions differ. Kempster *et al* (1987) discussed these differences and the Water Quality Management section of the Department of Water Affairs and Forestry are in the process of determining the fitness for use of different variables at different concentrations (figures 3 - 13)

4.4 Environmental water quality requirements

The most comprehensive database on the biota of the Buffalo River is of the riffle dwelling benthic invertebrates, which were collected monthly at 16 sites down the river between 1986 and 1988 by the Institute for Freshwater Studies, Rhodes University, as part of an FRD research contract. Physico/chemical measurements of water quality were collected simultaneously with the invertebrates. This database has been used to analyse water quality requirements for the natural biota of the river for the following reasons:

- The invertebrate fauna is very diverse, and therefore provides a range of species requirements.

- Invertebrates can colonise any suitable habitat, and therefore their absence is an indication of unsuitable conditions.

- Invertebrates have short lifespans and communities change quickly in response to adverse or advantageous conditions.

- Data on the fish fauna are much less comprehensive, and have not usually been collected in association with water quality measurements.

There were no data on the distribution of biota in the Buffalo River under pristine conditions. Nor were there experimental data on the tolerances of any of the species naturally occurring in the Buffalo River. It was therefore necessary to use the presence/absence of species in present conditions to infer species' tolerances to particular ranges of any water quality variable. This approach was thus utilised in this report.

RIVER ZONATION:

For the purposes of this section of the report, the following zones have been defined in terms of the sites sampled during the 1986-88 investigation.

Sites	Zone
0 & 1	Upper river to the inflow to Maden Dam
2 to 7	Middle river from Maden Dam outlet to the junction of the Buffalo and Mgqakwebe River just upstream of King William's Town.
8	The river flowing through King William's Town and Zwelitsha, to the inflow to Laing Dam.
9 & 10	From Laing Dam outlet to Bridle Drift inlet.
11 & 12	From Bridle Drift Outlet to the treated sewage inlet below the East London supply weir.
13	The lower river to the head of the estuary.

(Sites 8 and 13 are treated separately because they are the most polluted sites. The absence of species from these sites should indicate conditions beyond their tolerance).

DEFINITION OF TOLERANCE LIMITS:

The presence of large numbers of a species in a particular zone of the river is taken as an indication that conditions are suitable for the aquatic life stages of that species, which may last for a period varying from a few weeks to several months. Preliminary examination of the seasonality of many of the insects revealed that, with only two exceptions, all species occur during all seasons. Analysis of the distributions of the most common invertebrates within the river was therefore carried out independently of season (tables 6 to 9).

From tables 6 to 9 some of the species are obviously adapted only to conditions in the upper reaches of the river:

Baetis natalensis	(Mayfly)
Adenophlebia auriculata	(Mayfly)
Castanophlebia calida	(Mayfly)
Chimarra sp.	(Caddis)
Gyrinus	(Beetle)
Aulonogyrus sp.	(Beetle)
Psephenidae	(Beetle)

Other are adapted only to conditions in the lower reaches:

Caenid type B	(Mayfly)

Prosopistomatidae (Mayfly)

The invertebrates which are perhaps more useful for defining tolerances are those which have a distribution throughout the river, but tend to be missing, or are present in reduced numbers, at the more polluted sites, while being common at sites up- and downstream. Invertebrate species which were not present, or were rare, at polluted sites 8 and 13, included:

Baetis type B	(Mayfly)
Centroptiloides bifasciatum	(Mayfly)
Pseudopannota maculosum	(Mayfly)
Choroterpes elegans	(Mayfly)
Neurocaenis reticulata	(Mayfly)
Macrostemum capense	(Caddis)
Simulium damnosum	(True fly)
Elmidae	(Beetle)

Eight out of the 22 (36%) common species or groups distributed all along the river were absent or severely reduced at the more polluted sites. This represents a significant reduction in species diversity at these sites, and this reduction can be taken as an indication that the overall natural functioning of the system is impaired. Since these species were present throughout the year, it can be assumed that they were able to live in the conditions which applied in zones other than sites 8 and 13, for most of the time. We have therefore defined the highest values of different water quality parameters which occurred for 90% of the samples, at all sites other than sites 8 and 13, as being the tolerance limits for the natural biota of the river. Their water quality requirements can therefore be summarised from table 5, as being:

Conductivity	< 77 mS /m
Soluble Reactive Phosphate	< 0.38 mg/m
Temperature	< 24.3 °C
pH	< 8.7

Of these parameters, the highest temperature and pH readings were not found at sites 8 and 13, and the distribution of ubiquitous species does not appear to be related to them. Temperature and pH may therefore not be limiting except for those species restricted to the headwaters. Turbidity levels were highest in the zone below Bridle Drift dam (sites 11 and 12). This was because when the dam level is low, water is released from a low-level valve which carries high sediment concentrations. Low frequencies of

Centroptilum parvum (Mayfly)

Centroptilum exisum (Mayfly)
Simulium nigritarse (True fly)

indicated that turbidities (or perhaps suspended solid concentrations) were above tolerance limits in this zone. The tolerance limit for turbidity levels should therefore be defined in terms of high levels at other sites (table 5):

Turbidity < 82 NTU

These tolerance limits can only be considered approximate, in the absence of experimental information, but they are sufficiently distinct to form the management basis for the environmental requirements of the river until more comprehensive information becomes available.

Table 6: Mayflies and caddisflies from different zones of the Buffalo River - total numbers of individuals collected per zone.

INVERTEBRATE	SITES					
	0+1	2-7	8	9+10	11+12	13
Baetis harrisoni	5 457	44 619	27 410	35 287	35 098	23 377
Baetis natalensis	1 319	106	0	0	101	0
Baetis Type B	369	11	0	276	881	49
Baetis glaucus	0	1 094	4 720	586	643	64
Centroptiloides bifasciatum	180	1 697	26	1 361	853	159
Pseudopannota maculosum	0	8 319	4 857	38 946	27 952	9 244
Centroptilum parvum	7 239	24 067	1 766	7 063	865	6 661
Centroptilum exisum	0	1 108	931	2 957	762	3 610
Afronurus harrisoni	4 384	3 069	1 042	4 171	14 395	23 213
Adenophlebia auriculata	380	15 301	81	0	0	133
Caenid Type A	69	29 942	2 910	45 371	8 539	11 317
Caenid Type B	0	363	0	16	41 229	6 772
Castanophlebia calida	1 420	78	15	0	0	0
Choroterpes elegans	837	83 953	14 086	106 639	21 311	25 412
Neurocaenis reticulata	11 957	92 158	3 381	42 070	54 454	16 114
Prosopistomatidae	0	0	0	0	1 254	158
Ecnomus sp. Type 1	40	42	1 370	670	8	60
Macrostenum capense	400	62 237	1 353	103 967	37 382	17 494
Cheumatopsyche afra	6 788	66 528	38 811	145 947	49 196	49 144
Cheumatopsyche thomasseti	534	29 113	8 799	15 495	14 406	15 636
Chimarra sp.	4 699	25 489	28	0	20	0

Table 7: Mayflies and caddisflies from different zones of the Buffalo River - frequencies expressed as percentages of the total number of individuals sampled.

INVERTEBRATE	SITES					
	0+1	2-7	8	9+10	11+12	13
Baetis harrisoni	3.19	26.06	16.01	20.61	20.50	13.65
Baetis natalensis	86.44	6.95	0	0	6.62	0
Baetis Type B	23.26	0.70	0	17.40	55.55	3.10
Baetis glaucus	0	15.40	66.41	8.25	9.05	0.90
Centroptiloides bifasciatum	4.21	39.69	0.61	31.83	19.95	3.72
Pseudopannota maculosum	0	9.31	5.44	43.60	31.29	10.35
Centroptilum parvum	15.19	50.50	3.71	14.82	1.81	13.98
Centroptilum exisum	0	11.83	9.94	31.56	8.13	38.54
Afronurus harrisoni	8.72	6.10	2.07	8.30	28.63	46.17
Adenophlebia auriculata	2.4	96.26	0.51	0	0	0.84
Caenid Type A	0.07	30.51	2.96	46.23	8.70	11.53
Caenid Type B	0	0.84	0	0.03	85.22	14.00
Castanophlebia calida	93.85	5.15	0.99	0	0	0
Choroterpes elegans	0.33	33.15	5.56	42.11	8.42	10.43
Neurocaenis reticulata	5.43	41.86	1.54	19.11	24.74	7.32
Prosopistomatidae	0	0	0	0	88.81	11.19
Ecnomus sp. Type 1	1.83	1.92	62.56	30.60	0.37	2.74
Macrostemum capense	0.18	27.93	0.61	46.66	16.78	7.85
Cheumatopsyche afra	1.90	18.66	10.89	40.95	13.80	13.79
Cheumatopsyche thomasseti	0.64	34.66	10.47	18.45	17.15	18.62
Chimarra sp.	15.54	84.30	0.09	0	0.07	0

Table 8. Invertebrates found in different zones on the Buffalo River - total number of individuals sampled per zone.

INVERTEBRATE	SITES					
	0+1	2-7	8	9+10	11+12	13
Simulium adersi	3 261	127 012	106 703	416 094	83 220	120 687
Simulium nigritarse	11 803	216 330	38 477	67 226	6 174	21 881
Simulium damnosum	0	16 865	2 012	17 504	35 228	1 066
Burnupia sp.	10 425	32 790	17 793	33 324	16 083	16 450
Tanypodinae	534	3 025	333	274	130	147
Orthocladiinae	2 072	9 293	146	212	657	867
Chironominae	1 112	7 113	347	487	1 337	535
Gyrinus	98	5 955	141	144	280	16
Aulonogyrus	148	203	0	16	0	0
Psephenidae	1287	994	0	180	114	16
Elmidae	434	45 603	4 839	47 035	1 533	934

Table 9. Invertebrates found in different zones on the Buffalo River - frequencies expressed as percentages of the total number of individuals sampled.

INVERTEBRATE	SITES					
	0+1	2-7	8	9+10	11+12	13
Simulium adersi	0.38	14.82	12.45	48.55	9.71	14.08
Simulium nigritarse	3.26	59.77	10.63	18.57	0.97	6.05
Simulium damnosum	0	23.21	2.77	24.08	48.47	1.46
Burnupia sp.	8.22	25.85	14.03	26.27	12.67	12.96
Tanypodinae	12.02	68.09	7.49	6.17	2.93	3.31
Orthocladiinae	15.64	70.15	1.10	1.60	4.95	6.54
Chironominae	10.17	65.07	3.17	4.45	12.23	4.89
Gyrinus	1.47	89.76	2.13	2.17	4.22	0.24
Aulonogyrus	40.32	55.31	0	4.36	0	0
Psephenidae	49.67	38.36	0	6.95	4.40	0.62
Elmidae	0.43	45.43	4.82	46.86	1.53	0.93

Table 10.

a) Ninety percentile conductivity values (mS/m) for each zone (i.e. values which were only exceeded in 10% of the samples in each zone).

SITES					
0+1	**2-7**	**8**	**9+10**	**11+12**	**13**
10	46	114	77	60	84

b) Ninety percentile phosphate concentrations (mg/l) for each zone (i.e. values which were only exceeded in 10% of the samples in each zone).

SITES					
0+1	**2-7**	**8**	**9+10**	**11+12**	**13**
0.12	0.15	5.23	0.29	0.38	14.73

c) Ninety percentile temperature values (degrees Celsius) for each zone (i.e. values which were only exceeded in 10% of the samples in each zone).

SITES					
0+1	**2-7**	**8**	**9+10**	**11+12**	**13**
17.0	23.1	23.7	24.9	24.3	25.4

d) Ninety percentile turbidity values (NTU) for each zone (i.e. values which were only exceeded in 10% of the samples in each zone).

SITES					
0+1	**2-7**	**8**	**9+10**	**11+12**	**13**
7	24	82	70	100	45

e) Ninety percentile pH values for each zone (i.e. values which were only exceeded in 10% of the samples in each zone).

SITES					
0+1	2-7	8	9+10	11+12	13
7.5	7.9	8.3	8.7	8.6	8.2

4.5 Recreation water quality requirements

Kempster *et al* (1980) present water quality criteria for recreation and EPA (1986) discuss each variable separately and is a good guide in determination of the guidelines for water quality.

5. CONCLUSIONS

The water users in the catchment were unsure about their water quality requirements, indicating a necessity for guidance in defining their needs. The Department of Water Affairs and Forestry should use their expertise in determining the final guidelines and water quality requirements for the Buffalo river, taking into account the requirements of the various users.

The major users are :

- East London Municipality
- Ciskei Public Works
- King William's Town
- Da Gama Textiles - Zwelitsha Branch
- Irrigation Practices in the upper catchment

The major effluent producers are :

- Ciskei Public Works - Sewage treatment works (a number have been privatised)
- King William's Town
- Da Gama Textiles - Zwelitsha Branch - flood irrigation
- King Tanning - diluted effluent flood irrigation

6. INFORMATION SOURCES

Kempster, P.L., Hattingh, W.H.J. and van Vliet, H.R. (1980) *Summarised water quality criteria*. Department of Water Affairs, Technical Report TR108

Environmental Protection Agency (EPA) (1986) *Quality criteria for water 1986*. EPA 440/5-86-001. Office of Water Regulation and Standards. Washington, DC 20460.

Mr A. Lucas. Assistant Director : Water Quality, East London, Department of Water Affairs. August 1991 and November 1992.

APPENDIX D

WATER QUALITY IN THE BUFFALO RIVER CATCHMENT

by

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March 1993

CONTENTS

1. INTRODUCTION

Water quality is one of the major problems in South African water management. South Africa is a semi-arid country and this has led to the enforcement of effluent return flow from industries which do not have intractable substances in their effluent. It is therefore essential for management to be aware of the water quality in all South African water resources. The Buffalo River is one of the seven sensitive catchments in South Africa, where all effluent has to apply to the 1 mg/l special phosphate effluent standard. The Buffalo River is situated in an area that is earmarked for industrial development, despite the limitations in the water resources, and will thus need to carry a higher effluent load in the future. The managers in the system are looking at various options to overcome this problem. One of the options is to extend the Cyril Lord pipeline to King William's Town, so that the intractable effluent can be discharged into the sea at East London (Kapp Prestedge Retief, 1992). At present there appear to be problems with the pipeline and financial implications might make it unacceptable. Such a pipeline might also lead to a large reduction in return flows.

As far back as 1889 the inhabitants of East London perceived the Buffalo River water as being polluted, although Dr Hahn of the South African College, analysed samples and assured the municipality of East London that the water was of reasonable quality (Tankard, 1990). After this initial perception, the first recorded studies were carried out on the Buffalo River catchment by Thornton *et al* (1967) during 1961 - 1963. At this time Mdantsane was not yet developed. Reed and Thornton (1969) studied the system in 1966 -1967 shortly after the completion of the Bridle Drift Water Scheme. According to Hart (1982) the water quality degraded from a naturally elevated baseline condition (Thornton *et al*, 1967; Reed and Thornton, 1969) as a result of industrial, domestic and agricultural effluent, but the relative contributions to mineralisation and eutrophication are not known. Selkirk and Hart (1984) investigated the sensitivity of the major impoundments in the Buffalo River catchment to eutrophication.

Hart (1982) and Hart and Selkirk (1984) undertook studies on the Buffalo River during the early eighties and expressed real concern for the deteriorating water quality of the river. These studies were completed during a drought period and data show that the median concentrations did not decrease after that period. The main variables of concern were identified as mineralisation and nutrient enrichment for the middle and lower reaches of the catchment and bacteriological contamination in the Bridle Drift Dam area. The bacteriological contamination of the Buffalo River catchment is discussed in a separate section (Appendix E)

2. WATER QUALITY IN THE BUFFALO RIVER

This report covers all water quality variables for which data are available. The Hydrological Research Institute, Department of Water Affairs and Forestry (HRI - DWAF), East London Municipality (ELM) and the South African Bureau of Standards (SABS - for Water Quality Management (WQM)) measured electrical conductivity and ortho-phosphate concentrations at bi-weekly (HRI - DWAF, ELM) and monthly (WQM) intervals. There were few sites

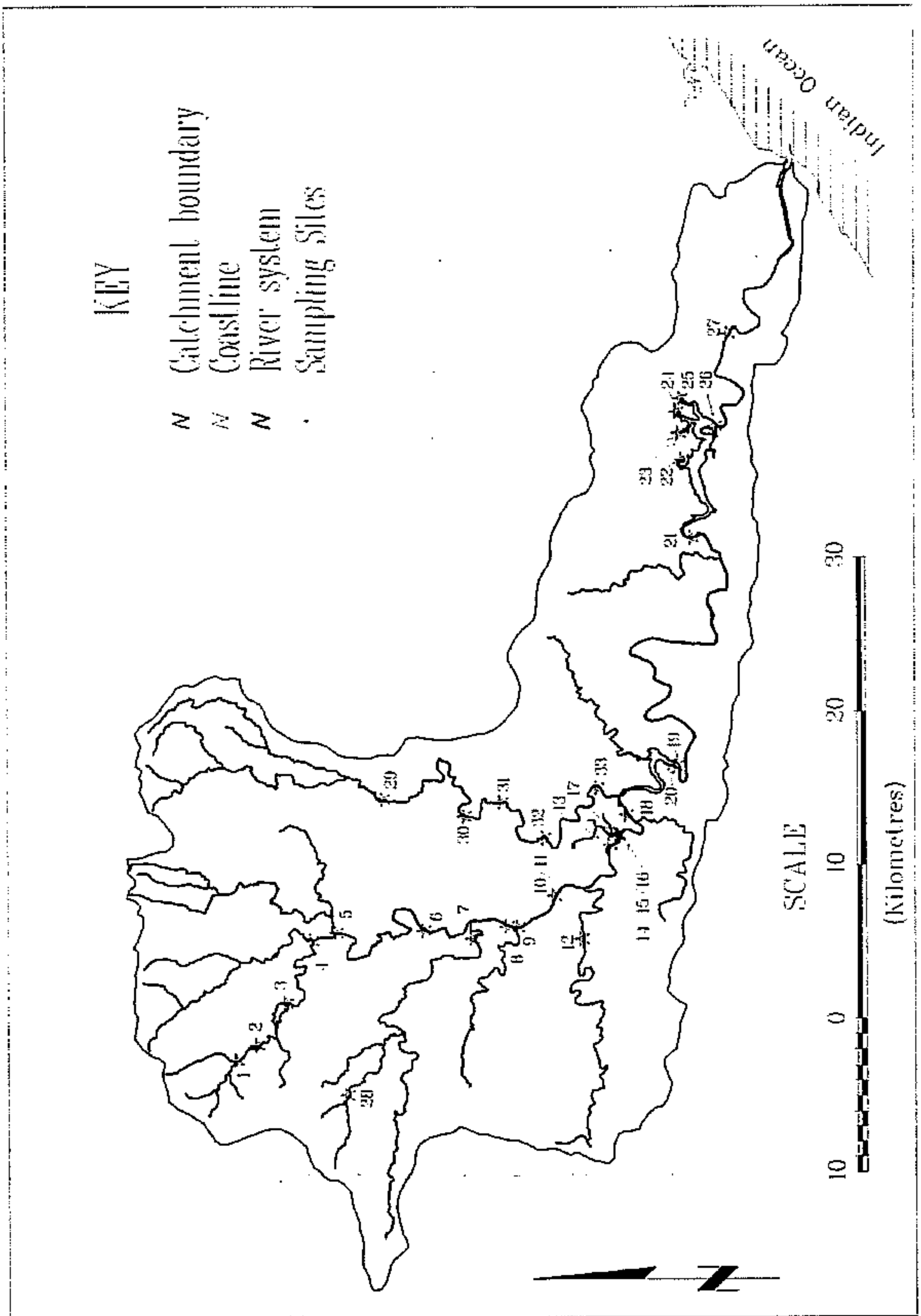

Figure 1. The Buffalo River catchment showing all the sampling sites for which water quality data is available.

which had had water quality analyses carried out for continuous periods of more than 15 years. The only site for which the data were continuous from 1967 to 1992 was the Bridle Drift Dam. All the other sites had periods of varying lengths of missing data. As a result all available data from different monitoring programmes which were conducted at the same site but over different periods of time, or even over the same period of time, were combined for each relevant site to give a more complete data set. The data were separated into Buffalo River data and Yellowwoods River data.

Figure 1 represents the sampling sites on the Buffalo and the Yellowwoods rivers for which data were available.

Numbers of samples, dates with available data, annual median, minimum, maximum, standard deviation and variance of concentrations were calculated for all chemical variables in the Buffalo River and are presented in a table for each site (tables 2 - 34).

3. FACTORS AFFECTING WATER QUALITY

3.1 Mineralisation

Total dissolved solids (TDS; mg/l) cannot economically be removed or reduced. Once added to water, minerals represent a permanent form of degradation. Upstream of King William's Town the geological formations result in deterioration of the water quality. Downstream of King William's Town, effluent irrigation is the main cause of the increase in mineral content of the water. The Isana Stream, which drains the tannery effluent was the main source of salt (Thornton *et al*, 1967) in the late sixties. Kapp Prestedge Retief (1992) found that the major saline effluent that enters Laing Dam originates from the King Tanning and Da Gama (KWT) plants. In 1982 Meiring *et al* (1983) estimated that 60% of the TDS of non-natural origin were contributed by Da Gama, 26% by King Tanning and 11% by domestic sewage treatment effluent. This is in contrast to the findings of Reed and Thornton (1969) which showed that the major input (± 61%) of mineralisation originated from natural geological sources, whilst ±27% came from industrial origins (textile and tannery) and only 12% from human outputs (Reed and Thornton, 1969).

During 1966 - 1967 farming activities were restricted to pastoral agriculture and fertilizers were not widely used (Reed and Thornton, 1969). However, salinity was already then regarded as one of the major problems in the catchment.

The mineral content of Laing Dam was high and appeared to be increasing to unacceptable levels according to Ninham Shand and Partners (1982). The mineral content of water in Laing Dam rose from about 150 mg/l to over 600 mg/l between 1978 and the end of 1982. This is in excess of the maximum desirable limit of 500 mg/l accepted for potable supplies (Bruton and Gess, 1988; Pike, 1989).

3.2 Nutrient enrichment

Phosphorus is an essential element for all life. In aquatic ecosystems it is often the growth or yield limiting nutrient (Wiechers and Heynicke, 1986). Selkirk and Hart (1984) found that the available phosphate in the sediments of Rooikrans was extremely low, but in Laing was very high. Toerien and Tow (1976) suggested that Laing Dam acts as a phosphorus trap and this proposal was also supported by O'Keeffe (1989) and O'Keeffe *et al* (1990). The dam might thus respond slowly to decreased external loading. Selkirk and Hart (1984) proposed that Laing Dam was nitrogen limited and Bridle Drift Dam was phosphate limited.

Laing Dam was potentially eutrophic due to total phosphate concentrations of higher than 50 μg/l which had caused algal growth related problems (Thornton *et al*, 1967; Reed and Thornton 1969; Tow, 1980a, 1980b; Walmsley and Butty, 1980; Selkirk and Hart, 1984; Schwab *et al* 1988). High turbidity (Hart, 1982; Van Ginkel and Theron, 1987; Schwab *et al*, 1988) inhibited the algal growth in Laing and Bridle Drift Dams. The algal biomass was nevertheless excessive (Ninham Shand and Partners, 1982) in spite of this 'natural' environmental control mechanism. Selkirk and Hart (1984) suggested that the conductivity in the system, especially in Bridle Drift Dam, should not be allowed to increase as it would have an increasing effect on the flocculation potential and thus increase in water transparency, with the threat of increasing algal blooms. According to A. Lucas (pers. comm., 1992) and a newspaper report (Daily Dispatch, 22/1/92), there have been major problems in the Bridle Drift Dam and in the purification works due to excessive algal blooms since January 1992. Ninham Shand and Partners (1982) reported that the uncontrolled discharge of sewage and industrial effluent, which is only partially treated, caused major problems in the water quality upstream and in Laing Dam. Selkirk and Hart (1984) expressed concern over the effect of the water from the Kubusi system on water quality, as it could cause re-suspension of sediments, releasing nutrients into the water.

Sewage and industrial effluents have been identified as the major point source contributors to the phosphorus loads in the fresh water environment in South Africa (Taylor *et al*, 1984). There were also major problems in the Buffalo River. Unknown quantities of purified effluent, diluted with water from leakages in the reticulation system of Mdantsane (Kahn, 1992; Lucas, pers. comm., 1992), contributed continuous phosphorus loads to the Bridle Drift Dam. These could play an important role in the high occurrence of algal blooms that are being experienced at the moment.

Thornton *et al* (1967) found that deterioration of the water quality downstream of King William's Town was mainly due to human activity and that the Buffalo River could not assimilate the pollution entering the Laing Dam. The main sources of nutrient enrichment were effluent from sewage works, industrial effluent and diffuse sources.

3.3 Heavy metals

Little is known concerning pollution by heavy metals in the Buffalo River catchment. Watling *et al* (1985) completed a metal survey during 1982-1983 and found that the Buffalo estuary and the Umzoniana and Ncabanga streams had the highest anthropogenic inputs of heavy metals yet recorded in the estuaries of the Eastern Cape. They analysed samples for copper, lead, zinc, iron, manganese, cobalt, nickel, cadmium, sodium, potassium, magnesium, strontium, chromium and mercury. The levels of lead and nickel were hundred times higher than the average values reported for Eastern Cape estuaries (Watling, 1985). No previous heavy metal analysis data were available for the rest of the Buffalo River catchment.

4. VARIABLES OF CONCERN

4.1 Downstream changes in water quality

The data collected during this study showed that the major area of concern involving mineralisation and nutrient enrichment was in the King William's Town area upstream of Laing Dam and in the Bridle Drift Dam (figures 2 and 3). Nutrient effects are now being experienced and are of major concern to the East London Municipality.

The main variables of concern are total dissolved solids (TDS - mg/l), nutrients, especially phosphorus (PO_4-P - mg/l) and faecal coliform (discussed in Appendix E). Figures 2 and 3 illustrate the spatial trends of median TDS and PO_4-P concentrations down the Buffalo River and clearly show the sites where the highest inputs and increases occur. For both substances high concentrations occur in the middle reaches of the catchment (Sites 12 - 18) and for PO_4-P problems exist in the Bridle Drift Dam inflowing streams from Mdantsane (Sites 22 - 25). The latest data incorporated into this analysis were collected in September 1992. According to Mr Kahn (pers. comm., 1993) the Zwelitsha Sewage Treatment Works had complied to the conditions of the special phosphate standard since October 1992. Mr Kahn was also working on the diversion of any runoff caused by spills from the sewerage and reticulation systems of Mdantsane, which might solve Bridle Drift Dam's pollution problems in the near future.

4.2 Temporal changes in water quality

As the downstream trends of the variables of concern are based on overall median concentrations, temporal and seasonal changes were determined by calculating annual median concentrations and monthly median concentrations.

4.2.1 *Total dissolved Solids*

Temporal changes in TDS concentration were determined for six selected sites in the Buffalo River catchment. These sites are representative of the three different sections of the Buffalo River catchment, namely the upper, middle and lower areas. The upper reaches of the catchment extend from the origin of the Buffalo river to the flow through King William's Town. In the upper reaches two sites were chosen: Sites 4 and 7, which are on the Quencwe and Mqakwebe rivers respectively. The Middle reaches of the catchment extend from King William's Town to the outflow of Laing Dam. In this stretch of the river Site 18, 20 and 33 were selected. These sited were situated at the point where the Buffalo River flows into Laing Dam, in Laing Dam at the dam wall and at the point where the Yellowwoods River flows into Laing Dam, respectively. The Lower reaches start below Laing Dam and stretch to the sea. The Bridle Drift Dam near the dam wall (Site 26) was chosen as being representative of the lower reaches. This study only covered the Buffalo River up to Bridle Drift Dam since the main users of the Buffalo River catchment extract their water at this point and the effluent discharge from Mdantsane, which does not need to apply to the 1 mg/l PO_4-P special effluent standard, is discharged into the river below the extraction weir of East London Municipality.

Upper reaches

At Site 4 (figure 4A), the water of the Buffalo River was pristine and had a maximum TDS

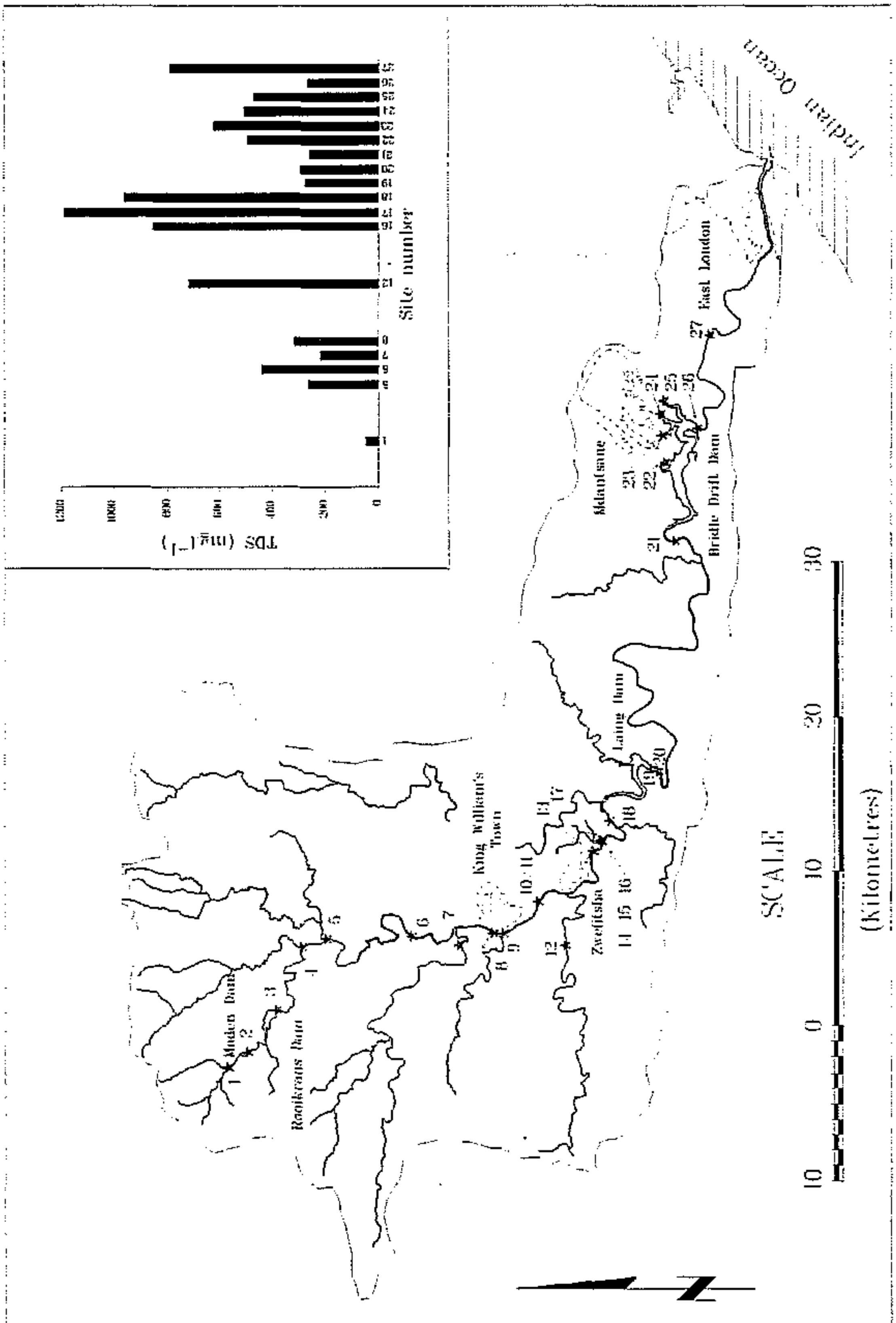

Figure 2. Downstream median TDS concentrations at the sampling sites in the Buffalo River catchment.

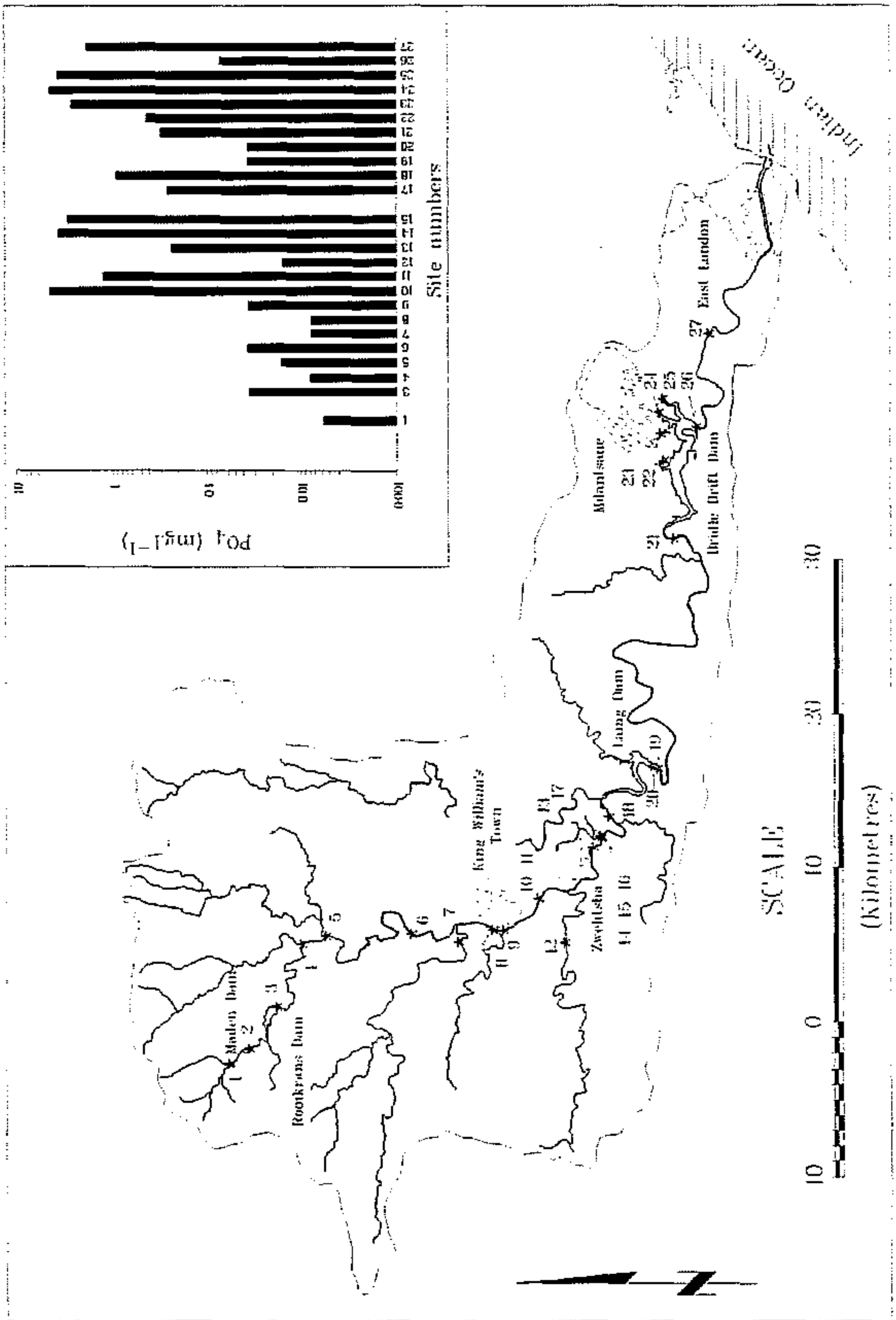

Figure 3. Downstream median phosphate concentrations at the sampling sites in the Buffalo River catchment.

concentration of 577 mg/l. These concentrations occurred during 1986. The annual medians varied between 195 and 399 mg/l during the period of available data. Unfortunately no data were available at this site after 1986. At Site 7 (figure 5A) in the Mqakwebe River and which originates in the Dimbaza area, the maximum concentration of 937 mg/l occurred during 1971. The annual median concentrations varied between 34 and 461 mg/l in 1992 and 1971 respectively. Figures 10A and 11A show the percentage of time for which the concentrations at these two sites exceeded the South African and international criteria for TDS concentrations. This criterion were determined for each site by multiplying the EC criterion of 75 mS/m with the TDS/EC ratio for each site. At both these sites the TDS concentrations did not exceed the criterion for more than 7% of the time.

Middle Reaches

At Site 18 (figure 6A) where the Buffalo River flows into Laing Dam and below the main areas of concern the maximum TDS concentration was 5130 mg/l. The median annual concentrations varied between 150 and 1116 mg/l during 1972 and 1983 respectively. At Site 33 (figure 7A) where the Yellowwoods River flows into Laing Dam the maximum TDS concentration was 1844 mg/l. The median annual concentrations varied between 330 and 1321 mg/l during 1972 and 1980 respectively. At Site 20 (figure 9A) which is the Laing Dam outflow, the maximum TDS concentrations was 476 mg/l. The median annual concentrations varied between 198 and 685 mg/l during 1962 and 1983 respectively. Figures 12A, 13A and 14A show that at the inflows of the Buffalo and Yellowwoods Rivers TDS concentrations exceeded the South African and international criterion for ± 80 % of the time. At Site 18, the inflow of the Buffalo River into Laing Dam, the Mlakalaka Stream inflows, which is the effluent from Da Gama Textile factory and the effluent wash-off from the Tannery irrigation, affect the high TDS concentration found at this site. The median TDS concentrations from the Buffalo and the Yellowwoods rivers flowing into Laing Dam were 960 mg/l and 692 mg/l respectively. In Laing Dam the median concentration is 289 mg/l. The decrease in Laing Dam salt concentrations is clearly seen. This can be explained by the dilution effect of the inflowing water into Laing dam and the effect of the retention in the reservoir.

Lower reaches

In the Bridle Drift Dam the maximum TDS concentration was 1242 mg/l. The annual medians fluctuated between 167 mg/l and 442 mg/l during 1980 and 1984 respectively. TDS concentrations exceeded the South African and international criteria for less than 5% of the time.

From these results it is clear that the main problem occurs in the urban-industrial area of King William's Town and Zwelitsha towards Laing Dam. The acceptable level of TDS as indicated by the users in the Buffalo River catchment is <800 mg/l and therefore the assimilative capacity in the middle reaches of the Buffalo River is zero as the concentrations reach unacceptable levels. There do not seem to be any meaningful temporal changes at any of the sites, although there was a drought period during the early eighties when concentrations were higher than usual. Highest TDS concentrations were experienced during 1983.

4.2.2 *Ortho-Phosphorus*

Upper reaches
Nutrient enrichment as phosphorus was very low in the upper reaches of the Buffalo River catchment. At Site 4 (figure 4B) in the Cwencwe River a maximum concentration of 4.27 mg/l was monitored. The annual median concentrations fluctuated between 0.001 and 0.063 mg/l during 1985 and 1977 respectively. At Site 7 (figure 5B) in the Mqakwebe River the maximum concentration was 0.24 mg/l. The annual median concentrations varied between 0.001 during 1985 and 0.05 during 1983. Although the maximum concentration at Site 4 was quite high, the concentrations that exceeded the effluent discharge concentration of 1 mg/l occurred for less than 1% of the time (figure 10B). The same applied at Site 7 (figure 11B).

Middle reaches
At the Buffalo River inflow into Laing Dam (Site 18 - figure 6B) the maximum phosphate concentration was 6.5 mg/l. The annual medians varied between 0.043 and 2.828 mg/l during 1977 and 1983 respectively. These high concentrations originate mainly from point sources, which should comply to the 1 mg/l phosphate effluent standard. In the Yellowwoods River (Site 33 - figure 7B) the maximum phosphate concentration was 14 mg/l. The annual median phosphate concentrations varied between 0.011 and 1.29 mg/l during 1972/1979 and 1986 respectively. In Laing Dam (figure 8B) the maximum phosphate concentration that occurred was 1 mg/l. The annual median phosphate concentrations varied between 0.00 mg/l and 0.3 mg/l during 1961-1967 and 1971 respectively. At Site 18 (figure 12B) the phosphate concentrations exceeded the South African effluent standard for 60% of the time, while at Site 33 the South African effluent standard was only exceeded for 7-8% of the time. Laing Dam exceeded this phosphate concentration for only 3% of the time. This indicates the extent of nutrient pollution in the middle reaches of the Buffalo River. Although Site 33 had higher maximum phosphate concentrations, concentrations in the Buffalo River were excessive for longer periods and thus contribute much higher loads to the Laing Dam. In Laing Dam nutrients are adsorbed, sediment into the soil and are taken up to such an extent that concentrations near the dam wall were well within limits.

Lower reaches
In Bridle Drift Dam (figure 9B) the maximum concentration of 8 mg/l was reached during 1983. The annual median phosphate concentrations varied between 0.05 and 0.70 mg/l during 1972/1979 and 1983. Phosphate concentrations exceeded 1 mg/l for less than 6% of the time.

The acceptable phosphate concentration limit indicated by users was <0.05 mg/l. This does not appear to be unreasonable, as concentrations were mostly above the acceptable limits.

5. OTHER WATER QUALITY VARIABLES

5.1 Heavy metals

The only data available on heavy metals were collected by the Water Quality Management section of the Department of Water Affairs in the East London area on the 1/4/92.

EPA standards were used to determine the severity of the heavy metal pollution in the

A B

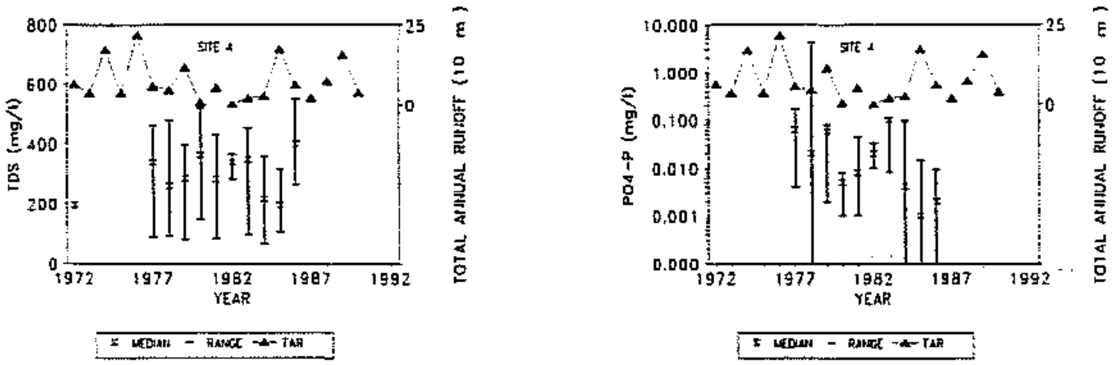

Figure 4. The temporal changes in TDS (A) and PO_4 (B) median annual concentrations in the Quencwe River (Site 4) flowing into the Buffalo River 1972 to 1989.

A B

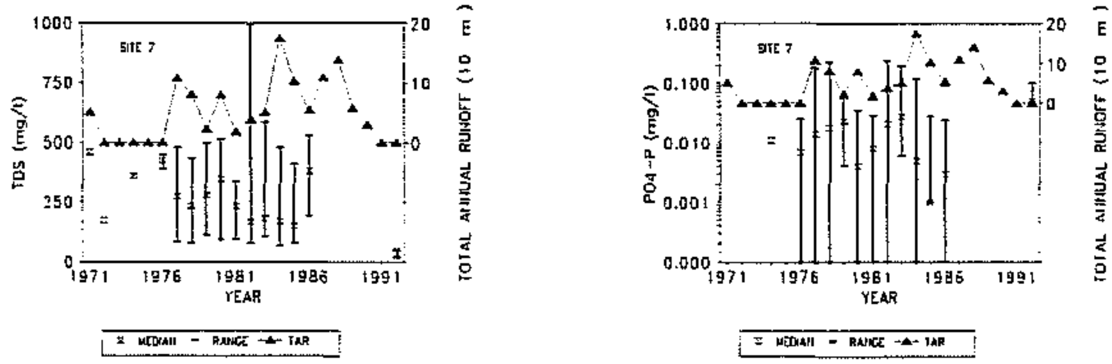

Figure 5. The temporal changes in TDS (A) and PO_4 (B) median annual concentrations in the Mqakwebe River (Site 7) from 1971 to 1992.

A B

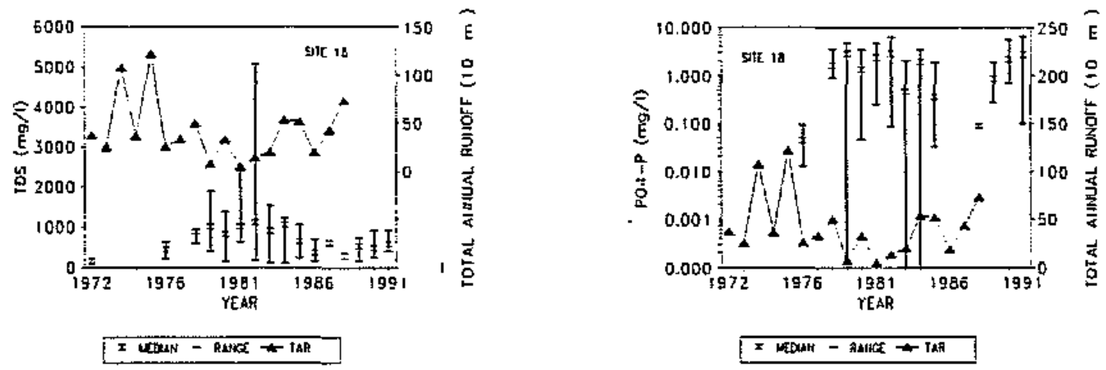

Figure 6. The temporal changes in TDS (A) and PO_4 (B) median annual concentrations in the Buffalo River (Site 18) from 1972 to 1992.

A B

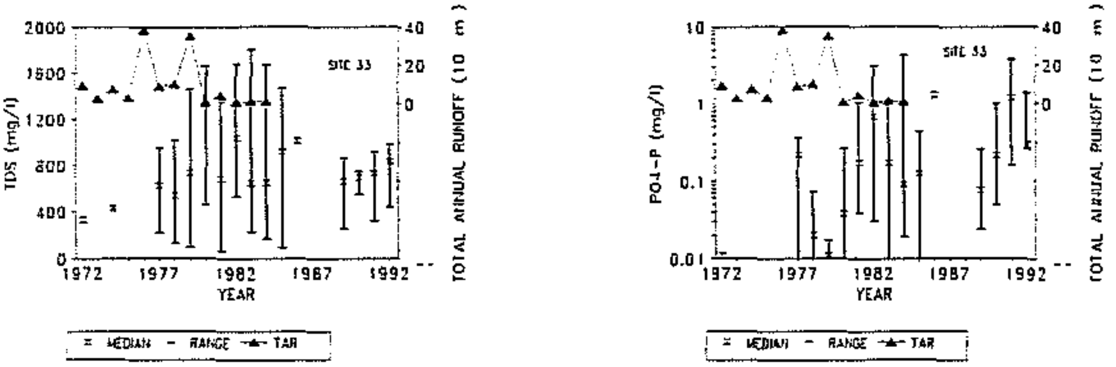

Figure 7. The temporal changes in TDS (A) and PO_4 (B) median annual concentrations in the Yellowwoods River (Site 33) from 1969 to 1991.

A B

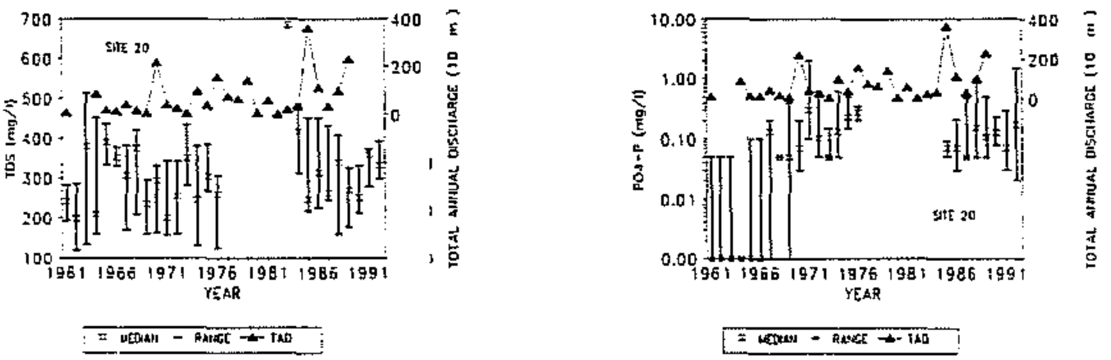

Table 8. The temporal changes in TDS (A) and PO_4 (B) median annual concentrations in the Laing Dam (Site 20) from 1961 to 1992.

A B

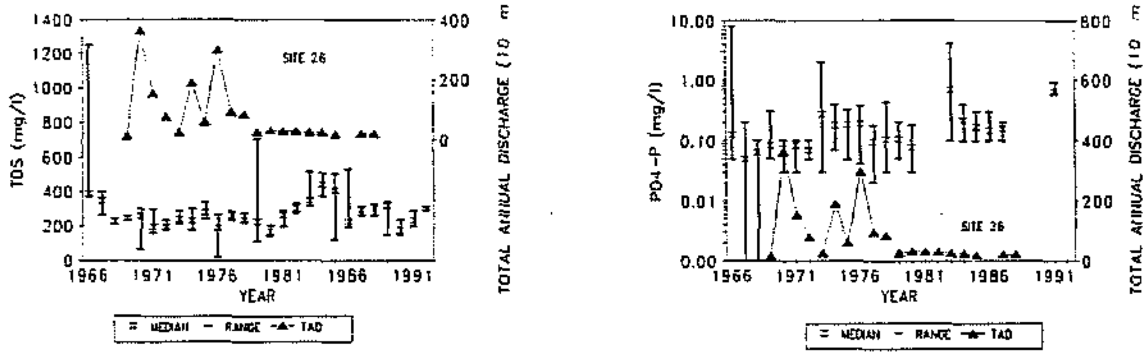

Figure 9. The temporal changes in TDS (A) and PO_4 (B) median annual concentrations in the Bridle Drift Dam (Site 26) from 1968 to 1991.

A B

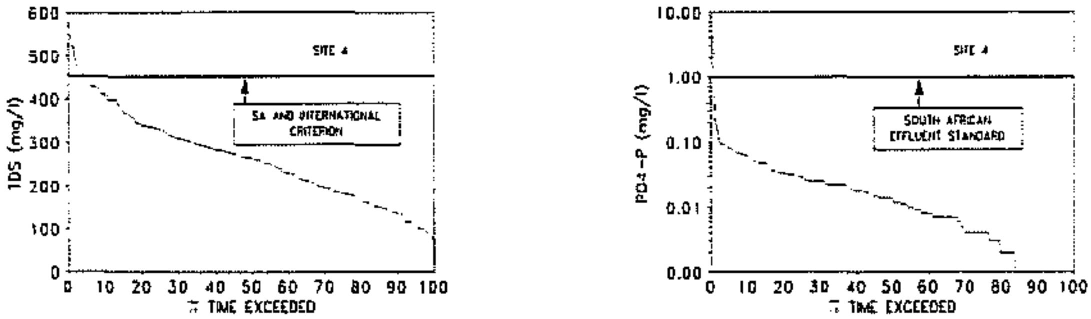

Figure 10. The percentage of time that TDS (A) and PO_4 (B) concentrations in the Quencwe River (Site 4) flowing into the Buffalo exceeded the international and South African criterion for TDS concentrations and the effluent discharge standard for PO_4 concentrations from 1972 to 1989.

A B

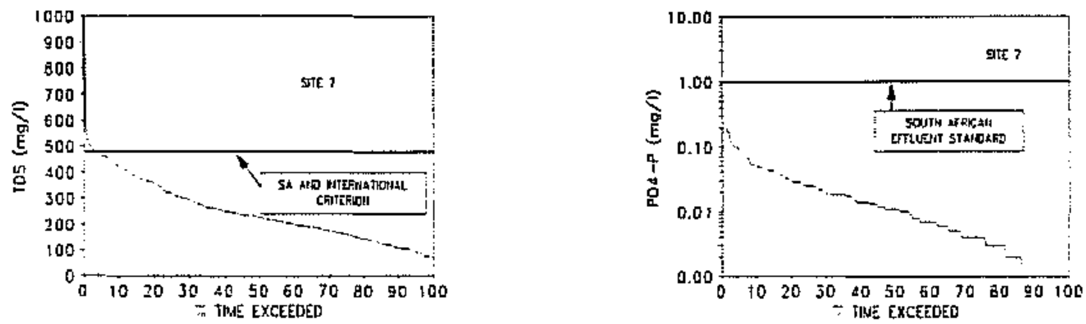

Figure 11. The percentage of time that TDS (A) and PO_4 (B) concentrations in the in the Mqakwebe River (Site 7) exceeded the international and South African criterion for TDS concentrations and the effluent discharge standard for PO_4 concentrations from 1971 to 1992.

A B

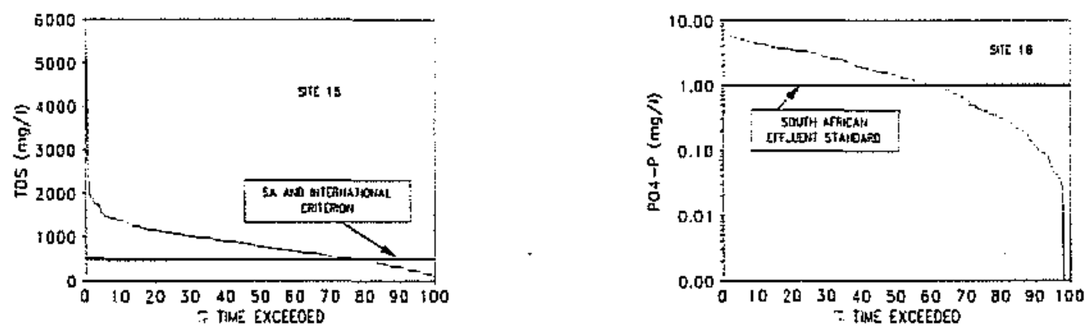

Figure 12. The percentage of time that TDS (A) and PO_4 (B) concentrations in the Buffalo River (Site 18) exceeded the international and South African criterion for TDS concentrations and the effluent discharge standard for PO_4 concentrations from 1972 to 1992.

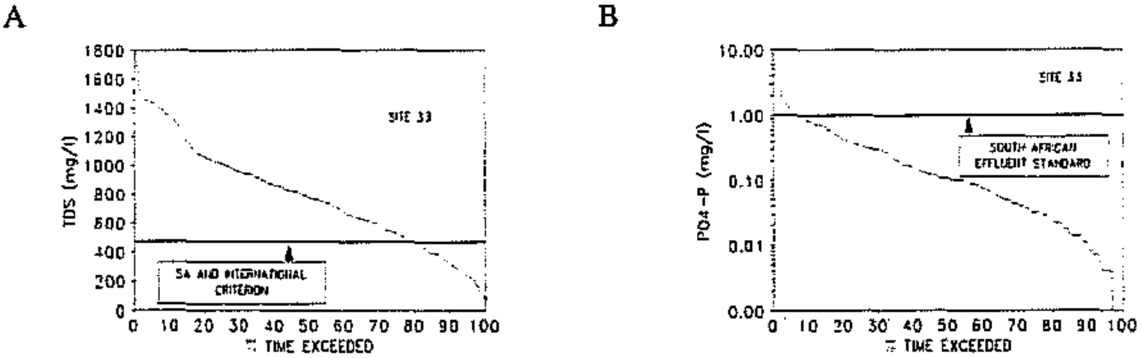

Figure 13. The percentage of time that TDS (A) and PO_4 (B) concentrations in the Yellowwoods River (Site 33) exceeded the international and South African criterion for TDS concentrations and the effluent discharge standard for PO_4 concentrations from 1969 to 1991.

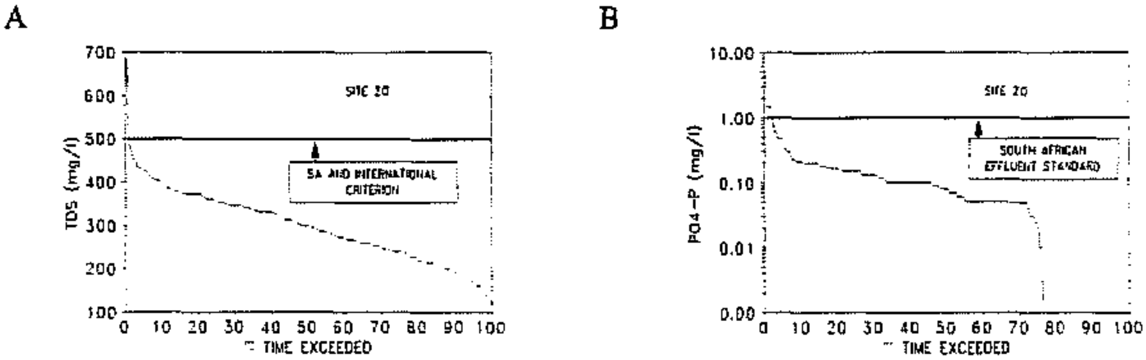

Table 14. The percentage of time that TDS (A) and PO_4 (B) concentrations in the Laing Dam (Site 20) exceeded the international and South African criterion for TDS concentrations and the effluent discharge standard for PO_4 concentrations from 1961 to 1992.

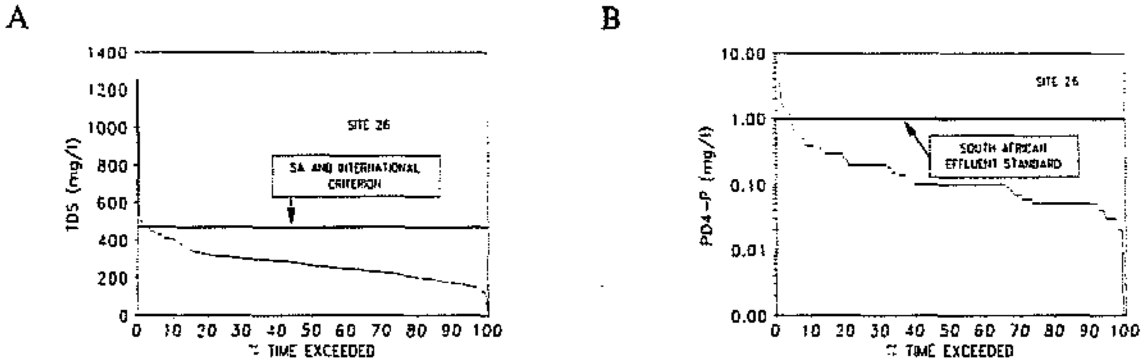

Figure 15. The percentage of time that TDS (A) and PO_4 (B) concentrations in the Bridle Drift Dam (Site 26) exceeded the international and South African criterion for TDS concentrations and the effluent discharge standard for PO_4 concentration from 1968 to 1991.

Buffalo River from a sample taken during April 1992. The toxicity of heavy metals is related to the hardness of the water. In table 1 the soft water relates to 50 mg/l $CaCO_3$ and the hard water relates to 150 mg/l $CaCO_3$. The chromium, copper, nickel and zinc concentrations were within the EPA standard limits for ecological and drinking water standards as the hardness of the Buffalo River water was usually above 100mg/l $CaCO_3$. The lead concentrations were higher than the EPA standard for drinking water at all the sites sampled.

Table 1. Heavy metal analysis at a few sites were done for samples taken on 1/4/92.

Site number	Cr (mg/l)	Cu (mg/l)	Nc (mg/l)	Pb (mg/l)	Fe (mg/l)	Zn (mg/l)
EPA Standard Ecological(Hardness dependent)	Soft-0.98 Hard-31	Soft-0.009 Hard-0.034	Soft-11 Hard-31	Soft-0.012 Hard-0.128	1.00	Soft-0.18 Hard-0.57
EPA Standard Drinking water	50	1	0.63	0.05	0.30	5
6	<0.05	<0.02	<0.05	<0.10	<0.05	0.03
7	<0.05	<0.02	<0.05	<0.10	0.06	0.04
9	<0.05	<0.02	<0.05	<0.10	0.84	<0.01
10	<0.05	<0.02	<0.05	<0.10	0.16	0.17
11	<0.05	<0.02	<0.05	<0.10	0.16	0.10
13	<0.05	<0.02	<0.05	<0.10	1.40	<0.10
15	<0.05	<0.02	<0.05	<0.10	0.47	0.05
17	<0.05	<0.02	<0.05	<0.10	0.38	<0.10
18	<0.05	<0.02	<0.05	<0.10	0.40	<0.01
20	<0.05	<0.02	<0.05	<0.10	1.64	<0.01
26	<0.05	<0.02	<0.05	<0.10	0.79	0.31
27	<0.05	<0.02	<0.05	<0.10	<0.05	<0.01

The iron concentrations were higher than the EPA standard for aquatic life at sites 13 and 20, and higher than the EPA standard for human health at sites 9, 13, 15, 17, 18, 20 and 26. This means that both the Laing Dam and Bridle Drift Dam, water supplies for the urban areas, had iron concentrations that might affect human health

5.2 Biological Data

The only data available on the biological conditions in the dams were collected from Bridle Drift Dam. The Hydrological Research Institute of DWAF collected water samples on a bi-weekly basis for chlorophyll, algal biomass and turbidity (Secchi depth) determinations.

The data were collected near the dam wall and results are shown in figure 16. Chlorophyll a concentrations reached a peak of approximately 40 mg/l early in 1987. Unfortunately the latest data received to date were from September 1991. There was wide variability in chlorophyll a concentrations and on only six occasions was *Microcystis* the dominant algal species (figure 16 A). The algal scum conditions that occurred during 1992 (Mr A Lucas, pers. comm., 1993) were not recorded on a regular basis. As *Mycrocystis* does occur in Bridle Drift Dam, and because of the physiological characteristics of this cyanobacterium (Zohary and Robarts, 1989), it uses conditions for ultimate production and *Microcystis* blooms will occur.

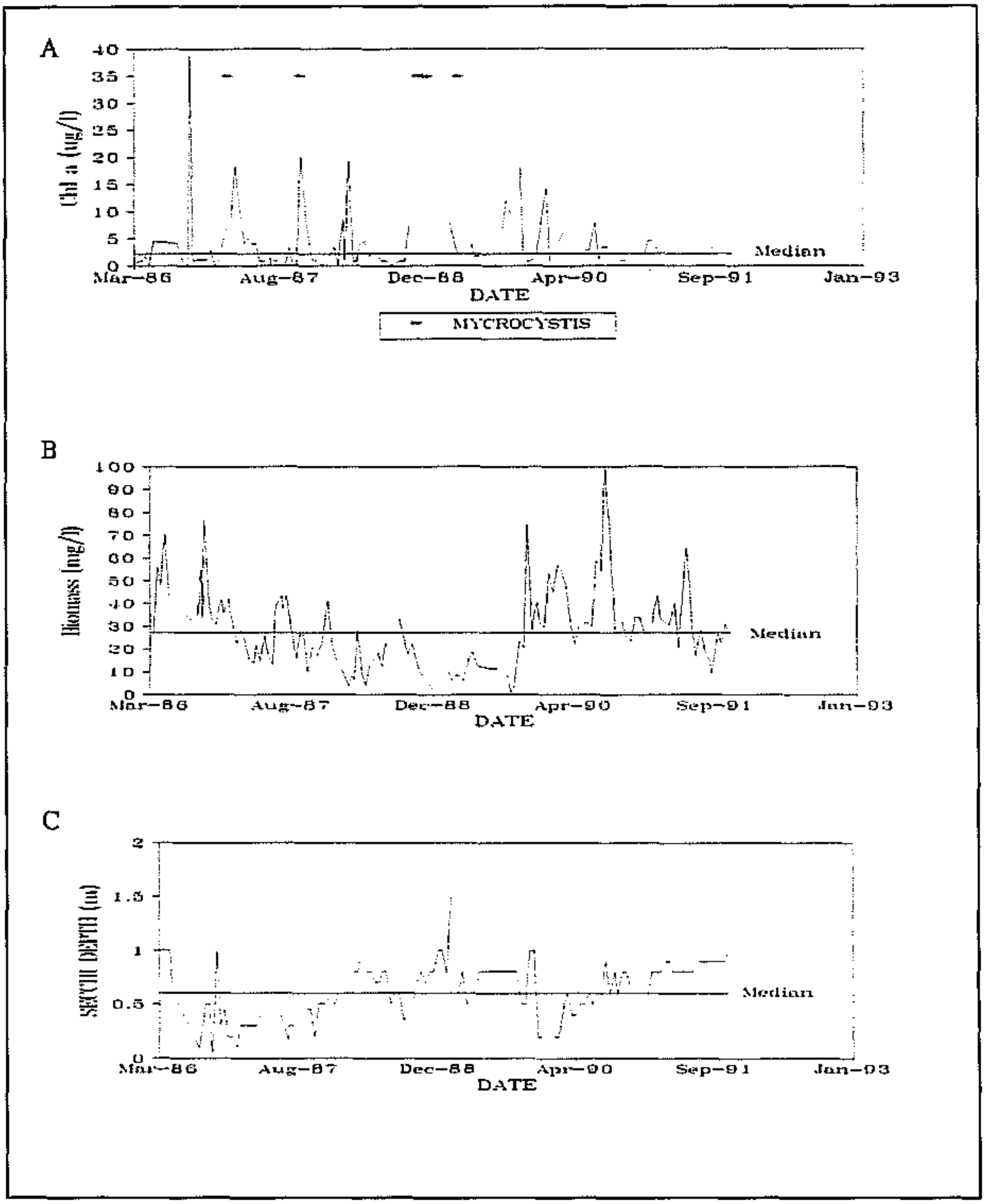

Figure 16. The chlorophyll a concentrations (A), biomass (B) and secchi depth (C) readings in the Bridle Drift Dam near the dam wall (Site 26).

6. CONCLUSIONS

The water quality in the Buffalo River catchment did not show major temporal deterioration trends during the periods for which data were available.

- The TDS concentrations did not show a consistent increase, but did show increasing trends during the drought period of the early eighties in the upper, middle and lower reaches.

- The phosphate concentrations showed no lasting temporal increases in the Upper reaches of the Buffalo River. In the Middle reaches the phosphate concentrations increased in the Buffalo River flowing into Laing Dam from 1976 to 1978 and then stayed fairly constant till 1991. In the Lower reaches of the River the phosphate concentrations showed no meaningful temporal trends.

- The urban development in the Yellowwoods River was responsible for the temporal increases in both the TDS and phosphate concentrations at the inflow of Laing Dam.

The periods of time for which TDS and phosphate concentrations exceeded acceptable limits was a major problem only in the Middle reaches of the river, specifically in the Buffalo and Yellowwoods rivers at the inflow into Laing Dam. This was the area in the catchment which received major inputs from sewage treatment return flows (phosphate) and industrial irrigation return flows (TDS contributions).

Little is known about the heavy metal concentrations in the Buffalo River. Sampling undertaken by WQM in the Middle reaches of the Buffalo River indicated that lead and iron concentrations might be a cause for concern.

In Bridle Drift Dam *Microcystis* blooms are furthered by the physiological characteristics of this cyanobacterium, which enable them to adapt to existing conditions.

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PERSONAL COMMUNICATIONS

Mr R. Kahn. Water quality manager : Ciskei public Works. June 1992 and January 1993.

Mr A. Lucas. Assistant Director : Water Quality, East London, Department of Water Affairs. August 1991, January 1993 and November 1992.

TABLE 2. Selected statistics of the water quality variables measured at Pirie on the Buffalo river (Site 1) from September 1971 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	47	23.50	8.00	17.00	15.36	3.70	13.66
CA (mg/l)	140	34.40	0.00	3.90	4.57	3.47	12.05
Cl (mg/l)	140	31.10	7.90	12.20	13.11	3.80	14.42
COD (mg/l)	ND	-	-	-	-	-	-
DOC (mg/l)	44	9.00	0.00	4.00	3.18	2.82	7.97
EC (mS/m)	187	22.00	5.20	9.00	9.39	2.48	6.14
F (mg/l)	140	0.44	0.00	0.04	0.07	0.09	0.01
K (mg/l)	137	3.28	0.02	0.60	0.69	0.38	0.15
KN (mg/l)	44	0.940	0.020	0.220	0.242	0.198	0.039
Mg (mg/l)	140	25.20	1.00	2.55	2.85	2.19	4.77
Na (mg/l)	140	77.50	1.40	7.40	8.35	6.26	39.14
NH_4 (mg/l)	135	0.43	0.00	0.04	0.06	0.06	0.00
NO_3+NO_2 (mg/l)	138	1.100	0.00	0.07	0.11	0.16	0.03
O2 (mg/l)	ND	-	-	-	-	-	-
pH	140	8.30	4.71	6.70	6.61	0.62	0.38
PO_4 (mg/l)	137	0.105	0.000	0.007	0.012	0.015	0.000
Si (mg/l)	135	10.82	3.40	7.44	7.51	1.44	2.07
SO_4 (mg/l)	140	12.10	0.00	2.50	3.67	3.17	10.03
Suspended solids (mg/l)	ND	-	-	-	-	-	-
TDS (mg/l)	135	182.50	32.20	52.10	57.49	21.35	455.61
TEMP (°C)	ND	-	-	-	-	-	-
Total alkalinity (mg/l)	140	60.60	0.00	17.50	19.12	8.90	79.13
TP (mg/l)	44	0.091	0.003	0.014	0.017	0.017	0.00
Turbidity (NTU)	ND	-	-	-	-	-	-

TABLE 3. Selected statistics of the water quality variables measured at Maden Dam (Site 2) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
EC mS/m	26	12.6	4.8	7.3	7.7	3.4	3.4
O2 (mg/l)	26	9.4	0.6	1.8	2.6	3.4	3.4
pH	24	8.9	6.6	7.3	7.3	0.3	0.3
Turbidity (NTU)	18	41.0	1.1	2.6	5.9	82.9	82.9

TABLE 4. Selected statistics of the water quality variables measured at Rooikrans Dam (Site 3) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
EC (mS/m)	26	9.0	6.3	7.4	7.4	0.6	0.4
O2 (mg/l)	26	3.2	1.2	2.1	2.1	0.5	0.3
pH	24	8.2	6.6	7.4	7.3	0.4	0.2
PO4 (mg/l)	2	0.049	0.049	0.049	0.049	0.000	0.000
Turbidity (NTU)	18	5.6	0.8	2.4	2.8	1.3	1.7

TABLE 5. Selected statistics of the water quality variables measured at the Cwencwe river at Braunschweig (Site 4) from 1972 to June 1989.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	ND	-	-	-	-	-	-
Ca (mg/l)	194	52.60	5.10	23.55	23.35	9.79	95.82
Cl (mg/l)	194	142.90	17.70	66.55	67.43	27.59	761.07
COD (mg/l)	ND	-	-	-	-	-	-
DOC (mg/l)	1	3.64	3.64	ND	3.64	0.00	0.00
EC (mS/m)	227	91.00	11.00	43.30	43.31	16.74	280.07
F (mg/l)	194	0.58	0.00	0.16	0.17	0.10	0.01
K (mg/l)	193	8.23	0.00	1.83	2.00	1.00	1.01
KN (mg/l)	79	2.30	0.13	0.47	0.55	0.37	0.13
Mg (mg/l)	194	31.60	3.50	14.15	14.00	5.87	34.41
Na (mg/l)	194	95.40	3.80	39.10	39.52	16.60	275.63
NH_4 (mg/l)	193	1.33	0.00	0.05	0.07	0.11	0.01
NO_3+NO_2 (mg/l)	194	2.04	0.00	0.18	0.29	0.35	0.12
O_2 (mg/l)	ND	-	-	-	-	-	-
pH	194	8.77	5.84	7.37	7.34	0.52	0.27
PO_4 (mg/l)	193	4.27	0.00	0.01	0.04	0.31	0.09
SI (mg/l)	193	14.30	0.00	9.73	9.48	1.85	3.41
SO_4 (mg/l)	194	105.20	0.00	11.10	14.90	14.72	216.74
Suspended solids (mg/l)	ND	-	-	-	-	-	-
Total alkalinity (mg/l)	194	209.60	0.00	83.50	84.74	42.77	1829.23
TDS (mg/l)	193	577.80	68.70	266.70	266.50	110.00	12099.92
Temp (°C)	35	25.00	4.00	18.00	16.56	5.13	26.30
TP (mg/l)	79	0.28	0.01	0.03	0.04	0.04	0.00
Turbidity (NTU)	ND	-	-	-	-	-	-

TABLE 6. Selected statistics of the water quality variables measured in the Buffalo River at Braunschweig (Site 5) from 1977 to September 1989.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	ND	-	-	-	-	-	-
Ca (mg/l)	115	58.80	6.10	28.00	26.35	8.72	76.09
Cl (mg/l)	115	324.90	19.60	76.30	84.96	53.93	2908.78
COD (mg/l)	ND	-	-	-	-	-	-
DOC (mg/l)	ND	-	-	-	-	-	-
EC (mS/m)	158	180.00	13.50	62.60	62.71	26.13	682.69
F (mg/l)	115	0.95	0.00	0.30	0.31	0.13	0.02
K (mg/l)	115	6.54	0.28	2.19	2.41	0.98	0.92
KN (mg/l)	ND	-	-	-	-	-	-
Mg (mg/l)	115	76.30	3.80	20.00	20.21	9.61	92.34
Na (mg/l)	115	199.80	17.20	72.20	72.70	34.02	1157.04
NH_4 (mg/l)	115	0.56	0.00	0.05	0.07	0.07	0.01
NO_3+NO_2 (mg/l)	115	2.01	0.00	0.47	0.58	0.47	0.22
O_2 (mg/l)	ND	-	-	-	-	-	-
pH	109	8.20	5.84	7.58	7.49	0.44	0.20
PO_4 (mg/l)	115	0.95	0.00	0.02	0.04	0.09	0.01
SI (mg/l)	115	16.31	0.41	9.40	9.22	2.76	7.64
SO_4 (mg/l)	115	39.10	0.00	12.10	13.06	7.65	58.48
Suspended solids (mg/l)	ND	-	-	-	-	-	-
Total alkalinity (mg/l)	115	490.10	26.20	180.30	169.02	71.19	5068.55
TDS (mg/l)	115	1279.20	105.30	440.20	428.86	179.28	32140.42
Temp (°C)	43	25.00	8.00	19.00	17.64	4.44	19.71
TP (mg/l)	ND	-	-	-	-	-	-
Turbidity (NTU)	ND	-	-	-	-	-	-

TABLE 7. Selected statistics of the water quality variables measured at Horseshoe Bend (Site 6) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	11	39.00	19.00	20.50	24.69	7.23	52.34
EC (mS/m)	75	102.00	9.60	38.00	40.77	21.21	449.76
Na (mg/l)	42	157.00	7.00	52.00	52.93	29.65	878.97
NH4 (mg/l)	3	0.20	0.00	0.18	0.12	0.09	0.01
O2 (mg/l)	72	9.50	1.00	2.70	3.12	1.66	2.75
pH	73	8.50	6.40	7.70	7.65	0.47	0.22
PO4 (mg/l)	62	0.25	0.00	0.05	0.06	0.04	0.00
Suspendid solids (mg/l)	2	9.90	9.90	9.90	9.90	0.00	0.00
Turbidity (NTU)	42	350.00	2.70	10.00	27.43	54.70	2991.76

TABLE 8. Selected statistics of the water quality variables measured at the inflow of the Dimbaza Stream into Buffalo River (Site 7) from September 1971 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	ND	-	-	-	-	-	-
Ca (mg/l)	274	40.00	4.40	15.80	16.98	7.99	
Cl (mg/l)	274	329.90	14.80	41.60	47.25	27.50	754.67
COD (mg/l)	5	32.00	19.00	19.00	22.20	5.04	89.58
DOC (mg/l)	4	5.20	3.68	4.59	4.52	0.56	3.51
EC (mS/m)	380	155.00	10.40	35.20	38.53	18.47	342.50
F (mg/l)	274	0.57	0.00	0.15	0.16	0.09	0.01
K (mg/l)	272	7.04	0.01	1.58	1.86	0.99	0.99
KN (mg/l)	139	8.03	0.19	0.41	0.54	0.71	0.50
Mg (mg/l)	274	40.00	3.10	13.20	14.90	8.20	67.48
Na (mg/l)	279	219.00	0.10	28.90	33.12	21.82	474.11
NH_4 (mg/l)	274	0.43	0.00	0.05	0.06	0.05	0.00
NO_3+NO_2 (mg/l)	279	1.67	0.00	0.23	0.38	0.41	0.16
O_2 (mg/l)	4	4.50	2.50	3.10	3.30	0.82	2.27
pH	285	8.60	5.82	7.43	7.42	0.51	0.46
PO_4 (mg/l)	277	0.24	0.00	0.01	0.02	0.03	0.00
SI (mg/l)	271	38.47	0.31	7.32	7.07	2.94	8.82
SO_4 (mg/l)	274	403.80	0.00	9.20	12.05	25.47	649.25
Suspended solids (mg/l)	3	18.00	9.90	9.90	12.60	3.82	40.70
Total alkalinity (mg/l)	280	241.60	0.00	83.35	89.81	51.82	2690.16
TDS (mg/l)	271	936.50	54.80	215.60	238.49	128.04	16411.15
Temp (°C)	71	25.50	8.00	15.00	16.42	4.81	26.51
TP (mg/l)	139	0.76	0.01	0.03	0.05	0.07	0.01
Turbidity (NTU)	ND	-	-	-	-	-	-

TABLE 9. Selected statistics of the water quality variables measured in the Buffalo River at King William's Town (Site 8) from January 1977 to August 1989.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	ND	-	-	-	-	-	-
Ca (mg/l)	84	42.10	6.00	20.85	20.76	7.78	60.54
Cl (mg/l)	84	112.80	16.00	65.20	64.54	24.96	623.02
COD (mg/l)	ND	-	-	-	-	-	-
DOC (mg/l)	ND	-	-	-	-	-	-
EC (mS/m)	133	77.30	12.90	45.90	45.98	15.10	228.04
F (mg/l)	84	0.61	0.03	0.20	0.22	0.09	0.01
K (mg/l)	84	5.32	0.31	1.61	1.71	0.87	0.76
KN (mg/l)	ND	-	-	-	-	-	-
Mg (mg/l)	84	28.80	3.60	16.30	16.03	6.59	43.46
Na (mg/l)	84	95.40	13.90	48.45	48.45	18.85	355.16
NH_4 (mg/l)	84	0.41	0.01	0.04	0.06	0.06	0.00
NO_3+NO_2 (mg/l)	84	3.94	0.00	0.55	0.63	0.50	0.25
O_2 (mg/l)	ND	-	-	-	-	-	-
pH	84	8.63	6.23	7.30	7.34	0.43	0.19
PO_4 (mg/l)	84	0.99	0.00	0.01	0.05	0.13	0.02
SI (mg/l)	84	9.96	0.40	7.19	6.58	2.37	5.62
SO_4 (mg/l)	84	32.80	0.00	12.85	12.87	6.64	44.09
SS (mg/l)	ND	-	-	-	-	-	-
TAL (mg/l)	84	225.80	28.90	118.50	115.07	42.75	1827.92
TDS (mg/l)	84	533.70	103.00	314.30	307.88	112.31	12613.55
Temp (°C)	25	25.00	8.00	15.00	15.78	4.65	21.58
TP (mg/l)	ND	-	-	-	-	-	-
TURBIDITY (NTU)	ND	-	-	-	-	-	-

TABLE 10. Selected statistics of the water quality variables measured at the King William's Town Rail Bridge (Site 9) from 1983 to 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	12	97.00	0.00	24.00	31.08	29.57	874.58
EC (mS/m)	74	135.00	11.50	47.00	49.55	25.14	632.07
Na (mg/l)	41	255.00	12.00	64.00	68.51	47.53	2258.79
NH4 (mg/l)	3	4.10	0.10	1.20	2.13	1.63	2.67
O2 (mg/l)	71	12.00	1.20	3.20	3.80	2.06	4.26
pH	72	8.90	6.50	7.60	7.71	0.53	0.29
PO4 (mg/l)	65	0.96	0.00	0.05	0.11	0.20	0.04
SS (mg/l)	2	27.00	26.00	26.00	26.50	0.50	0.25
TURBIDITY (NTU)	43	550.00	1.50	10.00	37.35	84.08	7070.09

TABLE 11. Selected statistics of the water quality variables measured at the old King William's Town Sewage Works (*Site* 10) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	73	260.00	20.00	61.00	68.34	35.12	1233.71
EC(mS/m)	75	83.00	45.00	60.00	61.03	8.45	71.40
Na (mg/l)	40	103.00	48.00	77.50	75.03	12.00	143.97
NH4 (mg/l)	73	36.00	0.19	4.40	7.43	8.00	64.04
O2 (mg/l)	72	25.00	4.20	8.10	8.73	3.38	11.46
pH	73	7.90	5.00	6.50	6.47	0.61	0.37
PO4 (mg/l)	69	16.00	0.70	8.00	7.54	2.59	6.72
SS (mg/l)	69	64.00	1.00	9.00	10.36	10.31	106.30
TURBIDITY (NTU)	2	18.00	10.00	14.00	14.00	4.00	16.00

TABLE 12. Selected statistics of the water quality variables measured at the new King William's Town Sewage Works (Site 11) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	42	171.00	0.00	37.50	41.33	24.71	610.46
EC (mS/m)	43	84.00	43.00	56.00	57.51	8.33	69.32
Na (mg/l)	35	106.00	60.00	77.00	77.60	10.96	120.07
NH4 (mg/l)	42	30.00	0.19	1.90	3.48	5.21	27.16
O2 (mg/l)	41	15.40	2.20	5.60	5.88	2.49	6.18
pH	40	7.90	4.00	6.75	6.55	0.84	0.70
PO4 (mg/l)	41	9.30	0.11	2.10	2.85	2.55	6.51
SS (mg/l)	40	22.00	1.00	8.00	7.01	4.60	21.13
TURBIDITY (NTU)	2	6.00	0.00	0.00	3.00	3.00	9.00

TABLE 13. Selected statistics of the water quality variables measured in the Ngqokweni Stream (Site 12) from January 1972 to June 1989.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	154	41.00	5.50	29.00	27.77	7.69	59.14
Cl (mg/l)	154	841.20	12.80	212.35	221.03	111.09	12341.17
EC (mS/m)	228	322.40	10.60	112.70	114.15	47.75	2279.62
F (mg/l)	154	1.02	0.05	0.40	0.41	0.15	0.02
K (mg/l)	153	12.13	0.54	2.04	2.18	1.02	1.04
Mg (mg/l)	154	75.20	3.10	28.10	28.76	13.09	171.25
Na (mg/l)	154	571.70	9.30	164.15	167.98	80.00	6400.61
NH_4 (mg/l)	152	0.42	0.01	0.05	0.07	0.07	0.00
NO_2+NO_3 (mg/l)	154	2.83	0.00	0.25	0.38	0.41	0.17
pH	154	8.90	6.50	7.89	7.85	0.46	0.22
PO_4 (mg/l)	153	0.37	0.00	0.02	0.03	0.05	0.00
SI (mg/l)	152	14.29	0.35	6.05	6.26	2.64	6.95
SO_4 (mg/l)	154	84.60	0.00	33.75	35.11	16.47	271.32
TAL (mg/l)	154	395.30	23.00	197.45	197.97	78.27	6126.62
TDS (mg/l)	152	2069.00	65.00	717.00	729.63	312.96	97941.39

TABLE 14. Selected statistics of the water quality variables measured at the Denis Radue Bridge (Site 13) from 1983 to 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	62	120.00	11.00	39.00	46.70	25.92	671.84
EC (mS/m)	115	213.00	14.40	75.00	74.72	31.64	1001.29
Na (mg/l)	42	183.00	28.00	89.00	92.90	40.69	1655.47
NH4 (mg/l)	12	3.50	0.09	0.19	0.93	1.16	1.34
O2 (mg/l)	112	14.20	0.70	4.60	5.02	2.27	5.13
pH	112	9.20	6.50	7.80	7.85	0.62	0.39
PO4 (mg/l)	108	7.30	0.01	0.35	0.75	1.09	1.19
SS (mS/m)	8	62.00	12.00	31.00	33.50	18.32	335.75
TURBIDITY (NTU)	39	550.00	4.50	15.00	42.75	92.17	8495.85

TABLE 15. Selected statistics of the water quality variables measured at the old Zwelitsha Sewage Works (Site 14) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	40	183.00	0.00	92.00	88.24	34.24	1172.23
EC (mS/m)	41	102.00	0.00	84.00	82.38	15.45	238.62
NA (mg/l)	8	114.00	0.00	101.00	88.11	32.01	1024.77
NH4 (mg/l)	40	31.00	0.00	15.95	15.84	8.72	76.00
O2 (mg/l)	40	19.20	0.00	10.50	10.69	3.74	13.98
pH	38	9.90	0.00	7.80	7.76	1.41	1.99
PO4 (mg/l)	33	12.50	0.00	6.30	6.10	2.48	6.17
SS (mg/l)	38	54.00	0.00	15.50	18.38	11.57	133.83
TURBIDITY (NTU)	1	4.80	0.00	0.00	2.40	2.40	5.76

TABLE 16. Selected statistics of the water quality variables measured at the new Zwelitsha Sewage Works (Site 15) from November 1983 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
COD (mg/l)	75	120.00	26.00	64.00	67.24	21.19	448.96
EC (mS/m)	77	114.50	27.00	80.00	79.68	13.99	195.76
Na (mg/l)	42	156.00	70.00	108.00	108.45	21.57	465.30
NH4 (mg/l)	73	30.00	0.00	6.20	8.79	8.96	80.22
O2 (mg/l)	73	61.00	4.60	8.00	9.18	6.70	44.96
pH	74	10.50	6.60	8.10	8.22	1.04	1.08
PO4 (mg/l)	69	13.10	0.25	5.10	5.10	3.19	10.20
SS (mg/l)	71	45.00	0.00	17.00	18.34	10.17	103.38
TURBIDITY (NTU)	2	28.00	12.00	20.00	20.00	8.00	64.00

TABLE 17. Selected statistics of the water quality variables measured in the Zwelitsha sewage work effluent (Site 16) from May 1959 to November 1960.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
AMMONIA F-NH_3 (mg/l)	37	3.04	0.18	1.09	1.25	0.78	0.60
AMMONIA A-NH_3 (mg/l)	25	4.80	0.04	2.20	2.42	1.26	1.59
Ca (mg/l)	47	30.00	5.10	17.30	11.62	5.54	30.69
Cl (mg/l)	46	67.00	29.00	50.00	50.24	6.57	43.17
EC (mS/m)	23	1332.00	400.00	920.00	923.26	201.78	40713.24
Mg (mg/l)	47	13.60	1.50	5.00	5.30	2.92	8.51
NO_2+NO_3 (mg/l)	47	0.16	0.00	0.00	0.02	0.03	0.00
P.V. (mg/l)	46	96.40	10.00	34.00	34.32	12.15	147.53
pH	47	9.40	7.10	7.90	7.98	0.52	0.27
PO_4 (mg/l)	47	0.21	0.00	0.00	0.01	0.04	0.00
SO_4 (mg/l)	47	78.80	14.50	51.00	50.05	15.31	234.50
Suspended Solids (mg/l)	44	431.00	12.00	82.50	100.80	86.52	7485.12
TDS (mg/l)	44	1233.00	410.00	853.00	843.68	166.37	27678.63
TOTAL HARDNESS (mg/l)	47	1270.00	212.00	478.00	509.40	226.16	51147.52
Total Alkalinity (mg/l)	47	760.00	236.00	378.00	388.81	89.28	7971.73
TURBIDITY (NTU)	44	500.00	80.00	175.00	198.72	97.40	9486.57

TABLE 18. Selected statistics of the water quality variables measured in the Mlakalaka Stream (Site 17) from January 1959 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
AMMONIA F-NH_3 (mg/l)	72	1.92	0.05	0.66	0.77	0.44	0.20
AMMONIA F-NH_3 (mg/l)	104	12.64	0.05	0.28	0.58	1.52	2.31
Ca (mg/l)	788	212.00	4.20	19.60	20.85	11.56	133.72
Cl (mg/l)	773	873.80	22.40	152.00	182.69	108.61	11795.87
COD (mg/l)	245	1140.00	39.00	226.00	305.95	249.13	62066.10
EC (mS/m)	867	711.70	77.90	152.00	133.48	90.17	8130.05
F (mg/l)	7	0.73	0.20	0.58	0.53	0.20	0.04
K (mg/l)	103	43.00	4.50	18.00	18.35	6.33	40.08
Mg (mg/l)	784	95.90	2.90	12.60	16.51	12.27	150.52
Na (mg/l)	115	1500.00	192.00	437.50	469.03	170.01	28904.10
NH_4 (mg/l)	158	24.10	0.00	3.33	6.05	6.42	41.25
NO_2+NO_3 (mg/l)	231	17.40	0.00	0.63	1.95	2.90	8.38
O_2 (mg/l)	116	300.00	1.00	65.00	82.52	78.49	6160.80
pH	908	10.10	6.70	8.10	8.16	0.49	0.20
PO_4 (mg/l)	326	7.20	0.00	0.40	1.05	1.32	1.82
SiO_2 (mg/l)	103	48.00	0.00	16.00	16.90	8.91	79.39
SO_4 (mg/l)	244	321.40	8.20	66.20	80.50	49.54	2454.23
Suspended Solids (mg/l)	628	720.00	0.00	43.00	62.01	75.65	5722.60
Total Alkalinity (mg/l)	788	4770.00	139.00	634.00	749.03	450.43	202887.25
TDS (mg/l)	639	4503.00	525.00	1189.00	1402.20	526.09	276770.60
TOTAL HARDNESS (mg/l)	783	456.00	14.00	102.40	116.89	60.38	3645.67
TOTAL-N (mg/l)	136	95.50	2.54	17.14	20.12	15.98	255.22
TURBIDITY (NTU)	783	490.00	0.40	42.00	62.27	72.80	5299.75

TABLE 19. Selected statistics of the water quality variables measured in the Buffalo River at the inflow into Laing Dam (Site 18) from January 1972 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	16	0.02	0.00	0.01	0.01	0.01	0.00
Ca (mg/l)	256	106.70	7.00	31.20	31.19	12.25	150.10
Cl (mg/l)	256	2469.70	31.20	203.70	212.96	172.27	29676.62
COD (mg/l)	52	187.00	4.00	52.00	58.60	31.40	98.80
DOC (mg/l)	19	27.12	0.00	8.42	9.31	5.91	34.90
EC (mS/m)	335	770.00	15.60	117.50	126.00	71.70	5136.60
F (mg/l)	256	1.22	0.00	0.32	0.33	0.15	0.02
K (mg/l)	255	29.99	0.00	9.30	9.83	5.19	26.89
KN (mg/l)	148	35.36	0.44	3.13	5.63	5.97	35.69
Mg (mg/l)	256	162.70	2.70	21.80	21.78	12.11	146.68
Na (mg/l)	284	1424.30	7.70	214.00	223.69	149.84	22459.40
NH_4 (mg/l)	263	14.25	0.00	0.10	1.24	2.70	7.29
NO_3+NO_2 (mg/l)	259	46.44	0.00	7.00	3.69	5.13	26.28
O_2 (mg/l)	25	12.50	3.40	5.80	6.44	2.12	4.51
pH	325	10.22	5.77	8.00	7.94	0.67	0.45
PO_4 (mg/l)	323	6.50	0.00	1.40	1.72	1.70	2.70
Si (mg/l)	255	17.52	0.00	6.00	5.94	2.00	4.00
SO_4 (mg/l)	256	294.10	3.30	85.10	93.28	58.53	3426.04
Suspended Solids (mg/l)	8	71.00	9.90	38.00	32.10	22.10	487.40
Total Alkalinity (mg/l)	259	1440.00	0.00	240.50	267.95	173.44	30080.14
TDS (mg/l)	255	5130.30	113.90	960.00	955.70	547.78	300059.54
Temp (°C)	165	28.00	9.00	18.00	18.40	3.16	9.99
TP (mg/l)	148	7.09	0.08	1.50	1.82	1.67	2.79
TURBIDITY (NTU)	11	90.00	3.00	5.10	27.87	30.79	947.86

TABLE 20. Selected statistics of the water quality variables measured in Laing Dam (Site 19) from January 1961 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	164	43.00	5.75	16.75	16.94	5.18	26.81
Cl (mg/l)	165	160.00	24.00	82.00	84.08	27.45	753.39
COD (mg/l)	142	298.00	0.00	23.20	25.90	25.05	627.37
EC (mS/m)	275	770.00	10.70	45.00	189.09	199.10	39639.92
F (mg/l)	31	0.40	0.00	0.30	0.26	0.07	0.01
K (mg/l)	98	8.80	1.00	4.00	4.18	1.57	2.47
Mg (mg/l)	164	41.00	4.30	12.30	12.54	4.85	23.50
Na (mg/l)	188	114.00	5.60	68.00	66.50	18.69	354.48
NH4 (mg/l)	238	1.50	0.00	0.07	0.13	0.17	0.03
NO2+NO3 (mg/l)	198	21.62	0.02	0.85	1.00	1.63	2.67
O2 (mg/l)	188	16.20	1.80	4.10	4.49	1.82	3.30
P.V. (mg/l)	159	17.20	1.40	4.40	4.71	2.13	4.54
pH	274	9.60	6.80	7.80	7.79	0.42	0.17
PO4 (mg/l)	221	2.00	0.00	0.05	0.13	0.24	0.06
SO4 (mg/l)	162	35.80	2.80	20.90	20.37	6.90	47.56
TDS (mg/l)	164	476.00	58.50	280.00	283.74	77.66	6030.70
TOTAL-N (mg/l)	142	4.73	0.06	1.92	1.98	0.75	0.57
Total Alkalinity (mg/l)	165	156.00	0.00	86.00	86.54	26.70	713.09
TOTAL HARDNESS (mg/l)	164	199.63	36.69	92.60	93.93	30.28	916.69
TURBIDITY (NTU)	208	700.00	5.50	93.50	135.48	124.65	15537.11

TABLE 21. Selected statistics of the water quality variables measured at Laing Dam Scourer (Site 20) from January 1961 to May 1976.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	149	34.80	6.80	17.2	17.27	4.96	24.56
Cl (mg/l)	150	158.00	18.00	84	85.10	27.73	768.90
COD (mg/l)	118	145.00	4.00	24	29.46	19.27	371.28
EC (mS/m)	149	755.00	11.30	382	370.40	181.00	32759.75
F (mg/l)	23	0.40	0.20	0.3	0.26	0.06	0.00
K (mg/l)	85	15.50	1.00	4	4.63	2.56	6.54
Mg (mg/l)	149	36.00	0.30	13	12.68	4.83	23.31
Na (mg/l)	105	114.00	15.00	71	67.39	20.98	440.22
NH_4 (mg/l)	125	0.78	0.01	0.07	0.15	0.17	0.03
NO_2+NO_3 (mg/l)	145	10.00	0.01	0.88	0.91	0.89	0.79
P.V. (mg/l)	144	18.80	1.90	4.6	5.52	3.01	9.07
pH	150	8.60	6.70	7.7	7.68	0.35	0.12
PO_4 (mg/l)	117	1.00	0.00	0.05	0.09	0.17	0.03
SO_4 (mg/l)	147	36.60	4.10	20.4	20.38	7.02	49.29
TDS (mg/l)	148	536.00	7.00	289.5	290.18	85.11	7243.04
Total-N (mg/l)	129	7.65	0.08	2.03	2.05	0.94	0.89
Total alkalinity (mg/l)	149	157.00	24.00	88	89.82	27.02	730.01
Total hardness (mg/l)	148	196.82	31.23	98.2	95.56	30.18	910.72
Turbidity (NTU)	149	1200.00	5.20	160	221.17	204.31	41741.19

TABLE 22. Selected statistics of the water quality variables measured in the Buffalo River flowing into Bridle Drift Dam (Site 21) from August 1989 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	7	22.70	13.40	18.60	17.91	3.60	12.95
Cl (mg/l)	7	112.00	64.00	75.00	87.14	20.12	404.98
COD (mg/l)	6	18.00	10.00	17.50	15.83	2.97	8.81
EC (mS/m)	7	60.40	38.10	41.70	47.39	9.60	92.19
K (mg/l)	7	7.80	4.20	4.60	5.14	1.20	1.43
Mg (mg/l)	7	41.00	13.10	18.70	20.57	8.99	80.78
Na (mg/l)	7	76.00	36.00	60.00	57.43	15.59	243.10
NH4 (mg/l)	4	0.29	0.04	0.25	0.21	0.10	0.01
NO2+NO3 (mg/l)	6	2.59	0.48	0.92	1.24	0.79	0.63
pH	7	8.10	7.60	8.10	7.94	0.20	0.04
PO4 (mg/l)	7	0.71	0.20	0.47	0.40	0.19	0.03
SO4 (mg/l)	5	30.80	18.00	28.60	25.84	5.32	28.34
TDS (mg/l)	7	373.00	235.00	260.00	292.29	58.54	3426.78
Total Alkalinity (mg/l)	6	117.00	63.00	95.00	91.83	24.11	581.47
TOTAL HARD (mg/l)	7	203.88	92.73	124.00	129.40	36.99	1368.55
TOTAL-N (mg/l)	1	1.36	1.36	1.36	1.36	0.00	0.00
TURBIDITY (NTU)	6	78.00	10.00	73.00	59.00	24.13	582.33

TABLE 23. Selected statistics of the water quality variables measured in the Shangani Stream (Site 22) from August 1989 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	4	27.20	13.70	24.70	22.58	5.52	30.42
Cl (mg/l)	4	198.00	97.00	143.00	145.25	35.89	1288.19
COD (mg/l)	3	41.00	9.00	32.00	27.33	13.47	181.56
EC (mS/m)	4	89.70	49.00	79.50	74.43	15.26	232.84
K (mg/l)	4	9.20	3.80	5.10	5.80	2.03	4.14
Mg (mg/l)	4	36.00	18.50	30.60	28.93	6.49	42.07
Na (mg/l)	4	150.00	63.00	112.00	109.25	32.89	1081.69
NH4 (mg/l)	3	0.44	0.08	0.14	0.22	0.16	0.02
NO2+NO3 (mg/l)	3	2.74	0.18	2.23	1.72	1.11	1.22
pH	4	7.90	7.20	7.70	7.63	0.27	0.07
PO4 (mg/l)	4	1.01	0.15	0.64	0.61	0.31	0.09
SO4 (mg/l)	2	26.00	25.00	25.50	25.50	0.50	0.25
TDS (mg/l)	4	550.00	300.00	490.00	457.50	94.17	8868.75
TOTAL ALK (mg/l)	3	174.00	112.00	148.00	144.67	25.42	646.22
TOTAL HARD (mg/l)	4	216.07	110.34	187.50	175.41	39.32	1546.29
TOTAL-N (mg/l)	1	1.86	1.86	1.86	1.86	0.00	0.00
TURBIDITY (NTU)	3	45.00	34.00	35.00	38.00	4.97	24.67

TABLE 24. Selected statistics of the water quality variables measured in the Sitotona Stream (Site 23) from August 1989 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	7	45.20	25.00	39.00	37.89	6.82	46.54
Cl (mg/l)	7	290.00	180.00	206.00	218.43	36.13	1305.10
COD (mg/l)	5	72.00	15.00	41.00	41.00	18.62	346.80
EC (mS/m)	7	143.70	90.30	101.60	109.54	16.71	279.37
K (mg/l)	7	18.00	7.50	10.30	11.01	3.14	9.86
Mg (mg/l)	7	45.00	25.00	32.10	33.57	6.01	36.16
Na (mg/l)	7	180.00	126.00	140.00	146.86	19.97	398.69
NH_4 (mg/l)	6	30.20	0.44	15.00	13.18	9.99	99.89
NO_2+NO_3 (mg/l)	6	7.20	0.18	2.97	3.46	2.76	7.60
pH	7	8.30	7.20	7.60	7.69	0.33	0.11
PO_4 (mg/l)	7	14.30	0.42	4.40	5.60	5.18	26.84
SO_4 (mg/l)	5	32.60	21.00	24.50	25.76	3.82	14.56
TDS (mg/l)	7	7588.00	560.00	630.00	1652.86	2425.00	5880605.84
TOTAL ALK (mg/l)	6	356.00	110.00	139.50	180.00	87.64	7681.00
TOTAL HARD (mg/l)	7	295.09	165.33	217.00	232.79	39.28	1542.74
TOTAL-N (mg/l)	1	29.80	29.80	29.80	29.80	0.00	0.00
TURBIDITY (NTU)	6	6.80	0.90	1.65	2.35	2.06	4.24

TABLE 25. Selected statistics of the water quality variables measured in the Tindelli Stream (Site 24) from August 1989 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	7	32.00	18.10	21.80	23.51	4.63	21.44
Cl (mg/l)	7	166.00	105.00	125.00	127.57	19.79	391.67
COD (mg/l)	5	51.00	35.00	38.00	40.80	5.74	32.96
EC (mS/m)	7	96.10	74.60	83.10	83.77	7.86	61.79
K (mg/l)	7	13.80	4.00	11.40	10.64	2.89	8.33
Mg (mg/l)	7	30.00	18.30	21.10	21.79	3.65	13.33
Na (mg/l)	7	140.00	51.00	92.00	93.14	27.13	736.12
NH4 (mg/l)	6	23.40	10.00	21.85	19.97	4.55	20.71
NO2+NO3 (mg/l)	6	6.00	0.80	2.52	2.94	1.73	3.01
pH	7	8.50	7.40	7.80	7.86	0.34	0.11
PO4 (mg/l)	7	13.30	3.00	7.80	8.16	3.30	10.87
SO4 (mg/l)	5	41.30	13.50	15.70	22.94	10.60	112.39
TDS (mg/l)	7	590.00	460.00	510.00	516.57	47.84	2289.10
TOTAL ALK (mg/l)	6	277.00	75.00	149.50	161.67	83.23	6926.56
TOTAL HARD (mg/l)	7	191.39	124.77	140.00	148.38	22.93	525.98
TOTAL-N (mg/l)	1	24.40	24.40	24.40	24.40	0.00	0.00
TURBIDITY (NTU)	6	4.60	0.90	1.80	2.05	1.25	1.57

TABLE 26. Selected statistics of the water quality variables measured in the Umdanzani Stream (Site 25) from August 1989 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	7	35.60	21.90	24.50	26.06	4.84	23.44
Cl (mg/l)	7	187.00	109.00	126.00	133.43	24.84	616.82
COD (mg/l)	5	104.00	38.00	45.00	60.80	25.53	651.76
EC (mS/m)	7	95.20	73.40	76.30	83.27	9.56	91.35
K (mg/l)	7	20.60	7.60	10.80	11.29	4.01	16.08
Mg (mg/l)	7	30.00	18.70	21.50	22.81	3.73	13.90
Na (mg/l)	7	150.00	45.00	79.00	91.86	32.13	1032.12
NH4 (mg/l)	6	28.40	9.00	21.50	20.43	6.41	41.09
NO2+NO3 (mg/l)	6	1.74	0.10	0.18	0.45	0.58	0.34
pH	7	8.10	7.30	7.50	7.61	0.25	0.06
PO4 (mg/l)	7	14.80	2.40	6.40	7.56	3.68	13.54
SO4 (mg/l)	5	35.30	19.80	21.00	24.62	6.00	36.06
TDS (mg/l)	7	590.00	456.00	471.00	515.29	59.21	3505.92
TOTAL ALK (mg/l)	6	266.00	77.00	141.50	161.00	82.29	6771.00
TOTAL HARD (mg/l)	7	200.89	132.91	159.00	158.98	22.44	503.39
TOTAL-N (mg/l)	1	14.90	14.90	14.90	14.90	0.00	0.00
TURBIDITY (NTU)	6	13.00	1.10	3.35	4.70	4.27	18.21

TABLE 27. Selected statistics of the water quality variables measured in Bridal Drift Dam near the dam wall (Site 26) from September 1968 to July 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Ca (mg/l)	434	186.00	4.40	16.20	16.56	10.15	102.93
Cl (mg/l)	481	558.00	7.80	83.00	83.88	33.39	1115.19
COD (mg/l)	498	242.00	0.00	17.00	18.20	18.14	329.21
TDS (mg/l)	477	1242.00	61.00	264.00	269.83	92.73	8599.18
EC (mS/m)	588	199.70	2.50	42.10	43.78	14.92	222.66
F (mg/l)	179	16.80	0.00	2.60	2.59	2.56	6.54
K (mg/l)	369	47.00	1.00	5.20	5.44	2.63	6.94
Mg (mg/l)	434	170.00	1.20	14.60	14.61	9.13	83.41
Na (mg/l)	422	265.00	5.00	58.00	62.24	24.03	577.20
NH4 (mg/l)	405	2.90	0.00	0.10	0.14	0.19	0.04
NO2+NO3 (mg/l)	357	3.26	0.05	0.90	0.96	0.53	0.28
O2 (mg/l)	80	16.80	1.80	3.40	4.18	2.49	6.19
P.V. (mg/l)	440	48.40	0.00	3.40	4.35	4.49	20.18
pH	593	9.50	6.80	7.90	7.91	0.41	0.17
PO4 (mg/l)	198	8.00	0.00	0.10	0.25	0.67	0.45
SO4 (mg/l)	261	61.10	0.10	19.20	21.07	9.25	85.53
TOTAL-N (mg/l)	435	64.50	0.20	1.73	2.03	3.22	10.36
TOTAL ALKALINITY (mg/l)	439	611.00	15.00	83.00	86.80	39.62	1569.92
TOTAL HARDNESS (mg/l)	417	229.00	0.00	100.00	96.50	25.07	628.65
TURBIDITY (NTU)	462	792.00	2.50	57.00	93.89	114.94	13212.28

TABLE 28. Selected statistics of the water quality variables measured in the Buffalo River at the Buffalo Pass (Site 27) from January 1972 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	ND	-	-	-	-	-	-
Ca (mg/l)	13	36.70	4.60	29.00	26.35	10.12	102.45
Cl (mg/l)	13	485.10	14.20	193.60	181.29	113.29	12834.46
COD (mg/l)	32	74.00	0.00	33.00	36.27	14.23	202.36
DOC (mg/l)	ND	-	-	-	-	-	-
EC (mS/m)	93	202.40	8.00	71.00	74.03	28.61	818.51
F (mg/l)	13	0.69	0.00	0.25	0.26	0.17	0.03
K (mg/l)	12	8.14	0.86	6.94	6.06	2.33	5.41
KN (mg/l)	1	0.220	0.220	0.220	0.220	0.000	0.000
Mg (mg/l)	13	52.90	2.50	19.10	19.58	11.88	141.08
Na (mg/l)	54	284.40	8.60	101.00	109.44	50.33	2533.41
NH_4 (mg/l)	32	8.34	0.00	0.19	1.11	2.16	4.67
NO_3+NO_2 (mg/l)	13	9.52	0.00	5.99	4.71	3.56	12.70
O_2 (mg/l)	78	13.40	2.80	7.05	6.26	1.97	3.88
pH	89	9.50	5.20	7.60	7.53	0.54	0.29
PO_4 (mg/l)	75	9.000	0.003	3.100	2.915	2.140	4.578
Si (mg/l)	12	10.18	1.29	6.14	5.99	2.01	4.05
SO_4 (mg/l)	13	99.10	0.00	69.40	57.03	30.25	915.01
SS (mg/l)	10	22.00	0.00	9.95	11.66	5.45	29.75
TAL (mg/l)	13	229.00	16.90	196.00	158.97	67.97	4619.77
TDS (mg/l)	12	1144.20	51.90	789.50	696.51	298.25	88951.17
TEMP (°C)	6	22.00	12.00	15.00	16.00	3.96	15.67
TP (mg/l)	1	0.004	0.004	0.004	0.004	0.000	0.000
TURBIDITY (NTU)	39	140.00	2.80	20.00	35.23	37.55	1410.24

TABLE 29. Selected statistics of the water quality variables measured in the Mgqakwebe River (Site 28) from 1971 to August 1986.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	ND	-	-	-	-	-	-
Ca (mg/l)	157	40.30	0.00	6.10	8.15	6.32	39.92
Cl (mg/l)	157	48.60	10.60	18.10	19.61	6.83	46.66
COD (mg/l)	ND	-	-	-	-	-	-
DOC (mg/l)	1	2.62	2.62	0.00	2.62	0.00	0.00
EC (mS/m)	206	43.60	6.60	13.30	14.70	5.91	34.97
F (mg/l)	157	0.49	0.00	0.09	0.10	0.08	0.01
K (mg/l)	155	2.92	0.11	0.90	0.93	0.41	0.16
KN (mg/l)	37	2.40	0.04	0.27	0.42	0.41	0.17
Mg (mg/l)	157	19.10	1.10	3.60	4.23	2.34	5.46
Na (mg/l)	157	52.00	6.10	11.60	12.93	5.85	34.23
NH_4 (mg/l)	153	0.50	0.00	0.05	0.06	0.07	0.01
NO_3+NO_2 (mg/l)	156	2.52	0.00	0.26	0.40	0.45	0.20
O_2 (mg/l)	ND	-	-	-	-	-	-
pH	157	9.98	5.32	6.90	6.86	0.59	0.35
PO_4 (mg/l)	155	0.28	0.00	0.01	0.02	0.04	0.00
Si (mg/l)	153	26.98	0.58	8.73	8.92	2.33	5.43
SO_4 (mg/l)	157	19.80	0.00	3.20	3.93	3.28	10.75
Suspended Solids (mg/l)	ND	-	-	-	-	-	-
Total alkalinity (mg/l)	157	112.50	0.00	26.60	32.09	19.78	391.30
TDS (mg/l)	153	272.60	45.80	79.80	90.81	39.46	1556.89
Temp (°C)	61	24.00	5.00	15.00	14.87	4.48	20.05
TP (mg/l)	37	0.20	0.01	0.03	0.04	0.04	0.00
Turbidity (NTU)	ND	-	-	-	-	-	-

TABLE 30. The statistical analysis of all the water quality variables in the Yellowwoods River at Lonsdale Bridge (Site 29) from February 1989 to July 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Absorbed O2 (mg/l)	10	10.80	2.00	4.40	5.34	2.51	6.31
COD (mg/l)	3	34.00	30.00	32.00	32.00	1.63	2.67
EC (mS/m)	10	91.00	33.00	72.50	67.80	20.30	412.16
Na (mg/l)	10	157.00	52.00	110.00	102.10	34.76	1208.49
NH4 (mg/l)	1	40.00	40.00	40.00	40.00	0.00	0.00
pH	10	8.70	6.90	8.05	8.00	0.52	0.27
PO4 (mg/l)	10	0.54	0.09	0.39	0.35	0.16	0.02
Suspended Solids (mg/l)	1	20.00	20.00	20.00	20.00	0.00	0.00
Turbidity (NTU)	7	90.00	6.00	60.00	49.43	32.91	1083.39

TABLE 31. Selected statistics of the water quality variables measured below Bisho in the Yellowwoods River (Site 30) from October 1989 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Absorbed O2 (mg/l)	9	24.00	6.00	10.30	11.78	4.99	24.90
COD (mg/l)	7	248.00	55.00	81.00	108.86	60.48	3657.27
EC (mS/m)	9	103.00	52.00	83.00	80.11	17.33	300.32
Na (mg/l)	9	158.00	74.00	120.00	117.67	26.44	698.89
NH4 (mg/l)	6	20.00	1.90	6.75	8.55	5.74	32.96
pH	11	8.10	6.60	7.40	7.41	0.38	0.15
PO4 (mg/l)	9	9.10	0.22	2.16	3.94	3.33	11.06
Suspended Solids (mg/l)	4	97.00	20.00	38.50	48.50	29.26	856.25
Turbidity (NTU)	3	70.00	25.00	55.00	50.00	18.71	350.00

TABLE 32. Selected statistics of the water quality variables measured below Bisho Sewage Works in the Yellowwoods River (Site 31) from October 1989 to 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Absorbed O2 (mg/l)	10	37.00	11.20	20.40	21.78	9.33	86.99
COD (mg/l)	8	338.00	127.00	249.00	231.13	80.57	6492.11
EC (mS/m)	9	108.00	32.00	98.00	86.56	22.73	516.69
Na (mg/l)	10	154.00	42.00	108.00	102.50	39.65	1572.25
NH4 (mg/l)	8	24.00	2.10	9.85	11.34	8.35	69.73
pH	8	7.90	6.90	7.40	7.46	0.31	0.09
PO4 (mg/l)	10	7.70	0.05	3.50	3.89	2.84	8.07
Suspended Solids (mg/l)	6	122.00	28.00	76.50	76.17	40.79	1663.47
Turbidity (NTU)	2	100.00	100.00	100.00	100.00	0.00	0.00

TABLE 33. Selected statistics of the water quality variables measured in the Yellowwoods River below Breidbach (Site 32) from November 1989 to August 1992.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
Absorbed O_2 (mg/l)	10	12.00	4.40	6.30	6.91	2.27	5.17
COD (mg/l)	7	57.00	35.00	46.00	38.80	6.71	45.06
EC (mg/l)	10	125.00	38.00	88.00	75.69	26.41	697.69
Na (mg/l)	10	217.00	48.00	131.50	118.69	50.71	2571.24
NH_4 (mg/l)	6	0.19	0.19	0.19	0.81	0.00	0.00
pH	10	9.20	7.20	8.05	7.65	0.53	0.28
PO_4 (mg/l)	10	5.10	0.19	0.60	2.44	1.82	3.31
Suspended Solids (mg/l)	4	19.00	6.00	13.95	10.84	5.46	29.85
Turbidity (NTU)	5	100.00	6.80	35.00	43.60	41.13	1691.51

TABLE 34. Selected statistics of the water quality variables measured in the Yellowwoods River at Fort Murray (Site 33) from January 1969 to June 1991.

	SAMPLE NOS.	MAXIMUM	MINIMUM	MEDIAN	MEAN	STD DEV.	VARIANCE
B (mg/l)	1	0.05	0.05	0.00	0.05	0.00	0.00
Ca (mg/l)	589	74.20	7.10	31.00	31.25	12.63	159.45
Cl (mg/l)	589	771.80	27.00	188.50	206.77	126.06	15892.29
COD (mg/l)	67	216.00	7.90	42.00	54.93	39.80	1583.75
DOC (mg/l)	7	17.35	0.00	10.24	10.17	5.13	26.34
EC (mS/m)	691	2643.00	1.10	156.20	443.67	555.19	308235.64
F (mg/l)	229	0.92	0.06	0.33	0.41	0.17	0.03
K (mg/l)	275	22.00	0.45	5.49	6.12	3.41	11.61
KN (mg/l)	95	7.84	0.62	1.28	1.71	1.32	1.73
Mg (mg/l)	589	69.70	2.20	23.80	25.31	13.24	175.19
Na (mg/l)	290	478.00	17.50	162.85	173.65	94.89	9004.15
NH4 (mg/l)	267	5.36	0.00	0.07	0.24	0.63	0.39
NO3+NO2 (mg/l)	591	19.00	0.00	0.52	0.60	1.50	2.24
O2 (mg/l)	13	11.20	3.30	5.10	5.71	2.13	4.53
pH	604	9.80	6.13	7.70	7.80	0.50	0.25
PO4 (mg/l)	285	14.00	0.00	0.15	0.57	1.24	1.54
Si (mg/l)	204	15.14	0.00	4.51	4.94	2.76	7.63
SO4 (mg/l)	278	223.20	0.00	32.50	40.10	30.87	952.81
Suspended Solids (mg/l)	2	68.00	33.00	50.50	50.50	17.50	306.25
Total alkalinity (mg/l)	208	381.70	26.30	192.45	188.01	75.90	5761.05
TDS (mg/l)	409	1844.00	8.00	692.00	730.02	375.09	140690.77
Temp (°C)	159	28.00	8.00	18.00	17.34	3.46	11.95
Total-N (mg/l)	72	20.72	0.10	5.34	5.73	3.59	12.88
TP (mg/l)	95	3.23	0.06	0.38	0.55	0.53	0.28
Turbidity (NTU)	388	2160.00	0.40	16.80	71.84	162.12	26283.62

APPENDIX E

BACTERIOLOGICAL CONTAMINATION IN THE BUFFALO RIVER

by

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CONTENTS

1. INTRODUCTION

This separate report on the bacteriological contamination in the Buffalo River catchment originated from the concern of East London Municipality over the high *E. coli* values which have been found since 1989 in the inflowing streams that originate in Mdantsane township and flow into Bridle Drift Dam.

2. PREVIOUS STUDIES

As early as 1899 some bacteriological samples from the Buffalo River (the exact sites are unknown) were analysed by Dr Edington, Director of the Bacteriological Institute at Grahamstown. He had been sent some bacteriological samples and he found the water to be of an unsatisfactory quality, although when he saw the discharge volumes, he stated that there would be less health risk from the bacteria (Tankard, 1990). The only other available bacteriological analysis on the Buffalo River was conducted by Thornton *et al* (1967). During this study a few samples were taken from tributaries of the Buffalo River (figure 1). This study was conducted before the development of Mdantsane Township and the Bridle Drift Dam. It gives a basic background of the bacteriological contamination in earlier years. The summarised data is shown in Table 1.

Table 1. A summary of the *E. coli* analysis of the Buffalo River during 1963 - 1964 after Thornton *et al* (1967).

Site	No. samples	Maximum	Minimum	Geo.mean
1 Below Maden Dam	4	35	11	17
2 Buffalo upstream of KWT	4	350	46	118
3 Buffalo upstream of KWT	4	540	33	147
4 King Tanning	6	3500	170	696
5 Below KWT	7	18000	110	1273
6 Sewage Farm	4	117000	32	755
7 KWT STW	5	3500	8	90
8 Zwelitsha STW	5	1100	49	272
9 Upstream Bridle Drift	2	49	13	26
10 Bridle Drift Site	37	1800	0	21
11	5	460	0	52
12 Yellowwoods below Breidbach	1	-	-	70
13 Green River	1	-	-	70
14 Mdantsane Stream	9	350	2	120
15 Umsoniana 1 before township	2	170	130	149
16 Umsoniana 2 before township	2	1600	700	1058
15 Umsoniana 1 after township	7	2800	0	130
16 Umsoniana 2 after township	7	1800	33	500

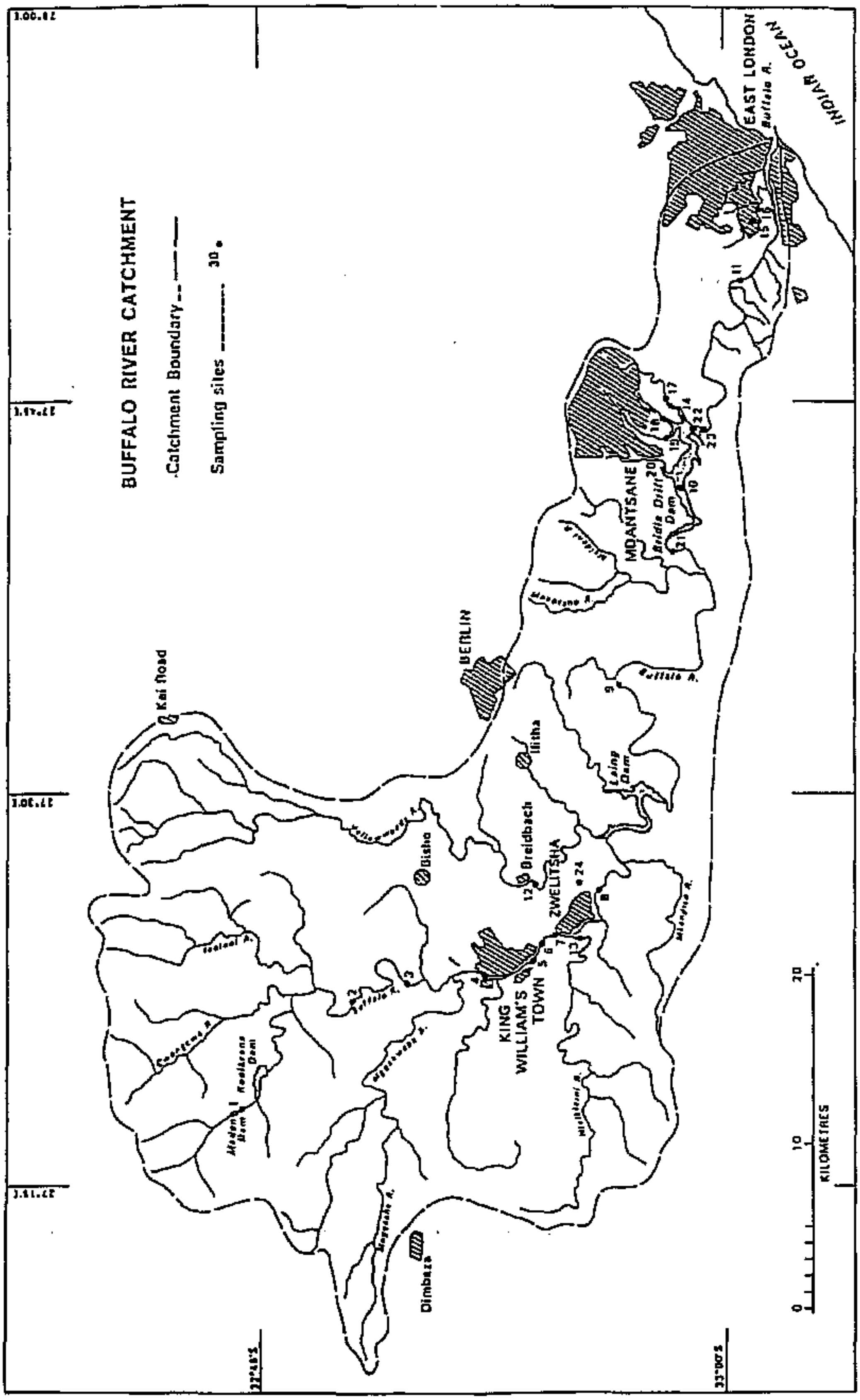

Figure 1. Bacteriological sampling sites in the Buffalo River catchment used by Thornton *et al* (1967) and East London municipality.

3. PRESENT DAY MONITORING PROGRAMMES

A routine monitoring programme is run by East London Municipality and occasional samples are taken by the Department of Public Works, Ciskei. The lack of bacteriological data for the middle reaches of the Buffalo River catchment led to the monthly sampling of the King William's Town area by the Institute for Water Research, Rhodes University. The most extensive sampling to date is done by the East London Municipality in the Bridle Drift Dam, as it concerns their water supply.

4. METHODS

Field sampling: Water samples for bacteriological analysis have been collected bi-weekly by ELM since 1989 at sites 17 - 22 (figure 1) in the four inflowing streams from Mdantsane township into Bridle Drift Dam, as well as at a site in the Buffalo River and in the Dam near the dam wall. These samples were analysed for faecal coliforms and *E. coli* by using the Most Probable Number (MPN) technique (SABS, 1976). Results are expressed as MPN/100ml. The Institute for Water Research did monthly sampling at the nine sites (figure 5) from November 1991 to August 1992. The MPN/100ml analysis method was used to determine faecal coliform counts. The Water Quality Management Directorate of the Department of Water Affairs and Forestry completed one sampling trip in April 1992 to determine the bacteriological contamination down the Buffalo River.

Statistical Analysis: The geometrical mean, minimum value and maximum value were determined for the bacteriological counts in the Buffalo River and the four inflowing streams (from Mdantsane) into the Bridle Drift Reservoir, a site at the dam wall and at all the sites in the King William's Town area. The geometrical mean is used to describe random variables that vary over several orders of magnitude, such as coliform counts (Sanders *et al*, 1983). The geometrical mean of a set of n numbers is given by the nth root of their product (Freund, 1974) namely :

$$\sqrt[n]{x_1 . x_2 ... x_n}$$

Time exceedence graphs were drawn up for ranked data for the sites in the Bridle Drift Dam area to determine the percentage of time that bacteriological counts exceeded the recommended recreational criteria for faecal coliform counts (Kempster *et al*, 1980) (figure 4 A-F).

5. RESULTS

5.1 East London Municipality results

The area of most concern during the study period was Bridle Drift Dam. Figures 2 and 3 show the temporal changes at the six sites in Bridle Drift Dam for faecal coliform and *E. coli* geometrical mean counts from 1987 to 1992. It was clearly shown that the four inflowing streams contributed the highest bacteriological contamination and that this contamination was orders of magnitude higher than that entering via the Buffalo River. No single incoming stream was consistently the greates contributor, since a different stream had the highest bacteriological count each year. There was some recovery from these streams towards the Dam Wall.

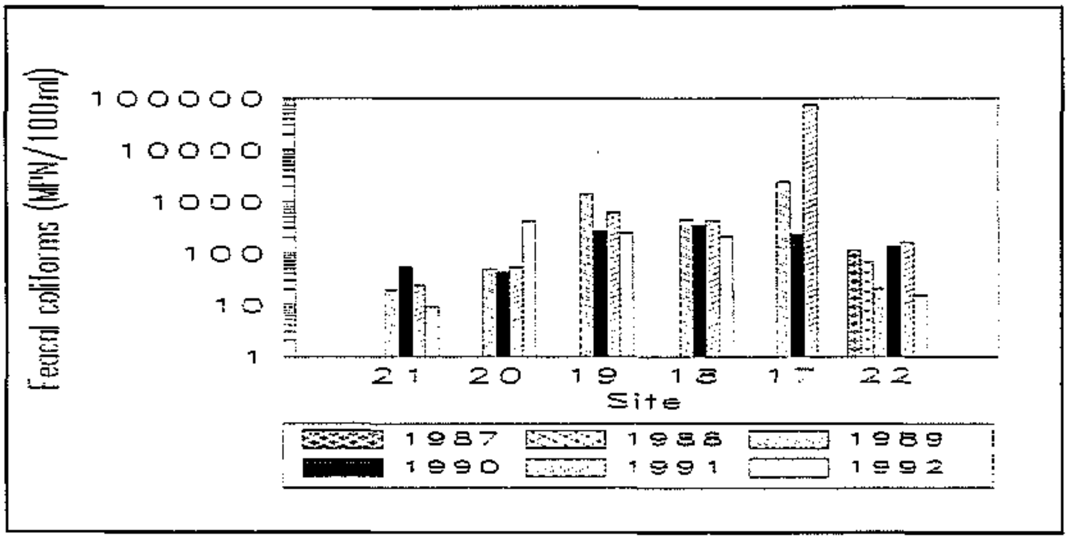

Figure 2. The temporal changes in faecal coliform geometrical mean counts at the six sites of the Bridle Drift Dam.

The counts at the inflow of the Buffalo river into Bridle Drift Dam only exceeded the recreational criterion set out by Kempster *et al* (1982) 4% of the time (figure 4 A). The concentration which most exceeded this recreational criterion was found in Sitotona Stream; the criterion was exceeded 82% of the time (figure 4 C). Shangani Stream exceeded the recreational criterion 57% of the time, although the highest geometrical mean faecal and *E. coli* counts in 1992 were found in this stream. Tindelli Stream exceeded the criterion 72% of the time and had the highest *E. coli* counts during 1989. No data were collected in the

Umdanzani Stream during 1992, but previous data indicated that concentrations exceeded the recreational criterion for faecal coliform counts (Kempster *et al*, 1982) 72% of the time (figure 4E).

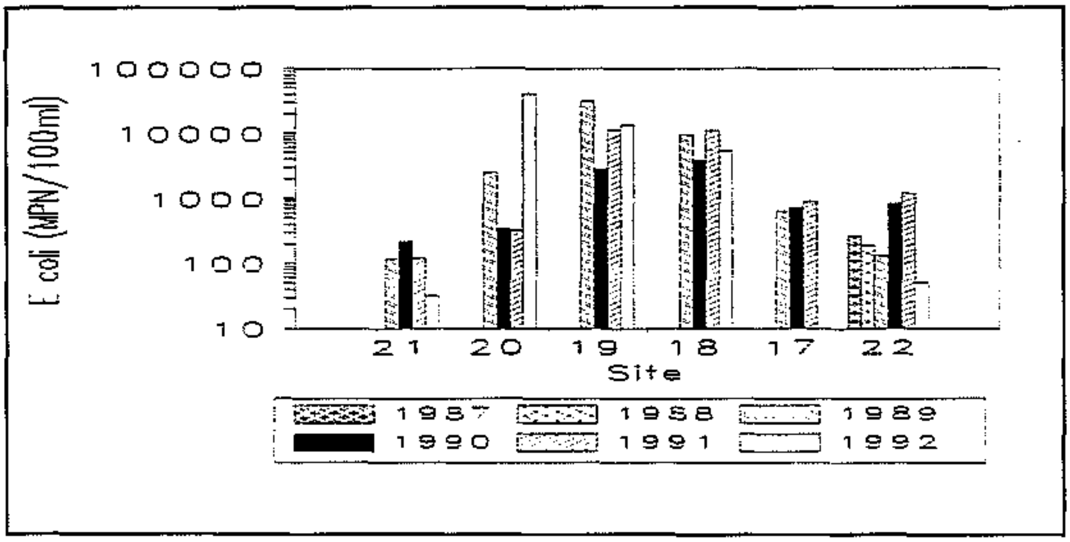

Figure 3. The temporal changes in *E. coli* geometrical mean counts at the six sites on the Bridle Drift Dam from 1987 to 1992.

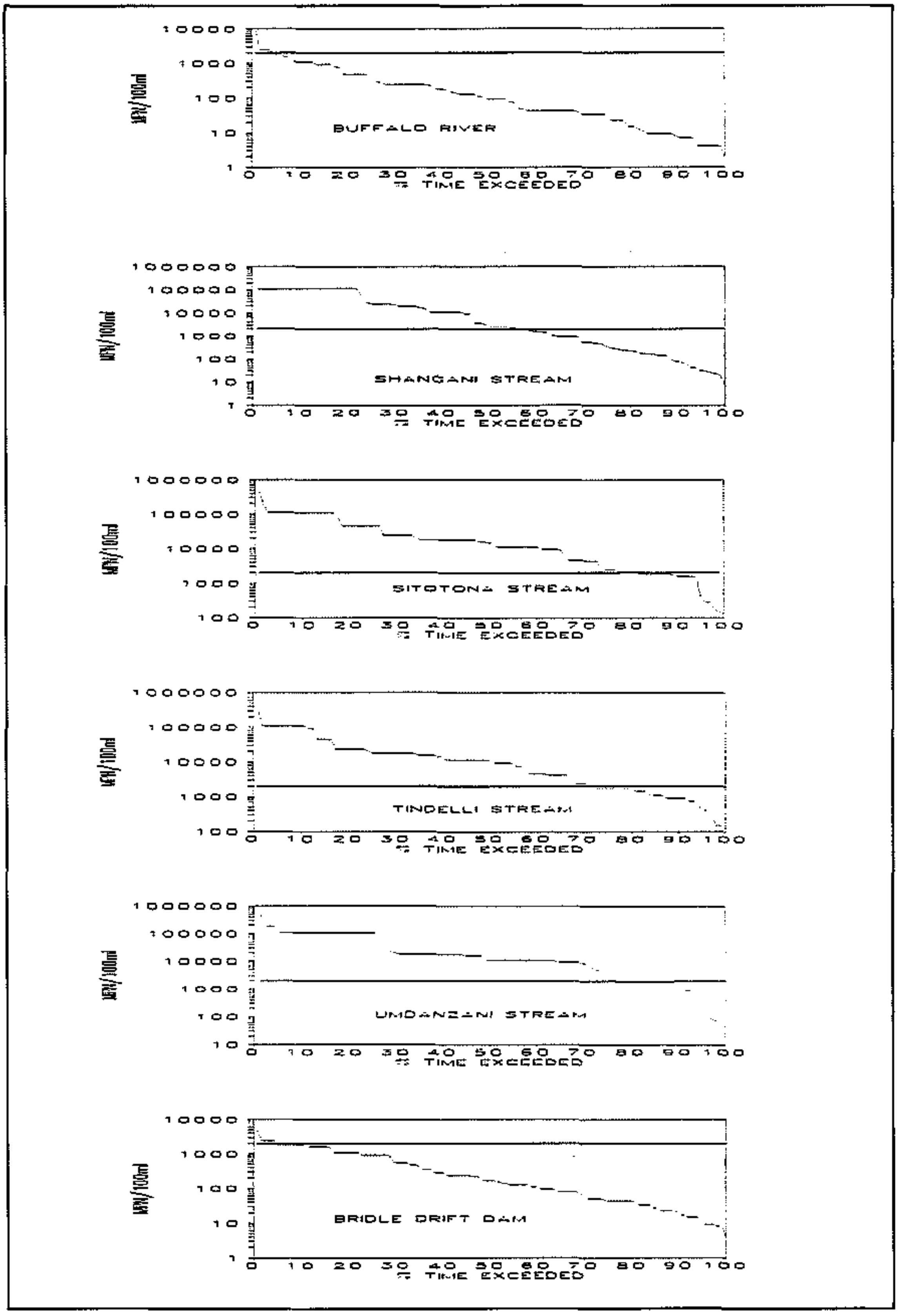

Figure 4. The percentage time that faecal coliform counts exceeded the recreational criterion of 2000 MPN/100ml in the Buffalo River (A), Shangani Stream (B), Sitotona Stream (C), Tindelli Stream (D), Umdanzani Stream (E) and near the dam wall of Bridle Drift Dam (F).

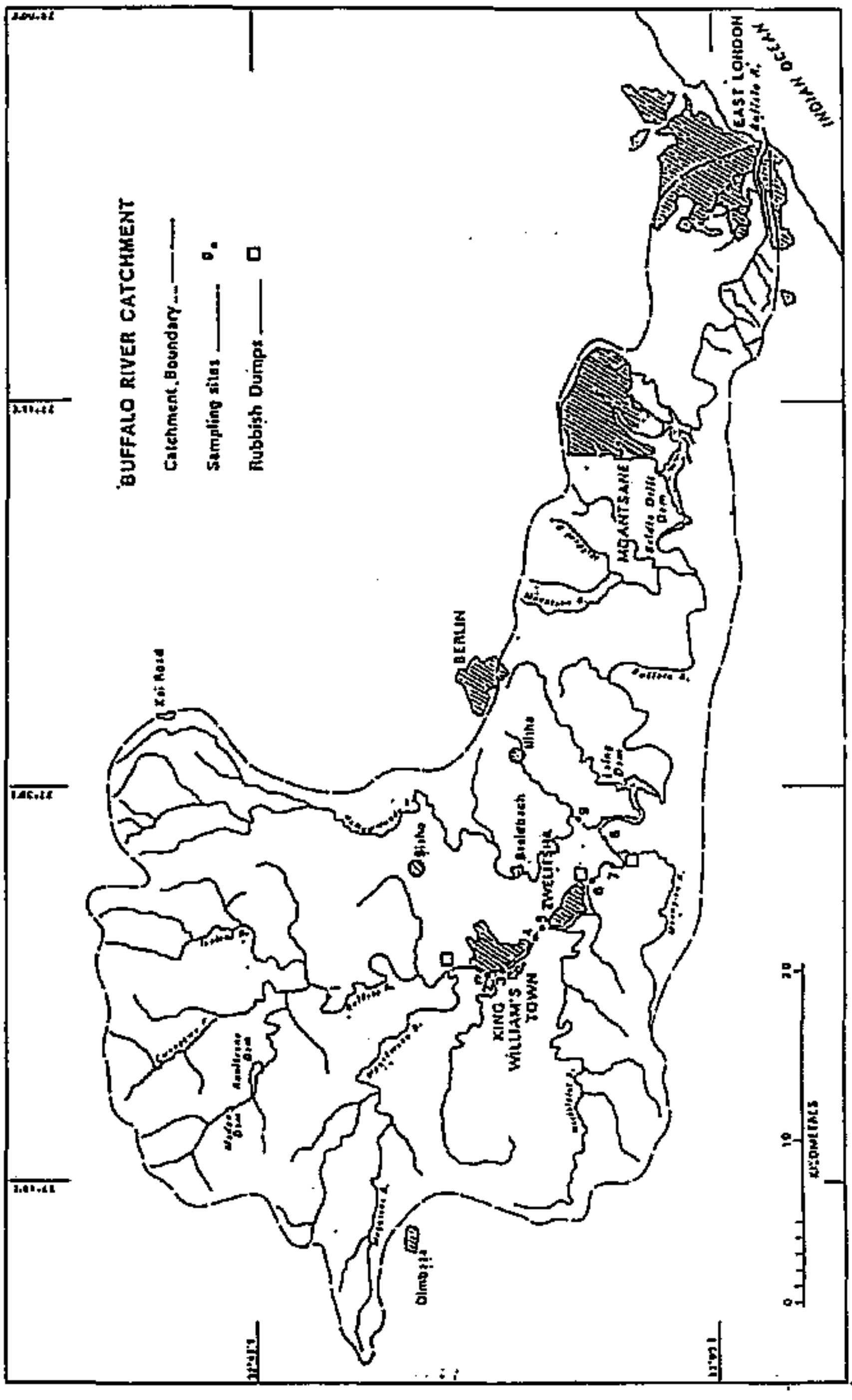

Figure 5. The bacteriological sampling sites in the Buffalo River catchment that were used by the Institute for Water Research, Rhodes University, during the project period.

5.2 Institute for Water Research results

Monthly sampling was undertaken at nine sites> Sites are indicated in figure 5 and results are expressed in figure 6. None of the sites exceeded the recreational criterion for faecal coliform counts. The highest geometrical mean was found at the outflow of the King William's Town sewage treatment works, but water quality recovered rapidly downstream as site 5 was only 100m downstream of the above mentioned discharge.

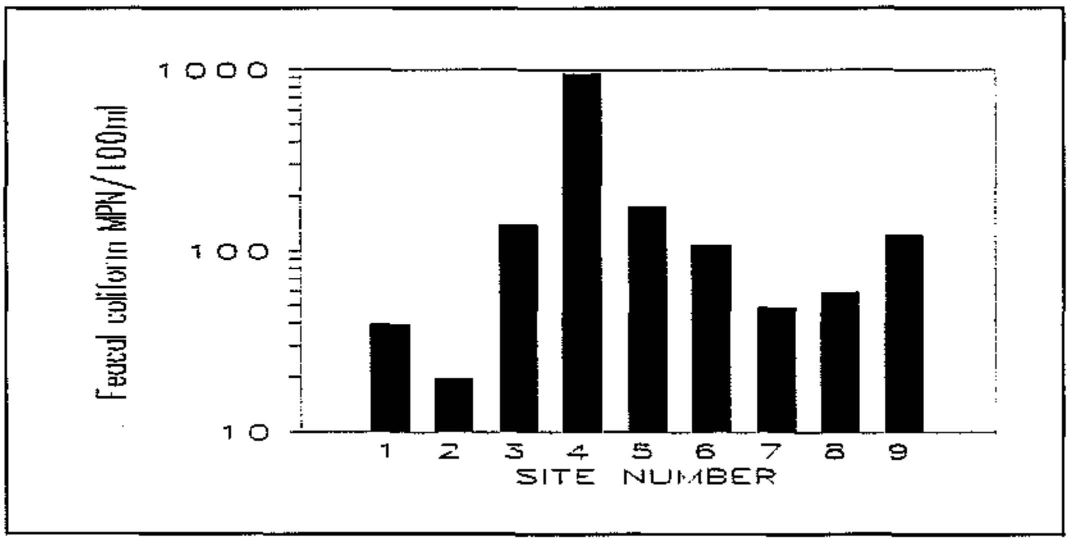

Figure 6. The spatial variation in faecal coliform count geometrical mean for the King William's Town area at the nine sites that were sampled by the Institute for Water Research during November 1991 - August 1992 (Sites as shown in figure 5).

5.3 Water Quality Management - DWAF

The single sampling visit (table 2) showed that the highest faecal coliform contamination is upstream and at the King William's Town sewage treatment works and the Mgqakwebe River. All of these counts were within the limits of the recreational criteria for faecal coliform counts (Kempster *et al*, 1982).

6. SOURCES OF POLLUTION

The sources of pollution and probably bacteriological contamination as well can be divided into three categories : a) point b) point/non point and c) non point sources. The Ciskei Sewage Treatment Works (STW) especially Mdantsane, Ilitha and Mount coke STW's were in very bad condition (Van Wyk & Louw Partnership, 1991; Ninham Shandand Partners, 1990 and Theodor Hoffmann & Mouton, 1990 & 1991) The Ciskei Public Works Department was at the time of writing in the process of evaluating and updating all the Sewage Treatment Works under their jurisdiction. The Zwelitsha and Potsdam Sewage treatment works were already privatised.

Table 2. The bacteriological counts as determined by the Water Quality Management Section of the Department of Water Affairs. The sampling date for the Buffalo River sites was 1/4/92 and for the Yellowwoods River sites 18/2/92.

Sampling site	River	Faecal coliforms	*E. coli*
Horseshoe bend	Buffalo	460	29
King William's Town rail bridge	"	1100	210
King William's Town STW old	"	0	0
King William's Town STW new	"	1100	1100
Dennis Radue bridge	"	43	15
Mlakalaka Stream	"	240	15
Zwelitsha STW	"	460	240
R2H010 Weir	"	43	43
Laing Dam	"	240	240
Bridle Drift Dam	"	43	9
Buffalo Pass	"	43	43
Dimbaza Stream inflow	"	1100	43
Lonsdale	Yellowwoods	460	460
Bisho STW	"	75	75
Below Bisho	"	43	43
Below Breidbach	"	23	23
R2H011 Weir	"	23	23

6.1 Point sources

6.1.1 *Potsdam STW*

Effluent from Potsdam STW was discharged by pipeline into the ponds at Mdantsane STW. Van Wyk & Louw Partnership (1991) stated that this plant was in very good operating state and could produce effluent which would conform to the required general and special standard specifications. This sewage treatment works was in the catchment of the Shangani Stream. Periodically over the last four years, especially during 1992, low quality water was found in this stream, but a colouring test done on the outflow of the Potsdam Sewage works, proved to end up in the Mdantsane Sewage treatment works (Mr R Kahn, pers. comm., June 1992).

6.1.2 *Zwelitsha STW*

The effluent of Zwelitsha STW was discharged directly into the Buffalo River upstream of Laing Dam. This plant was in good condition and should produce effluent which could conform to the required specifications. Some unacceptable results have been reported, which indicates that problems do occur (Van Wyk & Louw Partnership, 1991). This was confirmed by Mr Mbatani (pers. comm., August 1991). The data collected during this study have shown that the water quality of the effluent from this sewage treatment works did not comply to the 1 mg/l PO_4-P standard. However, there did not seem to be extremely high bacteriological contamination from this plant.

6.1.3 *Ilitha STW*

The effluent of Ilitha STW was discharged into a tributary of the Yellowwoods River, upstream of Laing Dam. This effluent posed a serious threat to public health and was a major source of pollution. The plant was in the process of being relocated, but this will only be finished by the year 2000 (Van Wyk & Louw Partnership, 1991).

6.1.4 *Mount Coke STW*

The effluent of Mount Coke STW was discharged into a tributary of the Buffalo River upstream of Laing Dam. The effluent could be classified as settled sewage or at best as septic tank effluent. This effluent also posed a serious threat to public health and was a major source of pollution (Van Wyk & Louw Partnership, 1991).

6.1.5 *King William's Town STW*

The King William's STW was situated below King William's Town and upstream of Zwelitsha. The samples taken by the Institute for Water Research at the nine sites in the King Williams Town area and the sample taken by the Water Quality Management section of DWAF showed that the effluent of this STW had geometrical mean faecal coliform counts of over 900 MPN/100ml. Water quality recovered rapidly, however, because at a site about 100 m downstream of the effluent input the geometrical mean of faecal coliform numbers was less than 200 MPN/100ml.

6.2 Point/non point sources

6.2.1 *Mdantsane Township reticulation system*

The effluent from the Mdantsane STW was discharged below the water draw-off point of the East London Municipality downstream of Bridle Drift Dam. According to Van Wyk & Louw Partnership (1991) this plant was in a poor state of operation. There was a major problem with the reticulation system of Mdantsane. Kahn (1992) stated that there was little doubt that the flow in the four streams in the Mdantsane catchment consisted mainly of raw sewage effluent diluted with potable water. This arose both from defective reservoirs and from the water supply reticulation network in Mdanstane. The inflow to the plant was approximately 2.0 to 4.0 Ml/d, while the expected flow to the works as estimated by Ninham Shand (1990) was 18 Ml/d (Van Wyk & Louw Partnership, 1991). This implied a total loss of between 14 Ml/d and 16 Ml/d. Mr Hassall (pers. comm., September 1991) believed that approximately 25Ml/d of raw sewage discharges into the Bridle Drift Dam via the natural streams. Mr Mbatani, who took the samples in the streams from Mdantsane, observed relatively high flows during dry periods (pers. comm., August 1991). The data from the four streams flowing out of Mdantsane into Bridle Drift Dam (figure 2) showed that the highest *E. coli* contamination was via the inflows of the Sitotona, Tindelli and Umdanzani streams. The relative contributions of these streams vary over time. These three streams exceeded the general criteria of 2000 MPN/100ml (Kempster, Hattingh & Van Vliet, 1982) for recreational purposes more than 50% of the time. There was no biological standard for river and dam water.

The main problems in Mdantsane according to Mr Bartell, Mr Hassall and Mr Martin (pers. comm., 1991) and Mr Kahn (pers. comm., 1992) were the following :

1. The wilful sabotage, vandalism and infrequent clearing of sewer chokes all caused overflows into the streams from Mdantsane to the Bridle Drift Dam. The old Mdantsane Special Organisation used to handle the clearing of these sewers. Since then the Ciskei Building Organisation and the Ciskei Public Works have taken over this task, but could not as yet manage to control the system, because of the above mentioned problems. There were an average of 10 breakages in the sewer system per day (Palmer *et al*, 1992)

2. The shorting of the electricity, also by wilful sabotage, stopped the functioning

of the pumping stations quite often.

3. The informal low-cost, high-density urban developments in the catchment of the Buffalo River, some of which were below the high water mark of the Bridle Drift Dam, might become a problem in the wet periods.

4. The population increase upstream of the Bridle Drift Dam might also become increasingly important in the polluting of Bridle Drift Dam.

The weirs in the four inflowing streams into Bridle Drift Dam were upgraded and flow measurements were possible, although there were no continuous flow meters at these sites. Mr Kahn (1992) suggested that the water at the weirs should be pumped into the pipeline from Potsdam STW into Mdantsane STW ponds. It would then bypass the Dam and be discharged into the Buffalo River downstream of the extraction point of East London water supply. Because the spills into the dam were not only in the sewer system, but also in the water reticulation system, this might cause quite a loss in water.

6.3 Non point sources

6.3.1 *Squatter areas*

There were a few squatter areas in the catchment. The major possible threat from these low-cost, high-density urban developments, might be during storm events. Mr Hassall noticed that areas adjacent to all the footpaths across open spaces and the public facilities were heavily contaminated with human faeces. The survival of bacteria on the ground surface is very low, however, so these areas should not contribute greatly to the bacteriological contamination.

7. DISCUSSION

It was quite obvious where the bacteriological contaminations originated and there was serious pollution from both the point sources and the point/non point sources, which were in a poor state of operation and where there was insufficient management. The major sources of pollution seemed to be Mdantsane Township and STW in the Bridle Drift catchment. Ilitha STW and Mount Coke STW, in the upstream catchment, seemed to be serious health hazards. The Ciskei Public Works Department was investigating all possible solutions to the problems. This included the updating and repairing of the plants, although it seemed (Van Wyk & Louw Partnership, 1991) that this would take many years to complete. Van Wyk & Louw Partnership (1991) suggested that all the STW's need repairing, especially those of Mdantsane, Ilitha and Mount Coke. Occasional bacteriological analyses were done on the Ciskei Sewage Treatment Plants (Mr Mbatani, pers.comm., 1991). Sampling by the Ciskei was started on the final effluents or in the receiving river water just downstream of these effluents on a monthly basis.

The bacteriological contamination in the King William's Town area did not seem to pose any health threat, since the sites with the highest geometrical mean counts were greatly diluted.

8. CONCLUSIONS

1. It was not possible to determine all the main sources of contamination in the whole catchment from existing data although it seemed that the point sources were the main contributors. The only extensive bacteriological data available were those of the East London Municipality. For the low-income, high-density urban developments in the catchment upstream of Bridle Drift Dam there were no data available. However, figures 2 and 3 imply that only very little of the known contamination in Bridle Drift Dam originated upstream of the dam.

2. Bacteriological contamination in the Bridle Drift Dam area was quite severe, but in the middle reaches there was no real concern regarding bacteriological contamination. If the water in Bridle Drift Dam was required to conform to recreational standards, then bacteriological contamination would be excessive in the main inflowing streams for more than 50% of the time. Maximum contamination in the dam itself appeared to be just within acceptable limits at the time of writing (figure 5), but may be cause for concern in the future if remedial measures are not taken.

3. The bacteriological monitoring in the King William's Town area showed that there was no real concern in the middle reaches of the catchment. There was only one event in which the effluent from King William's Town STW did not conform to the recreational criteria for faecal coliform counts (Kempster *et al*, 1982).

4. Since the sources of pollution in Bridle Drift Dam have been identified, urgent repairs should be made on the reticulation system, the operation of the STW's should be upgraded, and the system should be protected from vandalism. The Ciskei Government has already made extensive use of consulting engineers to determine different options for upgrading the Sewage Treatment Works.

9. INFORMATION SOURCES

9.1 References

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3. Ninham Shand and Partners (1990) *Proposals for reinstatement and refurbishments*. An investigation report for the Ciskei Government. (I was not allowed to see this report)

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6. Theodor Hoffmann & Mouton Consulting Engineers (1991) *Ilitha sewage treatment works Addendum 1 to Feasibility study*. Department of Public Works, Ciskei Government.

7. Thornton, G.P.K., Chutter, F.M. & D.H.R. Hellwig (1967) *Chemical and biological survey of the Buffalo River*. CSIR Special Report No. WAT 35. Pretoria

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9.2 Personal Communications

1. Mr R. Bartell. Chemist, City Engineering Office, East London Municipality. July 1991.

2. Mr R.O. Hassall. Project Engineer with Mdantsane Special Organization for 21

Years. Now retired. Written communication. September 1991.

3. Mr Z Mbatani. CSIR representative working in the Ciskei Laboratory of the Department of Public Works, Ciskei Government. August 1991.

4. Mr R. Kahn. Water quality manager : Ciskei public Works. June 1992.

5. Mr A. Lucas. Assistant Director : Water Quality, East London, Department of Water Affairs. August 1991 and November 1992.

APPENDIX F

DEMOGRAPHIC SURVEY

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March 1993

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1. INTRODUCTION

1.1 Aims of the Study

Eutrophication is a major problem in South African impoundments and there is an increasing need for more information on the nutrient contributions from diffuse sources into rivers and impoundments. Low-cost, high-density urban developments are classified under these diffuse sources, as the nutrient loads from these sources can not readily be measured. Nutrient inputs from diffuse sources in the Buffalo River catchment have never been measured, except in modelling studies done by Grobler and Rossouw (1988) in the Mgqakwebe and Ngqokweni Rivers, by using total phosphate and flow conditions in these rivers. In 1985 a study was done on Botshabelo to determine the nutrient inputs from the township (Grobler *et al*, 1986). A phosphate budget for the township was determined to verify the diffuse source phosphate inputs.

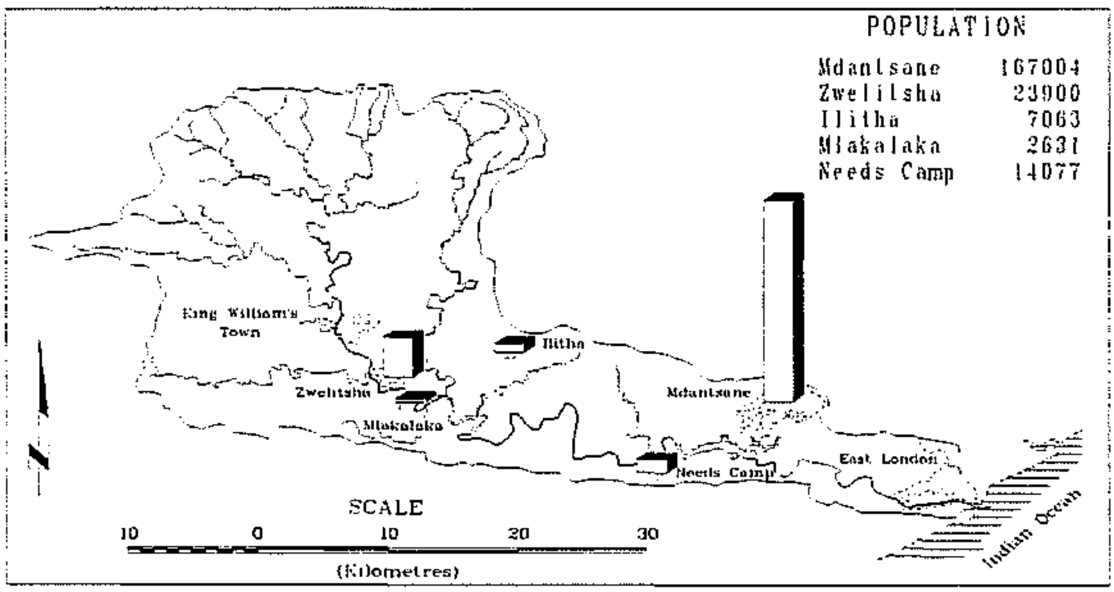

Figure 1. The five townships in the Buffalo River catchment that were surveyed showing the population numbers.

This demographic study was undertaken to provide information for the assessment of water quality in the Buffalo River, using similar techniques to those used in the demographic study performed in Botshabelo (Grobler *et al*, 1986). This survey was designed to increase our knowledge of the potential nutrient input from the low-cost, high-density urban developments in the Buffalo River catchment. The aims of this study were to determine the population numbers, sanitation habits and facilities and soap usage, and to assess the extent to which domestic animals are kept in different residential areas. The data presented in this report were used to determine the potential phosphate contributions from the townships and villages in the Buffalo river catchment.

1.2 The Study Areas

This demographic survey was based on a stratified sample of 300 households situated in the following urban and rural areas of the Buffalo River catchment (figure 1).

Urban:	Zwelitsha (130 households)
Urban:	Mdantsane (30 households)
Urban:	Ilitha (60 households)
Closer settlement:	Needs Camp (40 households)
Rural:	Mlakalaka (40 households)

Zwelitsha is a township situated on the outskirts of King William's Town and was founded in 1948. According to the township authorities this township has 3646 residential plots and the residents' main employment opportunities are in King William's Town and Bisho, the latter being the administrative centre of Ciskei. Zwelitsha has an un-serviced squatter camp on its outskirts which was included in the study and which consists of 75 households. The squatter camp is located near a cemetery alongside the Buffalo River. The camp began to emerge in 1989 when people who had no formal accommodation in Zwelitsha decided to build shacks in the area. The Ciskei administration has promised to provide the squatters with serviced plots but no definite plans have been made yet for the people living in this area.

The township of Mdantsane is situated about 25 kilometres from East London (figure 1) and, according to township authorities has 27011 residential plots. Mdantsane was started in the early 1960's after the demolition of a large portion of Duncan Village in East London. This resulted in a mass removal of thousands of people from Duncan village to Mdantsane which developed at a very fast rate. This rapid growth was also boosted by the influx of large numbers of rural people who chose to live in Mdantsane.

Ilitha is a relatively small township which is situated between Mdantsane and Zwelitsha (figure 1). Unlike Zwelitsha, which has been in existence for more than four decades, Ilitha was founded about 12 years ago. It has 1061 residential plots.

Needs Camp is located about 35 kilometres from East London (figure 1) and has about 2102 residential plots, according to information received from the Department of Development Aid in East London. It came into existence as a result of a re-location programme when people from surrounding farms decided to settle there following the demolition of another settlement known as Tsweletswele by the Ciskei government in 1987. After clashing with the Ciskei government the people left Tsweletswele at short notice - many losing their property during that conflict and eventually settling on an unoccupied farm. Their community came to be known as Needs Camp and is located in South Africa. There is a general feeling of insecurity in this community as the people feel that they may be told to go and settle elsewhere at any time. Moreover, most of the people of Needs Camp have lived as landless people on white-owned farms for several generations, hence they tend to have fewer material resources than people in the other communities which have been included in this study. Places such as Needs Camp which include resettled people are usually referred to as closer settlements or resettlement camps.

Mlakalaka is a typical rural community or village which is situated adjacent to Zwelitsha beside the Buffalo River, which separates the two areas (figure 1). Statistics available from the Ciskei authorities indicated that in this village there were 311 residential plots. Like other Ciskei villages the community does not have electricity and water-borne sewerage and experiences a serious shortage of potable water. There are only a few communal taps. The people who have means use water tanks to collect water from house roofs. However, these tanks normally dry up during periods of extended drought.

1.3 Method

Fieldwork for the demographic survey was undertaken by four field workers from mid-June to early July 1991. A standard interview schedule was used to gather information from the households (see Appendix). The field workers started at Zwelitsha and moved on to Mlakalaka. After making a start in Mdantsane they were prevented from completing their work there by members of the Mdantsane Residents' Association. Some members of this association perceived the exercise as being associated with the Ciskei census which was then due to start. The project team thus decided to switch focus from Mdantsane to the township of Ilitha. One advantage of this was the fact that a bucket system of sewerage disposal is used at Ilitha whereas this type of disposal system is not used at all in the other areas investigated. Thus, the study covered all types of sanitation systems that are used in the Ciskei/Border area.

The catchment includes the following low-cost, high density residential areas: 26 villages which are in Ciskei, three townships (Mdantsane, Zwelitsha and Ilitha) in Ciskei, one township (Ginsberg) in South Africa, one resettlement camp (Needs Camp) which is administered by South Africa and one resettlement camp (Potsdam) which is in Ciskei. Mdantsane was chosen for this study because it is the largest urban settlement in the target area. Zwelitsha was included in the study because it is of average size in terms of its population. As noted above, Ilitha was chosen for study after the research team was prevented from completing its work in Mdantsane. However, although Ilitha is much smaller in size than Mdantsane, its housing situation is similar to that of Mdantsane. Needs Camp (which is more or less the same size as Potsdam) did appear to be a representative case of a resettlement camp. Mlakalaka was a typical Ciskei village in terms of its size and infrastructure. It was for these reasons that it was included in the study.

<u>The relevance of house types</u>

Realising that the households in these communities vary a great deal in terms of their total monthly income, the study was designed to reflect a measure of economic differentiation. To this effect, eight distinct types of households were identified, as follows:

1. <u>The 'elite' or 'Bond' type of house (20 cases)</u>

These houses belong mostly to professional people (teachers, nurses, clerks, etc) who are entitled to government housing subsidies. Generally, household incomes in these homes are higher than in the other types of households. The purchase value of these houses varies according to the people's means, with the cheapest being about R45 000 and the most expensive double this amount. The size of the plots also varies, with the more expensive houses being built on what are referred to as double plots. Normal building materials are used, e.g. red bricks, corrugated iron or tiles for roofing and cement or wood for flooring. Many of these houses would fit into any lower middle class area in South Africa and others are more prestigious.

2. <u>'Improved township' house (42 cases)</u>

Often the township residents first occupy a typical township house built by the administration and later make substantial improvements to the house such as adding one or more rooms and other alterations. This type of house can be identified as an improved township house.

3. <u>'Typical township' house (76 cases)</u>
This is a standard municipal house which consists of two or four rooms and no substantial improvements have been made to it by the resident. Usually the walls are made of concrete blocks and asbestos is used for roofing. Most of these houses have concrete floors, though some of the older houses have wooden floors. Those with four rooms have two bedrooms, a sitting room and a kitchen.

4. <u>'Elite village' house (6 cases)</u>
At Mlakalaka there are a few relatively costly houses. On that account they need to be considered as a separate housing category from the other households in the village. These houses are financed by the residents' incomes since regulations prevent the house owners from building with the assistance of government subsidies. Some have more than six rooms of average size. The building materials that are used are either burnt bricks or cement blocks, corrugated iron for roofing and cement or wood for flooring.

5. <u>'Typical village' house (16 cases)</u>
In this case the main house may be a rectangular structure with walls which are made of mud bricks or cement blocks. In addition, there may be one or two additional rondavels on the plot.

6. <u>'Humble village' house (16 cases)</u>
This type of house is owned by people with a relatively low income and may consist only of one small house (sometimes a mud-walled rondavel or a shack). The house or houses may be thatched or old corrugated iron may be used for roofing. Most of them, if not all, have mud floors.

7. <u>'Backyard' house (54 cases)</u>
These are dwelling structures which are erected on a plot which also has a main house. Most of these dwellings are relatively cheap and are occupied by people with low to very low incomes. However, there are a few cases where these structures are more solid and may be used by adult children or other close relatives of people living in the main house. The latter tend to be of a better quality than those which are erected for the purpose of renting out to tenants. Many of these backyard houses have walls and roofs that are made of old corrugated iron. Also, many of them are in a relatively poor state of upkeep. The rooms are usually very small and not more than nine square metres in size. Because they are often built with poor and old materials, they tend to be impermanent and damp.

8. <u>'Squatter shacks' (70 cases)</u>
This type refers to relatively cheap and impermanent shacks which are built by people in the squatter areas and in the resettlement area. Since the people have settled informally in the areas, they know that they are likely to be moved to other places at some time in the future. The structure can be dismantled and re-erected at another site in a relatively short period of time. Many squatter shacks have corrugated iron walls and roofs. Sometimes old wooden boards or plastic sheets are used for the walls and roofs. Almost invariably the materials

used are of poor quality. The shacks have mud floors which are damp most of the time and some people have to vacate their shacks during floods. A shack usually consists of one or two rooms which are about nine square metres in size each.

1.4 Sampling procedures

A stratified random sampling procedure was effected by taking every fifth household in selected zones, except at Mlakalaka and Needs Camp where every 10th household was chosen. The Zwelitsha sample of 130 households was selected from housing Zones 6, 8, 10 and from the new squatter settlement referred to above. Housing Zones 6 and 8 are located in older portions of the township whilst housing Zone 10 is a fairly new housing Zone. The selection of two older Zones and one fairly new Zone was made in order to make the sample representative. There were a few individuals who refused to be interviewed (about 15 cases), for a variety of reasons. In some cases their response was due to the absence of their parents and in other cases the people concerned were suspicious of the interviewers. In these cases an effort was made to interview members of the household next door.

2. POPULATION

In Ciskei it is not easy to obtain reliable population figures. One important reason for this is the fact that no recent population census has been taken. By mid-1991 a general opposition to the administration of the area resulted in the failure of a census which was supposed to have started in May 1991. The census could not even start because of the widespread opposition from residents in the area.

Even though a great deal of time was devoted to the question of population figures for the areas which were surveyed in this study, there is no certainty that the figures are entirely correct. The present calculations take into account (a) the total number of house types in each area studied, (b) the average household size of each area, and (c) an estimate of the numbers of backyard houses where these exist. The average number of people per household in the various areas surveyed varies slightly. This is illustrated in table 1.1.

Table 2.1: Average number of people per household

	Range		
Information	Average no. of people per household	Min.	Max.
Needs Camp	5.52	1	18
Mlakalaka	5.12	1	17
Squatters (Zwelitsha)	4.12	2	9
Townships (Zwelitsha, Mdantsane, Ilitha)	5.01	1	13
Backyard Houses	3.92	1	11
Overall	5.37	1	18

In all of these communities, shortage of housing makes it necessary for people to erect extra dwellings, usually at the back of the main house. In this study these are referred to as backyard houses. The existence of these backyard dwellings must always be taken into consideration if a realistic estimation of the population is to be made. The number of backyard houses illustrated in table 2.2 is based on extrapolation from the sample population to the population as a whole (See Section 4.2).

The numbers of township and elite houses in Mdantsane, Zwelitsha and Ilitha were provided by officers in the rent collection offices of these townships. The same offices gave information about the number of elite houses in Mdantsane and Ilitha. The records of the Deeds Office were used in order to determine the number of elite houses in Zwelitsha whilst the number of squatter houses in Mdantsane and Zwelitsha was obtained by making a direct count of the houses in the areas concerned. The Ciskei Central Statistics Department provided an estimate of the number of households at Mlakalaka. This was based on an enumeration conducted by this department in July 1990. The number of houses in Needs Camp was supplied by the Department of Development Aid. The overall situation regarding populations is illustrated in table 2.2.

Table 2.2: Estimates of total numbers and types of houses, plus total numbers of residents for each location investigated

Information	Mlakalaka	Needs Camp	Ilitha	Mdantsane	Zwelitsha
No. of township houses	0	0	935	26 010	3 053
No. of elite houses	0	0	126	906	518
No. of backyard houses	265	631	446	8 103	1 458
No. of squatter houses	0	0	0	95	75
No. of temporary structures (excluding squatter houses)	0	2 102	0	0	0
No. of village houses	311	0	0	0	0
No. of people in elite & township houses	0	0	5315	134 849	17 891
No. of people in backyard houses	1 039	2 473	1748	31 764	5 715
No. of people in squatter houses	0	0	0	391	294
No. of people in temporary structures	0	11 603	0	0	0
No. of people in village houses	1 592	0	0	0	0
Total population in the location	2 631	14 077	7063	167 004	23 900

Table 2.3 provides population estimates of all low-cost, high density residential areas in the catchment. This information was obtained from the Ciskei Central Statistics Department and officials in South Africa.

Table 2.3: Population of low-cost, high-density residential areas in the catchment

Location	No. of Households	No. of Backyard Houses	Total Population (including backyard dwellers)
26 villages in Ciskei	9 837	4 751	77 655
3 townships (Mdantsane, Zwelitsha and Ilitha) in Ciskei	31 718	15 319	170 754
One township (Ginsberg) in South Africa	1 720	831	13 577
One resettlement camp (Needs Camp) in South Africa	2 102	1 015	15 076
One resettlement camp (Potsdam) in Ciskei	2 010	971	15 866

The total number of people in the catchment who are in the target area is 292 928. In the catchment the areas which are not of low-cost, high density nature are King William's Town (with 13 197 people) and Breidbach (with 4 860 people). The latter areas include 18 057 people who are in South Africa. According to the official figures, the total population of the Buffalo catchment is 310 985 people and the survey areas consisted of 188 471 people (60.6%).

It is necessary to compare the estimates of total population numbers obtained during this study with other earlier estimates. The figures which are used in this report are fairly close to those provided by the Development Bank of Southern Africa (1991) and Erasmus (1991) as shown in table 2.4.

Table 2.4: Population Estimates

Location	Present survey (Population in 1991)	Development Bank of Southern Africa (Population in 1990)	Erasmus (Population in 1990)
Mdantsane	138 770	162 454	162 454
Zwelitsha	23 921	28 494	28 494
Ilitha	7 063	7 458	7 458
Needs Camp	15 076	-	-
Mlakalaka	2 641	-	-

Even though with regard to Needs Camp and Mlakalaka we were not able to get any other population figures apart from those which were provided by officials, our acquaintance with these communities leads us to believe that the figures are acceptable.

3. HOUSEHOLD STRUCTURE AND EMPLOYMENT

It was necessary to consider household structure since it influences the nutrient contributions of the population. People of different ages and sexes have different nutrient inputs to the system. Particulars relating to work, namely the occupational status of the people, time of departure and time of return from work, also have a bearing on the nutrient contribution of the people. Those who work outside the catchment and return home after work make less nutrient input to the system compared to those who work in the catchment continually. Firstly, we took into account the people who lived in the households which were sampled. These were people who usually slept at home every night. These sampled households included 1613 individuals, with an age distribution as shown in table 3.1.

Table 3.1: Age Categories

Age in Years	0-5	6-10	11-20	21-30	31-40	41-50	51-60	61-70	70 +
No. of People	195	207	415	271	214	144	87	52	28

It can be seen that two-thirds of the household members are aged 30 years and below. Table 3.2 below provides this information by location.

Table 3.2: Age Categories (by location)

	Age in years									
Location	0-5	6-10	11-20	21-30	31-40	41-50	51-60	61-70	70+	Total
Mlakalaka	18	22	59	45	20	18	14	10	9	215
Needs Camp	27	41	71	29	21	17	16	11	5	238
Ilitha	42	47	84	42	47	29	11	10	1	313
Mdantsane	26	14	35	33	31	10	6	6	5	166
Zwelitsha	82	83	166	122	95	70	40	15	8	681
Totals	195	207	415	271	214	144	87	52	28	1613

Table 3.3 shows the actual number of people in the household.

Table 3.3: Number of people in different house types

House Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Elite	-	-	5	4	4	4	1	2	-	-	-	-	-	-	-	-	20
Improved Township	1	2	1	7	8	8	4	3	5	3	-	-	-	-	-	-	42
Typical Township	-	2	14	9	5	17	11	8	4	-	2	2	-	-	1	1	76
Elite Village	-	-	-	1	3	-	2	-	-	-	-	-	-	-	-	-	6
Typical Village	-	-	2	5	2	5	-	2	-	-	-	-	-	-	-	-	16
Humble Village	1	1	2	1	-	3	4	1	-	2	-	-	1	-	-	-	16
Temporary Structure	2	5	12	14	9	9	7	2	5	1	1	1	-	1	-	1	70
Backyard House	9	7	11	9	5	6	3	2	-	1	-	1	1	-	-	-	54

Table 3.4 illustrates that the distinct house types which are used here for analysis vary in size, the smallest average sizes being for backyard houses and elite houses.

Table 3.4: Average household size

House Type	No. of plots in survey	No. of people	Average household size
Elite	20	96	4.8
Improved Township	42	251	5.97
Typical Township	76	463	6.09
Elite Village	6	33	5.5
Typical Village	16	82	5.12
Humble Village	16	100	6.25
Temporary Structure	70	376	5.37
Backyard House	54	212	3.92
Total	300	1 613	5.37

Table 3.5 shows the occupational status of the occupants of the sampled households.

Table 3.5: Occupational status of people living at home

Occupation	Employed and Self Employed	Unemployed	Pensioners	Scholars	Young Children	Casual Workers	Total
No. of People	343	323	80	642	213	12	1 613

Scholars and young children constituted the largest category in the sample and included 855 individuals or 53 % of the total number of people in the surveyed households. Three hundred and twenty three (20 % of the total number of people) were unemployed. A further 320 people were in formal employment and 23 were self employed. Most of those who were self-employed operated from their homes. The 80 pensioners reflected above were people who were at home most of the time. Casual workers worked only on certain days of the week, e.g. two or three days a week. The young children were those who were not yet of school-going age. The places of work of those people who lived at home and who were employed or self-employed are shown in table 3.6.

Table 3.6: Places of work

Places of work	King William's Town	East London	Berlin	Home	Kidds Beach	Other	Total
No. of People	209	57	39	11	8	19	343

Table 3.7: Time of departure for work:

Time in the morning	2-2.59	3-3.59	4-4.59	5-5.59	6-6.59	7-7.59	8-8.59	Never Leave Home	Total
No. of People	7	44	120	125	25	10	1	11	343

Table 3.8: Time of return from work

Time in the afternoon/evening	2-2.59	3-3.59	4-4.59	5-5.59	6-6.59	7-7.59	8-8.59	9-10.00	Never Leave Home	Total
No. of People	10	13	38	127	84	41	10	9	11	343

It can be seen that most employees leave home before 7 a.m. each day, returning after 5 p.m. This absence of people has a significant effect on nutrient loss.

3.1 Other Household Members

Respondents were asked to list those household members who were away and who returned home from time to time. This information was sought in order to assess the nutrient contribution of such people during those times when they were at home. The respondents indicated that a total of 154 individuals, (88 males and 66 females) could be categorised as being periodically absent. These people were in the following age categories:

Table 3.9: Ages of absent household members

Ages in years	Up to 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	Total
No. of People	36	58	29	20	7	4	154

This means that the vast majority of the people who were away were adults. Table 2.10 below illustrates that about two-thirds (64.9%) of those away were working where they were and about a fifth of them (21.4%) were away at boarding schools or were accommodated elsewhere whilst they furthered their education.

Table 3.10: Occupational status of absent household members

Occupation	Employed	Unemployed	Pensioner	Scholar/Student	Casual Worker	Total
No. of People	100	17	2	33	2	154

The 154 people who were away were in the following places: East London (55 cases), King William's Town, Peddie and Dimbaza (36 cases), Port Elizabeth and Cape Town (27 cases), Transvaal (16 cases), Transkei (12 cases), Natal (1 case) and Middledrift, Fort Beaufort, Seymour and Sada (7 cases). Those who were away did, however, return home from time to time as shown in table 3.11 and spent the amount of time at home specified in table 3.12.

Table 3.11: Visits home by absent household members

Intervals	Every Weekend	Twice a month	Once a month	4 times a year	2 times a year	Once a year	Total
No. of Cases	48	11	24	28	9	34	154

Table 3.12: Time spent at home per year by absent household members

Information	No. of People	Total no. of days per year for all the people
2 days a week or 104 days a year per person	80	8 320
3 days a week or 156 days a year per person	6	936
2 weeks a year or 14 days a year per person	3	42
3 weeks a year or 21 days a year per person	32	672
One month a year or 30 days a year per person	31	930
6 months a year or 182 days a year per person	2	364
Totals	154	11 264

4. HOUSING

4.1 Number of Rooms in the Household

Housing constitutes an important part of the study since it directly reflects the quality of life of the people and the sanitation facilities that are available to them. The households which were included in the study vary a great deal in terms of their economic standing, with some people occupying relatively comfortable houses of the 'elite' type, whereas those with lowest incomes tend to live in temporary structures or shacks. The situation regarding the size of dwellings, as represented by the number of rooms in the sampled households, is illustrated in table 4.1.

Table 4.1: No. of rooms per household

No. of Rooms	1	2	3	4	5	6	7	8	9	10	Total
No. of Cases	62	58	12	105	28	21	5	7	1	1	300
Percentages	20.7	19.4	3.7	35.1	9.4	7.0	1.7	2.3	0.3	0.3	100

Many of the households had limited living space and some 40.1 % of houses consisted of only one or two rooms. Altogether there were 993 rooms and 1613 individuals. This means that on the average the room occupancy rate was 1.62 people per room. In table 4.2, the distinction is made in terms of location.

Table 4.2: No. of rooms per household (by location)

Location	1	2	3	4	5	6	7	8	9	10	Total
Mlakalaka	6	7	6	9	7	4	1				40
Needs Camp	12	25	2	1							40
Ilitha	6	6	1	34	7	5		1			60
Mdantsane	2			20	2	4		2			30
Zwelitsha	36	20	3	41	12	8	4	4	1	1	130
Totals	62	58	12	105	28	21	5	7	1	1	300

In the elite and improved township type of houses there were no homes with less than four rooms whereas as many as 105 of the temporary structures and backyard houses had only one or two rooms. Table 4.3 shows this disparity.

Table 4.3: No. of rooms per household (by house type)

House Type	No. of rooms										
	1	2	3	4	5	6	7	8	9	10	Total
Elite House				2	4	5	3	4	1	1	20
Improved Township				13	14	11	1	3			42
Typical Township	1	2	2	70		1					76
Elite Village			1	1	3	1					6
Typical Village	1	2	1	6	3	2	1				16
Humble Village	4	5	4	1	1	1					16
Temporary Struct.	32	34	2	2							70
Backyard House	24	15	2	10	3						54
Totals	62	58	12	105	28	21	5	7	1	1	300

4.2 Backyard Houses

In all these communities shortage of housing makes it necessary for people to erect extra dwellings, usually at the back of the main house. Out of the total number of houses sampled in 130 (48.3%) cases these 'backyard' dwellings were occupied by tenants who paid rent to the owner of the plot and in other cases they provided extra accommodation to the household members. The percentage of sampled plots with backyard houses was 80% in Mlakalaka, 30% in Needs Camp, 42% in Ilitha, 30% in Mdantsane and 40% in Zwelitsha. Extrapolating these figures to the total community gives the situation as depicted in table 4.4. It can be seen that there are few of these backyard dwellings at Needs Camp. One reason for this is that the community came into being only recently. There were also relatively few of these in Mdantsane, due to stricter enforcement of municipal regulations.

Table 4.4: No. of backyard houses (by location)

Location	Households with backyard houses		Households without backyard houses		Total no. of plots in the community
	%	No.	%	No.	
Mlakalaka	80	265	20	66	311
Needs Camp	30	631	70	1 471	2 102
Ilitha	42	446	58	615	1 061
Mdantsane	30	8 103	70	18 908	27 011
Zwelitsha	40	1 458	60	2 188	3 646

As shown in table 4.5 the only type of house that seldom had a backyard house was the elite type of house.

Table 4.5: No. of backyard houses (by house type)

House Type	Households with backyard houses		Households without backyard houses		Total no. of survey cases
	%	No. of cases	%	No. of cases	
Elite	10	2	90	18	20
Improved Township	60	25	40	17	42
Typical Township	45	34	55	42	76
Elite Village	33	2	67	4	6
Typical Village	56	9	44	7	16
Humble Village	63	10	37	6	16
Squatter	-	-	100	70	70

In those residential plots which have occupied backyard houses in the yard, the number of such dwellings can be high in some cases, as shown in table 4.6.

Table 4.6: No. of backyard dwellings per plot

No. of backyard dwellings	1	2	3	4	5	Total
No. of households	56	34	17	9	14	130

In 23 households (7.7% of the total) there were four or five extra dwellings erected on the plots occupied by the household owners. The large number of backyard houses has important implications for this study, in terms of increased population density, and therefore increased pressure on sanitation and refuse removal facilities, poor hygiene, and so on.

5. AVAILABLE FACILITIES

In order to assess the general standard of living of the people, information relating to motor vehicles and electricity was solicited.

5.1 Motor Vehicles

The respondents were asked whether they possessed a motor vehicle or not. In 46 (15.3%) households the people said they did. Of these, 37 households owned one vehicle, 8 households owned two and in one household which ran a taxi business there were six vehicles. Table 5.1 extrapolates these findings to the whole community.

Table 5.1: Ownership of vehicles (by location)

Location	Households with motor vehicles		Households without motor vehicles		Total no. of plots in the community
	%	No.	%	No.	
Mlakalaka	7	22	93	289	311
Needs Camp	5	105	95	1 997	2 102
Ilitha	18	191	82	870	1 061
Mdantsane	20	5 402	80	21 609	27 011
Zwelitsha	18	656	82	2 990	3 646

A large proportion of these motor vehicles belonged to the homes with better means.

5.2 Electricity

The question of availability of electricity is relevant because electricity is an alternative to fuels such as wood and coal (see below) and because it is an indication of quality of life. There were 107 (35.9% of the total) households which had electricity. At Mlakalaka and Needs Camp there was no electricity. This situation is extrapolated to the different communities in table 5.2.

Table 5.2: Availability of electricity (by location)

Location	Households with electricity		Households without electricity		Total no. of plots in the community
	%	No.	%	No.	
Mlakalaka	-	-	100	311	311
Needs Camp	-	-	100	2 102	2 102
Ilitha	57	605	43	456	1 061
Mdantsane	67	18 097	33	8 914	27 011
Zwelitsha	41	1 495	59	2 151	3 646

Those who did not have electricity were asked whether they would like to have it and pay for it. It has already been noted that in 107 households electricity was available. Of the remaining 193 cases, 130 (43.3% of the total) indicated that they would like to have it. Extrapolating these findings to the larger population table 5.3 indicates that the greatest need for electricity is in Mlakalaka.

Table 5.3: Desire for electricity (by location)

Location	Total no. of households desiring electricity		Total no. of households not desiring electricity		Total no. of plots in the community
	%	No.	%	No.	
Mlakalaka	80	249	20	62	311
Needs Camp	30	631	70	1 471	2 102
Ilitha	42	446	58	615	1 061
Mdantsane	30	8 103	70	18 908	27 011
Zwelitsha	40	1 458	60	2 188	3 646

Table 5.3 indicates that the majority of the people who do not have electricity would like to have it. There were 107 of the surveyed households which had electricity and of the remaining 193 cases, 130 noted that they would like to have it. So there were only 63 households (21% of the sample) where the people had no desire for electricity, largely because they could not afford it. Of the 130 respondents who would be prepared to pay for electricity table 5.4 shows the amounts that they would be prepared to pay per month.

Table 5.4: Amounts that people would pay for electricity

No. of Cases	Percentage	Amount per month
28	21.5	R20,00
12	9.2	R30,00
36	27.6	R40,00
28	21.5	R50,00
9	6.9	R60,00
4	3.0	R70,00
5	3.8	R80,00
3	2.3	R90,00
5	3.8	R100,00

6. INFORMAL ECONOMIC ACTIVITIES AND THE USE OF THE YARD

Informal economic activities were investigated because some of them contain components or waste products which produce phosphates. Likewise, the purpose for which the people used their yards had to be taken into account since some of the people used fertilizers and/or compost in their gardens and lawns.

6.1 Informal economic activities

Household members were asked whether there were any informal economic activities which they pursued, e.g. buying and selling goods, producing goods for sale, running a taxi or shebeen, etc. Just above a quarter (26.6%) of the households reported that they participate in informal economic activities. Of those who did, the following were the types of activities in which they were involved:

Table 6.1: Informal economic activities

No. of Cases	Percentage	Economic activity
38	47.5	Selling food or groceries
14	17.5	Selling liquor
12	15.0	Selling clothing
4	5.0	Selling paraffin
3	3.8	Doing carpentry
2	2.5	Running a taxi
2	2.5	Building
2	2.5	Backyard mechanic
3	3.8	Other

Commonly, these informal economic activities were done by the household members themselves. It was only in 5 (1.7%) cases in the sample where there were people who were employed on the premises of the respondents. Of these, three households employed one person, another household employed three people and the last one employed four people. The respondents were asked to indicate the number of hours the employees spent on the premises because this has an effect on the sanitation facilities which are used by the people. In four households the employees lived on the premises and did not leave even though they were not the members of these households. In one case they spent ten hours on the premises.

6.2 Use of the Yard

The purposes for which people used their yards are illustrated in table 6.2.

Table 6.2: Use of the yard

No. of Cases	Percentages	Purpose for which the yard is used
115	38	Gardening, trees and/or lawn
96	32	Nothing is done with the yard
89	30	Gardening

7. LIVESTOCK

Out of the total number of households sampled during this survey, respondents in 150 cases (50%) said that they keep livestock and/or domestic animals such as dogs and cats. The respondents who answered positively kept a total of 87 cattle, 90 goats, 73 pigs, 790 chickens, 10 donkeys, 149 dogs and 33 cats. Tables 6.1 and 6.2 show their distribution by location.

Table 7.1: Total number of livestock kept (by location)

Location	No. of Livestock						
	Cattle	Goats	Pigs	Chickens	Donkeys	Dogs	Cats
Mlakalaka	65	50	38	320	8	34	19
Needs Camp	15	30	35	260	-	14	4
Ilitha	7	10	-	60	-	25	5
Mdantsane	-	-	-	40	-	9	-
Zwelitsha	-	-	-	110	2	67	5
Totals	87	90	73	790	10	149	33

Table 7.2: Total number of livestock kept (by house type)

House Type	No. of Livestock						
	Cattle	Goats	Pigs	Chickens	Donkeys	Dogs	Cats
Elite	-	-	-	-	-	7	-
Improved Township	4	-	-	60	-	33	-
Typical Township	-	10	-	100	-	43	9
Elite Village	16	-	14	40	-	7	-
Typical Village	21	20	15	90	8	11	2
Humble Village	28	30	9	150	-	15	17
Temporary Structure	16	30	35	260	2	20	4
Backyard House	2	-	-	90	-	13	1
Totals	87	90	73	790	10	149	33

None of the households surveyed in Mdantsane and Zwelitsha reared cattle. People who kept cattle lived in Mlakalaka, Needs Camp and, to a lesser extent, Ilitha. The same trend applied to the rearing of goats. Most of the people who reared poultry lived at Mlakalaka and Needs Camp. The animals that were reared were fed in various ways. Cattle, goats and donkeys depended entirely on grazing. Chickens were fed mostly on maize and, to a limited extent, on food remains and factory-made chicken feed. Cats and dogs usually got left over food and in a few cases bought pet food. Pigs were given maize, maize meal, factory-made pig meal and vegetables when they were available.

Table 7.3 shows the average number of each type of livestock per household in the survey sample.

Table 7.3: Average number of livestock per household

	Cattle	Goats	Pigs	Chickens	Donkeys	Dogs	Cats
No. of Livestock	87	90	73	790	10	149	33
Average per Household	0.29	0.30	0.24	2.63	0.03	0.49	0.11

8. SANITATION FACILITIES

The type of sanitation facilities used by people influences the distribution of nutrients in the environment. Poor sanitation facilities can lead to greatest nutrient load as well as providing health risks. This survey was designed to gather information regarding the relative utilisation of water-borne toilets, pit latrines and bucket toilets and of chamber pots, the latter particularly at night. Problems with sanitation facilities which were perceived by local people were also identified.

8.1 Toilet Facilities:

Responses relating to the use of toilets show that 169 (56.3%) households used waterborne toilets, 84 (28%) households used pit latrines, 19 (6.3%) households used bucket toilets and 28 (9.4%) had no toilets at all.

Table 8.1 (a) illustrates the situation by location.

Table 8.1 (a): Sanitation facilities (by location)

Localities	Pit	Bucket	Flush Toilet	No Sanitation	Totals
	Cases	Cases	Cases	Cases	
Mlakalaka	39	0	0	1	40
Needs Camp	40	0	0	0	40
Ilitha	1	19	39	1	60
Mdantsane	0	0	30	0	30
Zwelitsha	4	0	100	26	130
Total	84	19	169	28	300

Based on these figures, the situation for the communities as a whole is shown in 7.1 (b).

Table 8.1 (b): Sanitation facilities (by location)

Location	Pit		Bucket		Flush Toilet		No sanitation		Total no. of plots in the community
	No.	%	No.	%	No.	%	No.	%	
Mlakalaka	303	97	-	-	-	-	8	3	311
Needs Camp	2 102	100	-	-	-	-	-	-	2 102
Ilitha	18	2	336	31	689	65	18	2	1 061
Mdantsane	-	-	-	-	27 011	100	-	-	27 011
Zwelitsha	112	3	-	-	2 805	77	729	20	3 646
Total	2 535	7.4	336	1.0	30 505	89	755	2.2	34 131

Table 8.2: Sanitation facilities (by house type)

House Type	Pit		Bucket		Flush Toilet		No sanitation		Total no. of survey cases
	No.	%	No.	%	No.	%	No.	%	
Elite	-	-	-	-	20	100	-	-	20
Improved Township	-	-	1	2	40	96	1	2	42
Typical Township	1	1	-	-	75	99	-	-	76
Elite Village	6	100	-	-	-	-	-	-	6
Typical Village	16	100	-	-	-	-	-	-	16
Humble Village	16	100	-	-	-	-	-	-	16
Squatter	44	63	-	-	-	-	26	37	70
Backyard	1	2	18	34	62	1	2	2	54
Totals	84	-	19	-	169	-	28	-	300

In the 169 households using water-borne toilets there were 84 cases where the toilet was inside the house. In 76 cases it was outside the house and in 9 cases there were two toilets, one inside and another one outside the house. Those who had no toilets were asked to specify what they used. Of the 28 cases 18 said they went to the bush or used the veld, in 6 cases they used their neighbours' toilets, in 2 cases (in a squatter area) they used toilets in the township and in 2 other cases (also in a squatter area) they used toilets at a cemetery which is close by. In response to the question "Are there any times when people do not use toilets?" the answer was 'yes' in 54 households. The occasions when people did not use toilets are indicated in table 8.3.

Table 8.3: Occasions when a toilet is not used:

No. of Households	Occasions when toilet is not used
16	All the time
14	When children are young
10	When one cannot find a toilet
7	When the bucket is full
3	When it is hot because the toilet stinks
2	During parties
2	Other

The people were also asked to indicate what they did on those occasions when they were unable to use their toilets. In most cases they used the veld (36 cases). In other cases they said they used their neighbours' toilets (11 cases, or solved problems such as full buckets by emptying the contents of the full buckets in the backyard or by using a spare bucket (4 cases). Full pits were sometimes solved by digging another pit (3 cases).

In the 272 households which had toilets the people were asked to indicate whether they had ever had a problem with their toilets or not. In 84 cases (30.8% of the total number of households), the people said they had problems with their toilets. The problems they encountered are illustrated below:

Table 8.4: Problems related to toilets

No. of Households	Problems
37	The toilet does not flush at times
12	The bucket leaks at times
11	The buckets become full because they are not emptied regularly
11	The pit latrine overflows when it rains
6	The toilet stinks or it smells. The buckets are left in the street for many hours
5	The toilet is too close to the house
2	The toilet is always full because there are many of us

Those who had problems with their toilets tried to solve these in various ways, although many felt that there was nothing that they could do about it, as shown in table 8.5.

Table 8.5: Measures taken to correct toilet problems

No. of Households	Measures taken to correct toilet problems
19	There is nothing we can do or there is nothing we have done
18	We call someone to attend to the toilet or we attend to it
16	We report it to the local authority
10	We report it to the Works Department and we pay
8	We dig a hole and empty the bucket or we dig another pit
6	We use the neighbour's toilet
3	Nothing, we use the bush
3	We pay someone to empty the bucket
1	We throw ash into the pit latrine to prevent smell

8.2 Use of a chamber pot

The use of a chamber pot at night was investigated. In 107 (35.7%) households a chamber was not used at night. Those who used a chamber at night (193 cases) disposed of the contents in the following ways:

Table 8.6: Disposal of chamber contents

No. of Households	Disposal methods
60	Throw contents on the ground or near the toilet
77	Place contents in the flush toilet
45	Place contents in the pit latrine
8	Place contents in the bucket toilet
2	Place contents in the neighbour's toilet
1	Throw contents into a street drain

9. WATER

9.1 Availability of Water:

The availability and usage of water constitutes an important part of the study because it enables us to determine the amount of water the people use. The amount of nutrients which are borne by the water system and the extent to which nutrients are transferred to the river are also affected by water availability. The households in the sample obtained water from four sources: 113 (37.7%) from communal taps located away from the properties, 90 (30%) from the taps on the property outside the house, 71 (23.6%) from taps in the house and also outside the house on the property and 26 (8.7%) from taps in the yard but not in the house. Table 9.1(a) below shows that all the people at Mlakalaka and Needs Camp obtained their water from communal taps.

Table 9.1 (a): Source of water (by location)

Location	Taps in the house	Taps outside the house, on the yard	Communal Taps	Taps inside and outside on the property	Total
Mlakalaka	-	-	40	-	40
Needs Camp	-	-	40	-	40
Ilitha	5	27	1	27	60
Mdantsane	11	8	-	11	30
Zwelitsha	10	55	32	33	130
Total	26	90	113	71	300

Table 9.1 (b) extrapolates these figures to the whole community.

Table 9.1 (b): Source of water (by location)

Location	Taps in the house		Taps outside the house		Communal taps		Taps inside and outside the property		Total no. of plots in community
	No.	%	No.	%	%	No.	%	No.	
Mlakalaka	-	-	-	-	311	100	-	-	311
Needs Camp	-	-	-	-	2 102	100	-	-	2 102
Ilitha	84	8	478	45	21	2	478	45	1 061
Mdantsane	9 994	37	7 023	26	-	-	9 994	37	27 011
Zwelitsha	292	8	1 568	43	875	24	911	25	3 646

The relationship between source of water and house type is shown in table 9.2.

Table 9.2: Source of water (by house type)

House Type	Taps in the house		Taps outside the house, in the yard		Communal taps		Taps inside and outside in the yard	
	No.	%	No.	%	No.	%	No.	%
Elite	7	35	-	-	-	-	13	65
Improved Township	9	22	8	19	3	7	22	52
Typical Township	8	11	33	43	-	-	35	46
Elite Village	-	-	-	-	6	100	-	-
Typical Village	-	-	-	-	16	100	-	-
Humble Village	-	-	-	-	16	100	-	-
Temporary Structure	-	-	-	-	70	100	-	-
Backyard	2	4	49	90	2	4	1	2
Totals	26	8.7	90	30	113	37.7	71	23.6

The table shows that the wealthier households have taps either in the house or in the house and also outside in the yard. Many of those with humble houses used communal taps. Of the 300 in the sample, only 156 (52%) households paid for water. The range in the amounts paid was as follows:

Table 9.3: Amounts paid for water

Amount per month	R1 - R10	R11 - R20	R21 - R30	R31 - R40
No. of Cases	93	40	18	5

The respondents were asked whether they would be prepared to spend money to improve their water supply. Primarily, this question was a means of soliciting the views of people who live in places where the provision of water is poor, e.g. the village of Mlakalaka. In 38 (12.7%) instances the people said they would be prepared to spend money in order to get better water supplies. The various amounts they would be prepared to pay per month are shown below in table 9.4.

Table 9.4: Amounts people would pay for water

Amount per month	R1 - R5	R5 - R10	R11 - R15	R16 - R20
No. of Cases	19 (50%)	11 (28%)	4 (11%)	4 (11%)

Table 9.5 shows that very few people were prepared to pay for water at Mdantsane, Ilitha and Needs Camp. Those who lived at Needs Camp did not know whether they would stay where they were longterm. At Mlakalaka nearly a quarter of the people interviewed were prepared to spend money to improve their water supply. The 23 households at Zwelitsha in which the people would spend money for better water provision included mostly those people who live in the squatter camp. On the basis of those in the sample who would be prepared to pay for water, one can extrapolate to the population as a whole as in table 9.5.

Table 9.5: Households prepared to spend money on better water provision

Location	Those who would pay		N/A		Total Plots
	%	No.	%	No.	
Mlakalaka	22.5	70	77.5	241	311
Needs Camp	5	105	95	1 997	2 102
Ilitha	5	53	95	1 008	1 061
Mdantsane	3	810	97	26 201	27 011
Zwelitsha	18	656	82	2 990	3 646

9 .2 Water Usage

The usage of water was investigated since it affects the way in which nutrients are distributed, with some flowing into the water system and others remaining on the ground and ending up in the river. All the households normally do their washing at home. It can be seen that more than three-quarters of the sample households used between 100 to 150 litres of water per household per day, as shown in table 9.6.

Table 9.6: Amount of water used per day (by household)

	No. of Litres										
	20	30	40	50	100	150	200	250	300	350	Total
No. of cases	4	7	9	28	180	53	13	2	2	2	300
Percentages	1.3	2.3	3.0	9.4	60.2	17.4	4.3	0.7	0.7	0.7	100.0

Tables 9.7 and 9.8 show the amount of water used per day by location and house type.

Table 9.7: Amount of water used per day (by location)

	No. of litres										
Location	20	30	40	50	100	150	200	250	300	350	Total
Mlakalaka	2.5	2.5	2.5	10.0	67.5	12.5	2.5	-	-	-	100.0
Needs Camp	-	2.5	5.0	10.0	70.0	12.5	-	-	-	-	100.0
Ilitha	3.3	-	1.7	5.0	68.3	21.7	-	-	-	-	100.0
Mdantsane	-	-	3.3	3.3	40.0	16.7	23.3	6.7	3.3	3.3	100.0
Zwelitsha	0.9	3.9	3.1	12.4	55.8	18.6	3.9	-	0.8	0.8	100.0
Total	1.3	2.3	3.0	9.4	60.2	17.4	4.3	0.7	0.7	0.7	100.0

Table 9.8: Percentages of the amount of water used per day (by house type)

House Type	No. of Litres										
	20	30	40	50	100	150	200	250	300	350	Total
Elite	-	-	-	-	40.0	15.0	20.0	5.0	10.0	10.0	100.0
Improved Township	-	-	-	-	58.5	29.3	2.4	-	-	-	100.0
Typical Township	-	-	-	-	61.8	21.1	9.2	1.3	-	-	100.0
Elite Village	-	-	-	-	66.7	33.3	-	-	-	-	100.0
Typical Village	-	-	-	12.5	68.8	12.5	6.3	-	-	-	100.0
Humble Village	-	-	6.3	12.5	68.8	6.3	-	-	-	-	100.0
Temporary Structure	1.4	5.7	4.3	11.4	65.7	11.4	-	-	-	-	100.0
Backyard House	3.7	5.6	5.6	16.7	53.7	14.8	-	-	-	-	100.0
Total	1.3	2.3	3.0	9.4	60.2	17.4	4.3	0.7	0.7	0.7	100.0

Clearly, households with higher incomes use much more water per day. This is because they use taps whereas those with smaller incomes must fetch their water from communal taps which are sometimes located at a good distance from the homes. People dispose of their waste water in the manner indicated in table 9.9. In many cases they gave more than one response to the question: "How do you dispose of waste water?" (e.g. sometimes bath water went on to the ground, and sometimes into the drain).

Table 9.9: Waste water disposal

Place	Bath Water		Water used for washing clothing		Other water used in the household	
	No.	%	No.	%	No.	%
Street	1	0.3	1	0.3	1	0.3
Ground	183	61	165	55	183	61
Drain	149	49.6	154	51.3	149	49.6
Sewerage	2	0.6	5	1.6	2	0.6

These data indicate that in most cases water was thrown on the ground and contributed significantly to the accumulation of nutrients on the ground. In many other cases the waste water was thrown into the drains and was absorbed by the drainage system.

The study also solicited information about how the people used the Buffalo River and how they perceived it. Only 18 (6%) households used the river in one way or another. The people used the river for swimming and for domestic water when taps were not in working order. In response to the question 'What is your perception of the quality of the water of the Buffalo River?' 104 (34.6%) people had no opinion about the river or there was not much they could say about it. One reason for this is the fact that, with the exception of Zwelitsha residents, people live far away from the river. Some of them did not even know that they were drinking water from this river. Of those who expressed an opinion about the quality of the water of the river 166 (55.3%) said the water is polluted or dirty, 14 (4.6%) said the water is clean, 9 (3%) said the water is not good for human consumption 4 (1.3%) said the water has poisonous chemicals from the factories and 3 (1%) said the water is not dirty because the river is flowing.

10. HOUSEHOLD DETERGENTS

Information regarding the use of household detergents was very relevant to this study because these detergents have a high phosphate output. Since our sample was highly stratified, it was not surprising that the amounts of household detergents used by the people varied a great deal. This reflected the variation in household income (as suggested by the house type) and the different sizes of the households. The situation was as follows:

Table 10.1: Weekly use of soap powder

No. of grams	No. of cases	Percentage of cases	Total mass per week in grams
25 g	5	1.66	125
50 g	2	0.66	100
100 g	7	2.33	700
150 g	29	9.66	4 350
200 g	9	3.0	1 800
250 g	77	25.66	19 250
300 g	6	2.0	1 800
350 g	0	0	0
400 g	0	0	0
450 g	0	0	0
500 g	135	45.0	67 500
750 g	2	0.66	1 500
1 kg	25	8.33	25 000
$1^1/_2$ kg	3	1.0	4 500
TOTAL	300	100	126 625

This is equivalent to an average usage of 422 grams per household per week. Tables 10.2 and 10.3 give the analysis by location and house type.

Table 10.2: Amount of soap powder used per week (by location)

Location	Mass in Grams													
	25	50	100	150	200	250	300	400	450	500	750	1 000	1 500	Total
Mlakalaka	1	-	3	1	4	7	-	-	-	19	-	4	1	40
Needs Camp	1	-	1	6	1	8	1	-	-	18	-	4	-	40
Ilitha	-	-	-	9	2	16	-	-	-	33	-	-	-	60
Mdantsane	1	-	-	-	1	10	2	-	-	13	1	2	-	30
Zwelitsha	2	-	3	13	2	36	4	-	-	52	1	15	2	130
Total	5	-	7	29	10	77	7	-	-	135	2	25	3	300

Table 10.3: Amount of soap powder used per week (by house type)

House Type	Amounts in Grams													
	25	50	100	150	200	250	300	400	450	500	750	1 000	1 500	Total
Elite					2	1	2			10	1	3	1	20
Improved Township				3		8				24		6	1	42
Typical Township	3		1	4	3	25	1			31	1	6		76
Elite Village					1	1				2		1	1	6
Typical Village	1				2	2				10		1		16
Humble Village			2	1	1	3				7		2		16
Squatter	1		2	10	1	20	2			30		4		70
Backyard			2	11		17	1			21		2		54
Total	5		7	29	10	77	7			135	2	25	3	300

Table 10.3 shows that the more humble households such as those of people living in shacks used less powdered soap than those in higher income households. Only 14 out of 62 households (22.5%) which were identified as the elite or improved township type used up to 250 grams of powdered soap, whereas 71 out of 140 households (50.7%) which were of the humble village type, squatter of backyard type used up to 250 grams of soap. The use of cake soap is illustrated in table 10.4.

Table 10.4: Weekly use of cake soap

No. of grams	No. of cases	Percentage of cases	Total mass used per week in grams
125	29	9.66	3 625
250	59	19.66	14 750
375	28	9.33	10 500
500	5	1.66	2 500
562	5	1.66	2 810
625	71	23.66	44 375
750	43	14.3	32 250
1 125	25	8.33	28 125
1 250	24	8.0	30 000
1 375	8	2.66	11 000
1 500	3	1.0	4 500
Total	300	100.0	184 435

On average a household used 614.8 grams of cake soap per week. The majority of the households (163 or 54.3% of the total number of households) used between 625 and 1 250 grams of cake soap per week. Tables 10.5 and 10.6 provide information about the usage of cake soap.

Table 10.5: Weekly use of cake soap (by location)

	Mass in Grams											
Location	125	250	375	500	562	625	750	1 125	1 250	1 375	1 500	Total
Mlakalaka	6	12	3	2	-	6	2	3	4	2	-	40
Needs Camp	4	11	4	-	-	7	6	4	2	2	-	40
Uitha	5	12	4	1	1	17	11	6	2	-	1	60
Mdantsane	4	6	5	1	2	1	3	4	3	-	1	30
Zwelitsha	10	18	12	1	2	40	21	8	13	4	1	130
Total	29	59	28	5	5	71	43	25	24	8	3	300

Table 10.6: Weekly use of cake soap (by house type)

House Type	Mass in grams											
	125	250	375	500	562	625	750	1 125	1 250	1 375	1 500	Total
Elite	-	1	1	1	1	3	4	3	4	1	-	20
Improved Township	2	9	8	1	2	5	7	3	4	-	1	42
Typical Township	9	15	11	1	1	13	9	8	6	1	1	76
Elite Village	1	2	-	-	-	1	-	-	1	1	-	6
Typical Village	3	7	-	1	-	2	1	1	1	-	-	16
Humble Village	1	3	3	1	-	2	1	2	2	1	-	16
Squatter	7	14	4	-	-	20	13	6	4	2	-	70
Backyard	6	6	1	-	1	25	8	2	2	2	1	54
Totals	29	59	28	5	5	71	43	25	24	8	3	300

11. USE OF FERTILISER, COMPOST AND COW DUNG

Since fertiliser, compost and cow dung contain varying amounts of phosphates, people were asked to indicate their use of these items. Of those who did some form of gardening 65 (21.7% of the total) said they used compost and/or fertiliser. The amounts they used per season (i.e. half yearly, spring and summer) are shown in table 11.1.

Table 11.1: Use of compost and/or fertiliser

No. of Kg (per season)	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	Total
No. of Households	20	16	7	8	5	3	0	3	2	1	65

In 73 (24.3%) households the people used cow dung. In 71 of these cases the dung was used for smearing floors and in two cases for smearing floors and as fuel. The dung makes the earth floors firm and prevents the accumulation of dust. In places where wood was in short supply people collected dung from the veld and used it as fuel. However, dung was scarce and would constitute only about 5% of the total fuel used. It was used mostly at Mlakalaka, Needs Camp and in the squatter camp in Zwelitsha as shown in table 11.2.

Table 11.2: Use of cow dung (by location)

Location	Using cow dung			Not using cow dung			Total plots in the community
	No. in sample	%	No. in community	No. in sample	%	No. in community	
Mlakalaka	20	50	155	20	50	156	311
Needs Camp	39	97.5	2 049	1	2.5	53	2 102
Ilitha	2	3.3	35	58	96.7	1 026	1 061
Mdantsane	-	-	-	30	100	27 011	27 011
Zwelitsha		9.2	335	118	90.8	3 311	3 646
Totals	73	24.3	2 574	227	75.7	31 557	34 131

The majority of those who used cow dung occupied typical and humble village houses and temporary structures in the shack area of Zwelitsha as illustrated in table 11.3

Table 11.3: Use of cow dung (by house type)

House Type	Using cow dung		Not using cow dung		Total in sample
	No. in sample	% in sample	No. in sample	% in sample	
Elite	-	-	-	-	20
Improved Township	1	2.3	41	97.7	42
Typical Township	1	1.3	75	98.7	76
Elite Village	-	-	-	-	6
Typical Village	8	50	8	50	16
Humble Village	11	68.7	5	31.3	16
Squatter	48	68.5	22	31.5	70
Backyard	4	7.5	50	92.5	54
Total	73	24.3	227	75.7	300

12. HOUSEHOLD REFUSE, FOOD AND VEGETABLE WASTE

Other nutrient contributions which potentially contaminate the river are derived from household refuse and from food and vegetable waste. Table 12.1 shows the amounts of refuse people accumulated per week.

Table 12.1: Refuse produced per household per week

No. of kg	1	2	3	4	5	6	7	8	9	10	Total
No. of cases	18	30	65	68	36	41	16	17	7	2	300

Tables 12.2 and 12.3 provide this information by location and house type.

Table 12.2: Refuse produced per household per week (by location)

	No. of Kg										
Location	1	2	3	4	5	6	7	8	9	10	Total
Mlakalaka	7	5	16	8	2	-	-	2	-	-	40
Needs Camp	3	5	22	9	-	-	-	1	-	-	40
Ilitha	1	6	12	20	5	12	3	1	-	-	60
Mdantsane	-	6	1	5	5	5	5	2	-	1	30
Zwelitsha	7	8	14	26	24	24	8	11	7	1	130
Total	18	30	65	68	36	41	16	17	7	2	300

Table 12.3: Refuse produced per household per week (by house type)

	No. of Kg										
House Type	1	2	3	4	5	6	7	8	9	10	Total
Elite	2	-	-	2	5	5	4	1	-	1	20
Improved Town	-	-	2	5	13	15	3	3	1	-	42
Typical Towns	2	8	8	20	8	13	8	5	3	1	76
Elite Village	1	1	3	1	-	-	-	-	-	-	6
Typical Village	3	3	5	2	1	-	-	2	-	-	16
Humble Village	3	1	7	4	1	-	-	-	-	-	16
Temporary Str	6	11	31	13	-	3	-	4	2	-	70
Backyard	1	6	9	21	8	5	1	2	1	-	54
Total	18	30	65	68	36	41	16	17	7	2	300

Rubbish disposal was a problem in all the communities which were surveyed. Only 45 households (15% of the total) noted that they were fully dependent on the use of a refuse removal service. The remaining 255 households (85% of the total) had to find other means of removing their refuse. In as many as 178 cases (59.2% of the total) people took their rubbish to any dumping site they could find. In a further 77 cases (25.7% of the total) the rubbish was dumped outside the yard and some of it was burnt. In the sample there were 188 households (62.6%) of the total which had a refuse removal service but only 45 of these agreed that it was adequate. The refuse was removed at the following frequencies for those households with a refuse removal service:

Table 12.4: Frequency of refuse removal

Periods	Twice Weekly	Weekly	Fortnightly	Monthly	Once in 3 months	Total
No. of cases	5	131	28	28	1	188

In the sample 146 (48.6%) cases had a problem with refuse removal in that it was not removed regularly. People tried to solve this problem in the following ways:

Table 12.5: Action taken to remove refuse

	No. of cases	Percentage	Action taken
	91	62	Burn or bury the refuse
	18	13	Store the refuse in plastic bags
	18	13	There is nothing I can do
	17	11	Dump the refuse outside the yard on open spaces or dumping grounds
	2	1	Report to the administration office
Total	146	100	

The amount of food and vegetable waste produced per week is reflected below.

Table 12.6: Weekly amount of food and vegetable waste

No. of Kg	1	2	3	4	5	6	7	8	9	10	Total
No. of cases	186	42	29	25	17	-	-	-	-	1	300
Percentages	62.0	14.0	9.7	8.3	5.7	-	-	-	-	0.3	100
Total Kg	186	84	87	100	85	-	-	-	-	10	552

This shows that on average a household had 1.84 kg of food and vegetable waste per week. The people disposed of food and vegetable waste as detailed in table 12.7.

Table 12.7: Disposal of food and vegetable waste

	No. of cases	Percentage	Waste disposal method
	126	42	Feed animals, e.g. dogs, pigs, cats
	95	32	Throw it into the rubbish bin
	75	25	Place it in the garden or backyard
	4	1	Use it as compost
Total	300	100	

The questionnaire included the question: "Would you like to have a refuse removal service?" In 191 cases out of the sample this question was not applicable in that the people had a refuse removal service. Out of 109 remaining cases there were 47 people who said they would like to have such a service. Table 12.8(a) shows that it was the Mlakalaka residents who needed this service most.

Table 12.8(a): Desire for a refuse removal service (by location - numbers of houses visited)

Location	No. of cases desiring service	No. of cases not desiring service	Total in sample
Mlakalaka	26	14	40
Needs Camp	3	37	40
Ilitha	-	30	30
Mdantsane	-	30	30
Zwelitsha	18	112	130
Total	47	253	300

Table 12.8(b): Desire for a refuse removal service (by location - total number of houses per location)

Location	Cases desiring service		Cases not desiring service		Total plots in community
	%	No.	%	No.	
Mlakalaka	65	202	35	109	311
Needs Camp	7.5	158	92.5	1 944	2 102
Ilitha	-	-	100	1 061	1 061
Mdantsane	-	-	100	27 011	27 011
Zwelitsha	14	510	86	3 136	3 646

Table 12.9 shows the amounts people were prepared to pay for a garbage removal service.

Table 12.9: Amounts that people would pay for refuse removal

No. of cases	Percentage	Amount per month
39	83	R5
7	14.5	R10
1	2,5	R20

The majority (83%) of these respondents were prepared to pay R5,00 per month for an effective rubbish (garbage) removal service, while the remaining 17% of these respondents were prepared to pay between R10 (14.5%) and R20 (2.5%) per month for such a service.

13. FUEL

It was necessary to investigate fuel since items such as coal and wood contain nutrients. Coal and wood ash are disposed of by throwing them into the ground, thus these nutrients may find their way into the water supply. Well over 80% of these households used paraffin and the amounts that were used are shown below.

13.1 Paraffin

Table 13.1: Weekly use of paraffin oil

Winter

Litres	1-2	3-4	5-6	7-8	9-10	11-12	13-18	19-25	Total
No. of cases	26	45	88	23	54	15	6	9	266
Percentages	9.8	16.9	33.1	8.6	20.3	5.6	2.3	3.4	100

Summer

Litres	0	1-2	3-4	5-6	7-8	9-10	11-12	13-18	19-25	Total
No. of cases	3	62	72	71	23	23	3	5	4	263
Percentages	0	23.6	27.4	27.0	8.7	8.7	1.1	1.9	1.5	100

The less affluent households used more paraffin compared to those with higher incomes because many of the latter used electricity. Similarly, in the sample all the households at Mlakalaka and Needs Camp used paraffin since these communities did not have electricity. This is illustrated in tables 12.2, 12.3, 12.4 and 12.5.

Table 13.2: Use of paraffin in winter (by location)

Location	1-2	3-4	5-6	7-8	9-10	11-12	13-18	19-25	Total
Mlakalaka	2	3	17	6	6	4	-	2	40
Needs Camp	7	10	10	4	5	4	-	-	40
Ilitha	3	11	27	-	7	3	1	-	52
Mdantsane	5	3	6	1	7	-	-	-	22
Zwelitsha	9	18	28	12	29	4	5	7	112
Total	26	45	88	23	54	15	6	9	266

Table 13.3: Use of paraffin in winter (by house type)

House Type	No. of Litres								
	1-2	3-4	5-6	7-8	9-10	11-12	13-18	19-25	Total
Elite	7	3	2	-	2	1	-	-	15
Improved Township	3	5	8	-	6	1	2	2	27
Typical Township	4	12	23	4	15	2	2	3	65
Elite Village	1	-	2	1	1	1	-	-	6
Typical Village	1	2	5	2	4	1	-	1	16
Humble Village	-	1	9	3	-	2	-	1	16
Temporary	7	14	19	10	14	4	-	2	70
Backyard	3	8	20	3	12	3	2	-	51
Total	26	45	88	23	54	15	6	9	266

Table 13.4: Use of paraffin in summer (by location)

Location	No. of Litres									
	0	1-2	3-4	5-6	7-8	9-10	11-12	13-18	19-25	Total
Mlakalaka	0	5	13	13	5	2	-	1	1	40
Needs Camp	0	12	10	13	3	2	-	-	-	40
Ilitha	0	12	20	11	2	5	1	-	-	51
Mdantsane	3	7	6	6	1	1	-	-	-	24
Zwelitsha	0	26	23	28	12	13	2	4	3	111
Total	3	62	72	71	23	23	3	5	4	266

Table 13.5: Use of paraffin in summer (by house type)

House type	No. of Litres									
	0	1-2	3-4	5-6	7-8	9-10	11-12	13-18	19-25	Total
Elite	0	10	4	-	-	-	-	-	-	14
Improved Township	0	10	5	-	4	3	2	-	-	26
Typical Township	3	9	23	19	2	7	1	2	1	67
Elite Village	0	1	1	4	-	-	-	-	-	6
Typical Village	0	2	7	3	2	1	-	-	1	16
Humble Village	0	2	7	3	2	1	-	1	-	16
Temporary	0	15	16	25	8	4	-	2	-	70
Backyard	0	13	11	15	5	7	-	-	-	51
Total	3	62	72	71	23	23	3	5	4	266

13.2 Electricity

In the sample 106 households (35.3% of the total) used electricity. Both electricity and paraffin were used in some of the households. The amounts that people paid per month for their electricity are shown in tables 13.6, 13.7, 13.8 and 13.9.

Table 13.6: Monthly cost of electricity in winter

Amounts in Rand	1-10	11-20	21-30	31-40	41-60	61-100	101-140	141-200	201-250	Total
No. of cases	2	15	17	29	13	6	5	13	6	106
Percentages	19.1	14.2	16.0	27.4	12.3	5.7	4.7	12.3	5.7	100

Table 13.7: Monthly cost of electricity in summer

Amounts in Rands	1-10	11-20	21-30	31-40	41-60	61-100	101-140	141-200	201-250	Total
No. of cases	3	32	22	9	13	6	7	12	2	106
Percentages	2.8	30.2	20.8	8.5	12.3	5.7	6.6	11.3	1.9	100

Table 13.8: Cost of electricity in winter (by location)

Amounts in Rands	1-10	11-20	21-30	31-40	41-60	61-100	101-140	141-200	201-250	Total
Mlakalaka	-	-	-	-	-	-	-	-	-	-
Needs Camp	-	-	-	-	-	-	-	-	-	-
Ilitha	1	11	8	8	3	2	-	-	-	33
Mdantsane	-	1	3	6	2	1	2	3	2	20
Zwelitsha	1	3	6	15	8	3	3	10	4	53
Total	2	15	17	29	13	6	5	13	6	106

Table 13.9: Cost of electricity in winter (by house type)

Amounts in Rands	1-10	11-20	21-30	31-40	41-60	61-100	101-140	141-200	201-250	Total
Elite	-	-	3	6	1	2	1	5	2	20
Improved Township	-	6	2	13	4	-	-	5	3	33
Typical Township	2	8	8	8	7	4	2	2	-	42
Elite	-	-	-	-	-	-	-	-	-	-
Typical Village	-	-	-	-	-	-	-	-	-	-
Humble Village	-	-	-	-	-	-	-	-	-	-
Temporary	-	-	-	-	-	-	-	-	-	-
Backyard	-	1	4	2	1	-	2	1	-	11
Total	2	15	17	29	13	6	5	13	6	106

13.3 Wood

There were 89 (29.6%) households using wood as fuel in winter and in summer. The amounts used are shown in table 13.10.

Table 13.10: Weekly use of wood in winter

Amounts in kg	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	Total
No. of cases	7	8	25	1	-	22	-	1	25	89
Percentages	7.9	9.0	28.1	1.1	-	24.7	-	1.1	28.1	100

Table 13.11: Weekly use of wood in summer

Amounts in kg	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	Total
No. of cases	8	15	32	1	2	14	1	3	13	89
Percentages	9.0	16.9	36.0	1.1	2.2	15.7	1.1	3.4	14.6	100

Wood was used mostly by people who live at Needs Camp and Mlakalaka as shown in table 13.12.

Table 13.12: Use of wood in winter (by location)

	No. of Kg									
Location	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	Total
Mlakalaka	-	6	7	-	-	6	-	-	4	23
Needs Camp	2	-	6	1	-	9	0	1	19	38
Ilitha	-	1	2	-	-	-	-	-	-	3
Mdantsane	2	-	2	-	-	-	-	-	-	4
Zwelitsha	3	1	8	-	-	7	-	-	2	21
Total	7	8	25	1	-	22	-	1	25	89

Table 13.13: Use of wood in winter (by house type)

	No. of Kg									
House Type	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	Total
Elite	1	-	-	-	-	-	-	-	-	1
Improved Township	2	-	2	-	-	1	-	-	-	5
Typical Township	-	1	5	-	-	1	-	-	-	7
Elite Village	-	1	-	-	-	-	-	-	-	1
Typical Village	-	1	3	-	-	2	-	-	1	7
Humble Village	-	3	4	-	-	4	-	-	2	13
Temporary	4	1	11	1	-	14	-	1	20	52
Backyard	-	1	-	-	-	-	-	-	2	3
Total	7	8	25	1	-	22	-	1	25	89

Most of the people who used wood were those in squatter or resettlement areas.

13.4 Gas

Unlike many urban areas in the Transvaal where coal is relatively cheap, usage of coal in the study area was negligible. Only 2 households (0.6% of the total) used coal in winter and summer, one household using one kilogram per week and another two kilograms per week.

Gas was used only by a small proportion of the homes. Forty eight households (16% of the total) and 47 (15.6% of the total) used it in winter and summer respectively, as illustrated below.

Table 13.14: Weekly use of gas in winter

No. of Kg	1	2	3	4	5	6	7	8	9	Total
No. of cases	5	12	13	9	2	2	3	1	1	48
Percentages	10.5	25.0	27.1	18.7	4.2	4.2	6.3	2.1	2.1	100

Table 13.15: Weekly use of gas in summer

No. of Kg	1	2	3	4	5	6	7	8	9	Total
No. of cases	7	17	11	5	5	-	-	-	-	47
Percentages	19.1	36.2	23.4	10.6	10.6	-	-	-	-	100

Table 13.16: Weekly use of gas in winter (by location)

Location	No. of Kg									
	1	2	3	4	5	6	7	8	9	Total
Mlakalaka	-	1	2	1	-	2	1	1	-	8
Needs Camp	-	-	-	-	-	-	-	-	-	-
Ilitha	-	5	4	-	-	-	1	-	-	10
Mdantsane	3	1	-	2	-	-	-	-	-	6
Zwelitsha	2	5	7	6	2	-	1	-	1	24
Total	5	12	13	9	2	2	3	1	1	48

Table 13.17: Use of gas in winter (by house type)

House Type	No. of Kg									
	1	2	3	4	5	6	7	8	9	Total
Elite	2	1	1	3	1	-	-	-	1	9
Improved Township	1	4	3	2	-	-	1	-	-	11
Typical Township	1	4	5	3	-	-	-	-	-	13
Elite Village	-	1	1	1	-	1	1	-	-	5
Typical Village	-	-	1	-	-	1	-	1	-	3
Humble Village	-	-	-	-	-	-	-	-	-	-
Temporary	1	1	-	-	-	-	1	-	-	3
Backyard	-	1	2	-	1	-	-	-	-	4
Total	5	12	13	9	2	2	3	1	1	48

13.5 Manure

Only 6 households (2% of the total) used manure as fuel. However, it seems that this constituted only a tiny proportion (maybe about 5%) of their total fuel use. All of these households were humble village households at Mlakalaka.

13.6 Disposal of ash

Since coal, wood and cow dung contain phosphates, it was necessary to establish the manner in which people disposed of the ash. Of the 97 cases of people who used these materials, 85 (28% of the total) said they placed the ash somewhere in the yard and in 12 other cases (4% of the total) they threw it into the rubbish bin. Tables 13.18 and 13.19 illustrate this by location and house type, with the sample survey results extrapolated to the entire population in table 13.18.

Table 13.18: Disposal of ash (by location)

Location	Yard		N/A		Rubbish Bin		N/A		Total no. of plots in community
	%	No.	%	No.	%	No.	%	No.	
Mlakalaka	62.5	194	37.5	117	-	-	-	-	311
Needs Camp	97.5	2 049	2.5	53	-	-	-	-	2 102
Ilitha	5.0	53	95.0	1 008	3.3	35	96.7	1 026	1 061
Mdantsane	0.7	189	99.3	26 822	2.3	621	97.7	26 390	27 011
Zwelitsha	12.3	448	87.7	3 198	5.4	197	96.6	3 449	3 646
Totals	28.3	2 933	71.7	31 198	4.0	853	96.0	30 865	34 131

Table 13.19: Disposal of ash (by house type)

House Type	Yard		N/A		Rubbish Bin		N/A		Total no. of survey cases
	%	No.	%	No.	%	No.	%	No.	
Elite	-	-	100	20	10	2	90	18	20
Improved Township	-	-	100	42	14.3	6	85.7	36	42
Typical Township	5.3	4	94.7	72	5.3	4	94.7	72	76
Elite Village	16.7	1	83.3	5	-	-	-	-	6
Typical Village	50	8	50	8	-	-	-	-	16
Humble Village	87.5	15	12.5	1	-	-	-	-	16
Temporary Structure	75.7	53	24.3	17	-	-	-	-	70
Backyard House	7.4	4	92.6	50	-	-	-	-	54
Totals	28.3	85	71.7	215	4.0	12	96.0	288	300

14. GENERAL DISCUSSION

Tha standard of living varied dramatically amongst household types in the different communities studied. At one end of the economic scale, people occupied relatively expensive 'elite' houses whilst at the lower end of the scale, people lived in basic shacks. This range of economic differentiation in the rural areas of the Ciskei has been recorded previously in the Keiskammahoek district (De Wet *et al*, 1992). Those people with the best standard of living in such areas tend to own land and to be educated whilst poorer people are often farm employees who own no land and have less schooling (Manona, 1988).

The available sanitation facilities differed amongst and within communities. Only 55% of the households surveyed had water-borne toilets. Problems were experienced with all other types of facilities from pit latrines to buckets (often with no reliable means of disposal) to a total lack of any facilities. Overcrowding exacerbated these problems, particularly amongst the squatters, the people who live at Needs Camp and those who lived in backyard dwellings. In the sample as a whole, 40% of the household members had only one or two rooms. Nearly half of the households thus had sanitation facilities which were clearly inadequate and which must impact significantly on the water quality of the neighbouring streams.

There were also problems with the availability of water. Water shortages were experienced by those living in rural areas such as Mlalaka and Needs Camp and squatters on the outskirts of Zwelitsha had to carry water long distances to their homes. Although we would argue that all people should have access to water, this may be logistically difficult in the Ciskei at this time. The provision of water to poorer people would probably increase the total water usage in communities within the Buffalo River catchment since people in more expensive houses where water was more readily available used larger volumes.

Refuse removal in the communities studied was either extremely inadequate or non-existent. This problem was most visible in the urban areas largely because of the high population density in those areas. In urban areas open spaces outside the yards were used as dumping sites and many of the larger spaces in these townships contained large heaps of litter. Apart from being a source of despair to residents, such sites present potential health hazards and in addition are potential sources of pollution for local streams and rivers.

Only 35% of the sample households utilised electricity as a source of fuel. Many people in rural areas where electricity was not available would prefer to better their circumstnces given the opportunity (McAllister *et al*, 1992), and in this study it was found that people in Mlakalaka wanted access to electricity and piped water. Improved access to electricity woud alter the nutrient impacts on the river from the uses of wood and dung as fuel, although this impact may not be very significant since the majority (> 80%) of the households in this study used paraffin as a source of fuel.

The standard of living of many of the people surveyed in this study was thus very low in terms of sanitation facilities, water availability, fuel provision and rubbish disposal. Social services problems appear to result from the economic, infrastructural and administrative poverty of the Ciskei. This poverty is most pronounced in rural areas where the standard of infrastructure is generally lowest and which receive minimal funding for development (Manona, 1985; De Wet & Bekker, 1985). Additional problems in such areas are the lack of land and the insecurity experienced by local people, who have little control over their environment, and hence the construction of temporary communities. For example, the people who live in Needs Camp have had to move several times in recent years. Most of them were victims of forced removals from farms in the Border area who decided to live in a closer settlement and eventually settled on an unoccupied farm which later became known as Needs Camp. Even now, these people have no assurance that they will be able to occupy this site permanently. Similarly, the people living in the squatter area of Zwelitsha do not know whether they can settle there permanently or rather will be moved to another place in the future. The insecurity imposed by landlessness thus exacerbates the poverty in the region and does not facilitate the development of improved conditions and provision of better services.

In conclusion, this demographic survey has described the living conditions of people in the communities in the Buffalo River catchment, and has highlighted some of the inadequacies of services, particularly sanitation facilities, water and fuel usage and rubbish disposal, which may impact upon the water quality in this catchment area.

15. SUMMARY

Survey Design

This demographic survey was based on a stratified sample of 300 households situated in the following urban and rural areas of the Buffalo River catchment:

Urban: Zwelitsha
Urban: Mdantsane
Urban: Ilitha
Rural: Needs Camp (a resettlement camp)
Rural: Mlakalaka

The infrastructure in the urban areas was slightly better than that in the rural areas and this, in turn, influenced the provision of social services to these communities. Needs Camp was a representative case of a resettlement camp and Mlakalaka was a typical Ciskei village. A squatter area in Zwelitsha was included in the survey. Since the households in these communities varied a great deal in terms of their total income, eight different types of households were identified for investigation.

Sanitation facilities

The type of sanitation facilities available to these communities varied significantly. In the sample 56.3% of the households used water-borne toilets, 28% used pit latrine, 6.3% used bucket toilets and 9.4% had no toilets at all. Most of those who had no toilets were people who reside in the squatter area. Many of those who used bucket toilets complained about the fact that the buckets were not emptied regularly. Sometimes people had to dig a hole and empty the contents of the bucket into the hole.

Water

The households which were surveyed obtained water from four sources: 37.7% from communal taps outside their properties, 30% from taps on the property outside the house, 23.6% from taps in the house and also outside the house and 8.7% from taps in the yard but not in the house. More than three-quarters of the households used between 100 and 150 litres of water per household per day. The wealthier households had taps either in the house or in the house and also outside the yard. All of the people living in the rural areas obtained their water from communal taps and some supplemented this with water from their tanks.

Rubbish Disposal

Rubbish disposal was a problem in all the communities which were studied. Only 15% of the households noted that they were fully dependent on the use of a refuse removal service. The others had to find means of removing their own refuse becasue rubbish was not removed regularly. Some took the rubbish to any dumping site they could find outside the yard and some of the rubbish was burnt or buried in the yard. Thirty-six percent of the households did not have access to a refuse removal service, mostly people living either in the rural areas or in the squatter areas. Forty-three percent of those who did not have this service said they would like to have it and would be prepared to pay for it.

Livestock

Fifty percent of the households keep livestock and/or domestic animals such as dogs and cats. Cattle and goats were kept mostly by people living in the rural areas. A small proportion of people reared pigs and chickens.

Fuel

Well over 80% of the households used paraffin. Those with less means used more paraffin compared to those with better means because many of the latter used electricity. Similarly, all the households in the rural areas used paraffin since they did not have electricity. In the sample 35% of the households used electricity. Wood was used in 29% of the households and gas in 15% of the households. The proportion of those who used coal was negligible.

Administrative constraints

The problems which were noted here with regard to the provision of sanitation facilities result mainly from the economic and administrative poverty of black residential areas and Ciskei in particular. These communities lack efficient administration and this directly affects the delivery of social services generally.

16. COMPARISON WITH OTHER STUDIES

In South Africa there were no studies of this nature which have been conducted previously apart from a pilot survey which was conducted by Grobler *et al* (1987) in the township of Botshabelo which is situated 50 kilometres east of Bloemfontein. This section begins with a brief comparison between the main findings of the present study and those of the Botshabelo survey. Botshabelo consisted of 16 residential units or sections which included:

(a) An 'elite' section where people used a water-borne sewerage system.

(b) A section which was served by a system of bucket latrines.

(c) Another section in which people used pit latrines.

In the Botshabelo study the households which were sampled were chosen from 11 residential sections and, as in the present study, all available sanitation systems were covered. The Botshabelo survey included 102 households, about a third of the number which were interviewed in the present survey.

Housing pattern

As in the case of sanitation facilities, Botshabelo consisted of three distinct types of houses, namely, 'elite' houses, owner built houses and shacks or temporary structures. There are huge contrasts in the housing situation with regard to Botshabelo and the three urban communities which were included in the present study as illustrated in table 16.1.

Table 16.1 Housing comparison

Type of house	Botshabelo		Mdantsane, Zwelitsha and Ilitha	
	No. of houses	%	No. of houses	%
Elite houses	578	1.9	1 550	4.9
Owner-built houses	15 300	50.4	0	0
Township houses	0	0	29 998	94.6
Shacks or temporary houses	14 500	47.7	170	0.5
Total	30 378	100	31 718	100

Botshabelo was a sprawling squatter settlement which consisted of no less than 14 500 shacks constituting 47.7% of the total number of houses in the community. The present study included only 170 shacks amount to 0.5% of the total number of houses in the urban areas which were investigated. Similarly, in Botshabelo the elite houses constituted only 1.9% of the total number of houses there whereas a comparative figure for the present study was 4.9%. This shows that Botshabelo was much worse off than the urban areas included in the present survey at least in terms of housing. The owner-built houses at Botshabelo do seem to be similar to the township houses included in the present study because both types of houses are permanent structures.

Population estimates

As in the present survey, the researchers who completed the Botshabelo survey found that the population estimates of their study area varied widely. They based their own estimate on the total number of houses in the area which they multiplied by the average number of people per household. A similar approach was adopted in the present survey: the total number of households in each community was multiplied by the average number of people per households in each location. The Botshabelo survey used aerial photographs and this count included backyard dwellers in the population estimates.

Livestock

In Botshabelo 18.3% of the households in the sample kept livestock, usually a small number of chickens and in a few cases a single sheep or goat. This is not surprising since Botshabelo is an urban area. In the present study area which includes two rural areas 38% of the households in the sample kept varying numbers of cattle, goats, poultry, pigs and few donkeys. In the Botshabelo survey questions relating to household pets were removed after the first stage of the survey.

Sanitation

Compared with the three urban areas investigated during the present survey, sanitation facilities at Botshabelo were extremely poor, as shown in table 16.2.

Table 16.2: Sanitation facilities in selected areas

	Sanitation available			
	Pit	Bucket	Flush Toilet	No Sanitation
Location	%	%	%	%
Botshabelo	51	44.1	4.9	-
Mdantsane	-	-	100	-
Zwelitsha	3	-	77	20
Ilitha	2	31	65	2

In the urban areas selected for the present survey a relatively large proportion of residents had access to flush toilets, 100% in Mdantsane, 77% in Zwelitsha and 65% at Ilitha. Only 4.9% of residents of Botshabelo used flush toilets. Similarly, 51% of people in Botshabelo used pit latrines and 44.1% used bucket latrines. In the present survey bucket latrines were used in the urban areas only at Ilitha by 31% of the residents.

Refuse removal

As in the present study, the removal of refuse at Botshabelo was a serious problem. Because this service was irregular, people deposited their rubbish at street corners and open spaces which eventually became rubbish dumps. Some of these rubbish dumps were often only cleared of rubbish on a quarterly or half-yearly basis. Similar problems were encountered in the urban areas which were investigated and there was little effort made to remove the rubbish in these dumps.

16.2 The Silvertown case study

In July 1992 the Palmer Development Group reported the results of its case study from the Silvertown area of Khayelitsha outside Cape Town. It had interviewed residents of 100 households to find out how people perceived the bucket latrine system which was used there. The results indicated widespread dislike of the system with the majority of people complaining of odour, the tendency for flies to breed in the area and poor service by the workers emptying the buckets. Silvertown was a transit area and the fact that buckets were shared by two households was a source of conflict between neighbours. However, the scope of this study was very limited. What must be stressed is the fact that as yet no comprehensive work has been done with regard to relatively poorly housed communities which are growing in size and the impact of this development on the environment. This survey is hopefully a contribution towards a better understanding of that problem.

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APPENDIX

Questionnaire used in this Study

Institute of Social and Economic Research

Rhodes University, Grahamstown

The aims of this research is to find out what happens to all the waste which is produced by this community. In addition, we are collecting information about important matters like sanitation and use of fuel. This research is undertaken independently by Rhodes University. it is a long-term undertaking which is not going to produce benefits to the community immediately. The information you supply will be confidential and we thank you for your cooperation.

1. Survey No.: ....
2. Interviewer: ....
3. Location: ....
4. Address: ....

   ....
5. Zone/Area: ....
6. Date: ....
7. Type of house occupied:

   1. "Purchase" or "Bond" type
   2. Improved township house
   3. Typical township house (no improvements)
   4. Elite village house (Mlakalaka)
   5. Typical village house (blocks/bricks)
   6. Humble village house (mud walls) Mlakalaka
   7. Temporary structure
   8. Backyard shack
   9. Other: ....

8. List all members of the household who usually sleep here every night.

First Names	M/F	Age	Occupation (scholar, housewife, employed, unemployed, self-employed, pre-school, pensioner, other)
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			

9. For those who are employed/self employed:

First Name	Place of Work	Time Leaving	Time Returning
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

10. List the members of this household who are away and do not sleep here every night.

First Name	M/F	Age	Occupation (scholar, housewife, employed, self-employed, pre-school, pensioner, other......)	Where are they	How often at home	How long at home each time
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

11. Is there any member or members of this household engaged in informal activity or activities (e.g. buying and selling goods, producing goods for sale, taxi, shebeen, etc)

    1. Yes
    2. No

12. If yes, what are these activities?

....

....

13. Are there any people employed in these activities on these premises?

    1. Yes
    2. No

14. If yes, how many people are employed? ....

15. How long do the people spend here? ....

HOUSING

16. How many rooms are there in this house? ....

17. Do you have electricity? ....

18. Are there any other occupied structures in this yard?

    1. Yes
    2. No

19. If yes, how many? ....

20. How many people live in each structure, including those who are temporarily absent?

	Number of Children	
	Adults	Children
Structure 1		
Structure 2		
Structure 3		
Structure 4		
Structure 5		

21. What do you use the yard for?

1. Gardening
2. Trees
3. Lawn
4. Other: ....

22. If you do gardening, do you use compost and/or fertiliser?

1. Yes
2. No

23. If yes, how much per season? ....

24. Do you have a motor vehicle or vehicles?

1. Yes
2. No

25. If yes, how many? ....

LIVESTOCK

26. Do you keep livestock, what type do you keep?

Type	Number	Animal Feed
Cattle		
Sheep		
Goats		
Poultry		
Pigs		
Mules/Donkeys		
Dogs		
Other		

28. Do you use dung?

  1. Yes
  2. No

29. If yes, for what purpose?

....

SANITATION:

30. What kind of toilet do you have?

  1. Pit Latrine
  2. Bucket system
  3. Waterborne toilet
  4. No sanitation system
  5. Other ....

31. Is the toilet inside or outside? ....

32. If you do not have a toilet, what do you use?

....

33. Are there any times when people do not use toilets?

1. Yes
2. No

34. If yes, on what occasions?

....

35. What do they do on those occasions?

....

36. If you use a chamber at night how do you dispose of the contents the next day?

....

37. Do you have any problems with your toilet?

1. Yes
2. No

38. If yes, what problems are you encountering?

....

....

39. What do you do when you have this sort of problem?

....

40. Where do you get your water?

1. Taps inside
2. Taps outside on the property
3. Communal taps
4. Stream or spring
5. Other ....

41. Do you pay for water?

1. Yes
2. No

42. If yes, how much do you pay?

....

43. Would you be prepared to spend money to improve your water supply?

1. Yes
2. No

44. If yes, how much per month? ....

45. Do you use the Buffalo River?

1. Yes
2. No

If yes, for what purpose?

....

....

46. How often do you use it? ....

47. What is your perception of the quality of the water from this river?

....

....

HOUSEHOLD DETERGENTS

48. What kind of soap do you use for washing clothing?

Type of Soap		Amount per week (kg)
Powdered Soap		
Cake Soap		

49. Where do you normally wash clothes?

1. At home
2. River
3. Other ....

50. How do you dispose of the waste water?

	Bath	Washing	Household
1. Street			
2. Ground			
3. Drain			
4. Sewer			
5. Other			

51. How much water does your home use per day?

.... litres

RUBBISH DISPOSAL

52. How much refuse do you have per week (on average) and how do you dispose of it?

Removal Service	Burning	Burying	Other

53. If you remove it yourself, where do you dump it?

....

54. If you have a refuse removal service, how often is the refuse removed?

....

55. Do you experience problems with refuse removal?

1. Yes
2. No

56. If yes, what problems?

....

57. If the refuse is not collected regularly, how often is it not collected?

....

58. What do you do to solve these problems?

....

....

59. How much food and vegetable waste do you have (kg per week)?

....

60. What do you do with it?

....

....

61. If you do not have a refuse removal service, would you like to have it?

1. Yes
2. No

62. Would you be willing to pay for it?

1. Yes
2. No

63. If yes, how much per month?

....

64. What fuel do you use and how much of it do you use per week?

Amounts used per week

Type of Fuel		Winter	Summer
Paraffin		lts	lts
Gas		kg	kg
Electricity		R's	R's
Wood		kg	kg
Coal		kg	kg
Manure		bags	bags

65. If you use coal or wood or manure, where do you deposit the ash?

1. In a rubbish bin
2. Place it somewhere in the back yard

3. Other

....

66. If you do not have electricity, would you like to have it?

1. Yes
2. No

67. How much would you be prepared to pay for it per month if you do not have it?

....

APPENDIX G

HYDROLOGICAL MODELLING OF THE SUB-CATCHMENTS OF THE BUFFALO RIVER

by

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December 1992

CONTENTS

1. INTRODUCTION

This chapter describes the approaches used and the results obtained from simulating the hydrology of the Buffalo River system down to the point at which East London abstracts water below Bridle Drift Dam.

The section is divided up into sections which describe the system, outline the available data and its limitations, provide a brief summary of the methodology and summarise the results.

2. THE SYSTEM.

In broad terms the Buffalo River can be divided up into three major zones. Further details can be obtained from several chapters of Ninham Shand and Partners (1976) or Hart (1982).

i) The high rainfall and generally mountainous area in the northern part of the catchment. Some parts of this region, particularly the area above Rooikrans Dam, are covered with indigenous forest.

ii) The lower rainfall middle section of the catchment, down to Bridle Drift Dam and including the major urban centres of the area. Apart from the urban areas and villages, the land use is mixed agricultural with largely subsistence cultivation and a great deal of overgrazed land.

iii) The areas closer to the coast which receive somewhat higher coastal rainfalls and are covered with areas of coastal bush and forest. Most of this zone lies outside the region of interest.

Apart from simulating the historical and current situations with respect to the natural hydrology, it has also been necessary to take into account the influence of water usage by the major urban and industrial centres. The majority of this is derived from the four dams (Maden, Rooikrans, Laing and Bridle Drift) within the catchment, but some of the supply to Mdantsane is met by the Nahoon Dam, which is external. In brief terms the components of the water supply system are as follows :

i) Maden Dam supplies the King William's Town area (including some major local industrial users).

ii) Rooikrans Dam supplies the King William's Town area but also releases compensation flow to downstream riparian users.

iii) Laing Dam supplies the King William's Town area and Zwelitsha.

iv) Bridle Drift supplies both the Mdantsane area and East London.

v) Nahoon Dam supplies the Mdantsane area.

vi) There are several places where relatively small irrigation schemes abstract water directly from the Buffalo River or its tributaries.

Return flows from these supplies re-enter the system as follows :

i) Wastewater from the King William's Town area either re-enters the river at the King sewerage works or is diverted to several irrigation schemes.

ii) Wastewater from Zwelitsha re-enters the river below the town and above Laing Dam.

iii) Wastewater from the Mdantsane area either re-enters the system through several streams flowing directly into Bridle Drift, or flows back into the river from the sewerage works below the Dam and the supply abstraction point.

iv) Wastewater from East London is not returned to the river and has no effect on the part of the catchment being modelled.

v) A certain proportion of the irrigation water is likely to drain back into the river.

In future a further component of the system will become important. This involves water imported from the Amotola Scheme to the north east of the catchment and transferred using the Yellowwoods River as a natural conduit. This water is intended to supply the Ciskei towns in the vicinity of King William's Town and the return flow from this supply will clearly have an effect on the hydrology and water quality of the Buffalo River system.

The Buffalo River catchment was divided into 38 sub-catchments, partly on the basis of the above components and partly related to the location of rainfall and streamflow monitoring sites. These sub-areas are shown in figure 1.

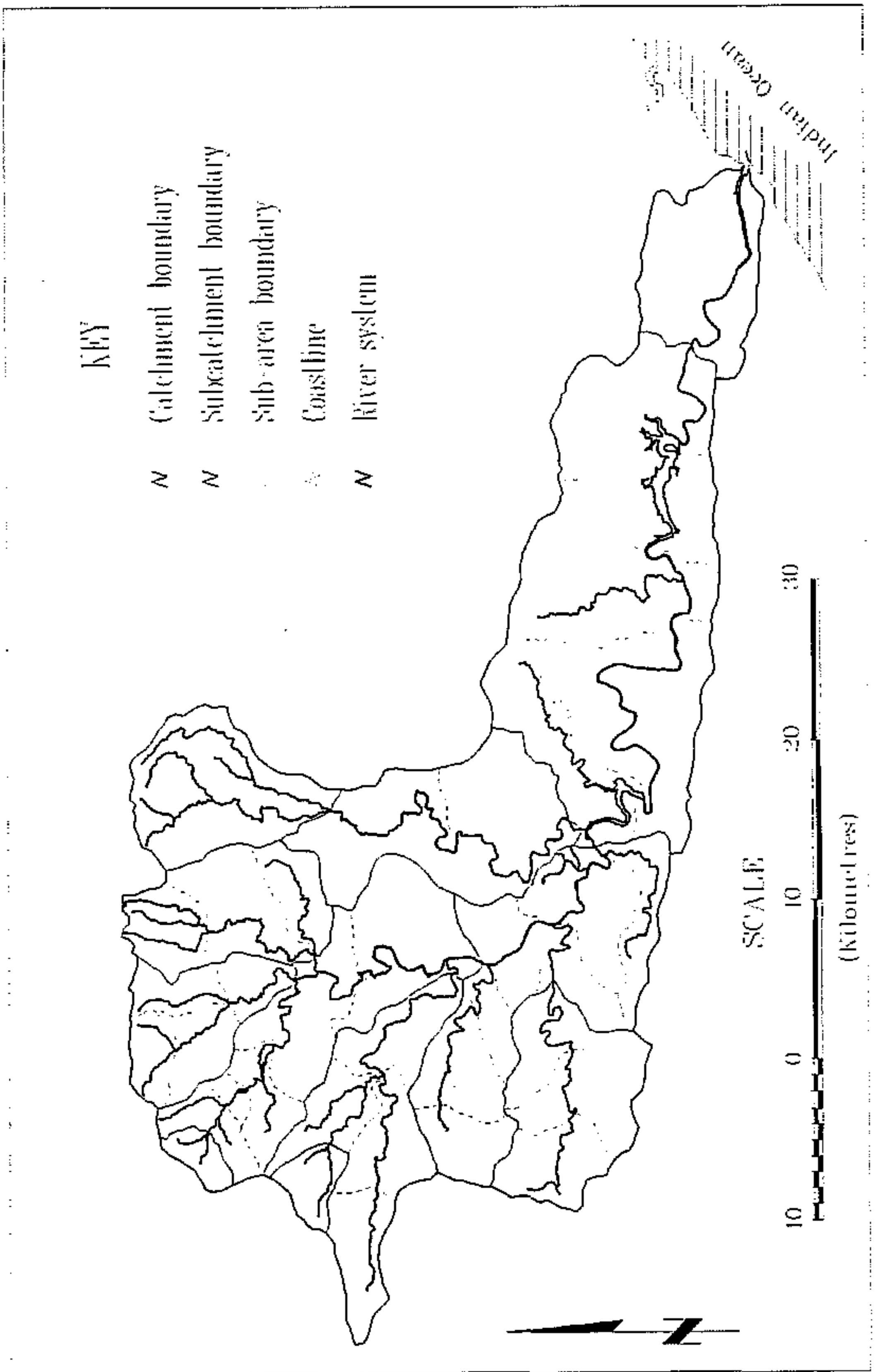

Figure 1. The Buffalo River catchment showing the 38 sub-catchment areas that were used in the hydrological modelling.

3. AVAILABLE DATA

The basic information required for a simulation of the hydrology (water quantity) of this system includes the following, all of which should be available in a distributed form (i.e. for the different zones of the whole area) :

i) Rainfall input to the system.

ii) Information on the atmospheric evaporation demand.

iii) Some streamflow data for model calibration or checking purposes.

iv) Some reservoir storage and abstraction data for model calibration or checking purposes.

v) Information on soils, their depth and hydrological characteristics.

vi) Information on land use, how it has varied over time and the extent to which the hydrology is likely to be affected.

vii) Information on the water usage by various consumers.

viii) Information on the amount of flow returned to the system from the various consumers.

The amount, quality and spatial distribution of the available information for these eight categories are discussed below, highlighting the constraints that the data might place on the type of modelling approach that can be realistically applied.

3.1 Rainfall data

Figure 2 indicates that there are over 20 Weather Bureau daily rainfall stations located within, or close to the boundary, of the Buffalo River catchment. However, figure 3 and table 1 indicate that many of these stations have only short lengths of record or do not have very long periods of overlapping record. Figure 3 also paints an overoptimistic picture as it does not indicate the periods of missing data within the main data period. These may occur as isolated groups of a few days, a few months, or in several cases periods in excess of a year. As the simulations of the downstream areas rely upon the output from the simulations

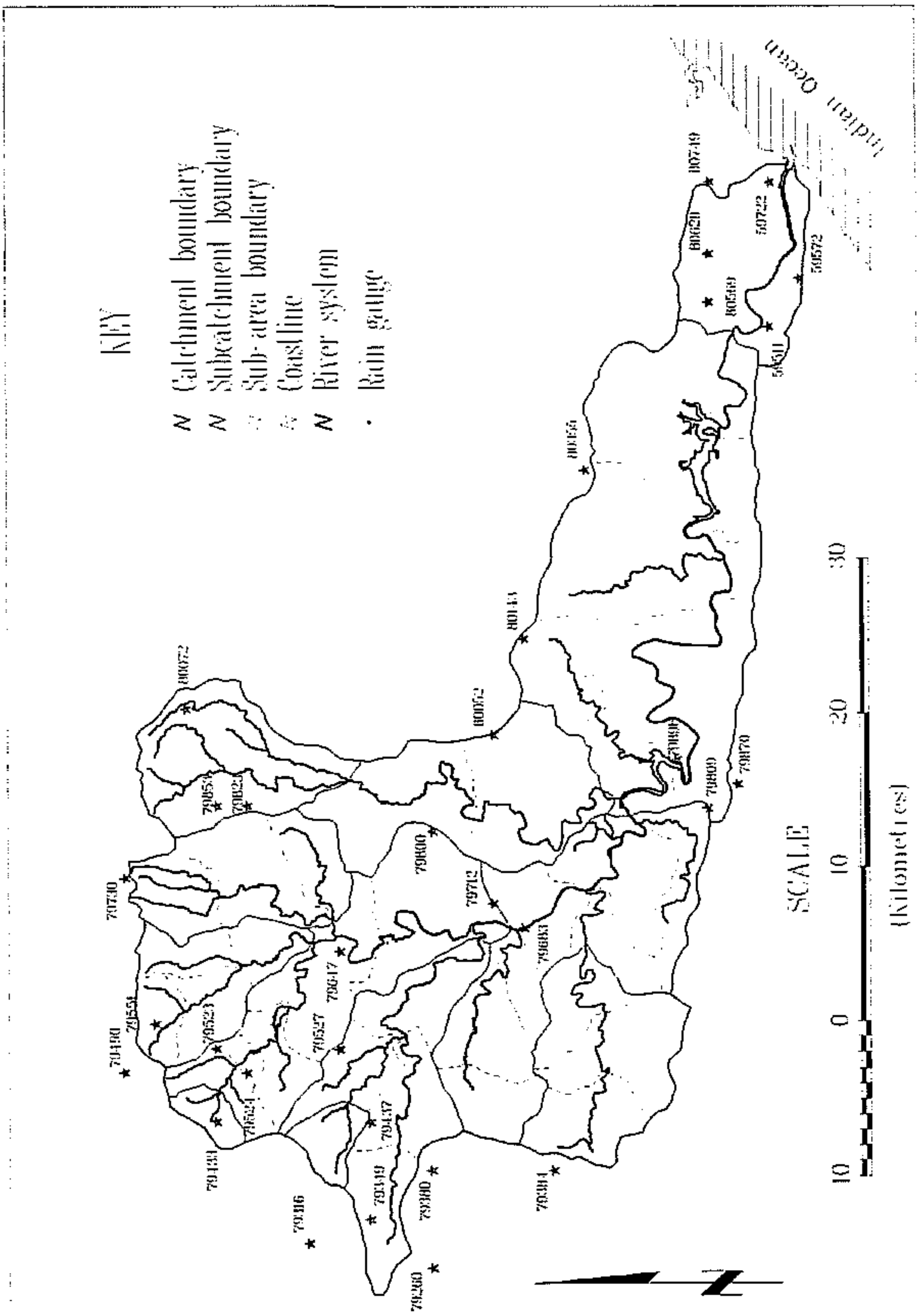

Figure 2. The rain gauge site in the Buffalo River catchment area.

of the upstream areas, it is essential that for the modelling period chosen the rainfall stations used have coincident records. Figures 2 and 3 and table 1 indicate that the main problem areas are the central and lower parts of the catchment, where there are only one or two gauges with records of sufficient length.

While the northern parts of the catchment are reasonably well covered, the rainfall gradient from the mountain areas toward the south and east is very steep. There is not a sufficient density of gauges to adequately represent this gradient. However, the Department of Agricultural Engineering at the University of Natal, Pietermaritzburg has generated median monthly rainfalls for each 1' * 1' of a degree grid for the whole of South Africa. These data are available from the Computing Centre for Water Research (CCWR) and can be used to provide weighting factors to assist with the generation of representative time series of areally averaged rainfall from sparse rain gauge data.

The CCWR also has a facility to provide longer periods of station rainfall data using a stochastic generating procedure (Zucchini *et al*, 1984). However, this approach is of no value to this study as it is based on a point stochastic method and ignores spatial interactions between individual gauges.

3.2 Evaporation data

There are two pan evaporation stations in the region, one at Rooikrans Dam and one close to East London. Alternatively, mean monthly pan evaporation values are available from several sources.

3.3 Streamflow data

There are 9 streamflow recording sites within the Buffalo River catchment (figure 2) and these are reasonably well distributed between the different headwater catchment areas, the major tributaries and the main Buffalo River itself. From a practical point of view the data are available from the Department of Water Affairs and Forestry as either mean daily flow rates or as monthly flow volumes. However, all the measuring structures are only designed to measure a limited range of flows and the available figures can grossly underestimate real volumes during high flow periods.

Table 1. List of rainfall gauging stations in the Buffalo River catchment.

No.	Station ID	Start Year	End Year
1	059/511	1968	1985
2	059/572	1940	1972
3	059/722	1960	1991
4	079/260	1912	1943
5	079/316	1914	1990
6	079/349	1924	1940
7	079/380	1900	1925
8	079/384	1949	1977
9	079/433	1986	1990
10	079/437	1921	1927
11	079/490	1900	1990
12	079/523	1964	1985
13	079/524	1948	1974
14	079/527	1900	1936
15	079/551	1930	1990
16	079/647	1949	1974
17	079/683	1900	1951
18	079/712	1969	1990
19	079/730	1909	1990
20	079/800	1985	1986
21	079/809	1900	1976
22	079/823	1916	1975
23	079/853	1919	1975
24	079/870	1949	1982
25	079/898	1959	1960
26	080/052	1904	1953
27	080/072	1900	1990
28	080/143	1900	1984
29	080/355	1968	1991
30	080/569	1920	1990
31	080/629	1918	1990
32	080/749	1931	1964

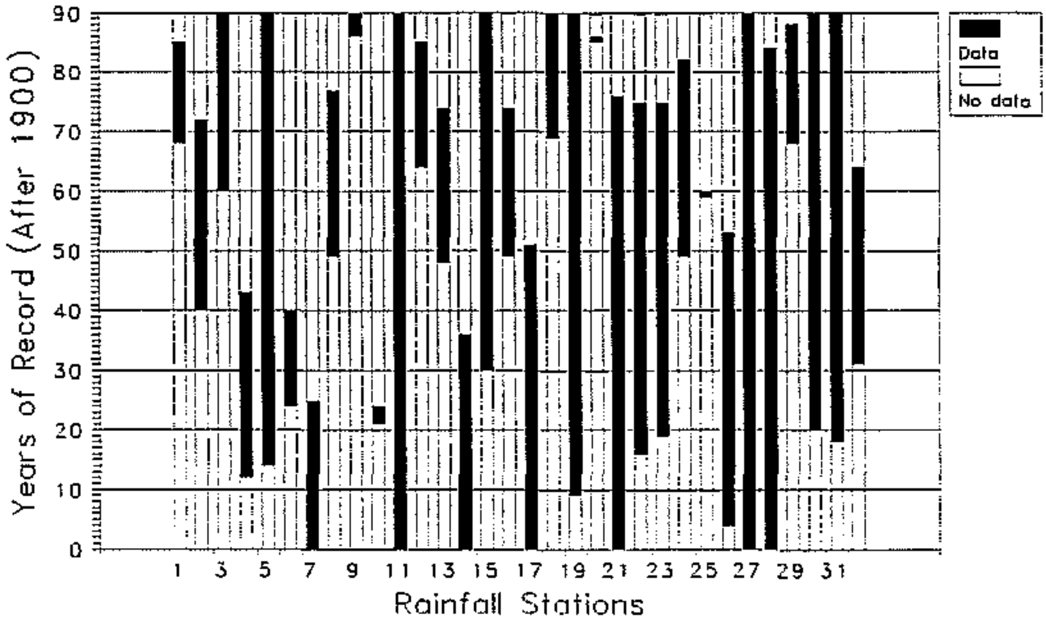

Figure 3 Length of record for rainfall gauging stations in the Buffalo River catchment (the X-axis labels refer to the numbers in column 1 of table 1)

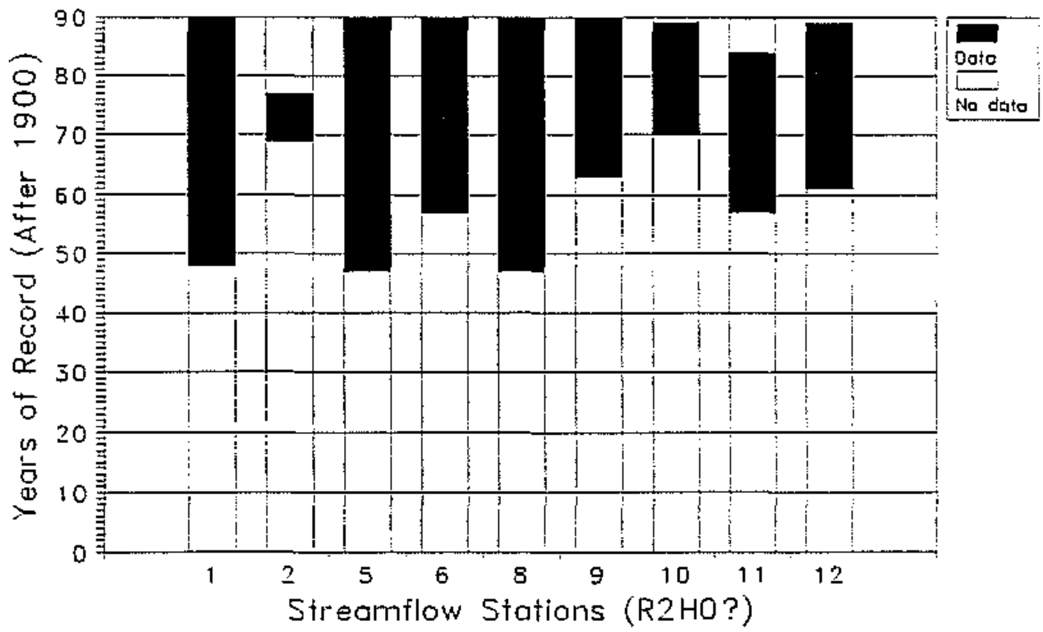

Figure 4 Length of record for flow gauging stations in the Buffalo River catchment.

In most cases the records are reasonably long (figure 2), but unfortunately they do not always correspond to the best period for modelling suggested by the available rainfall records.

3.4 Reservoir records

The Department of Water Affairs and Forestry has reasonable records for the volumes of storage, evaporation losses, abstraction, downstream releases and spillage for Rooikrans, Laing and Bridle Drift dams on a monthly basis. Figures for inflow volumes are also provided, but are based on water balance calculations from the other components. Any inaccuracies are therefore compounded and these figures cannot always be considered to be reliable. For example, the reservoir records for Laing Dam often indicate that the inflows are substantially less than the combined flow recorded at R2H010 (Buffalo) and R2H011 (Yellowwoods), the two major inflow streams.

The major values of the reservoir records are therefore to provide observed monthly time series of stored water volumes and to provide information on the current and historical patterns of abstractions and releases.

3.5 Soils Information

The most complete soils information for the various regions of South Africa is usually available from the Soils and Irrigation Research Institute (SIRI) of the Agricultural Research Council. However, due to the fact that the basic information is not yet available for Ciskei, the Buffalo River catchment area is not covered by the published data. There is therefore only very generalised information available on the soil characteristics of the region.

3.6 Land use

There is similarly very little specific information on land use, although the major variations are relatively simple to identify at the scale of the sub-catchments of the whole system. The north west mountainous areas are covered by forest and the downstream areas, close to East London, are covered by dense coastal bush and forest. Apart from the urban concentrations, the remainder of the area is occupied by a combination of grazing land and subsistence agriculture. There are a few areas of more intensive cultivation based on irrigation, but these are minor with respect to the overall patterns of land use.

3.7 Water consumption

The main users of water are the municipal areas of King William's Town, Zwelitsha, Mdantsane, Potsdam and East London. In addition, there are several major industrial consumers in the King William's Town area. In general terms, there is adequate information on the volumes of water supplied to these various users, as well as the source of the water. With several sources of supply and historically a relatively rapid expansion in water consumption, it is inevitable that the short and medium term variation in water usage is highly dynamic and somewhat difficult to represent in a simulation model.

Smaller scale users of water include direct abstractions from the rivers for irrigation purposes, as well as consumption from small farm or community dams. There is very little information on this type of water usage and including its impact on the hydrology of the system as a whole has been based on little more than an educated guess using interpretation of topographic maps and some limited field observations.

3.8 Return flows from water consumers

The major return flows are from the sewerage works of the large urban areas. Information for the King William's Town and Zwelitsha areas appears to be reasonably reliable and complete. However, the same can not be said about the Mdantsane urban area. Theoretically, most of the return flow should emerge at the sewerage works outflow below Bridle Drift Dam. However, there seems to be a great deal of doubt about what proportion of the wastewater bypasses the sewerage reticulation system and returns to the system directly into Bridle Drift Dam via the streams flowing into the dam. This problem has serious implications with respect to coupling the water quantity and quality simulations.

4. BASIC METHODOLOGY

Given the quantity and quality of the available data, it was decided that a monthly time-step modelling approach would be the most appropriate and that the most suitable model to use would be the widely known Pitman model. All the basic information required to set the model up for the different parts of the region is available. In addition, initial estimates of the model parameter values are available from the relevant volume of the Water Resources of South Africa (Middleton, *et al*, 1981).

To simulate the conditions in the major dams of the system, a version of the RESSIM simulation program developed at the Institute for Water Research, Rhodes University (Hughes, 1992) has been used. Both of these models are contained within an integrated software package that allows several different types of model to be operated within the same environment.

The total Buffalo River catchment has been divided up into 38 relatively homogeneous sub-catchments on the basis of the available information on land use and climate characteristics as well as the position of the streamflow gauging stations and the location of the major abstraction or return flow points. The distribution of these sub-areas is illustrated in figure 1, while table 2 provides some further information.

The initial simulation exercise involved a progessive calibration of Pitman's rainfall-runoff model, starting in the upstream areas and gradually working down to the outlet at R2H002. Part of this process also involved simulating the historical conditions in the major reservoirs. The starting point for paramater value estimation was always the regional values specified in Middleton *et al* (1981). As the calibration exercise progressed downstream, more and more sub-areas became involved where observed data were not available for calibration purposes. In these cases the parameter values were transferred from similar sub-areas already calibrated, but accounting for any major differences in land use or water consumption. This calibration exercise was based on 10 years of data from 1964 to 1973.
Once an acceptable parameter set was derived for all the sub-areas a common period of 46 years (1930 to 1975) was used to simulate a typical flow regime that may be considered applicable to the current day situation. This means that any parameters of the rainfall-runoff and reservoir water balance models that relate to water consumption, or other historically dynamic conditions, were fixed to reflect present day situations. Thus, the simulated time-series of flow may be considered representative, but cannot be compared with historical flow records.

Table 2. Sub-areas identified for simulation purposes.

Sub-area ID	Outlet Point.	Description.
Rooi 1		
Rooi 2	Gauge R2H001	
Rooi 3	Maden Dam	
Rooi 4	Rooikrans Dam	
R2M8 1		Cwengcwe R.
R2M8 2		Cwengcwe R.
R2M8 3		Cwengcwe R.
R2M8 4	Gauge R2H008	Cwengcwe R.
R2M6 1	Gauge R2H012	Mgqakwebe R.
R2M6 2		Mgqakwebe R.
R2M6 3		Mgqakwebe R.
R2M6 4		Mgqakwebe R.
R2M6 5	Gauge R2H006	Mgqakwebe R.
R2M9 1		Ntsikizini R.
R2M9 2		Ntsikizini R.
R2M9 3	Gauge R2H009	Ntsikizini R.
R2M9 4		Ntsikizini R.
R2M5 1		Iseleni R.
R2M5 2		Iseleni R.
R2M5 3		Iseleni R.
R2M5 4		Inflows from Iseleni, Rooikrans and Cwengcwe.
R2M5 5	Gauge R2H005	Upstream of KWT
R2M10 1		Tshoxa R.
R2M10 2		Tshoxa R.
R2M10 3		Tshoxa R.
R2M10 4		Inflows from R2H005 & includes KWT.
R2M10 5	Gauge R2H010	Buffalo R. flow to Laing Dam, includes Zwelitsha
R2M10 6		Mkangiso R.
R2M11 1		Yellowwoods R.
R2M11 2		Yellowwoods R.
R2M11 2	Gauge R2H011	Yellowwoods R. flow to Laing Dam
Berlin 1		Upstream area south of Berlin
Berlin 2		Trib. flow to Laing Dam
Bridle 1		Downstream of Laing Dam
Bridle 2	Bridle Drift Dam	Buffalo R. flow to Bridle Drift Dam
Bridle 3		N. inflow to Bridle Drift Dam, includes Mdantsane
Bridle 4		S. inflow to Bridle Drift Dam
R2M2 1	Gauge R2H002	Outlet of whole system

5. SIMULATION RESULTS

5.1 Calibration

Two main problems are associated with calibration against the available data set. The first is that all the high flows are under-represented by the observed data, making it difficult to determine whether the models are generating acceptable mean monthly or annual runoff values. The second is that the relative paucity of useful raingauge records, particularly in the central parts of the catchment, suggest that it is not always possible to be confident that a representative time series of rainfall is being provided as input.

As the final simulated time-series are to be used in association with water quality data to determine loads, it was essential that an emphasis be placed on simulating low flow conditions with a reasonable degree of confidence. This is not a straightforward problem to solve when the model is not really designed for this purpose and there is very little information on the minor water users. These may have only a small influence on medium to high flows, but can significantly affect low flows. Nevertheless, given these constraints, the calibration exercise attempted to concentrate on the low flow conditions.

Figures 5 to 8 illustrate the calibrated values of the four major runoff producing parameters of the rainfall-runoff model (Pitman, 1973). It can be seen that the major differences are in the western headwater areas where the land use and topography are very different to elsewhere in the catchment.

Table 3 lists some of the statistics for the calibration results. Some of the discrepencies between observed and simulated flows can be ascribed to the inadequacy of the flow measuring structures to measure high flows, while others are certainly related to the relatively poor representation of the true spatial patterns of rainfall. It should, however, be stressed that a monthly time step model, which does not take into account the time distribution of rainfall within the month, can rarely be expected to accurately reproduce sequences of observed runoff volumes. Given the above constraints, the calibrated parameter values would appear to be suitable for generating representative sequences of monthly flow volumes for the Buffalo River catchment.

No results are given for R2H002, situated below Bridle Drift Dam, largely because there is very little overlap between the calibration period and the observed data. The situation is further complicated by the fact that both Laing Dam and Bridle Drift Dam simulations impact on the results at R2H002. Setting up the calibration simulations for the two dams was difficult because of the highly dynamic patterns of demand during the period.

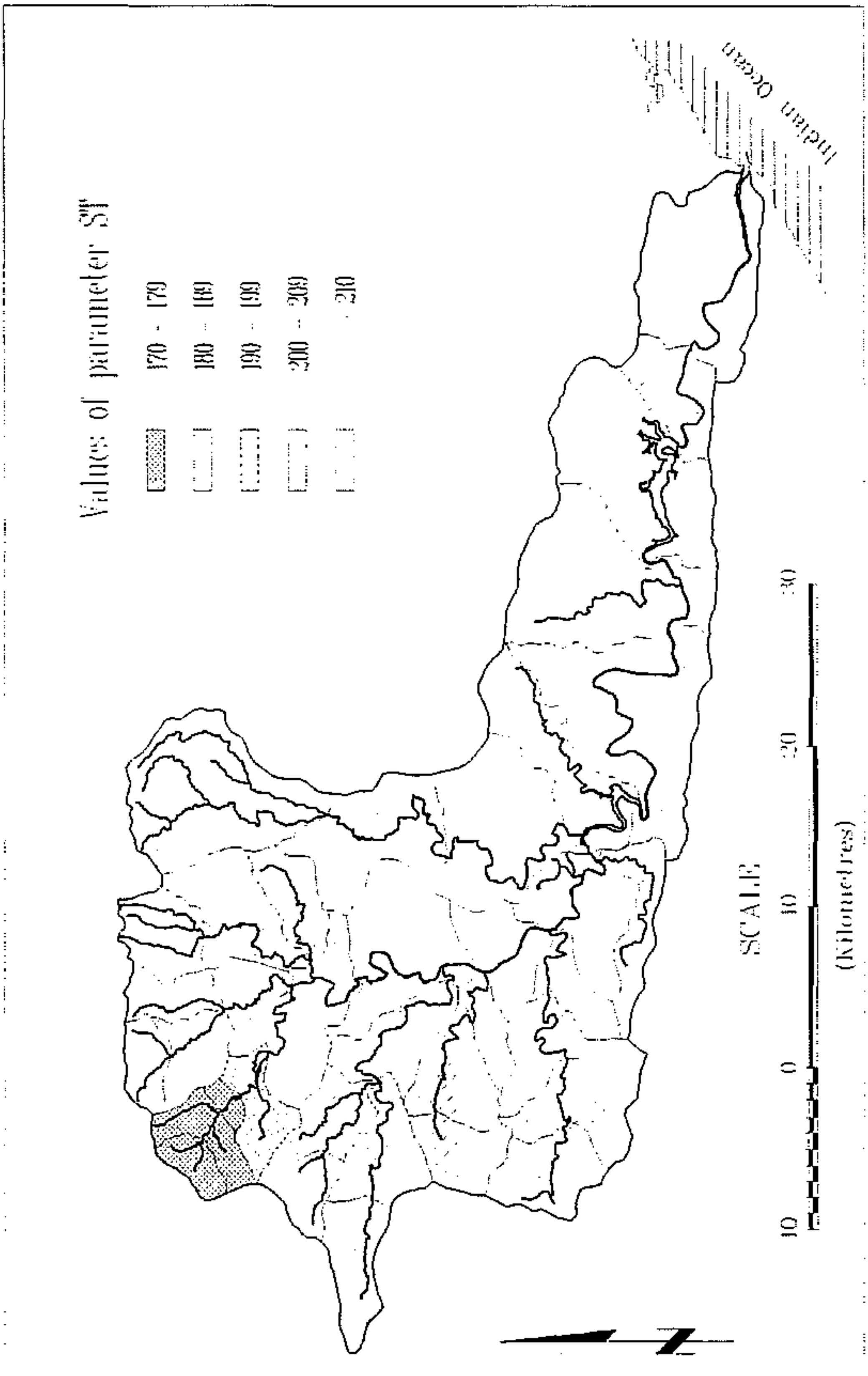

Figure 5. The Buffalo River catchment showing parameter ST (maximum soil moisture capacity in mm).

However, the patterns of simulated storage volumes corresponded closely enough with the observed patterns to allow a reasonable degree of confidence to be expressed in both the simulations of the runoff and the reservoirs' behaviour.

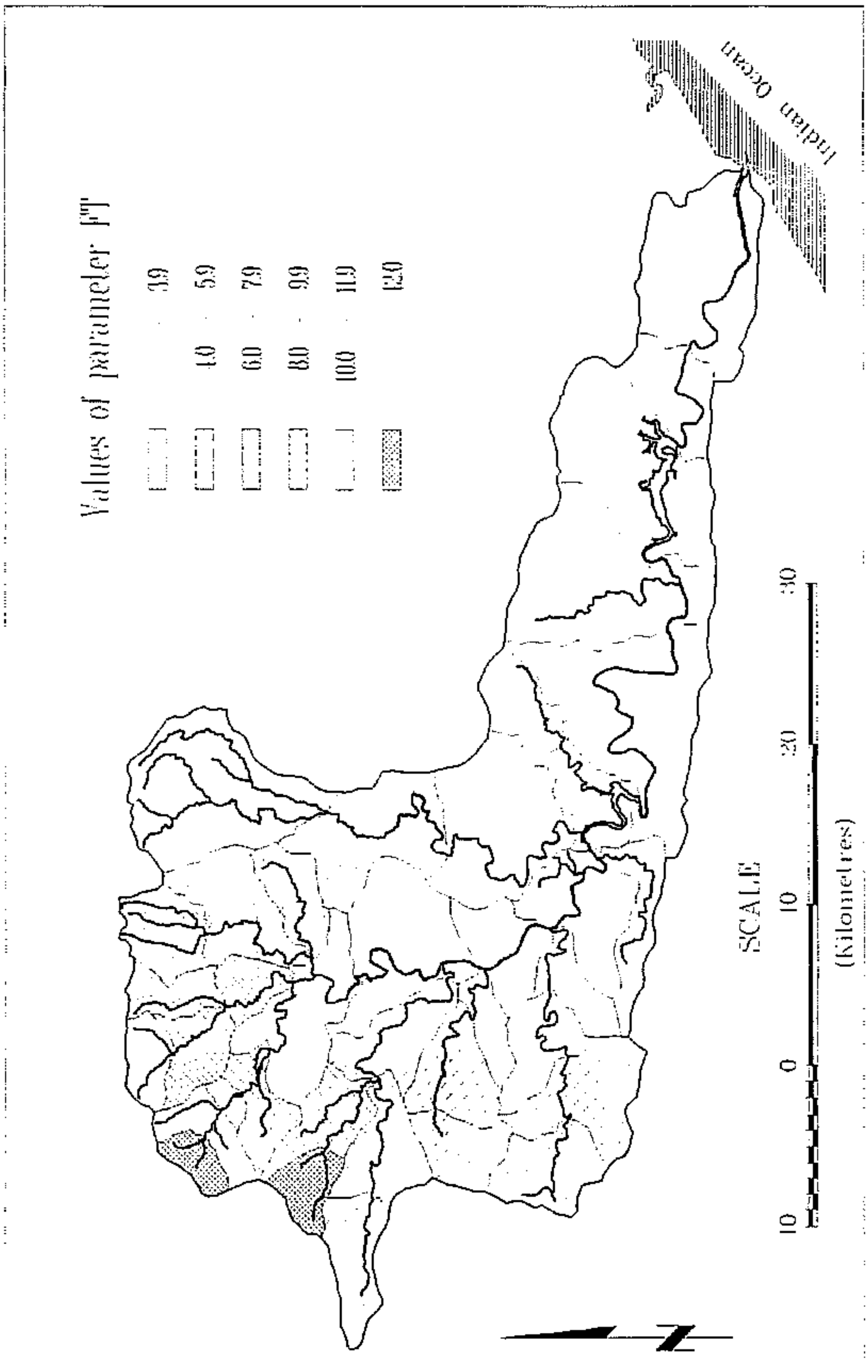

Figure 6. The Buffalo River catchment showing the parameter FT (runoff from soil moisture at full capacity: mm/month).

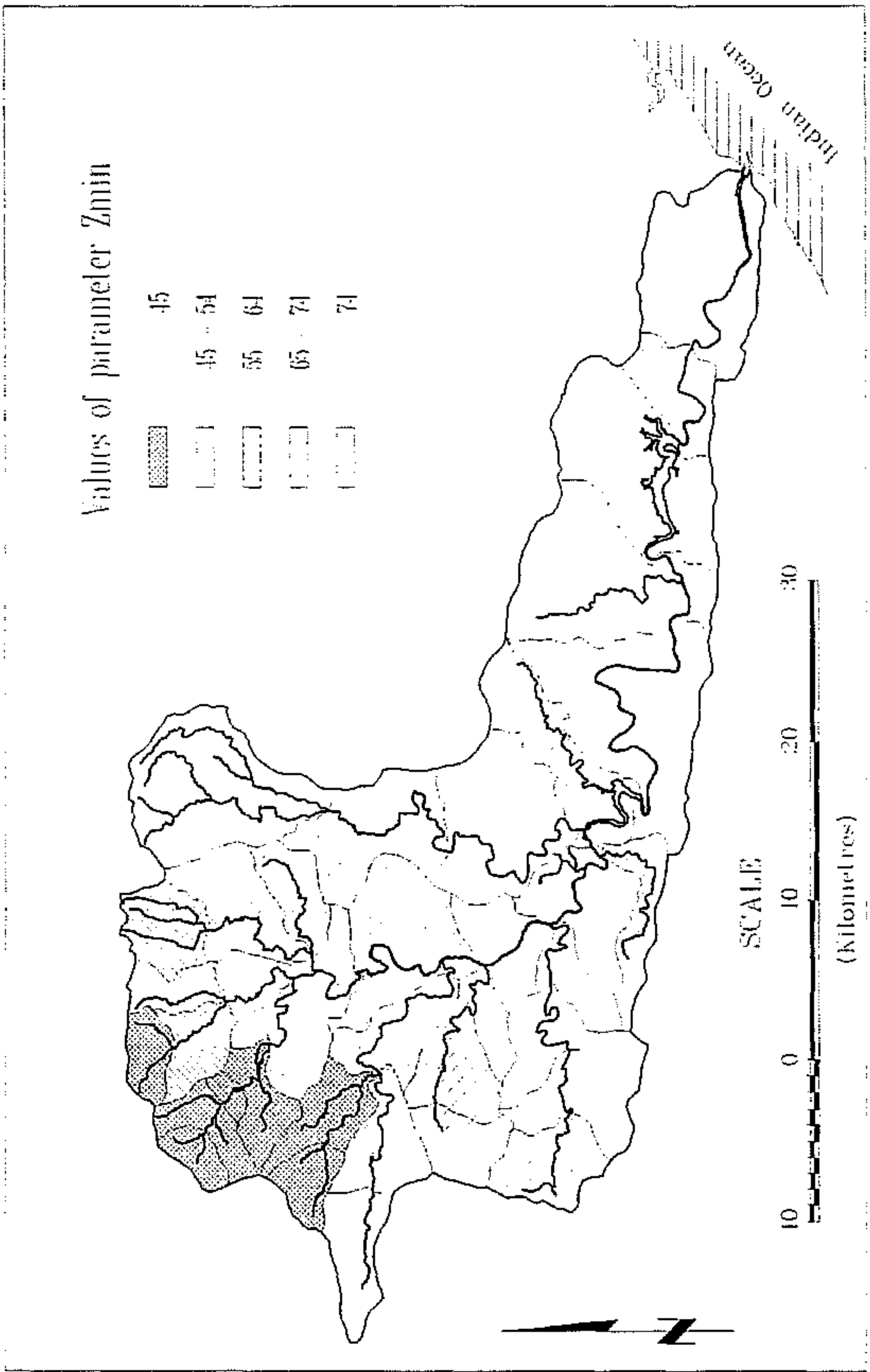

Figure 7. The Buffalo River catchment showing parameter ZMIN (minimum catchment absorption rate).

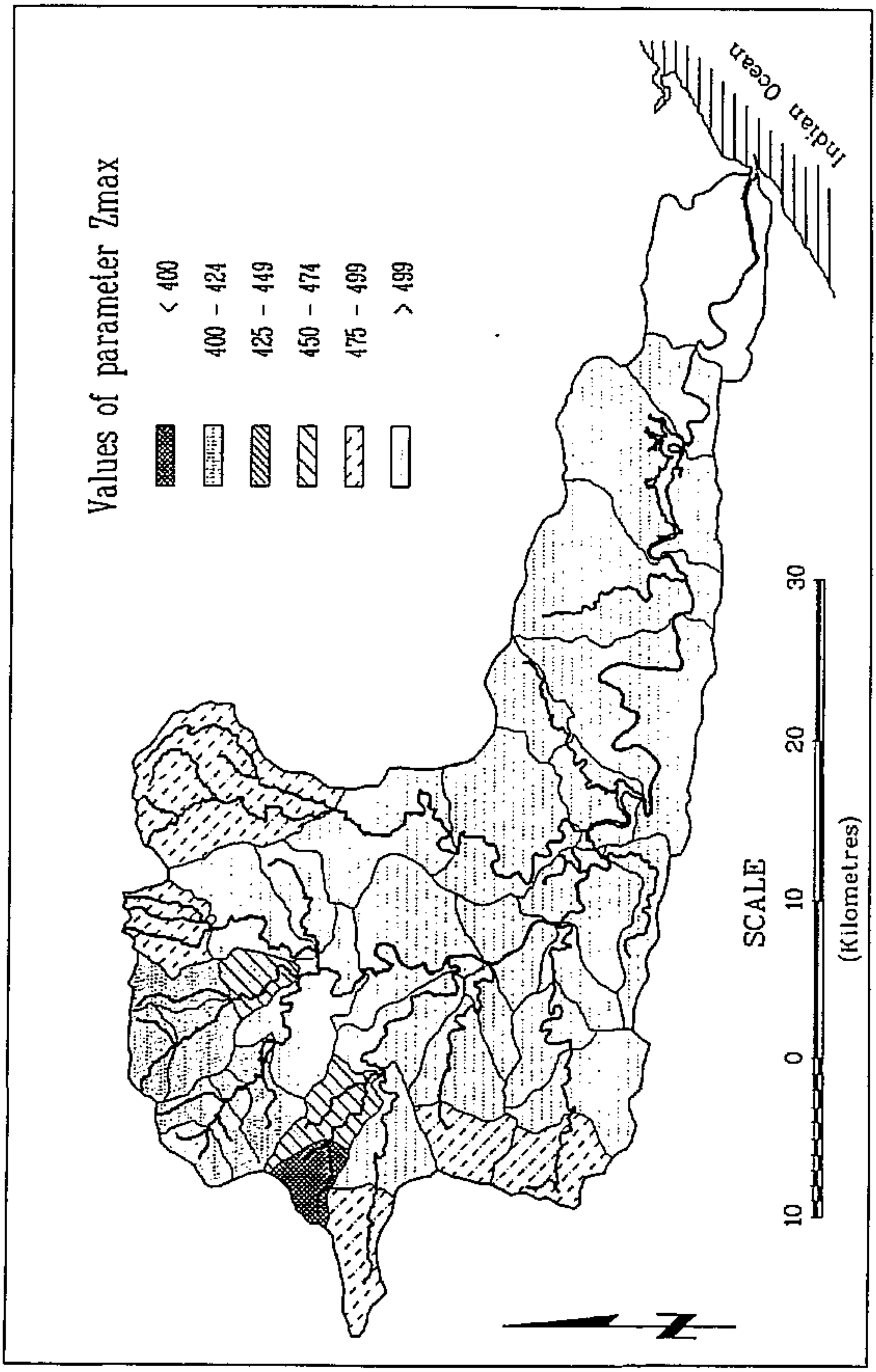

Figure 8. The Buffalo River catchment showing parameter ZMAX (maximum catchment absorption rate).

Table 3. Calibration results.

Gauging Station ID	No. Months	Mean Log of Monthly flow Volume (Ml)		St. Dev. Log of Monthly flow volume (Ml)		Statistics of Log-Log relationship.			
		Obs.	Sim.	Obs.	Sim.	Slope	Intercept	R^2	CE
R2H001	120	5.94	5.83	1.13	1.31	0.71	1.78	0.68	0.56
R2H008	108	4.34	4.63	2.32	2.04	0.87	0.30	0.59	0.57
R2H012	120	5.02	4.80	1.13	1.36	0.68	1.75	0.67	0.48
R2H006	109	5.70	5.72	1.44	1.51	0.79	1.16	0.69	0.64
R2H009	84	3.40	3.80	2.37	2.19	0.74	0.58	0.47	0.39
R2H005	119	6.55	6.36	2.09	2.08	0.63	2.57	0.37	0.31
R2H010	39	7.68	7.68	1.12	1.24	0.76	1.86	0.70	0.63
R2H011	117	3.41	4.22	2.86	2.70	0.75	0.25	0.50	0.36

5.2 Representative 46 year period

The period of rainfall records chosen to provide input into the models for the purpose of generating a long sequence of flows representative of the current situation was 1930 to 1975. The choice was largely constrained by the data available for key rainfall stations within the area (figure 2) and can be considered representative in that it contains periods of drought as well as periods of sustained wet conditions.

The same model parameters were used as for the calibration period, except where modifications were considered necessary to reflect the current situation as opposed to the conditions prevailing during the calibration period. This issue mainly concerns the reservoir simulations and the parameters related to full capacity and demand, but also concerns the runoff simulations with regard to the volumes of return flow from some of the major urban areas.

The results are mainly presented as a series of GIS maps illustrating the contributions of each sub-catchment in the system to the total water resources of the area. Figure 9 shows the variation in mean annual rainfall over the catchment, clearly illustrating the higher rainfall

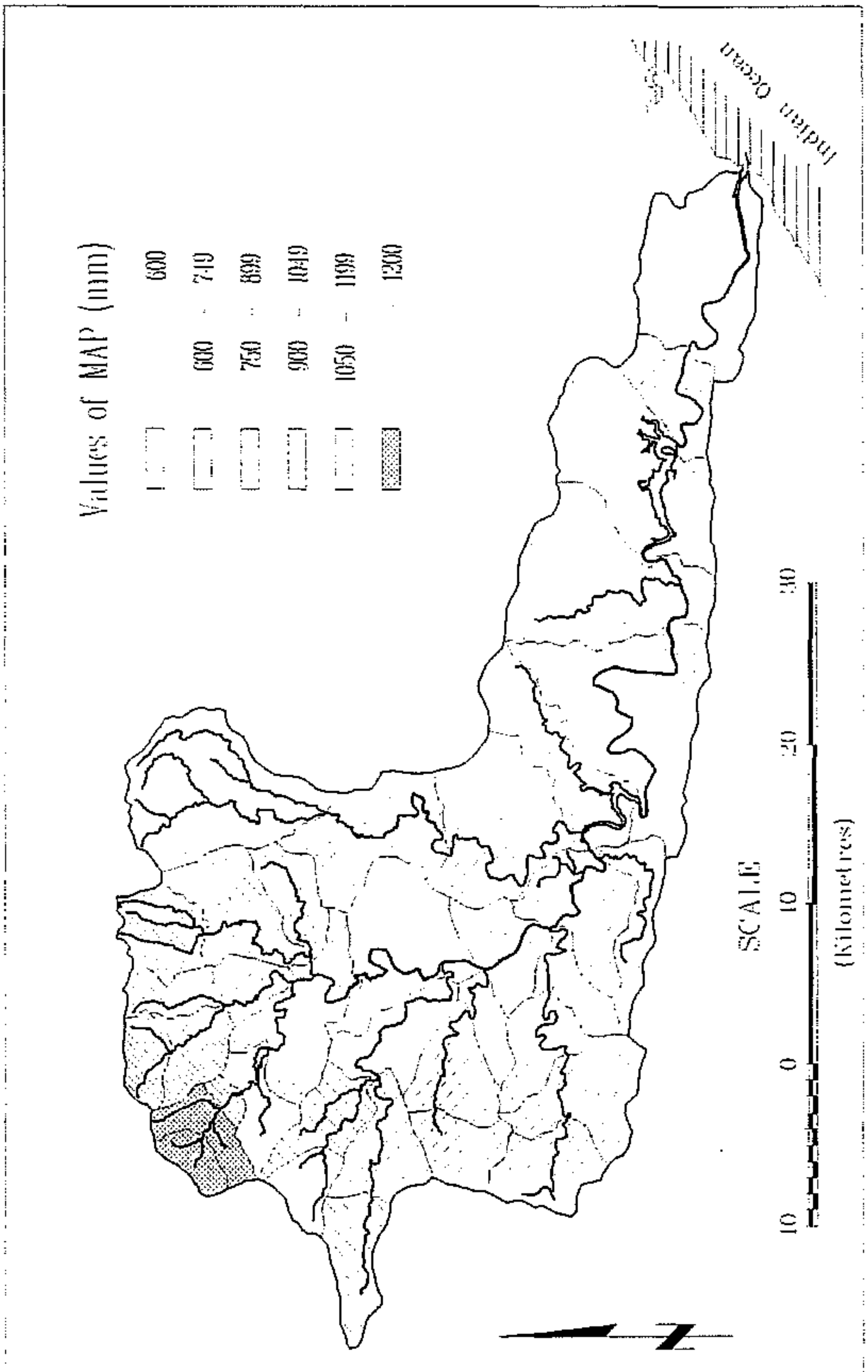

Figure 9. The Buffalo River catchment showing the distribution of the parameter MAP (mean annual precipitation: mm).

in the north-west, the lower rainfall areas in the central part of the catchment and the coastal influence around Bridle Drift Dam and East London. Figure 10 illustrates the contribution to total runoff of each sub-area in the distribution system. The mean annual runoff is expressed in mm to facilitate comparison between sub-areas as well as with the rainfall input provided in the previous figure. Again the major runoff generating areas are the headwater sub-areas in the north-west, while the lowest are the drier central areas above King Williams Town. The influence of the Mdantsane Urban area can be seen in the relatively high amount of runoff generated by the sub-area to the north of Bridle Drift Dam.

Figure 11 illustrates the total mean annual runoff volume (Ml) at the outlet of each sub-area and therefore includes the cumulative effect of upstream runoff as well as the influence of the demand from the major reservoirs. This effect is probably more clearly seen in the following two diagrams (figures 12 and 13) which illustrate the minimum 6 month summer (October to December and January to March) and winter (April to September) flow volumes estimated for the 46 year simulation period. The general trend of increasing (or similar) discharge downstream seen in the mean annual volume figures is much less evident and the influence of the demands for water down the system are more evident. These two figures illustrate the reliability of the low flows throughout the catchment.

6. SUMMARY

The aim of this study was to produce a hydrological model of the Buffalo River. For the purposes of hydrological analyses, the catchment was divided into 38 sub-catchments on the basis of rainfall, location along streams, water usage and siting of monitoring areas. Available rainfall, evaporation and streamflow data were collected in addition to reservoir records, soil classification and information on land and water uses.

A monthly time step modelling approach using the Pitman model was taken. The initial simulation involved progressive calibration of Pitman's rainfall-runoff model, concenraing on low flow conditions. Discrepancies between observed and simulated flows were probably related to inadequate measurement of high flows and to paucity of rainfall data. However, the model appeared to be suitable for generating monthly flow volumes for the catchment. The major rainfall and runoff areas were in the upper headwater sub-areas, but the general trend of increased flow in more downstream areas was ofset by demands for water usage in central and lower areas of the catchment. Because low flows are important and even minor users may impact on them, emphasis was placed on the production of estimates of low flows in summer and in winter.

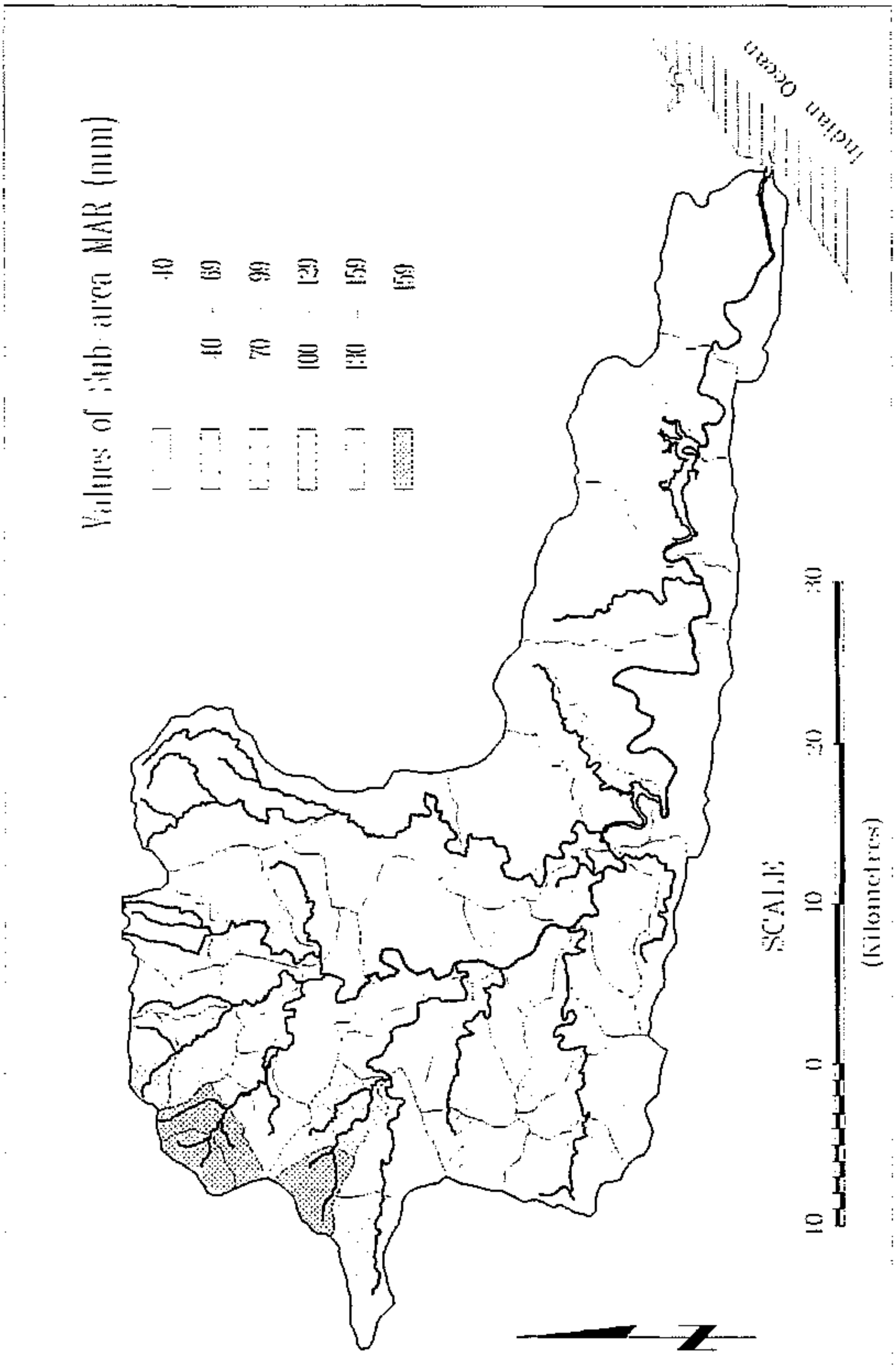

Figure 10. The Buffalo River showing the distribution of total runoff (MAR - mean annual runoff) for each sub-area.

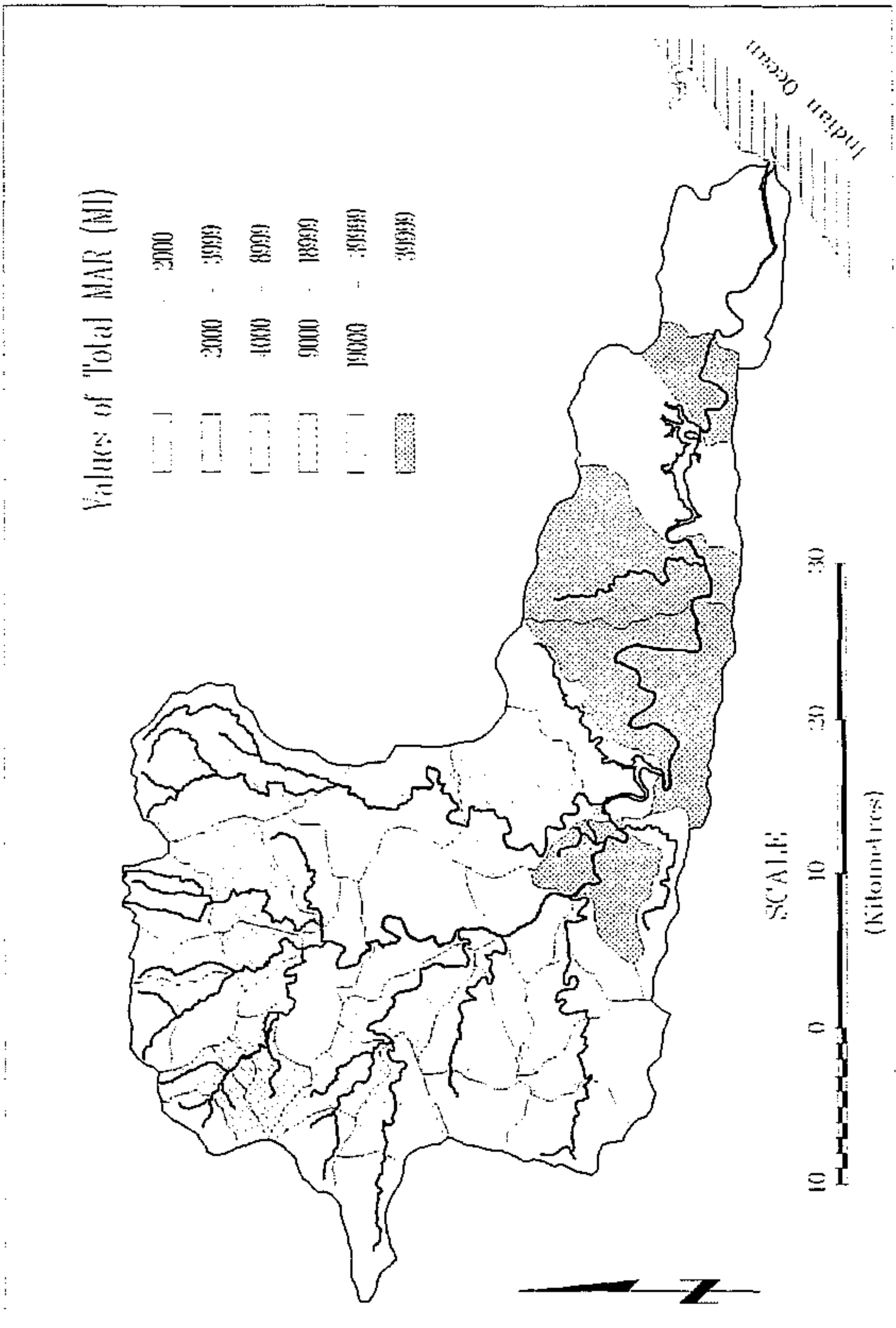

Figure 11. The Buffalo River catchment showing the mean annual runoff (MAR) at the outlet of each sub-area.

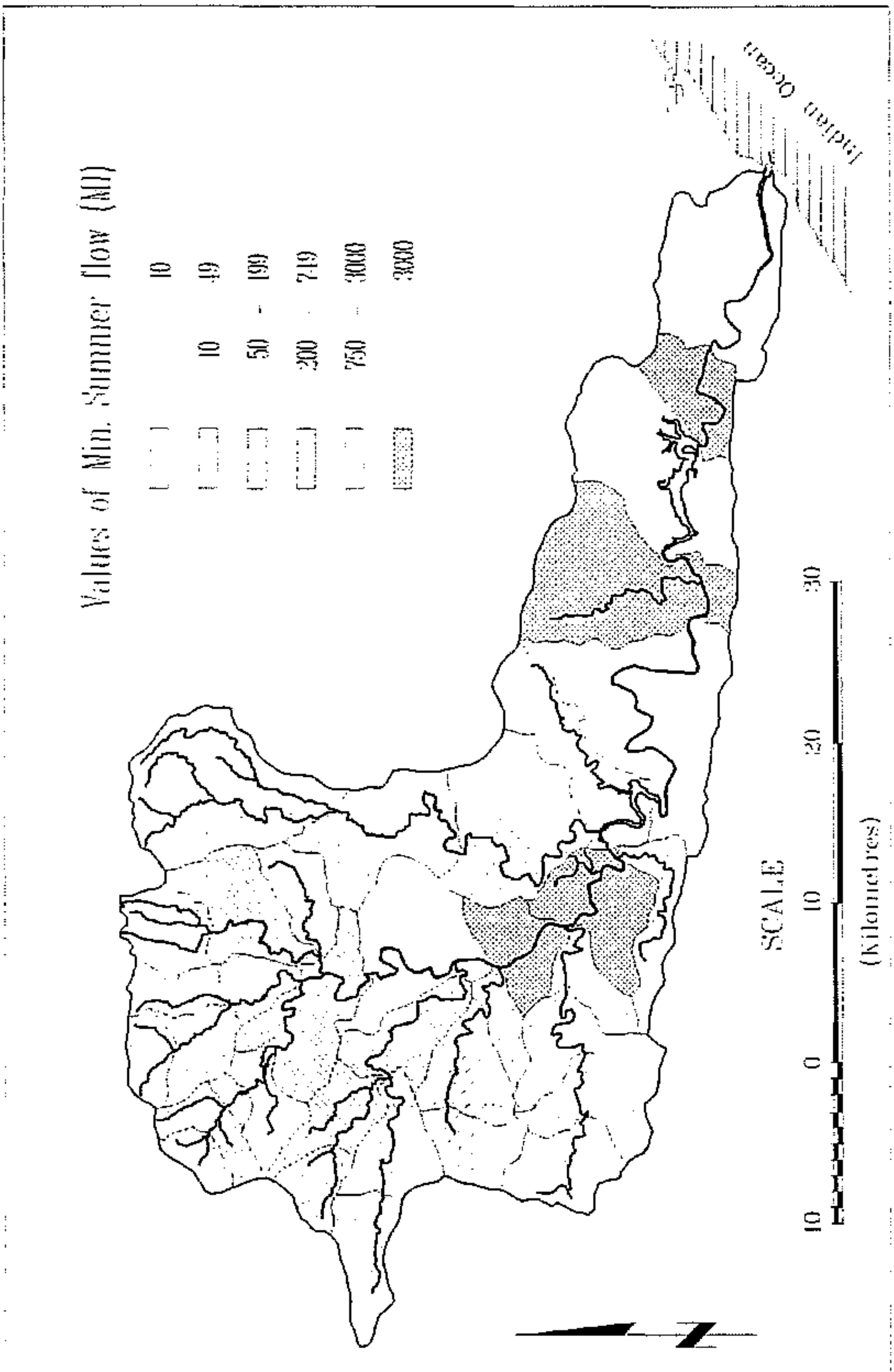

Figure 12. The Buffalo River catchment showing the simulated minimum summer flow volumes for each sub-area.

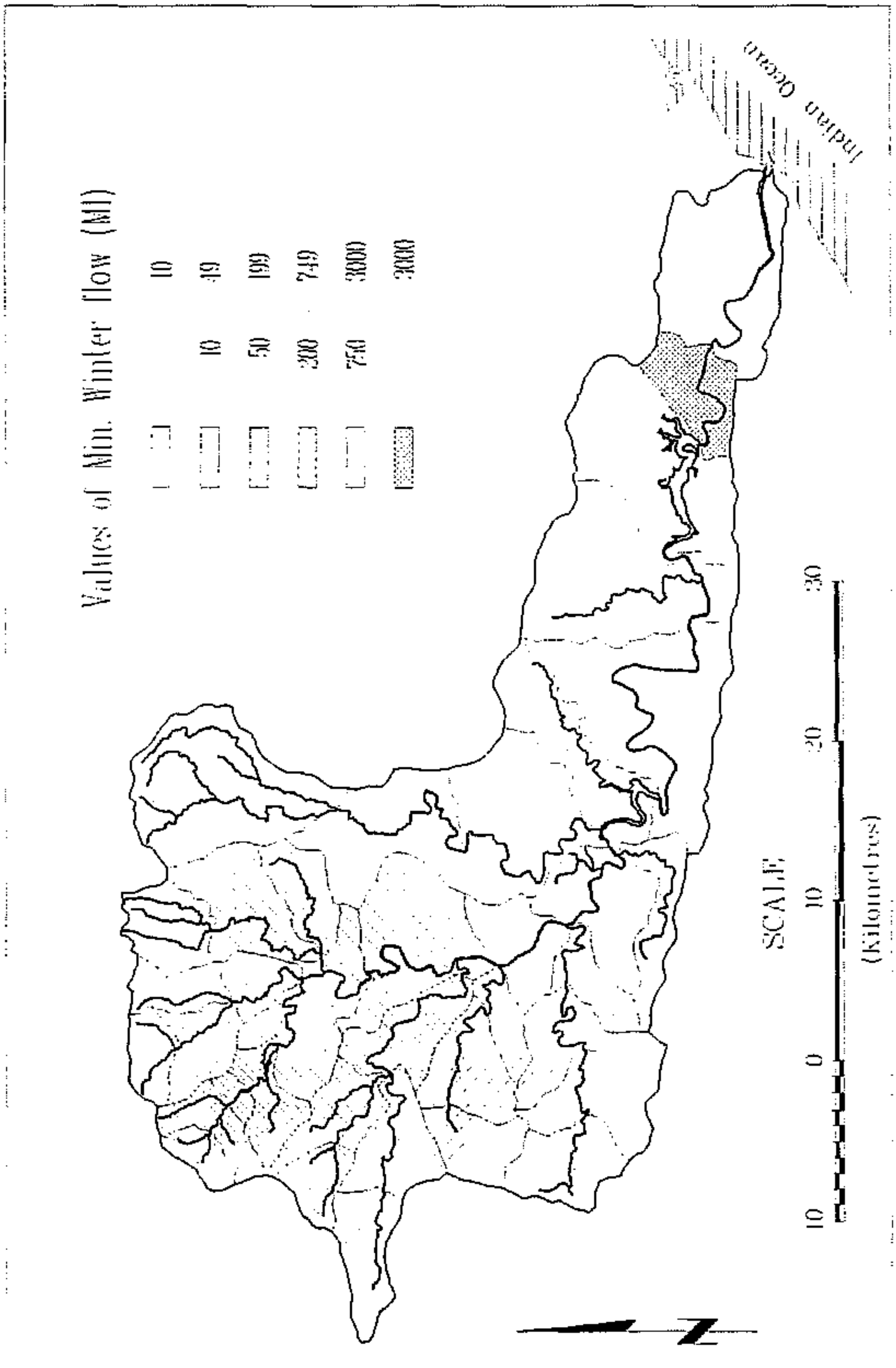

Figure 13. The Buffalo River catchment showing the simulated minimum winter flow volumes for each sub-area.

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7. ACKNOWLEDGEMENTS

We would like to thank CCWR and the Department of Water Affairs and Forestry for their cooperation in the data collection process for this project.

APPENDIX H

PHOSPHORUS BUDGETS

by

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March 1993

CONTENTS

1. INTRODUCTION

The determination of the potential phosphorus input from low-cost, high-density settlements is essential in defining nutrient inputs from these diffuse sources. The demographic survey conducted for this study was designed to determine the potential phosphorus input from these townships. The townships can be divided into three different types of township, namely urban (Ilitha, Mdantsane and Zwelitsha), typical rural village (Mlakalaka) and closer settlement (Needs Camp) (figure 1).

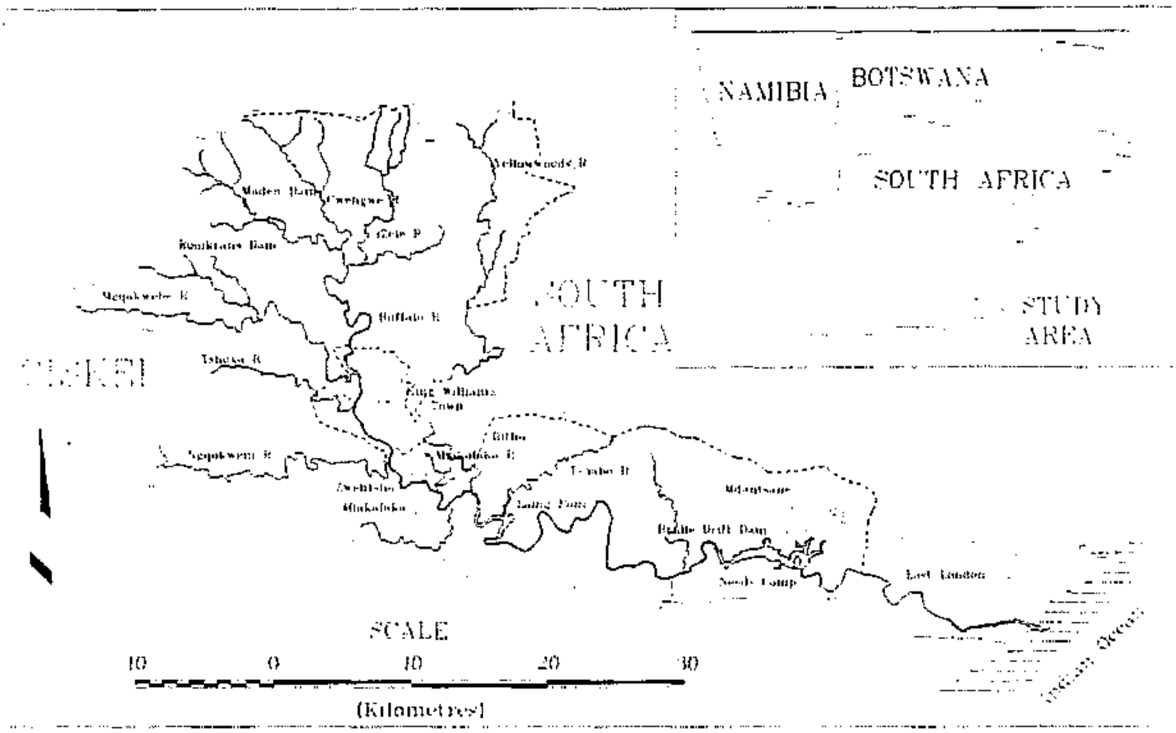


Figure 1. The Buffalo River catchment, showing the different townships studied in the demographic survey.

In all the townships there was very little phosphorus contribution by wood or coal. The main contributors of phosphate were sanitation, soap/detergents and food wastes in the urban townships, and animal waste in the typical rural village and the closer settlement.

2. ANALYSIS METHODS

The data from the demographic study (Appendix F) were used to determine the phosphorus budgets for the five townships that were studied. To determine the phosphorus budgets for each township the following calculations have been used :

Median values were determined from the questionnaire data for each of the variables as shown in Tables 1 - 5. The number of each house type for each township were then calculated.

2.1 Sanitation

The total phosphate input from sanitation was determined in metric ton/year as the sum of phosphate input from each type of house by the following equation :

$$(((N1xP_a)xP_{out})+((N1xP_b)xP_{out})+((N1xP_c)xP_{out}))/1000 \text{ x } 365$$

N1	=	Number of houses in township of a specific house type			
P_a	=	Mean number of children under 5 years			
P_b	=	Mean number of persons between 6 and 15 years			
P_c	=	Mean number of persons over 16 years			
P_{out}	=	Phosphate output for specific age groups in g/day			
		< 5 years	-	0.818	
		6 - 15 years	-	1.343	
		> 16 years	-	1.685	From (Documenta Geigy, 1962)

The questionnaire (Appendix F) determined the number of people that work out of the townships and it was found that the majority of these people are out of the township for 50% of the day. An appropriate value was deducted from the total phosphorus production of the township. Numbers of chamber pots were used to determine the amount of urine that did not go into the sewer system but was thrown out onto the ground every morning.

The total phosphate production that end up in sanitation facilities was calculated as the total phosphorus production minus 50% of that of people working out of town and minus that released via chamber pots.

2.2 Soaps/detergents

Washing powders and detergents are required by law (SABS Standard 892, 1976) to contain at least 6.7% phosphorus (as phosphorus, by mass). In practice, these compounds contain between 20 and 24% P_2O_5, (approximately 22% P_2O_5 on average, by mass (Dunstan, 1987, pers. comm.), which is equivalent to 9.8% (by mass) phosphorus as phosphorus.

The mean amount of soap/detergents used in each type of house was calculated for every township. These values were multiplied by the number of houses of each house type. The phosphate proportion of 9.8% was used to determine the total P input from soaps/detergents in each township.

2.3 Coal ash

Coal has an average ash content of 13.5% (by mass), which, in turn, has an average phosphorus content of 0.53% (by mass, of the ash) (Kruger, 1987, pers. comm.). It is important to note that during combustion, approximately 50% of the phosphorus in coal is transformed together with silicates into a form of slag or glass that renders the phosphorus unavailable (Kruger, 1987: pers. comm.).

To determine the coal ash phosphorus contribution, the input from every type of house was determined by the sum of the mean amount of coal used per house type multiplied by the total number of each house type in the township.

2.4. Wood ash

Dry firewood has an average ash content of 1.0% (by mass), with an average phosphorus content of 0.5% (by mass, of the ash) in the ash (Hose, 1987, pers. comm.).

The questionnaire (Appendix F) determined the amount of wood that was used seasonally in kg/season. From this the annual usage of wood was determined and the phosphorus input was calculated from the wood ash.

2.5 Animal wastes

The total number of different animals per house type was determined by the demographic survey (Appendix F). The total animal waste phosphate production was determined as tonnes/annum by the sum of the productions per animal type. To determine the production for each animal type the following formula was used:

$$\Sigma(H_T \times N_A) x TP/1000$$

where H_T = house type

N_A = number of animals per house type

TP = total phosphate production per animal (kg/animal/annum)

The phosphorous production per animal of each species is shown in Table 6.

Table 1. The median values for all of the variables, for each house type, which were important in the determination of the phosphorus budget components for Ilitha.

ILITHA (60)	Improved municipal (10)	Typical municipal (30)	Backyard shacks (20)
No of people/household	4.7	5.3	4.9
No of adults (15 yrs- over)/household	2.20	3.33	2.85
No. of children (6-15 yrs)/household	1.9	1.4	1.5
No. of children (up to 5 yrs)/household	0.60	0.63	0.70
Waterborne toilets (%)	80	96.67	10
Pit latrines (%)	0	3.33	0
Bucket systems (%)	10	0	90
No toilet facilities (%)	10	0	0
Amount of soap powder (g/week)	405	358.6	380
Amount of water used (litre/day)	95	108.3	102
Disposal of water on ground (%)	35.14	21.70	81.0
Disposal of water in sewer system (%)	64.86	78.3	19.0
Refuse production (kg/week)	0	13.1	3.7
Food and vegetable waste (kg/week)	1.9	2.4	2
Compost used per season (kg/year)	15	27.5	9.17
Cattle (No.)/household	.4	0	0.15
Goats (No.)/household	-	0.33	-
Poultry (No.)/household	0.67	0.67	1.00
Pigs (No.)/household	0.2	0.56	0.30
Donkeys (No.)/household	-	-	-
Dogs (No.)/household	0.2	0.56	0.30
Cats (No.)/household	-	-	-
Wood (kg/week/winter)	3	2.5	-
Wood (kg/week/summer)	2	2.0	-
Coal (kg/winter)	-	-	-
Coal (kg/summer)	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-

Table 2. The median values for all of the variables, for each house type, which were important in the determination of the phosphorus budget components for Mdantsane township.

MDANTSANE (30)	Elite (10)	Improved municipal (2)	Typical municipal (16)	Squatters (0) (Extrapolated from Zwelitsha)	Backyard shacks (2) (Extrapolated from Zwelitsha)
No of people/household	5.1	4.0	6.31	4.03	3.47
No of adults (15 yrs- over)/household	3.2	3.0	4.31	2.53	2.30
No. of children (6-15 yrs)/household	1.4	1.0	0.75	0.90	0.73
No. of children (up to 5 yrs)/household	0.5	0.0	1.31	0.87	0.43
Waterborne toilets (%)	100	100	100	0	100
Pit latrines (%)	0	0	0	13.3	0
Bucket systems (%)	0	0	0	0	0
No toilet facilities (%)	0	0	0	86.7	0
Amount of soap powder (g/week)	470	375	339.06	333.3	348.3
Amount of water used (litre/day)	190	150	143.75	86.67	83.33
Disposal of water on ground (%)	0	0	6	100	33.02
Disposal of water in sewer system (%)	100	100	94	0	66.98
Refuse production (kg/week)	2.4	2.5	2.69	3.93	3.53
Food and vegetable waste (kg/week)	1.8	2.0	1.56	1.6	1.67
Compost used per season (kg/year)	0.75	3.75	7.66	7.5	15
Cattle (No.)/household	-	-	-	-	-
Goats (No.)/household	-	-	-	-	-
Poultry (No.)/household	-	-	1.87	-	0.67
Pigs (No.)/household	-	-	-	-	-
Donkeys (No.)/household	-	-	-	-	-
Dogs (No.)/household	0.4	0	0.31	0.2	0.2
Cats (No.)/household	-	-	-	-	-
Wood (kg/week/winter)	0.1	0.5	0.38	1.93	0.3
Wood (kg/week/summer)	0.1	0.5	0.31	1.53	0.27
Coal (kg/winter)	-	-	-	-	-
Coal (kg/summer)	-	-	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-	-	-

Table 3. The median values for all of the variables, for each house type, which were important in the determination of the phosphorus budget components for Zwelitsha township.

ZWELITSHA (130)	Elite (10)	Improved municipal (30)	Typical municipal (30)	Squatters (30)	Backyard shacks (30)
No of people/household	4.7	6.83	6.2	4.03	3.47
No of adults (15 yrs- over)/household	3.5	4.63	4.17	2.53	2.30
No. of children (6-15 yrs)/household	1.0	1.53	1.80	0.90	0.73
No. of children (up to 5 yrs)/household	0.2	0.63	0.73	0.87	0.43
Waterborne toilets (%)	100	100	100	0	100
Pit latrines (%)	0	0	0	13.3	0
Bucket systems (%)	0	0	0	0	0
No toilet facilities (%)	0	0	0	86.7	0
Amount of soap powder (g/week)	660	571.67	447.5	333.3	348.3
Amount of water used (litre/day)	170	114.83	115	86.67	83.33
Disposal of water on ground (%)	6.06	26.72	29.57	100	33.02
Disposal of water in sewer system (%)	93.94	73.28	70.43	0	66.98
Refuse production (kg/week)	4.9	5.8	1.47	3.93	3.53
Food and vegetable waste (kg/week)	3.1	2.1	2.03	1.6	1.67
Compost used per season (kg/year)	4.17	4.5	16.39	7.5	15.0
Cattle (No.)/household	-	-	-	-	-
Goats (No.)/household	-	-	-	-	-
Poultry (No.)/household	-	1.33	1.67	-	0.67
Pigs (No.)/household	-	-	-	-	-
Donkeys (No.)/household	0.2	-	-	-	-
Dogs (No.)/household	0.3	1.03	0.7	0.2	0.2
Cats (No.)/household	-	-	0.17	-	-
Wood (kg/week/winter)	-	0.33	0.4	1.93	0.3
Wood (kg/week/summer)	-	0.3	0.3	1.53	0.27
Coal (kg/winter)	0.1	0.07	0	-	-
Coal (kg/summer)	0.1	0.03	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-	-	-

Table 4. The median values for all of the variables, for each house type, which were important in the determination of the phosphorus budget components for Mlakalaka township.

MLAKALAKA (40)	Elite Village (6)	Typical Village (16)	Humble village (16)	Backyard shacks (2) (Extrapolated from Zwelitsha)
No of people/household	5.5	5.0	5.88	3.47
No of adults (15 yrs- over)/household	3.83	3.44	3.75	2.30
No. of children (6-15 yrs)/household	1.0	1.19	1.63	0.73
No. of children (up to 5 yrs)/household	.033	0.19	0.75	0.43
Waterborne toilets (%)	0	0	0	0
Pit latrines (%)	100	100	100	50
Bucket systems (%)	0	0	0	0
No toilet facilities (%)	0	0	0	50
Amount of soap powder (g/week)	658.33	432.81	425	348.3
Amount of water used (litre/day)	116.67	106.25	88.13	83.33
Disposal of water on ground (%)	100	100	100	100
Disposal of water in sewer system (%)	0	0	0	0
Refuse production (kg/week)	2.67	3.25	2.94	3.53
Food and vegetable waste (kg/week)	2.0	1.5	1.63	1.67
Compost used per season (kg/year)	1.67	10.0	7.34	15.0
Cattle (No.)/household	2.67	1.31	1.75	-
Goats (No.)/household	-	1.25	1.88	-
Poultry (No.)/household	6.67	5.63	9.38	0.67
Pigs (No.)/household	2.33	0.94	0.56	-
Donkeys (No.)/household	-	0.50	-	-
Dogs (No.)/household	1.17	0.69	0.94	0.2
Cats (No.)/household	-	-	-	-
Wood (kg/week/winter)	0.33	2.0	3.75	0.3
Wood (kg/week/summer)	0.33	1.31	3.06	0.27
Coal (kg/winter)	-	-	-	-
Coal (kg/summer)	-	-	-	-
Manure (bags/winter/household)//(kg/winter) (1Bag = 20kg)	-	-	2.31//46.25	-
Manure (bags/summer/household)//(kg/summer)	-	-	1.56//31.25	-

Table 5. The median values for all of the variables, for each house type, which were important in the determination of the phosphorus budget components for Needs camp township.

NEEDS CAMP (40)	Typical municipal (0) (Extrapolated from Mlakalaka)	Squatters (40)	Backyard shacks (0) (Extrapolated from Zwelitsha)
No of people/household	5.0	6.05	3.47
No of adults (15 yrs- over)/household	3.44	3.43	2.30
No. of children (6-15 yrs)/household	1.19	2.00	0.73
No. of children (up to 5 yrs)/household	0.19	0.83	0.43
Waterborne toilets (%)	0	0	0
Pit latrines (%)	100	100	100
Bucket systems (%)	0	0	0
No toilet facilities (%)	0	0	0
Amount of soap powder (g/week)	432.81	413.13	348.3
Amount of water used (litre/day)	106.25	96.9	83.33
Disposal of water on ground (%)	100	100	33.02
Disposal of water in sewer system (%)	0	0	66.98
Refuse production (kg/week)	3.25	3.06	3.53
Food and vegetable waste (kg/week)	1.5	1.35	1.67
Compost used per season (kg/year)	10.0	4.72	15.0
Cattle (No.)/household	1.31	0.37	-
Goats (No.)/household	1.25	0.75	-
Poultry (No.)/household	5.63	6.50	0.67
Pigs (No.)/household	0.94	0.88	-
Donkeys (No.)/household	0.50	-	-
Dogs (No.)/household	0.69	0.35	0.2
Cats (No.)/household	-	0.08	-
Wood (kg/week/winter)	2.0	6.43	0.3
Wood (kg/week/summer)	1.31	5.28	0.27
Coal (kg/winter)	-	-	-
Coal (kg/summer)	-	-	-
Manure (bags/winter/household)//(kg/winter)	-	-	-
Manure (bags/summer/household)//(kg/summer)	-	-	-

Table 6. The total phosphorus production per animal that was used in the determination of the total annual phoshorus input from the animals in the catchment

Animal type	TP production (kg/animal/annum)
Cattle	6.57
Goats	1.53
Poultry	0.39
Pigs	5.48
Donkeys	6.21

2.6 Compost

The amount of compost used by the people of the townships was determined for different types of houses. This usage was determined as kg/year. The total amount of compost used per township was determined by the following formula:

$$\Sigma(H_T \times C_U) \times (6.57 \times 0.7)/558/1000$$

H_T = house type
C_U = compost usage per house type (kg/year)

The 6.57 value (kg/animal/year) was derived from the phosphorus output of cattle and the 0.7 value account for the fact that only 70% of the phosphorus output is derived from manure, which is used as compost. The value of 558 is a correction factor as it is the total dry matter produced by an animal per year as (kg/animal/year).

3. RESULTS

3.1 Phosphorus budgets

A phosphate flow diagram was drawn up for each township to determine the total phosphate input as tonnes per annum. Figures 1 to 5 show the distribution of potential phosphate flow in each of these five townships.

The total phosphate input from Ilitha (figure 2), which had a population of 7063 (Appendix E) was 11.21 tonnes/year. Only 41.5% of this phosphate input was returned to the river. Ilitha was the only township that had a bucket system; all the other townships had either water borne sewage systems or pit latrines.

Mdantsane township had a population of 167 004 and had mainly water borne sewage. The total phosphate input from Mdantsane (figure 3) was 235.83 tonnes/year of which 40.06% ended in the river. This might be an underestimation as high inflow from Mdantsane into Bridle Drift Dam was noticed during dry periods (Mr Z. Mbatani, pers comm.), and thus a higher percentage of sewage effluent was discharged into the river than indicated in the flow diagram.

Zwelitsha is an urban township with mainly water borne sewage and only a small squatter area, consisting of 75 houses. The occurrence of backyard houses increased the total population and density. The total phosphate input from Zwelitsha (figure 4) with a population of 23 900 was 47.95 tonnes/year and approximately 41% returned to the river.

In the urban townships the main contributors of phosphate to the catchment were sanitation, soaps/detergents and food wastes. The urban townships had very few animals compared to the typical rural village and the closer settlement, where the animal wastes contributed between 40 and 70% of the phosphate input to the catchment.

The total phosphate input of Mlakalaka (figure 5) was 11.06 tonnes/year of which 90.93% returned to the river via potential runoff. The population of Mlakalaka was 2631 (Appendix F). The village did not have a sewage treatment works, but sewage was built into the flow diagram as the village was situated across from the Zwelitsha sewage treatment works, and it was assumed that the pit latrine waste would be transferred to the Zwelitsha sewage treatment works when it was pumped out.

The total phosphate input from Needs Camp (figure 6) was 41.8 tonnes/year for a population of 14077. Of the total input, 75.36% returned to the river. It was assumed that only 50% of the animal waste ended up on the ground surface as there was moderate vegetation cover between Needs Camp and the Bridle Drift Dam.

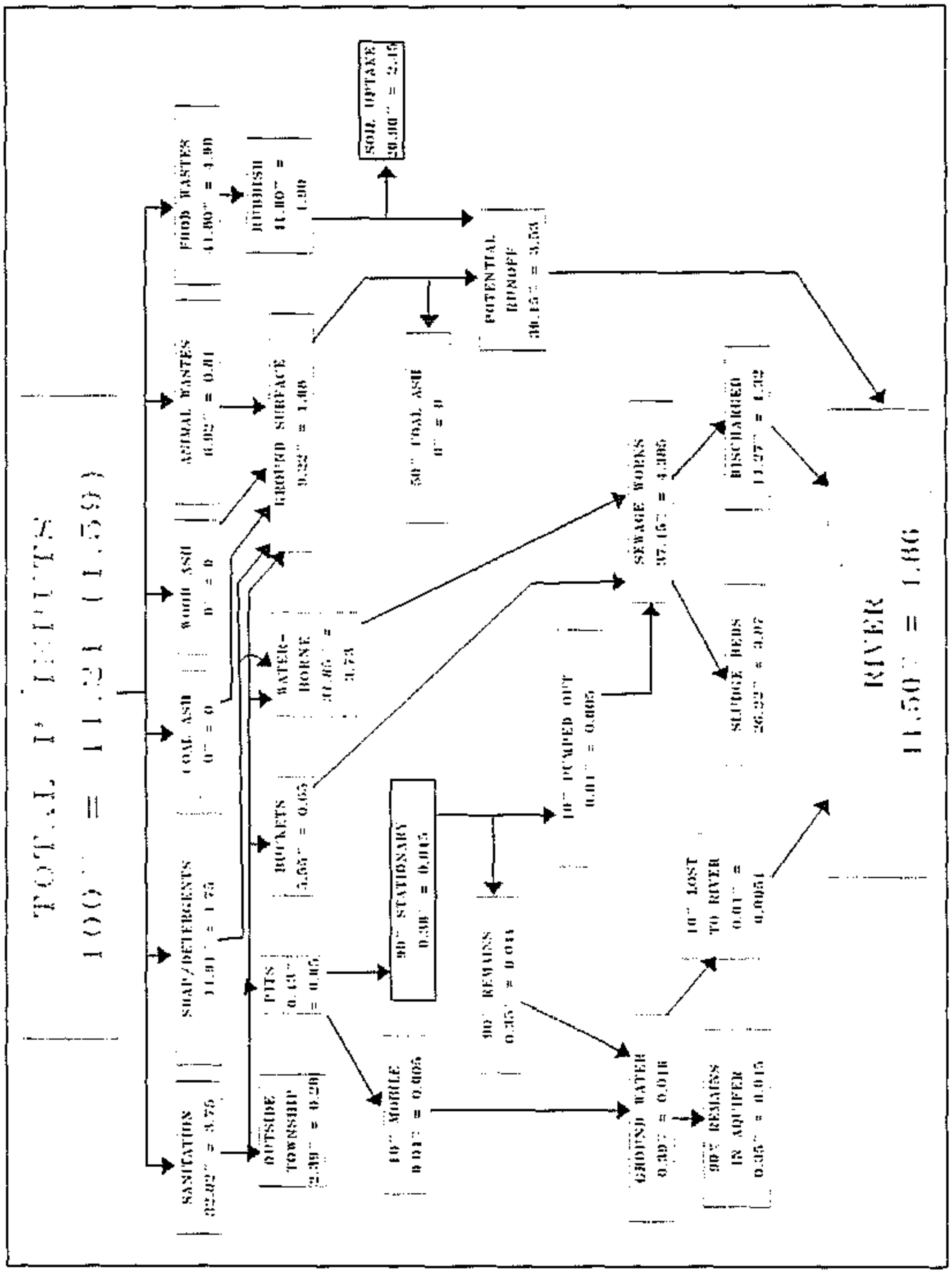


Figure 2. The phosphate budget for Ilitha township in tonnes/year. The bracketed value is the total phosphate input per 1000 persons.

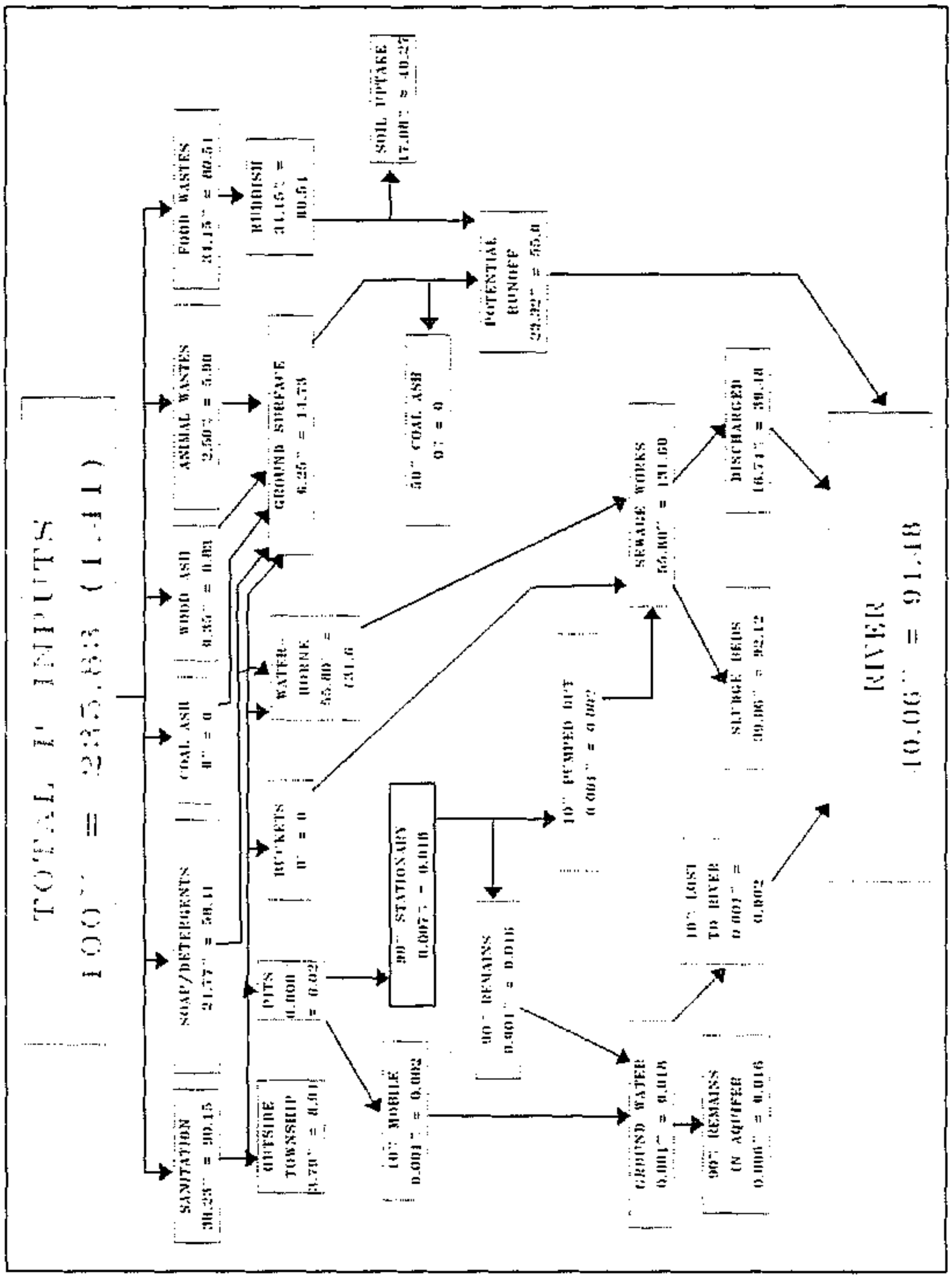


Figure 3. The phosphate budget for Mdantsane township in tonnes/year. The bracketed value is the total phophate input per 1000 persons.

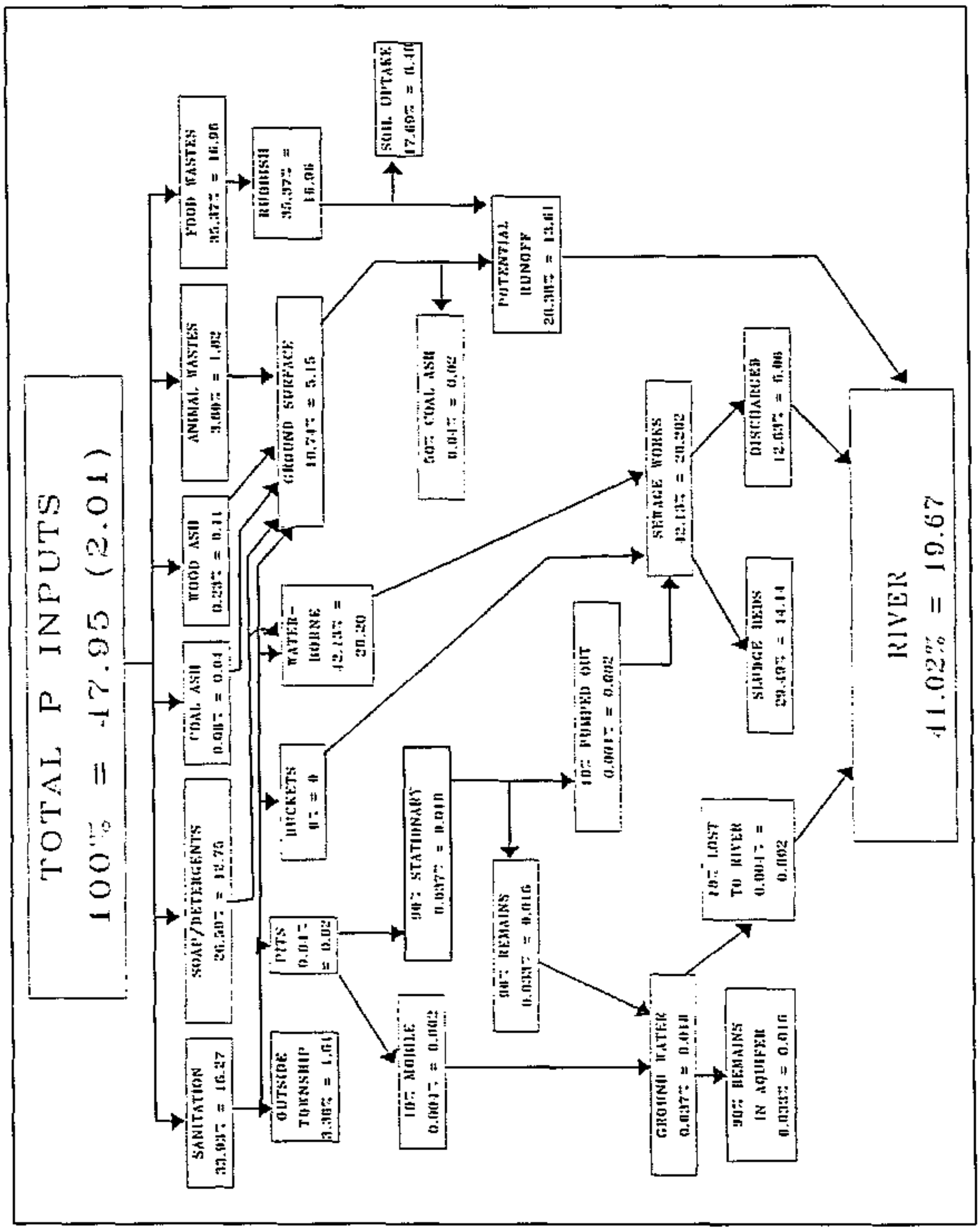


Figure 4. The phosphate budget for Zwelitsha township in tonnes/year. The bracketed value is the total phosphate per 1000 persons.

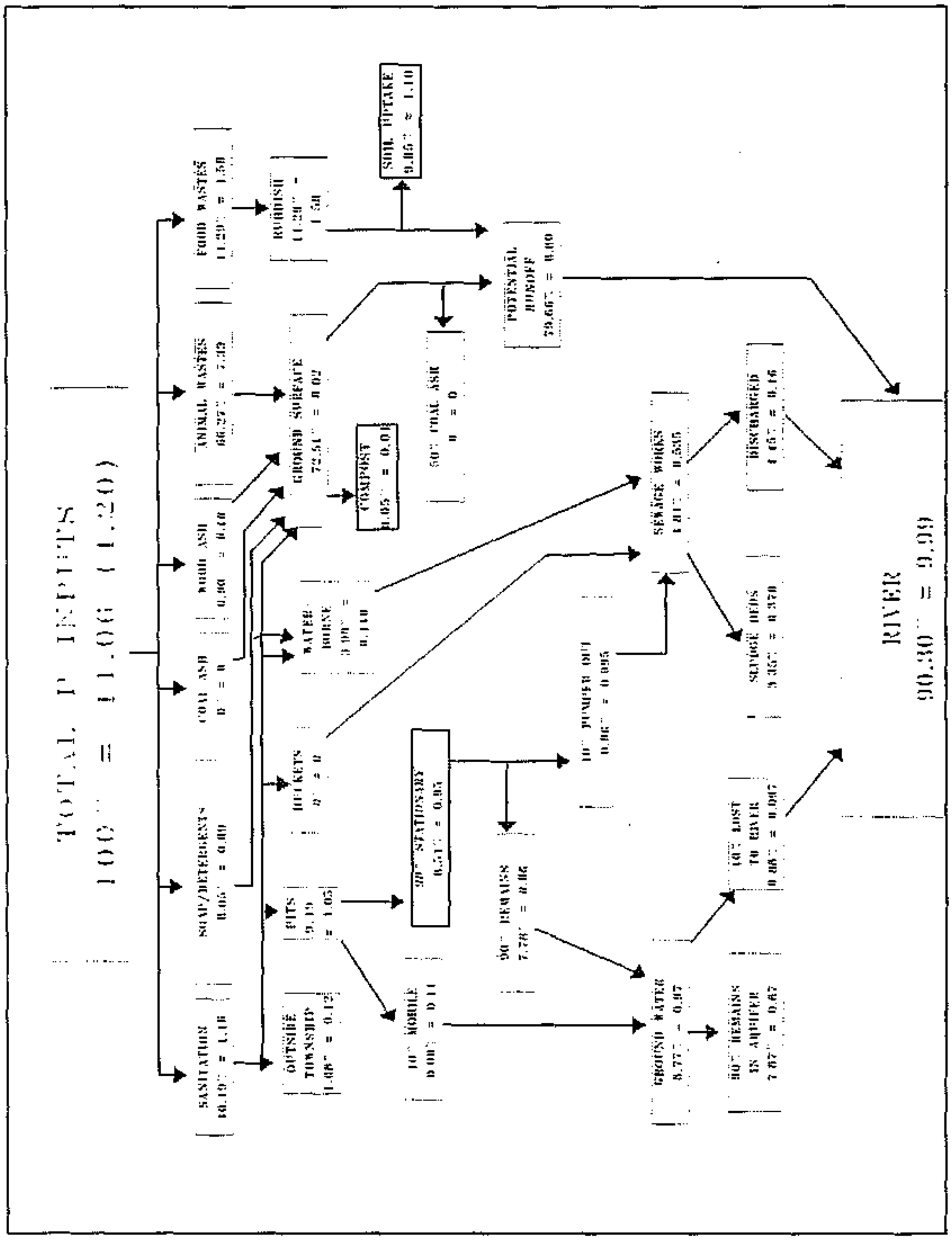


Figure 5. The phosphate budget for Mlakalaka township in tonnes/year. The bracketed value is the total phosphate input per 1000 persons.

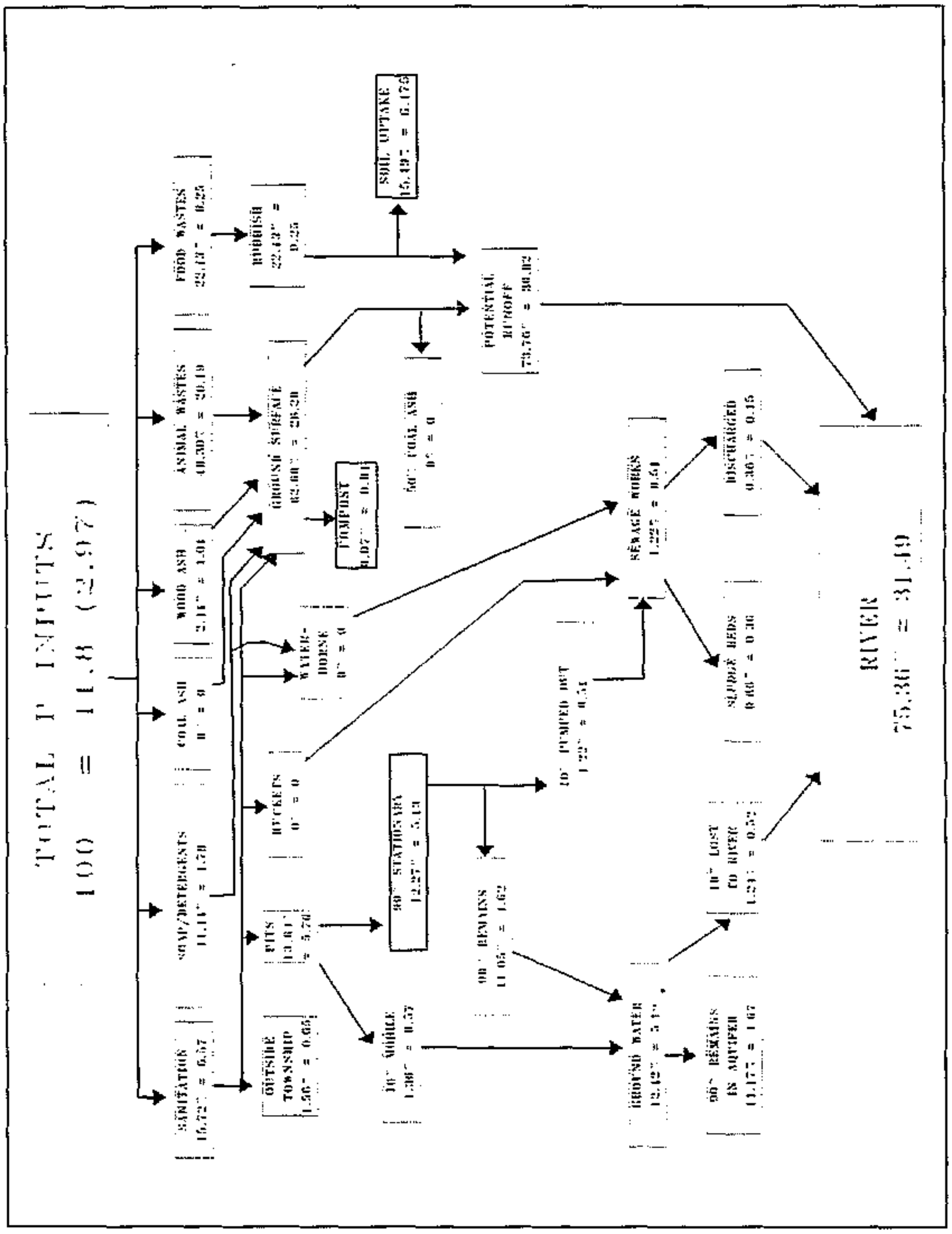


Figure 6. The phosphate budget for Needs Camp township in tonnes/year. The bracketed value is the total phosphate per 1000 persons.

the United States) type runoff generation algorithm with a storage depletion nutrient mass balance function. The daily inputs of phosphorus are estimated from the socio-economic surveys according to the methods outlined in Grobler *et al* (1987) and the proportion of the amount in storage at any one time that is washed off is determined using a non-linear relationship with runoff. The major problem with using the model is estimating the shape of this non-linear relationship in the absence of any field data to define the nature of the processes involved, or against which to calibrate the model. The results generated from applying such a model must therefore be treated with caution until such time as they can be confirmed. However, given the lack of real data, the same is true of any estimation technique applied to this problem.

The model has been applied to Botshabelo as well as the five townships of the Buffalo River catchment covered by the socio-economic surveys. The same 46 year period of data has been used here as was used to simulate representative monthly runoff regimes for the rest of the catchment. The output of daily runoff volumes and phosphate storage and exported loads have been condensed into monthly values and these subjected to frequency-duration analysis.

The Botshabelo results suggest mean and median monthly non-point loads of 6.4 and 0.9 tonnes/month respectively (a ratio of 7.1:1), while the equivalent annual figures are 76.5 and 63.8 tonnes/year. The medians are therefore substantially higher than the values suggested by the approach adopted by Grobler *et al* (1987) and the monthly distribution significantly less skewed. Part of the reason for this is that the Orange Free State experiences relatively frequent high intensity rainfalls during the summer months which generate runoff and depletion of storage to a variable extent depending upon the 'power' of the runoff event, where 'power' is a function of the rainfall intensity and amount of runoff. However, few events occur during the winter months and what is removed by summer events tends to be replenished during the dry winter months. The maximum storage level during the 46 year period was simulated as 185 tonnes (or 180% of annual input), while the mean and median storage levels were 72 tonnes (70%) and 66 tonnes (65%). It is possible that the model is under-simulating the amount of phosphate washed-off during some of the larger runoff events and therefore generally over-simulating the average storage level. If this were the case the load distribution would be more skewed and the median values somewhat reduced.

The patterns of runoff and phosphorous load simulated by the model for the Buffalo River townships is quite different. Most of the differences can be ascribed to the differences in the rainfall-runoff regimes. The Buffalo River catchment area does not experience the same thunderstorm dominated rainfall regime and has far more occurrences of long duration events with lower intensities but far greater total storm rainfall. The way in which the model is currently formulated means that these large events are likely to cause very high wash-off loads which deplete the storage to virtually zero. The smaller events between rarely have the same 'power' as the type of thunderstorm event that occurs in Botshabelo and consequently, the storage levels are not likely to be depleted as much. This will inevitably give rise to a pattern of higher overall levels of storage but with occasional (approximately once every 5 years or so) depletion of the storage to zero. This raises a question about the fate of those nutrients which have a relatively long residence time on the catchment. Should they really be considered to be available for wash-off, or are they consumed by some process and the storage depleted *in-situ*? This issue will have to be resolved before the model can be further refined.

Table 7 Summary of simulation results.

Township	Area (km^2)			Annual phosphorus Input (Tonnes)		Daily Rainfall Distribution factor (h)	
	Total	Impervious	Pervious	Impervious	Pervious	Summer	Winter
Botshabelo	11.0	9.5	1.5	66	36	3	16
Mdantsane	17.1	11.6	5.5	20	35	8	16
Zwelitsha	2.61	1.85	0.80	5.8	7.7	8	16
Needs Camp	0.912	0.512	0.400	14.6	18.2	8	16
Ilitha	0.594	0.444	0.150	1.4	2.2	8	16
Mlakalaka	0.430	0.250	0.180	2.5	6.6	8	16

Some of the important model parameters for Botshabelo and the five Buffalo River urban areas are listed in table 7. The rainfall distribution factors are used to account for different rainfall intensities from the same amount of daily rainfall occurring in different regions.

Table 8 Summary of simulation results.

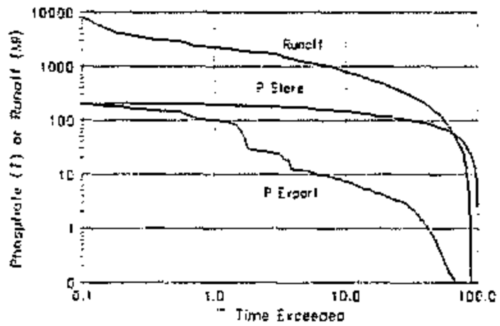
				Median Monthly Values			
Township	Area (km^2)	Annual P Input (tonnes)	Max. Store (% annual input)	Runoff (Ml)	Store (tonnes)	Load (tonnes)	Median Annual Load (tonnes)
Botshabelo	11.0	102	180	119	66	0.90	63.8
Mdantsane	17.1	55	368	132	74	0.47	30.2
Zwelitsha	2.6	14	413	20	20	0.07	8.1
Needs Camp	0.9	33	368	6.5	43	0.30	18.1
Ilitha	0.6	3.6	366	4.5	2.9	0.01	2.2
Mlakalaka	0.4	9.1	389	3.1	11	0.05	5.3

The simulation results are illustrated in table 8 and figures 6 to 10. The major differences amongst the townships of the Buffalo River can be ascribed to their sizes, the annual phosphorus inputs as determined from the socio-economic surveys and the assumed proportions of the urban areas that are occupied by impervious or pervious surfaces.

The simulation results indicate that much higher levels of storage (maximums close to 400% of annual input) are reached in the Buffalo River townships than in Botshabelo, but that the medians for all areas are relatively similar (about 60% of annual input). Part of the reason for this has already been highlighted and is related to the assumed nature of the rainfall-runoff regimes. The proportions of the Buffalo River townships that have been identified as pervious are also higher than in Botshabelo and this has a major effect due to the differences in the relative amounts of runoff that are generated from the two types of area (greater for impervious).

Given that the model is based on an incomplete understanding of the processes involved in the storage and wash-off of nutrients, it need hardly be emphasised that the simulation results are tentative and should be treated with caution.

A



B

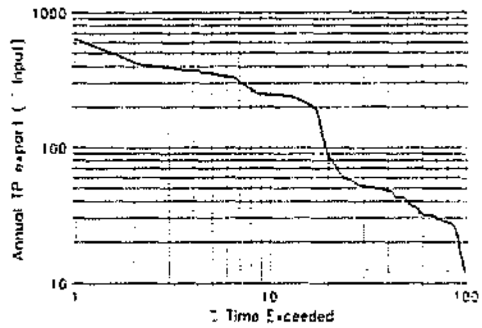
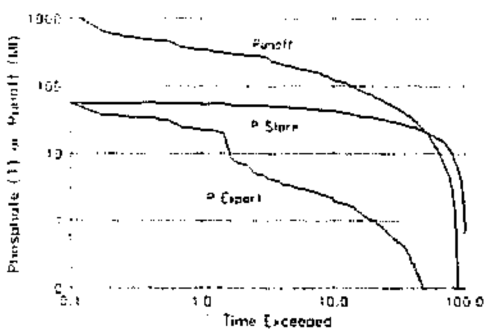


Figure 7. The % time exeedance of monthly runoff (Ml), phosphate export (tonnes/month) and storage (tonnes) in the Mdantsane catchment (A) and the annual phosphorus export as a percentage of the annual input (B).

A



B

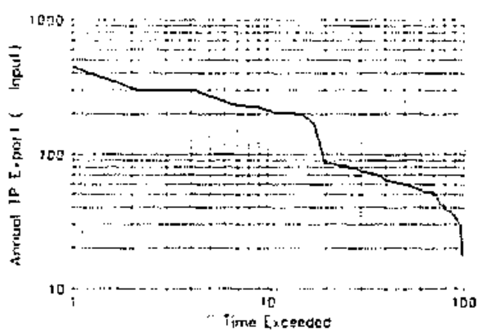


Figure 8. The % time exeedance of monthly runoff (Ml), phosphorus export (tonnes/month) and storage (tonnes) in the Zwelitsha catchment (A) and the annual phosphorus export as a percentage of the annual input (B).

A B

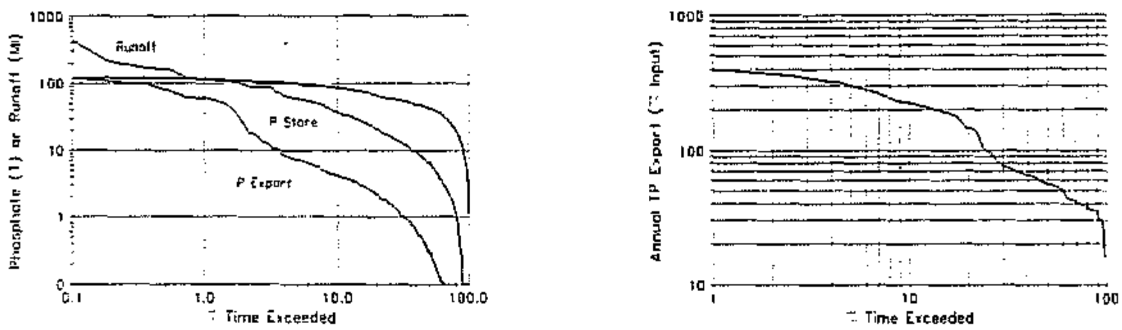


Figure 9. The % time exeedance of monthly runoff (Ml), phosphorus export (tonnes/month) and storage (tonnes) in the Needs Camp catchment (A) and the annual phosphorus export as a percentage of the annual input (B).

A B

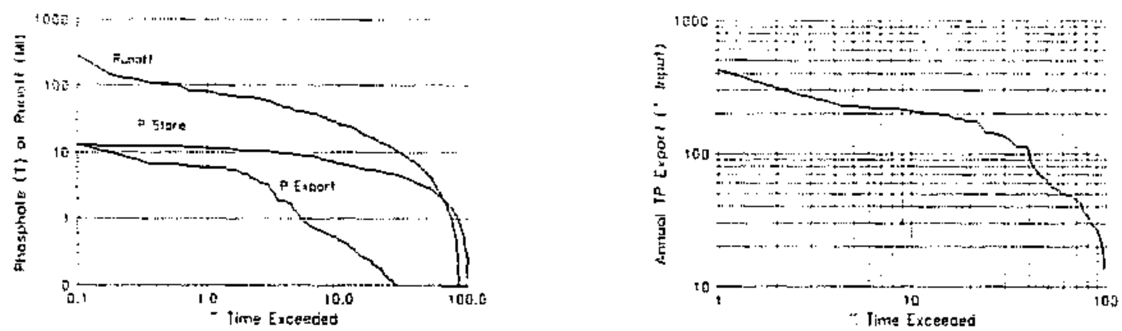
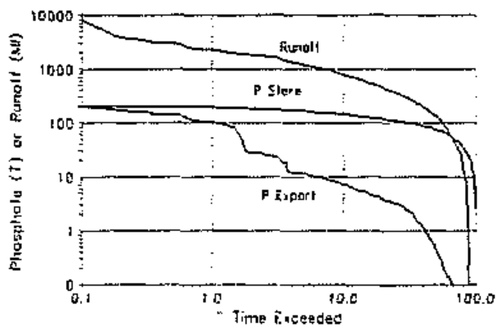


Figure 10. The % time exeedance of monthly runoff (Ml), phosphorus export (tonnes/month) and storage (tonnes) in the Ilitha catchment (A) and the annual phosphorus export as a percentage of the annual input (B).

A



B

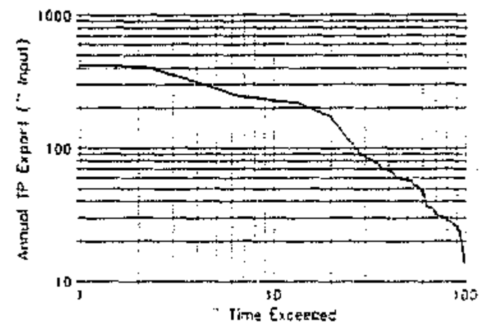


Figure 11. The % time exeedance of monthly runoff (Ml), phosphorus export (tonnes/month) and storage (tonnes) in the Mlakalaka catchment (A) and the annual phosphorus export as a percentage of the annual input (B).

3.3 Loads from different sources.

The phosphate load contributions by the catchment, point sources and urban areas are impotant in determining the management options in the Buffalo River catchment. If for instance the point sources contribute the highest loads for 10% of the time rather than for 80% of the time, the management of these effluents would not have the same impact on the loads entering the reservoirs. The loads from these different sources were therefore determined as follows :

Catchment loads	-	the Grobler and Rossouw (1988) method was used to determine catchment contributions from the sub-catchments.
Urban loads	-	the phosphate export data from each township was determined by the phosphate export simulations as discussed in the previous section.
Point source loads	-	the mean monthly discharges of each point source were multiplied by the median total phosphate concentration to determine the loads from the point sources.
Laing Dam load	-	The inflowing concentrations were used to calculate the outflowing concentrations and load taking into account the phosphate losses due to phosphate retention time in the reservoir (figure 12).

These different methods were used to determine the variability of the different contributors to the total phosphate load. These were calculated for the inflows into both Laing and Bridle Drift dams. In Laing Dam the contributors to total load were divided into urban, point source and catchment (figure 13). Zwelitsha, Ilitha, Mlakalaka and King William's Town supplied part of the urban contributions. King William's Town STW, Zwelitsha STW and Mlakalaka Stream were considered to be point sources. Figure 14 zooms in on the 20-100% contribution of the different phosphate sources, so that the main contributors during low flow are clearly indicated to be the point sources (70% of the time at the inflow into Laing Dam).

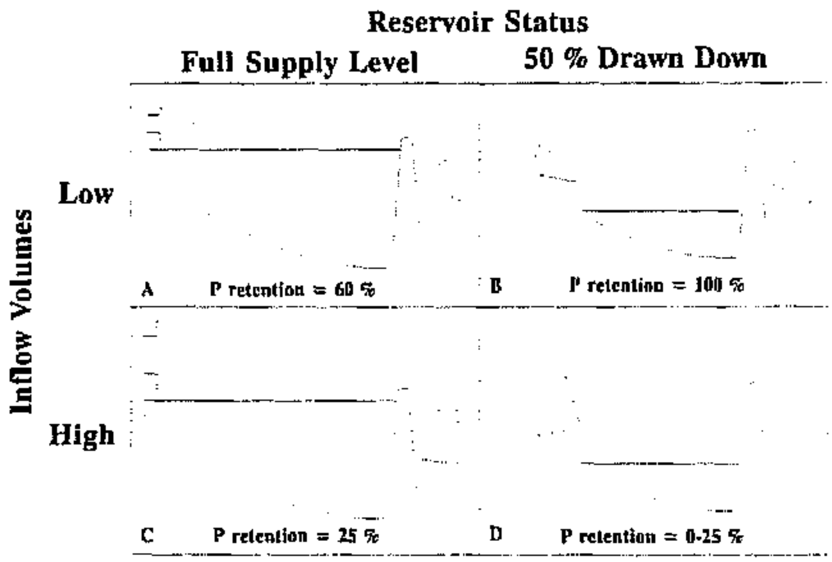


Figure 12. The reservoir status options showing the relationship to phosphate retention in the reservoir.

The contributors to the total phosphate load flowing into Bridle Drift reservoir are shown in figure 15. In Bridle Drift Dam, Laing is a separate contributor to the total phosphate load. Needs Camp and Mdantsane contribute to the urban loads and sewer spills from Mdantsane were used as point source contributors. Figure 16 zooms in on the 50-100% distribution of the phosphate load sources.

The catchments' highest contribution to the total phosphate load is less or equal to the point source loads during the high flows, but is negligible during low flows, as expected.

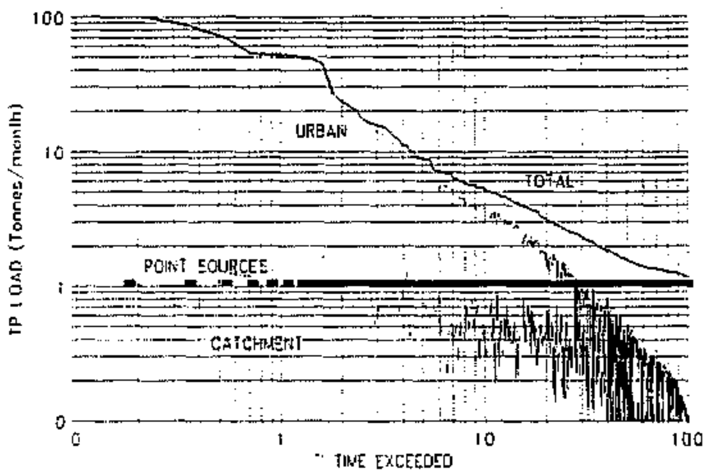


Figure 13. A distribution curve indicating the urban, point source and catchment contributions to the total phosphate load into Laing Dam.

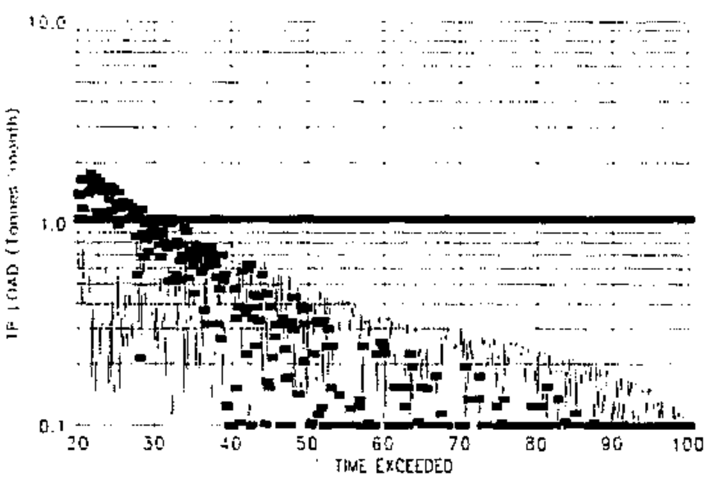


Figure 14. A distribution curve highlighting the 20-100 % distribution of contributors load to the total phosphate load into Laing Dam.

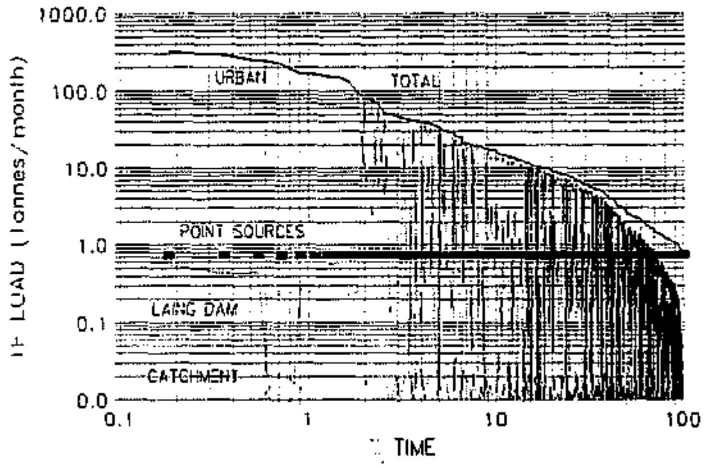


Figure 15. A distribution curve indicating the contributors to the total phosphate load into Bridle Drift Dam.

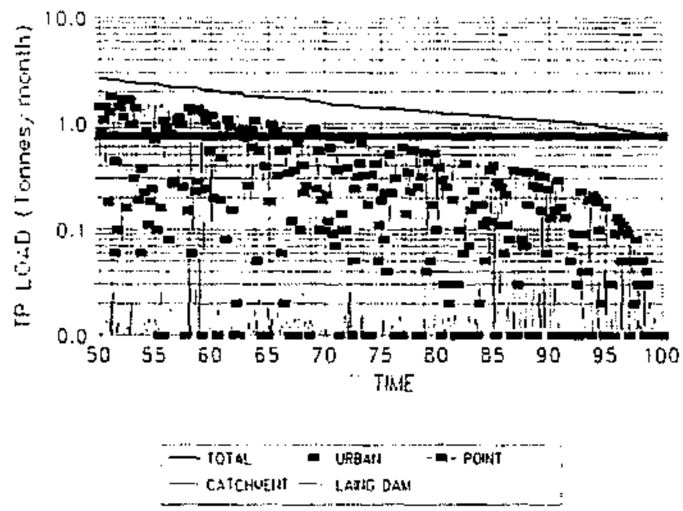


Figure 16. A distribution curve highlighting the 20-100 % distribution of phosphate source contributions to the total phosphate load into Bridle Drift Dam.

These graphs show that the urban phosphate loads are important during the extremely high flows, but that point sources are important during the low flows and for longer periods of time.

4. CONCLUSIONS

The total phosphorus input from each townships varied with the population size of the township and the nature of its waste disposal system. Mdantsane had a similar population to that of Botshabelo in 1987 ($\pm$160 000) and had a total phosphorus input of 235.8 tonnes/year compared to the total input estimated for Botshabelo of 149 tonnes/year.

From the phosphorus budgets drawn up for the different townships it can be seen that in the urban townships (Ilitha, Mdantsane and Zwelitsha) the contribution per 1000 persons was of the same order of 1 to 2 tonnes/year. In Mlakalaka and Needs Camp the total annual phosphorus inputs per 1000 persons were 4.2 and 2.97 respectively. The higher concentrations were caused mainly by the higher occurrence of animals per household in the latter two townships. They also did not have water borne sewage and the input of sanitation onto the ground surface would therefore be higher than in the more conventionally urbanised areas.

The potential diffuse source derived phosphorus load contributed annually by the townships was between 48 and 70% of the total annual input for the different townships according to the model simulations. This caused a build up of the storage which was only infrequently depleted by major runoff events, but it suggests that the impact of the diffuse source might be higher than that estimated for the Botshabelo area (Grobler *et al*, 1987). However, the median figures used in the earlier report were based on mean to median ratios which are considered here to be far too high.

One of the important considerations in assessing the relative impact of the diffuse sources derived from the townships was the likelihood of concurrence of high loads with generally high runoff volumes in the Buffalo system as a whole. If they were concurrent, it was likely that the high loads would not remain in the system, but would be washed downstream of Bridle Drift Dam. If, on the other hand, they occurred when storage levels in Bridle Drift Dam are low, or there were no large scale flow volumes from upstream, then the exported loads could be largely trapped, albeit temporarily, within the system.

The contributions and periods of occurrence of the different phosphate sources in the catchment showed that urban non-point sources were the main contributors during the extremely high flows, but that the point sources were important for longer periods. The catchment contributions to the total loads into the major reservoirs were minor compared to the urban and point sources.

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APPENDIX I

INFORMATION SOURCES

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March 1993

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2. PERSONAL COMMUNICATIONS

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