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 1

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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Assimilative Capacity: The ability of the river to absorb pollutants without serious detriment to the recognised users.

DWAF: The Department of Water Affairs and Forestry

Eutrophication: The process of nutrient enrichment of water which frequently leads to the growth of algal scums.

House Types:

Elite	Owned by well-off professionals
Improved Township	Municipal houses improved by owner
Typical Township	Municipal houses of 2-4 rooms
Elite Village	Large brick-built multi-room houses
Typical Village	Rectangular house built of mud, bricks or cement blocks
Humble Village	Small mud-walled rondavel or shack
Backyard House	Room or rooms behind the main house on the plot.
Squatter shacks	Cheap impermanent housing.

Nutrients: Chemicals that are essential foods for plants, and particularly for planktonic algae when dissolved in water. Common examples are Phosphates, Nitrates, Nitrites, and Ammonium.

Salinity: Dissolved salts in water. In the Buffalo River these are predominantly Sodium and Chloride, derived from the old marine shales in the catchment and from industrial effluents. Other common ingredients are Calcium, Magnesium, Potassium, and Carbonates. Salinity is expressed in terms of Total Dissolved Salts (TDS), measured in mg/l, or as Electrical Conductivity, which increases with the concentration of salts in the water.

Types of water quality requirement:

ID	:	Ideal conditions for all user requirements.
AC	:	Acceptable conditions for all user requirements.
TO	:	Tolerable conditions for all user requirements.
UN	:	Unacceptable conditions for all user requirements.
TA	:	Target concentration set by the Department of Water Affairs water quality guidelines (1993).
NO	:	No impact concentration limit set by the Department of Water Affairs water quality guidelines (1993).
SL	:	Slight impact limit set by the Department of Water Affairs water quality guidelines (1993)
SI	:	Significant impact limit set by the Department of Water Affairs water quality guidelines (1993).
MA	:	Major impact limit set by the Department of Water Affairs water quality guidelines (1993).
UP	:	Upper limit for a Department of Water Affairs water quality guideline.
LO	:	Lower limit for a Department of Water Affairs water quality guideline.

Variables of Concern: The water quality variables which actually or potentially exceed the requirements of users or the DWAF water quality guidelines.

W Q Guidelines: Guidelines defined by the Department of Water Affairs and Forestry (1993), which provide general target concentrations for each water quality variable for different users.

W Q Situation analysis: A description of the current status of water quality in a water body, using existing information to define water quality trends and to identify sources of water quality problems.

1. INTRODUCTION

The catchment of the Buffalo River occupies a pivotal position on the east coast of South Africa, and forms one of the three main centres of development on the east coast, the other two being Durban and Port Elizabeth. It forms the main corridor into the Ciskei and Border regions, and contains the major foci of dense populations and industrial development in the region. The port of East London, at the mouth of the Buffalo River, provides the major access point to the region, and is the only river mouth port on the South African coast. Historically, the catchment was a frontier between the white settlers encroaching northwards and the established Xhosa nation extending southwards. As a result, the history of the region in the nineteenth century is a patchwork of numerous skirmishes and short wars, interspersed with periods of uneasy truce. A legacy of the mixed population distribution in the area is that the catchment is a patchwork of segments administered by the Republic of South Africa, and others belonging to the Republic of the Ciskei (Figure 1.1). This arrangement complicates the management of the catchment and its water resources, and an agreement between the Ciskei and South Africa makes provision for the formation of a Permanent Water Commission to coordinate the use and protection of water

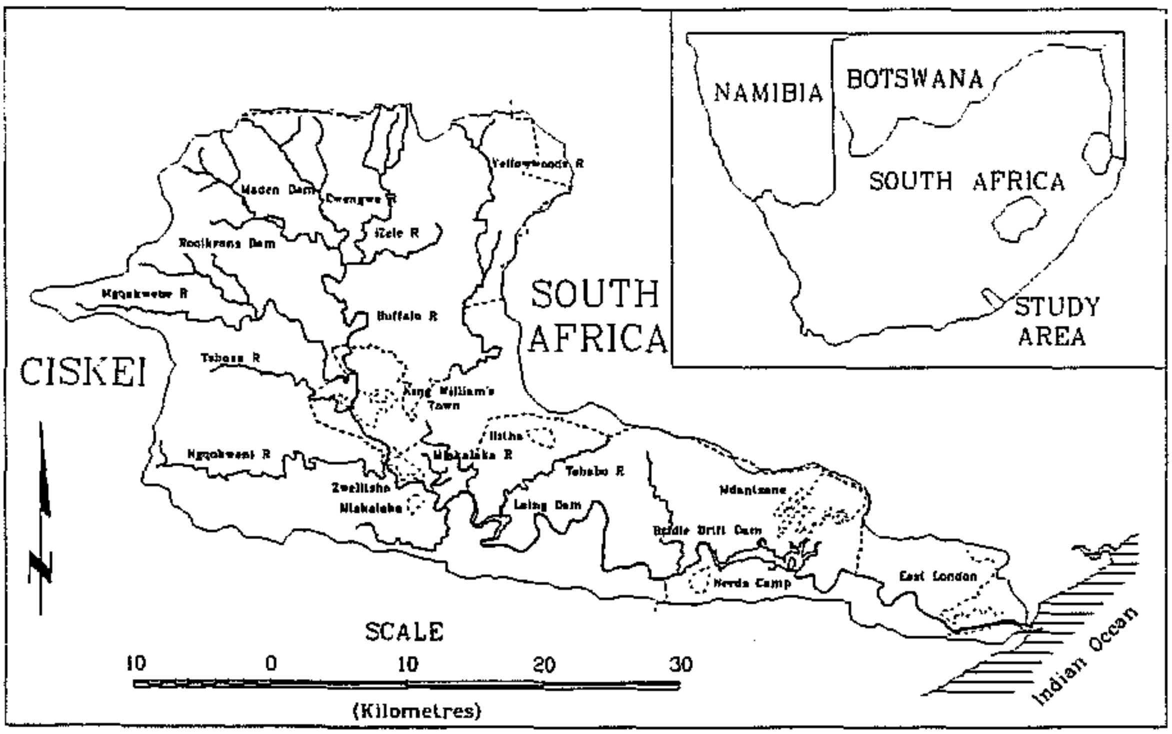


Figure 1.1 The Buffalo River catchment showing the main rivers, tributaries, towns, townships and international boundaries.

resources between the two countries. The RSA has trained and established a water pollution control inspectorate in Ciskei, and a multilateral agreement ensures that water quality standards applicable to effluent standards in the RSA also apply to the Ciskei (Department of Water Affairs, 1986). The catchment supports a rapidly-growing population of ± 311 000 people, partly in the Ciskei, and partly in the Republic of South Africa. Major urban centres in the catchment include King William's Town, Zwelitsha, Mdantsane and East London.

The Buffalo River rises in the Amatole Mountains and flows Southeast for 125 km (Figure 1.1). It is a small (fourth order) river with a Mean Annual Runoff (MAR) of 85 x $10^6 m^3$ (O'Keeffe *et al.*, 1990). The water resources of the Buffalo River catchment are almost fully developed, and may be adequate to meet demands up to 1992 (Bruton & Gess, 1988), when the expected increase in water demand in the Border region will have to be met from neighbouring catchments or local water reclamation (Stoffberg, 1985). The water in the Buffalo River catchment is required for domestic, agricultural, industrial, recreational and environmental uses. In addition, many low-cost high density urban settlements are expanding, increasing the demand for domestic water within the catchment. Concurrently these settlements increase the production of both point and non-point source pollutants.

The Buffalo River catchment has been divided into three reaches which can be subdivided into six land-use zones (O'Keeffe, 1989):

Upper reaches

- Montane forest in the upper reaches down to Maden and Rooikrans Dams. This part of the catchment area generates 42 % of the total runoff of the river, and is important for timber, nature conservation and recreation (hiking and angling).

- Extensive and intensive agriculture (mainly grazing and irrigated market gardening) between Rooikrantz Dam and King William's Town.

Middle reaches

- The urban/industrial complex of King William's Town/Zwelitsha.

- Extensive agriculture on the undulating coastal plain from Laing Dam to Bridle Drift Dam.

Lower reaches

- Low altitude coastal forest in conservation and forestry areas from Bridle Drift Dam to the head of the estuary.

- The estuary, surrounded by the city of East London, and forming the harbour.

This land use zonation of the river provides a framework for prioritizing water uses along different river reaches. The river is impounded in four places - two small dams (Maden and Rooikrans) have been built in the upper reaches as the river leaves the Amatole Mountains, and these supply high quality water principally to King Williams Town and Zwelitsha; Laing Dam in the middle reaches, downstream of Zwelitsha, and providing its main water supply; and Bridle Drift Dam in the lower reaches, which supplies East London and Mdantsane.

For some time, the management of the river and its water resources have been a cause for concern to both South Africa and Ciskei. In particular, a deterioration in water quality in the middle and lower reaches of the river has given rise to worries that water supplied from the river will be unfit for domestic and industrial use, or that water treatment will have to become more sophisticated and more expensive. In the middle reaches, the main supply reservoir, Laing Dam, is downstream of the urban/industrial complex of King Williams Town and Zwelitsha, and receives industrial and urban wastes. Major concerns about water quality in Laing Dam are high concentrations of dissolved salts, and nutrient enrichment resulting in algal blooms (Hart, 1982; Hart and Selkirk, 1983, Kapp Prestedge Retief, 1992). In the lower reaches, Mdantsane dominates the immediate catchment of Bridle Drift Dam, which receives overflow water from Laing Dam, and is the main water supply for Mdantsane and East London. Major concerns about the quality of water in Bridle Drift Dam are bacterial contamination from treated and untreated sewage effluent flowing into Bridle Drift Dam, and, as in Laing Dam, nutrient enrichment causing algal blooms (A. Lucas, *pers. comm.*, 1992 & 1993). The decomposition by-products of these algal blooms are difficult and costly to remove from water which has to be treated to potable standards by the local municipalities. The most recent attempt to improve the water quality in the middle and lower reaches of the river has been the application of a Special Effluent Phosphate Standard (implemented in 1980 by the Department of Water Affairs and Forestry), which required all effluents released into the river to contain less than 1 mg P/l. However, this has proved ineffective as a sole management tool. Schwab, Botha & Van der Merwe (1988) recommended that the 1 mg P/l standard be enforced on the point sources in the Laing Dam catchment, which were exempted prior to 1988.

The realisation of these and similar water quality problems elsewhere has caused the DWAF to change their approach to the protection of water quality from pollution control to water quality management in order to achieve Receiving Water Quality Objectives (RWQO) (Grobler, 1990; Van der Merwe & Grobler, 1990; Department of Water Affairs, 1991). Figure 1.2 summarizes the pathways through which water quality guidelines are compared with existing conditions to define the assimilative capacity of the river. The impacts of different effluents can then be assessed

and waste loads allocated by the Department of Water Affairs and Forestry. The RWQO approach takes into account non-point and point sources of pollution to the degree necessary to maintain the desired water quality. This approach recognises that the receiving water has a certain capacity to assimilate pollution without serious detriment to the quality requirements of recognised users (Department of Water Affairs and Forestry, 1991).
This study is one of the first to provide information for the new RWQO approach on a catchment scale and in a system with diverse water quality problems and contributors. The major aim of this project was therefore to undertake a situation analysis of water quality in the Buffalo River catchment, based on existing data, and from this to provide the information to the DWAF, from which Receiving Water Quality Objectives could be set.

An additional aim of the project was to assess in detail the contribution of runoff from different types of low-cost, high- density housing settlements to the total nutrient load in the river. During the course of the project, there has been an evaluation of the type and adequacy of the water quality information available for different reaches of the Buffalo River, and recommendations have been offered to improve the monitoring systems, since the sensible management of these important water resources relies entirely on the accuracy and availability of existing water quality information.

Several water quality issues in the Buffalo River basin have been investigated in previous studies. Reed and Thornton (1969) reported that high salinity was a major cause for concern, with ± 61 % of salinization originating from natural geological sources, ± 27 % from industrial origins and only 12% directly from human sewerage output. Later studies conducted by Ninham Shand and Partners (1982) and Hart (1982) showed that total dissolved salt concentrations (TDS) had risen from about 150 mg/l in 1978 to over 600 mg/l by the end of 1982 and concluded that the salinity of Laing Reservoir was high and appeared to be increasing to unacceptable levels. Laing Dam is also the main sink for excess nutrients in the middle reaches of the Buffalo River. Palmer and O'Keeffe (1990) found that nutrient concentrations at the dam outflow were substantially lower than at the inflow, and concluded that Laing Reservoir is a nutrient trap, where phosphates are taken up by phytoplankton and/or settle out into the sediments. Selkirk and Hart (1984) measured very high levels of turbidity in the reservoir and concluded that algal blooms are rarer than might be expected, despite the high nutrient concentrations, due to the light-inhibiting turbidity in the reservoir. Due primarily to the role of Laing Dam as a nutrient trap, nutrient concentrations in Bridle Drift are not as high as in Laing. However, sporadic occurrences of algal blooms and unacceptably high faecal coliform concentrations appear to be caused by sewage spills from Mdantsane (Figure 1.1).

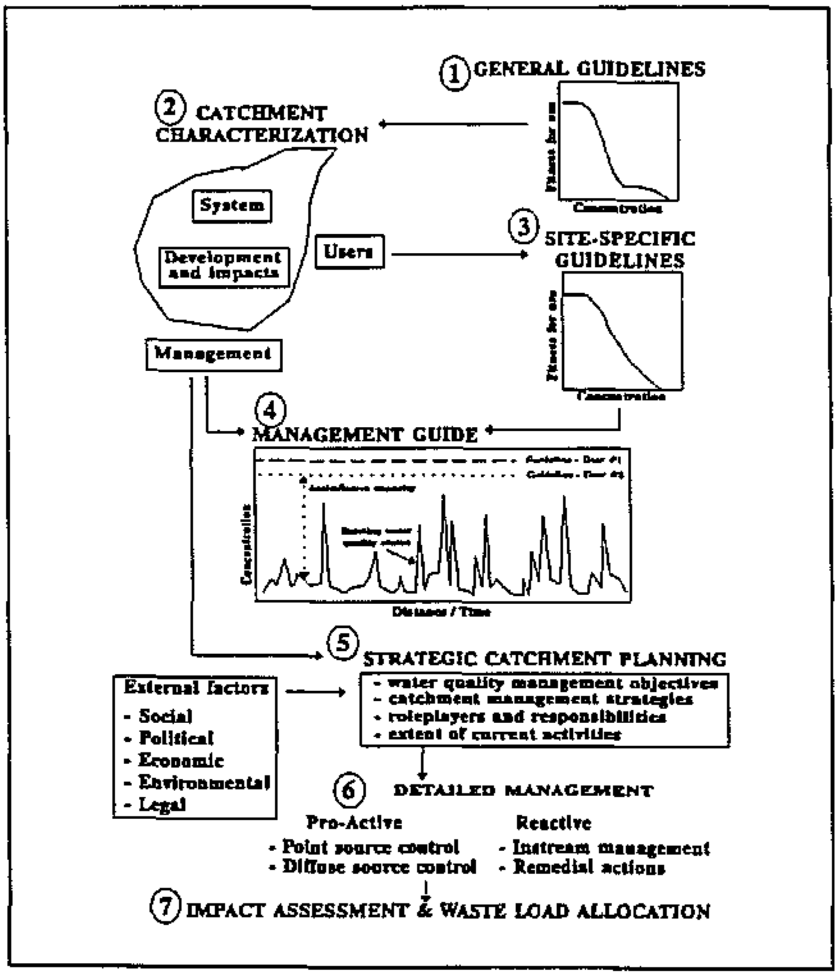


Figure 1.2 The Water Quality Management approach of the Department of Water Affairs and Forestry. (From Van Zyl and Kühn, 1992)

Detailed objectives of the project and the methods used

The objectives of this project were addressed using several methods. A situation analysis is defined as a study using existing data, but in this case additional data were collected to fill in particular information gaps about the river. The users of the river were first identified, and canvassed as to their water use, and water quality requirements. From their responses, and from more general regional water quality guidelines, it was possible to set a framework of requirements for the river. All previous hydrological and water quality data for the river were collected and synthesized in order to obtain a picture of historical and present water quality conditions down the river. These conditions were matched with user requirements to define variables of concern, and to identify any sources of water quality change over time and in different parts of the river. Point and diffuse sources of pollution have been identified and quantified as far as possible, either from existing records, or by additional field measurements.

Salinity and nutrient loads generated in different sections of the river were simulated from concentration and discharge data, although in many cases these simulations cannot be calibrated or verified due to a lack of historical data. Nutrient budgets from low-cost, high-density housing areas were generated by means of interviews with householders. The resulting input of nutrients to the river under different hydrological conditions was then simulated using a storage/runoff model.

Having determined the user requirements, the present water quality, and sources of pollution in the river, the final parts of the report identify water quality problems, areas where they occur, and suggest possibilities for remedial action. The monitoring system for water quality and quantity on the Buffalo River is assessed, and suggestions for improvement are made.

The following is a list of the aims of the project, as defined in the terms of reference, followed in each case by a short description of the approach and methods used to achieve each aim:

1. Identify the major users of water from the Buffalo River and their water quality requirements. (chapter 3)
   Lists of primary users (those who abstract water directly from the river) and secondary users (those who use water supplied by e.g. the municipalities) were collected from a variety of sources. A questionnaire was then distributed to all the users asking them to define their water usage, and water quality requirements in terms of a list of chemical and physical variables. In addition to the commonly recognised users such as industry, agriculture, domestic and recreation, the environmental water quality requirements were estimated empirically, using presence/absence data for invertebrate species, matched against the water quality records for different sites.

2. Define water quality guidelines and criteria for the different water users in the Buffalo River catchment. (chapter 3)
   The user-defined water quality requirements and the DWAF-defined water quality

guidelines were used to identify catchment-specific or regional guidelines applicable to different types of water users in different parts of the catchment.

3. Assess the present water quality in the Buffalo River catchment and define the water quality variables of concern. (chapters 5 and 6)
Water quality monitoring data for different variables were available over short or long time spans from 33 different sites in the catchment. These data sets had been collected by a number of different agencies, but primarily by DWAF and East London Municipality. Water quality variables of concern were defined as those variables which actually or potentially exceed the guidelines or user requirements. Obviously, in the Buffalo River catchment, salinity, nutrient eutrophication and bacterial contamination are the variables which cause most concern, but there are, in addition, variables such as calcium, magnesium, silica, sulphate, alkalinity, turbidity, and pH, all of which reach unacceptable concentrations in the river at some time, and which are therefore also defined as variables of concern.

4. Identify and quantify the sources of pollution, including both point and non-point sources. (chapters 4 and 8)
Sources of pollution were identified from DWAF records, from the responses to the user questionnaires, and from the literature survey of previous reports. Point sources included all sewage treatment works (STW's), pipes, and inflowing tributaries containing effluents. Non-point sources were evaluated in two sections: Runoff from urban areas (see 7 below), and catchment runoff assessed from the hydrological modelling.

5. Supply the Department of Water Affairs and Forestry with the existing water quality situation from which they will determine the assimilative capacity of the catchment for the water quality variables of concern. (chapters 5 and 7)
Assimilative capacity is defined from a comparison of the concentrations of variables of concern in the river with the guidelines and user requirements. This varies for each variable of concern, for different parts of the river, for different seasons, and for different levels of acceptability (from no impairment to barely acceptable).

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. (chapter 8)
Five different types of township/village were identified in the catchment for the assessment of the effects of urban runoff. Unfortunately, since the urban areas are all concentrated in the middle and lower parts of the catchment, where the climate is relatively homogeneous,

it was not possible to make a comparison between different climatic zones.

7. Evaluate the temporal and spatial distribution of phosphorous loads from these urban developments and their effects on water quality in downstream impoundments. (chapter 8)

   Three hundred house to house interviews were carried out in 5 different types of townships, to ascertain the demographics, water use, effluent disposal, waste treatment practices etc. From the results, it was possible to calculate phosphorous loads and to model runoff to the river.

8. Quantify and compare the impacts of both point and non-point source phosphorous loads. (chapter 8)

   From the results of 4 and 7 above, it was possible to calculate and compare the relative loads entering different parts of the river. However, it should be realised that the problems caused by nutrient eutrophication are secondary - usually manifested as the development of algal scums, and that these events are often mediated by physical conditions such as temperature, turbidity, turbulence, and stratification, rather than responding simply to the concentration of phosphorus in the water.

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. (chapter 9)

   Having identified the variables of concern and the zones of the river where most of the problems are situated, it was possible to evaluate the present monitoring programmes in terms of their coverage of important variables, and their spatial and temporal adequacy. Recommendations have been made to fill the apparent gaps.

11. Recommend possible management actions to ameliorate or reduce the impacts of the variables of concern.

    In the final sections of the main report (chapters 10, 11, and 12), the potential management options are discussed, conclusions from the study are drawn together as to the water quality status of the river, and recommendations are offered on ways of improving the water quality, and of monitoring problem areas in the river more effectively.

2. THE PHYSICAL SYSTEM

The Buffalo River is a short (125 km.) coastal system typical of the eastern seabord of South Africa. It originates in the afforested, high rainfall area of the Amatole Mountains between King Williams Town and Stutterheim at an altitude of 1300 m (Palmer & O'Keeffe, 1989a), and runs in a south-easterly direction, passing through King Williams Town, Zwelitsha and Mdantsane, and discharging into the sea at East London, the only river port in South Africa. The catchment covers an area of 1276 km^2, 70% of which falls under the jurisdiction of the Ciskei Government (figure 1.1).

The river consists of a mountain reach zone, characterised by steep, turbulent, clear water, in shallow, narrow channels; followed by a foothill zone which extends from downstream of Rooikrans Dam all the way to the estuary. This lower zone consists of riffle/pool sequences, with the riffles becoming less frequent and the pools more extensive as the river becomes larger. The turbidity of the water also increases downstream as a result of the entrainment of sediments and the development of phytoplankton. The river, in common with most of the coastal rivers of the region, lacks a well-developed floodplain in the lower reaches, and in fact flows through a deeply incised valley as it nears the sea.

The riffle/pool sequences have important implications for the water quality in the river, since the turbulent flow through the riffles helps to aerate the water, while the pools act as settling ponds where organic matter is processed. The structure of the channel therefore has a considerable influence on the self-purification capacity of the river.

The four impoundments on the main channel form major discontinuities in the development of the river. Apart from their effect as physical barriers, reducing flow downstream and hindering movements of the riverine fauna, O'Keeffe *et al.* (1990) found that the dams caused a number of profound alterations to the state of the river downstream: changing the water temperature regimes; reducing salinity downstream (by storing low salinity flood water); altering the state and quantity of organic and inorganic matter; and having variable effects on the nutrient concentrations. The largest tributaries: the Cwengwe; Mgqakwebe; Yellowwoods; Ngqokweni; and Tshabo all join the mainstream above Laing Dam wall, but none are themselves impounded.

2.1 Climate

In broad terms the Buffalo River can be divided up into three major climatic zones.

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 rainfall and are covered with areas of coastal bush and forest. Most of this zone lies outside the region covered by this project, which is restricted to the exploitable freshwater reaches of the river, effectively ending at Bridle Drift Dam.

2.1.1 *Rainfall and evaporation.*

Mean annual precipitation (MAP) over the whole catchment is 736 mm, of which only 8.5% reaches the river as streamflow, due to an average evaporation rate of 1360 mm per year (Hughes and Görgens, 1982). Most of the rain falls at the top of the catchment, with between 1500 and 2000 mm at the watershed in the Evelyn valley, generating more than 40% of the runoff for the entire catchment. From Rooikrans Dam to Bridle Drift Dam the MAP is between 500 - 625 mm, generating local runoff only when there are episodes of heavy rain. At Bridle Drift and Mdantsane MAP increases to 700 mm and to more than 800 mm in East London. Variation in rainfall between years is less extreme than for many catchments in southern Africa, with coefficients of variation (= standard deviation/mean) for most of the rainfall stations of less than 0.25 (Hughes and Görgens, 1982). In the past decade, however, there have been severe droughts, particularly during the early 1980's, and in the last 2 years (1991 and 1992). There is distinct seasonal variation in rainfall, with summer rains (from October to March) practically twice the volume of winter rains (May to August). Evaporation rates peak in December and January at 160 - 170 mm per month, reducing to 70 mm per month during June and July. As a result of this inverse correlation between rainfall and evaporation, seasonal streamflow variability is not as marked as that for rainfall.

Figure 2.1 indicates that there are over 20 Weather Bureau daily rainfall stations located within, or close to the boundary of the Buffalo River catchment. However, many of these stations have only short lengths of record or do not have very long periods of overlapping record. This paints an over-optimistic picture of data availability 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. Figure 2.2 shows the rainfall distribution for each sub-area in the Buffalo River catchment. There are only two Symon's pan evaporation sites in the

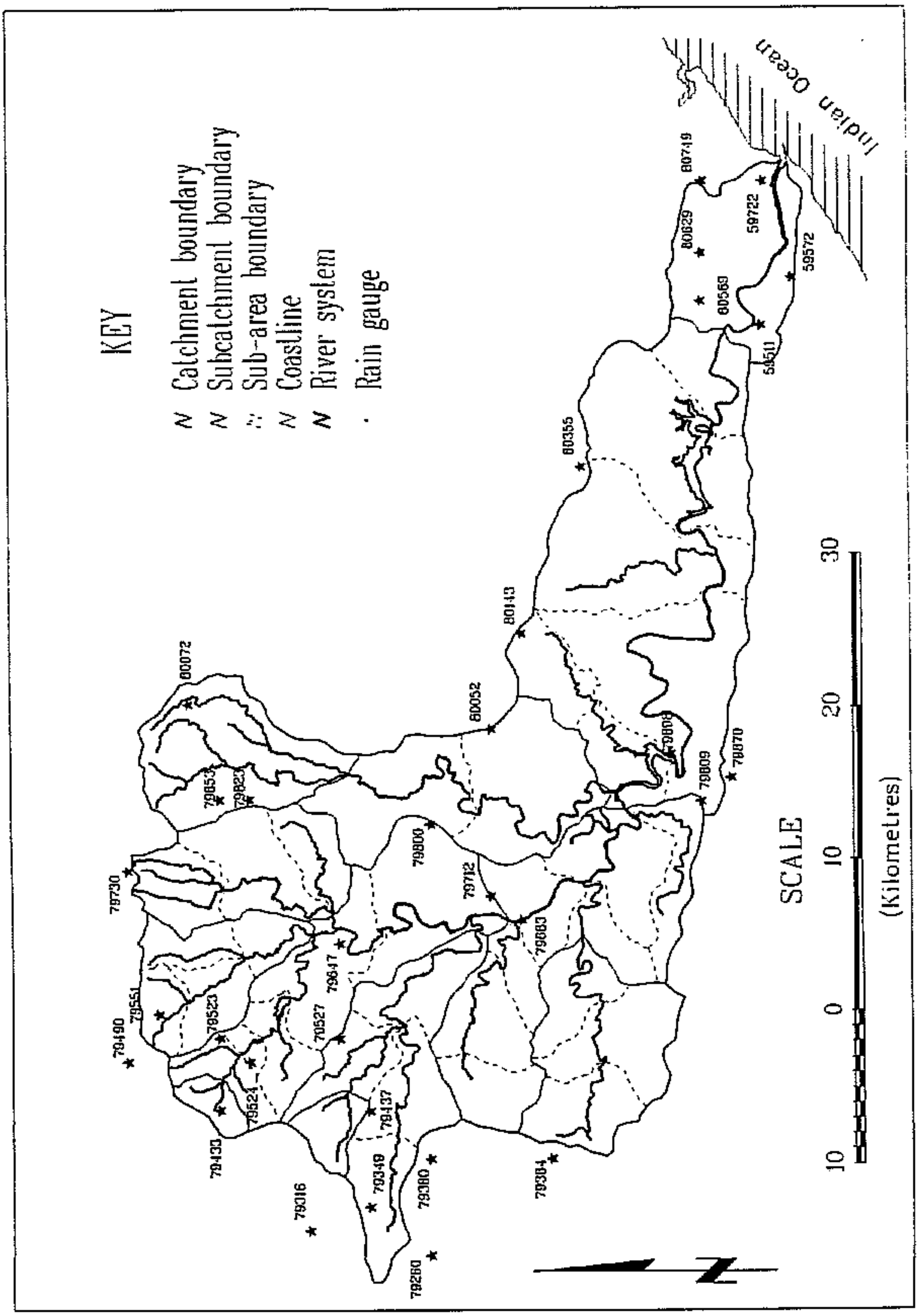


Figure 2.1 The rain gauge sites in the Buffalo River catchment area.

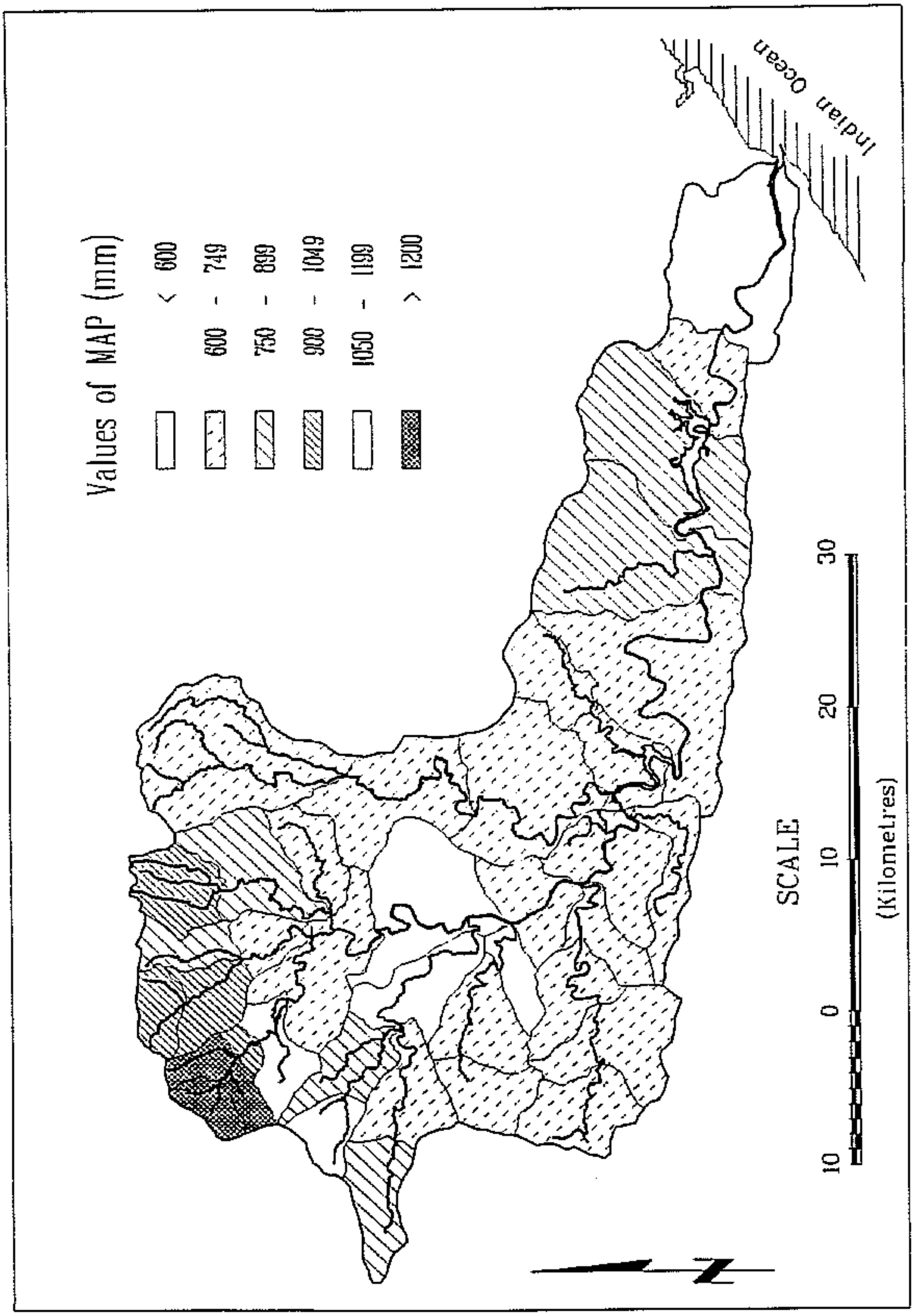


Figure 2.2 The mean annual precipitation for each sub-area in the Buffalo River catchment.

catchment, at Rooikrans and Laing Dams, so that there is little possibility of discerning spatial variation in evaporation.

The effects of climate on water quality are obviously of overriding importance. Rainfall in the upper catchment is the major diluting factor for the effluents in the middle and lower catchment. Unfortunately,the lowest rainfall in the catchment occurs in the lower and middle reaches where the highest water abstractions and return flows occur, and therefore dilution is minimal. Water quality conditions are seldom a great cause for concern during periods of high flow, but critical conditions recur during droughts and in the drier season. In these conditions, a virtual closed loop water supply may be formed between King Williams Town/Zwelitsha and Laing Dam, with increasing concentration of intractable pollutants due to evaporation and a lack of diluting flow from upstream.

2.2 Geology and soils

The Buffalo River catchment lies just within the shallow structural basin of the Karroo and is just beyond the eastern limits of the Cape Fold Belt (Stone, 1982). The principle rock outcrop over 78% of the catchment consists of sedimentary rocks of the Lower Beaufort Series (Adelaide Subgroup) of the Karoo System (Mountain, 1945, 1974, Thornton et al., 1967, Hiller & Stavrakis, 1981, Hart, 1982, Stone, 1982, Weaver, 1982) with dolerite outcrops mainly concentrated in the upper catchment at Evelyn Valley, below Rooikrans Dam, and at the northern and southern rim of the middle and lower catchment (Stone,1982). The river is generally deeply incised, and 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 & 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.

Mountain (1945, 1962, 1974), Bader (1962), Stone (1982) and Weaver (1982) discuss 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) report that the catchment has a sediment yield of 150 t/km²/annum. Weaver (1982), based on Rooseboom & Coetzee (1975), found the sediment production to be 1000 t/km²/annum in the upper catchment, 500 t/km²/annum in part of the middle plateau and 150 t/km²/annum in the coastal belt of the catchment. The total annual sediment yield according to the sediment map is estimated at 66 x 10^4tons (Weaver, 1982).

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.

Since the geology and soils of the majority of the catchment, and especially in the immediate vicinity of the middle and lower river, are of marine derivation, it is not surprising that the natural background concentration of dissolved salts in the river is high (see section 2.5 below). In addition, the friable nature of the soils results in heavy suspended sediment concentrations and turbid waters. The steep and inaccessable slopes of the upper and lower catchment have also played a role in the protection of the river, by preventing development near the river banks. For example, it is doubtful whether the coastal state forestry areas in the lower catchment would have been conserved had the local topography been more gentle.

2.3 Vegetation and land use

The natural vegetation of the Buffalo catchment consisted of four main types (following the designations of Acocks, 1975): small areas of False Macchia (similar to Fynbos) at the summit of the Amatole Mountains; Afro-montane (Yellowwood) forest on the slopes of the mountains; False Thornveld of the eastern province (dominated by grassland and *Acacia karroo*), which covered the middle catchment from below Rooikrans to Bridle Drift Dam; Valley Bushveld in the immediate river valley; and Coastal Forest and Thornveld in the lower reaches. Little of the natural vegetation now remains, except for the forests in the upper and lower parts of the catchment which cover an area of approximately 140km².

The Buffalo River rises as small mountain streams in an area of open heathland and commercial forestry in the Amatole Mountains between King Williams Town and Stutterheim. the steep upper reaches of the river flow through natural montane forest dominated by Yellowwood trees, into the upper two impoundments (Maden and Rooikrans). This is the high rainfall section of the catchment, where the river never stops flowing, and the clear mountain water supports breeding populations of introduced rainbow trout. Downstream of Rooikrans Dam the catchment is largely occupied by a combination of grazing land and subsistence agriculture. There are areas of more intensive cultivation based on irrigation, especially in the upper/middle catchment from Rooikrans to King Williams Town, but these are minor with respect to the overall patterns of land use. Within the matrix of agricultural landuse are the urban/industrial areas: King Williams Town; Berlin; and East London in South Africa; and Zwelitsha; Bisho; Breidbach; Illitha; and Mdantsane in the Ciskei.

2.4 Hydrological characteristics

There are a number of DWAF gauging weirs on the Buffalo River system (table 2.1), and these provide a picture of the range of flows experienced in different parts of the system. Only the gauges at sites 4, 18, and 27 are situated on the main stream, so that, for example, there is no information on flows between Laing Dam and Bridle Drift. The mainstream flows permanently in the upper reaches to Maden Dam, but the short stretch between Maden and Rooikrans Dams is often reduced to pools. Below Rooikrans there is always flowing Water due to releases to maintain the Pirie Trout Hatchery. By the time the river reaches King William's Town, it is often reduced to a trickle during the dry season, by transmission losses, evaporation, and abstraction for irrigation. Return flows from industries and STW's maintain the flow into Laing Dam, but there is no compensation flow downstream of the dam, and the reaches between Laing and Bridle Drift rely on seepage to maintain any base flow during the dry season. Water is released from Bridle Drift Dam to the Umzaniana weir, from which water is abstracted for East London and Mdantsane. Immediately below the weir, treated sewage effluent from Mdantsane enters the river, and forms most of the base flow into the estuary.

2.5 Natural background water quality

The water quality in the upper and upper middle reaches of the Buffalo River has been little changed by development. Salinity is generally less than 20 mSm^{-1}, pH varies from 6.1 in the headwaters to 7.4 downstream of Maden Dam, and median phosphate concentrations are less than 0.1 mg/l (Palmer and O'Keeffe, 1990). The water is therefore of suitable quality for any uses, and Maden and Rooikrans Dams supply consistently good quality water to the King Williams Town/Zwelitsha area, although the supply is limited.

From work done by Palmer and O'Keeffe (1990) and O'Keeffe *et al.* (1990), it is possible to estimate typical natural values for a number of the water quality variables in the middle reaches. Since both salinity and phosphates increase markedly in the middle reaches of the river, but then reduce again downstream of Laing Dam due to the dilution and sedimentation effects of the dam, an extrapolation of conditions from below Rooikrans Dam to below Laing Dam provides a likely rate of change for these variables under natural conditions. Using this method, natural values for

Table 2.1 The medians and fifth and ninety-fifth percentiles of mean daily discharge, measured at DWAF gauging sites on the Buffalo River. (Flows measured as m^3/s).

Site	5 Percentile	Median	95 Percentile
Site 4 (R2H008)	0.602	0.022	0.0001
Site 7 (R2H006)	0.904	0.086	0.011
Site 8 (R2H005)	6.058	0.434	0
Site 12 (R2H009)	0.318	0.013	0
Site 18 (R2H010)	4.085	0.22	0.002
Site 27 (R2H002)	8.329	0.875	0.378

salinity in the vicinity of Zwelitsha would average 50 to 60 mS/m during the dry season and 30 to 35 mS/m during wet seasons. Extrapolating to the Bridle Drift area is more difficult, but concentrations would probably not be very different from the middle reaches. Phosphate concentrations would have been less than 0.3 mg/l at Zwelitsha, and slightly lower at Bridle Drift. The water in the middle and lower reaches of the river is naturally alkaline, and pH would have been between 7.5 and 8.0 for most of the time.

The salinity in the middle and lower reaches of the river is naturally high because of the geological conditions on the middle plateau. Reed and Thornton (1969) found that the major input (± 61%) of salinisation originates from natural geological sources, while ±27% came from industrial origins (textile and tannery) and only 12% from domestic wastes. This has now been confirmed by the present study in which a catchment salinity runoff model indicates that the catchment contributes ± 65% to the total TDS load in the King William's Town-Zwelitsha area (Chapter 5).

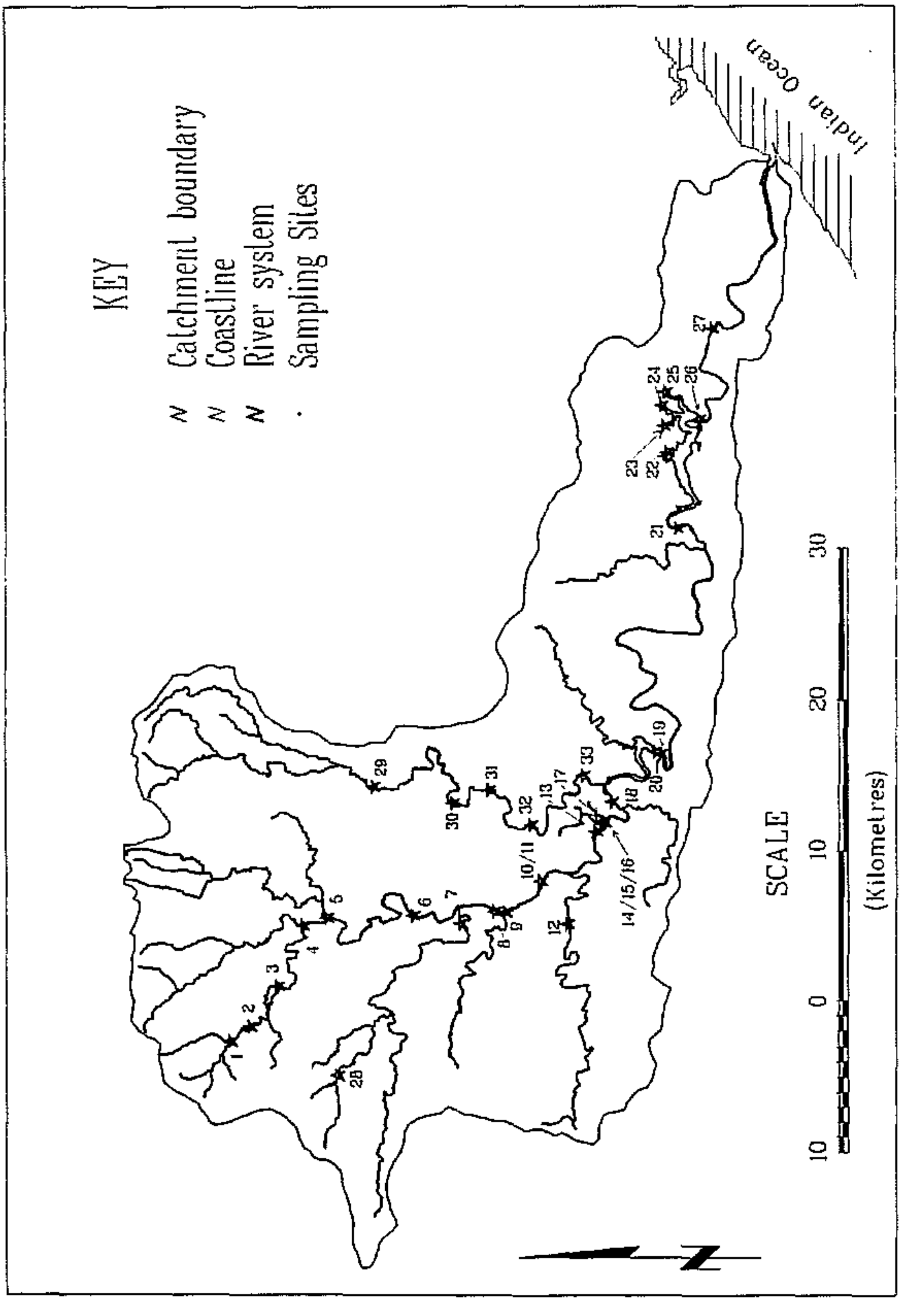


Figure 2.3 The sampling sites in the Buffalo River catchment that are monitored by the different monitoring programmes.

Table 2.2 Selected hydrological characteristics of the four major impoundments in the Buffalo River catchment (MAP - mean annual precipitation; MAR - mean annual run-off; FSL - full supply level)(Ninham, Shand & Partners, 1976; Tow, 1980a, 1980b, 1981, Balzer, 1985; Palmer & O'Keeffe, 1989a, DWA, 1990a, 1990b)

Hydrological characteristics	MADEN	ROOIKRANS	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 (as % of runoff)	0.5	0.5	0.2	0.2
Areas served	KWT	KWT Da Gama Zwelitsha	KWT Zwelitsha Mount Coke Ndevane Berlin Ilitha Phakamisa Bisho	East London Mdantsane Potsdam

3. WATER USERS AND REQUIREMENTS

This section is discussed in more detail in Appendix C.

3.1 Water supply from the Buffalo River

The water usage by the major urban and industrial centres 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 (figure 3.1). 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 and Zwelitsha area but also releases compensation flow to downstream riparian users.

iii) Laing Dam supplies the King William's Town area and Ciskei in the upper and middle reaches.

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.

In the near future there will be the potential to augment the water supply to the Buffalo catchment from the neighbouring Kubusi River, using the Amatole Scheme, by which water from the Wriggleswade Dam to the northeast of the catchment is transferred via a pipeline and canal to the Yellowwoods River. 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 precise effects will depend on how and where the water is to be stored and used, and this has yet to be decided.

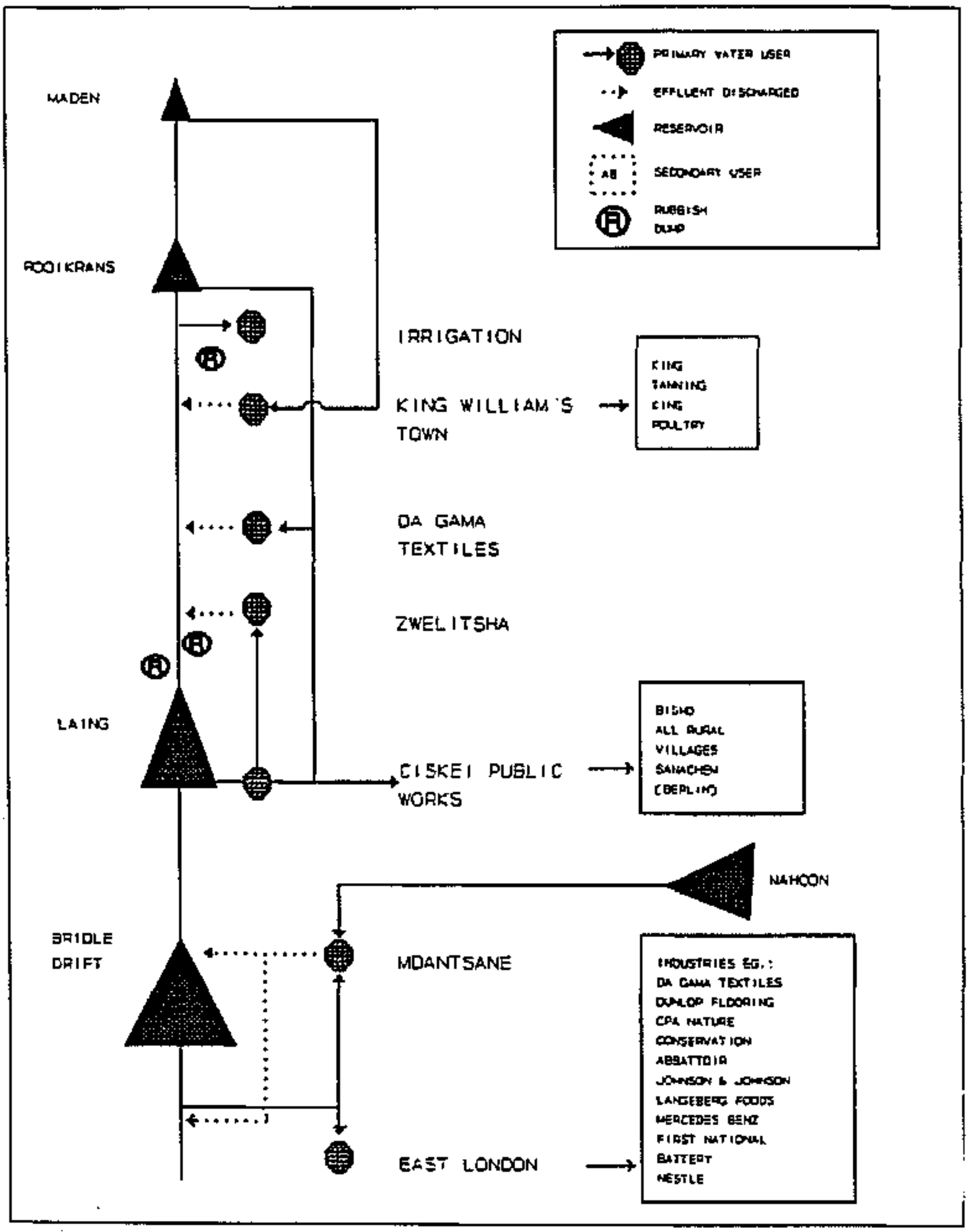


Figure 3.1 A systems diagram showing the situation of the primary users, effluent producers and secondary users in the Buffalo River catchment.

3.2 Major water users and their requirements

3.2.1 *Quantity requirements*

A list of users was originally provided by Water Quality Management, Department of Water Affairs in East London. This was a starting point to determine the main users of the Buffalo River. By using questionnaires, this list was updated during the project to include all relevant users (table 3.1) The Department of Water Affairs and Forestry has identified five main water uses : domestic, agriculture, industry, ecology and recreation. The primary users of the raw Buffalo River water are the King William's Town (47 000 kl/month) and East London (80 000 kl/month) municipalities and Ciskei Public Works (607 500 kl/month) (Ciskei Government) and Da Gama Textiles (3 660 kl/month) (figure 3.1).

These users supply all the other secondary users in the catchment with their water supplies (table 3.2). The agriculture section in the Buffalo River is split between forestry, comprising an area of 90 km^2 and a relatively minor area of 31 ha of irrigation land. Water for environmental needs is not at present being released from the dams, but downstream releases from Rooikrans Dam through the Pirie trout farm, and from Bridle Drift Dam for the East London water supply, do partially fulfill this requirement. There are however, no downstream releases from Laing Dam, and the river flow down to Bridle Drift has to rely on seepage except when the dam is overflowing.

3.2.2 *Water quality requirements*

Two methods were used to assess the water quality requirements for different users in different parts of the river. The water quality requirements (as concentrations) of all the water users were determined by sending questionnaires to all the users asking them to define their needs. The feedback from the users ranged from those who had no idea as to their water quality requirements, to those who used the SABS water quality criteria as their requirements, to users who were very specific as to their water quality requirements, of which some were unrealistic. The water quality requirements of all the users, taken as the minimum or most stringent requirements, were summarized as ideal, acceptable, tolerable and unacceptable in each reach of the river (tables 3.3 to 3.5). In each case the most stringent requirements were used, so as to provide for all the users in the Buffalo River catchment. The second method was to use the DWAF General Water Quality Guidelines, which have been developed for each type of water use, and which are of most use in cases where none of the users were able to define their requirements for a particular variable, or where the user requirements were clearly too stringent to be managed.

Table 3.1 The water users in the Buffalo River catchment users. Names in bold indicate the primary users, ie those who use extract raw water from the river.

Water users	
RSA	**Ciskei**
East London	**Ciskei Public Works**
King William's Town	Municipalities :
Amatola Regional Services Council	Bisho Municipality
Border combing	Frankfort Township
Consolidated textiles	Ilitha Township
Da Gama Textile company	Mdantsane Township
Distillers Corp.	Phakamisa Township
Dunlop Flooring	Potsdam Township
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	
Nature Conservation, Forestry	Rural areas :
Nestle	Kwalini
First National Batteries	Bonke
Sanachem	Tyutyu Resettlement
South African Abattoir corporation	Jongumsovbomvu Military Base
South African Breweries	Zinyoka
Steiner services	Skobeni
Tek Industrials	Mlakalaka
	Ndevana
	Tshabo
	Mncotsho
	Ciskei Technicon/Potsdam
	Tembeni
	Frankfort
	Industrial :
	Da Gama Textiles
	Fumiwe School
	Kei Brick
	Khambusho Youth Training Centre
	Mount Coke Hospital
	Thembelihle School for the Blind
	Zwelitsha Abbattoir

Table 3.2 The major water 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	Water supply	Purpose of water usage	Water treatment	Amount water discharged per month	Monitoring programmes	Destination of effluent	Water quality at discharge
Da Gama Textiles (EL)	± 45 200 kl	Nahoon Dam	Fabric processing	Yes	14 933,7 kl	Yes	Cyril Lord pipeline	pH 10-10.5
Distillers Corp.							Cyril Lord pipeline	
Dunlop Flooring	33 000 kl	Municipal	Boiler, cooling, etc	Yes, Oxygen digestion with chemical plant	± 17 000 kl	No	Sea	-
EL Municipality	80 000 kl	Municipal	Municipal supply	Yes		Yes	Sea	SABS
Johnson & Johnson	±11 214 kl	Municipal	Process + human consumption	Yes, Aeration + activated sludge	±7 214 kl	No	Irrigation land	DWA
King Tanning KWT	2109 kl	Municipal	Leather processing	Yes Flood irrigation	± 1900 kl	No	Buffalo River + irrigation	-
KWT Municipality	±47 000 kl	Maden Rooikrans Laing	Urban + Industrial	Yes	±47 000kl	No	Sea	pH 8.5 Cl 0.4 Turb 1.0 NTU
Langeberg Coop.	±315 000	Municipal	Processing	Solids removed Lime-dosed	±236 250 (not measured)	Yes	Sea	pH 6 - 12
Mercedes Benz	± 18 000 kl	Municipal	Domestic electrocoating, etc.	Yes, In house	± 12 000 kl	No	Sea	-
Nestle	50 000 kl	Municipal	Cleaning	Yes Fat separation	±37 825 kl	Yes	Sea	Sugar content Permanganate Soluble solids - 5000ppm
First National Batteries	2 615 kl	Municipal	Process + production	Yes, Neutralization	2 613 kl	Yes	Sea	pH 6-12 Lead <5mg/l
Sanochem	30 000 - 60000 kl	Municipal	Agricultural chemicals	Yes	Sea output	Yes	Sea	pH 7-8
East London Abattoir corp.	±6000 kl	Municipal	Drinking Slaughtering	No	± 5500 kl	No	Sea	SABS
Tek Industrials	30.000	Municipal	Rinsing during electroplating	No	30.000 kl	No	Sea	pH 5.5
Bisho STW	27 750 kl	Bisho, Police College, Military base & Bisho hospital	Sewage treatment	Yes, oxidation ponds & irrigation (not used at the moment)	Assume 70% of total used	Yes Regional lab	Yellowwoods	Primarily treated for irrigation
Ilitha STW	64 800 kl	Ilitha	sewage treatment	Yes, building new plant	ND	Yes, regional lab	Tributary of Yellowwoods	ND
Mdantsane STW	700 000 kl	Mdantsane & Potsdam	sewage treatment	Yes, biol. filter & evaporation ponds	Zone 3 - 180 000 kl	Yes, Regional lab	Buffalo below EL weir	SABS, general standard

Variable / Industry	Water used per month	Water supply	Purpose of water usage	Water treatment	Amount water discharged per month	Monitoring programmes	Destination of effluent	Water quality at discharge
Potsdam	277 200 kl	Potsdam	Sewage treatment	Yes, biol. filter - Mdantsane evap. ponds	Zone 14 - 90 000 kl	Yes	Mdantsane STW	SABS
Zwelitsha STW	.	Zwelitsha, Phakamisa	Sewage treatment	Yes, Biol. filtration & maturation ponds	72 000 kl	Yes, Regional lab	Buffalo River upstream of Laing Dam	SABS, Special standards
Da Gama (KWT)		Rooikrans Dam	Fabric processing	Yes Evaporation ponds	ND	Yes Regional lab	Irrigation upstream of Mlakalaka Stream	SABS, special P standard
Kei brick		Laing Dam	Processing	Yes, septic tanks	ND	ND	ND	ND
Mount Coke STW	6 000 kl	Mount Coke hospital	Sewage treatment	Yes	ND	Yes, Regional Lab	ND	SABS, special P standard
Zwelitsha abattoir		Laing Dam	Washing blood and intestines	Yes, irrigation and Zwelitsha STW	ND	ND	Irrigation and Zwelitsha STW	ND
Southern Combing Co.		Sandile scheme	Processing	Yes, oxidation ponds, effluent into Buffalo	ND	Yes, Regional Lab	Mgqakwebe River	SABS, special P standard
Bonny bird farms Ciskei		Bridle Drift Nahoon		Yes, pretreatment; into Mdantsane STW	± 90% of total used	Yes, Regional Lab	Mdantsane STW	SABS, Special standard
Proglove Enterprises		Laing Dam		Yes, ponds - evaporation and seepage	ND	Yes, Regional Lab	ND	SABS, special standard

NA = Not applicable

Table 3.3 The most stringent water quality requirements indicated by users in the upper reaches of the Buffalo River catchment.

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)	0.03	-	-	>0.1
Human faecal bacteria (cells/100ml)	-	-	-	
NO2 + NO3 (mg/l)	-	-	-	-
Taste and odour	-	-	-	-
Colour (Hazen units)	-	-	-	-
Turbidity (NTU)	-	-	-	>82
Temperature	-		-	>24.3°C
Suspended solids	-	-	-	-
Total solids (mg/l)	-	-	-	-

Table 3.4 The most stringent water quality requirements indicated by users in the middle reaches of the Buffalo River catchment.

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
NO2 + NO3 (mg/l)	-	-	-	-
Taste and odour	-	-	-	-
Colour (Hazen units)	0	<10	<20	>20
Turbidity	-	<5	-	-
Suspended solids (mg/l)	-	<5	-	-
Total solids	-	<800	-	>1000

Table 3.5 The most stringent water quality requirements indicated by users in the lower reaches of the Buffalo River catchment.

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
NO2 + NO3 (mg/l)	<1	<2	<5	>0
Taste and odour	None	None	None	Any
Colour (Hazen units)	-	-	-	-
Turbidity	-	-	-	-
Suspended solids (mg/l)	-	-	-	-
Total solids	-	-	-	-

One of the DWAF's recent policy decisions has been to take account of environmental water requirements in managing rivers. There are at present no generally accepted methods of setting water quality guidelines for the environment, and the methods described above for other users are obviously not suitable for the natural components of the system. We have therefore developed an empirical method of defining environmental water quality guidelines for the Buffalo River, based on the changes in the invertebrate community at different points on the river. Briefly, the two most polluted sites on the river were identified and the invertebrate fauna from these sites was compared to that from nearby sites up- and downstream. Eight widespread species were found to be absent or rare at the two polluted sites, and this was taken as an indication that water quality was beyond the tolerance range of these species at these sites (the method and results are described in more detail in section 4.4 of Appendix C). The ninetieth percentile concentrations of selected variables, most likely to be the cause of the absence of these species, was then defined as the upper limit for their survival. This is a fairly crude method of defining tolerance limits, but, in the absence of any experimental data, is probably the most realistic method available. Using this method, the salinity tolerance for the natural invertebrate fauna in the middle and lower reaches of the river was estimated at 77 mS/m (equivalent to a TDS of 516 mg/l), and the tolerance for orthophosphate at 0.38 mg/l. Although the data are too crude for the identification of separate ideal, acceptable, tolerable and unacceptable limits, the values above would most likely be equivalent to the tolerable rather than unacceptable limit.

3.3 Impact of development potential on the water quality requirements

The Guide-plan (1993) for the East London/Berlin/King William's Town subregion suggests that the major areas of development in this region will be in population, industry and an increased focus on tourism. The plan does not foresee major changes in the agricultural and conservation areas of the region. The existing centres such as the King William's Town, Berlin, North-west of East London, and Mdantsane will be the nodes for future development . Any development in the area will be encouraged to spread west of the Buffalo River. Population growth up to 600 000 - 750 000 in the Buffalo River catchment will lead to increases in domestic and recreational needs. The need for the development of industries in the region will be increased as the unemployment rate in 1985 in Mdantsane was in excess of 50%, and is unlikely to have improved since then.

As a result of the likely increases in population and industrial development, Kapp Prestedge Retief (1992) estimated that there will be a 4% annual growth rate in intractable industrial effluent, which could rise to 11 800 kl/day, and 119 000 kl/day of domestic and bio-degradable industrial effluent. The largest increases in both saline and sewage treatment effluent were projected for the Mdantsane/Potsdam area.

Only moderate increases or even decreases in saline effluent were foreseen for the King William's Town/Zwelitsha area (Kapp Prestedge Retief, 1992). This situation has changed during 1992 as the Da Gama plant in East London has now been moved to the Zwelitsha plant, increasing the output. Until the move, the Zwelitsha plant had been running at 30% capacity for the last few years (A. Lucas, *pers. comm.*, 1993). The move, and consequent increase in saline effluent, will increase the pressure on the water quality in the middle reaches of the Buffalo River catchment and may cause severe salinisation problems in this area. However, there is the potential to import high quality water via the Amatole inter-basin transfer scheme, and this could improve TDS concentrations in Laing Dam.

Although no growth in the agricultural sector is foreseen, upgraded farming techniques and the reincorporation of Ciskei in South Africa is likely to increase the use of fertilizers. An increase in the diffuse source nutrient loads from the agricultural sector is therefore likely.

Table 3.6 The South African Department of Water Affairs and Forestry water quality guidelines 1993.
NO = No Impact SL = Slight Impact
SI = Significant Impact MA = Major Impact
Concentration as mg/l

VARIABLE	DOMESTIC	INDUSTRIAL		AGRICULTURAL			RECEREATION
		Tanning	Textile	Irrigation	Livestock	Aquaculture	
Aluminium	0 -.15						
Algae (chla)	0 - 5						0 - 15
Alkalinity		0 - 150	0 - 100			0 - 0.025	
Boron				0.0 - 0.2 NO 0.2 - 0.9 SL 0.9 - 1.5 SI 1.5 - 3 MA			
Calcium					0 - 1000		
Chloride				0 - 105 NO 105 - 140 SL 140 - 350 SI > 350 MA			
CO_2						2 - 5	
COD		0 - 20	0 - 10				
DOC	0 - 5						
EC (*mS/m*)	0 - 70	10 - 70	10 - 70	< 40 NO 40 - 90 SL 90 - 270 SI 270 - 540MA			
Floride	0 - 1.0			0 - 2.0	0 - 2		
Faecal coliforms	0						
Hardness as $CaCO_3$	100	0 - 250	0 - 25			20 - 175	
H_2S						0 - 0.002	
Iron	0 - 0.1	0.0 - 0.2	0.0 - 0.2				
Magnesium					0 - 500		
Manganese	0 - 0.05	0.1 - 2.0	0.0 - 0.1	0 - 0.20	0 - 10		
Mercury	0 - 0.005						
NH_4						0 - 0.025	
NO_3	0 - 6				0 - 10	0.06	
NO_2					0 - 100		
Oxygen dissolved						> 8	
pH	6 - 9	6 - 8	7 - 8.5	6.5 - 8.4		6 - 9	6.5 - 8.5
Sodium				0 - 70	0 - 2000		
Sulphate		0 - 200	0 - 250		0 - 1000		
Suspended solids		0 - 5	0 - 5			25 - 80	
TDS				> 500 NO 500 - 2000 SL-SI > 2000 MA			
Temp.						Depending on species	
Total nitrogen				< 5 NO 5 - 30 SL-SI > 30 MA			
Turbidity (NTU)	0 - 1						
Zinc				0.0 - 1.0	0 - 20		

4. EFFLUENT PRODUCERS

Of the water abstracted from the river, a large proportion returns to the river in the form of treated or untreated effluent, or as diffuse runoff. Most of the effluent produced is returned to the river via a treatment works, through which there is some control over the water quality. However, in the Buffalo catchment, by design or accident, there are four types of effluent: Treated domestic and industrial effluent from sewage treatment works; runoff from irrigation schemes which are designed to dispose of industrial effluents; raw or partially treated sewage from faulty pipes; and agricultural irrigation return flows. The following are the major sources of return flow to the river:

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

ii) Waste water from Zwelitsha re-enters the river below the town and upstream of Laing Dam.

iii) Waste water from the Mdantsane area either re-enters the system accidentally through several streams flowing directly into Bridle Drift Dam, or is returned to the river from the sewerage works below the Dam and the abstraction point for East London at Umzaniana.

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

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

The effluent discharge points in the Buffalo River catchment are shown in figure 3.1 in the previous chapter. The primary effluent discharge points and therefore pollution point sources are the sewage treatment works of King William's Town, Zwelitsha, Bisho, Ilitha and Mdantsane and the industrial effluent from Da Gama Textiles (Zwelitsha) and King Tanning that is irrigated onto land next to the Buffalo River. Rubbish dumps next to the river are indicated, because it is likely that seepage during local rainfall events has an effect on water quality, but this effect has yet to be quantified.

Table 4.1 Organisations which produce effluent in the Buffalo River catchment. * indicates those producers that irrigate their effluent onto farming land in the catchment.

Effluent producers	
RSA	**Ciskei**
Breidbach	Bisho STW
King William's Town (STW)	Da Gama Textiles
King Poultry Farm cc. Chicken abattoir *	Ilitha STW
King Tanning Company *	Mount Coke Hospital STW
Da Gama Textiles *	Potsdam and Mdantsane STW
	Proglove
	Zwelitsha STW
	Zwelitsha abattoir

4.2 Present water quality standards for effluents

All effluent producers in the Buffalo River catchment are required to comply with the general effluent standard (See table 4.3.1 in Department of Water Affairs, 1986) and the 1 mg/l special phosphate effluent standard.

4.2.1 *Domestic*

After treatment, domestic waste water discharged into the river still contains nutrients and dissolved salts, normally in excess of the concentrations in the receiving waters. Such effluents will therefore serve to increase the concentrations of these variables of concern.

In the Buffalo catchment return flows from domestic users emanate mainly from King William's Town, Zwelitsha, Bisho, Ilitha and Mdantsane. East London return flows are discharged into the sea, and have therefore no effect on the water quality of the Buffalo River.

4.2.2 *Industrial*

Two industries in the Buffalo catchment use irrigation schemes to dispose of their effluent untreated onto agricultural plots next to the river or its immediate tributaries. They are King Tanning, a leather tannery in King William's Town, and Da Gama Textiles, a textile factory just outside Zwelitsha. Tannery effluent carries high concentrations of dissolved salts, oil and grease, organic wastes and sodium (Buckley *et al.*, 1983). Textile effluent contains high concentrations of water colorants, dissolved salts, organic wastes, insecticides, pesticides, chemical wastes, alkalis, sodium and detergents (Buckley *et al.*, 1983). The tannery effluent is first diluted with domestic sewage effluent, and then discharged into irrigation canals on the South bank of the river. None of the effluent reaches the river during dry periods, but residues are inevitably washed into the river during episodes of heavy rainfall. The textile effluent stands initially in evaporation ponds, and is then sprayed onto land adjacent to the Mlakalaka tributary, from which much of the effluent runs directly into the Buffalo River.

The effect of the run-off from these irrigated lands has not been quantified. Ninham Shand (1982) estimated that 88% of the salt load entering the river from other than natural sources, originates from these two factories. The tannery irrigation scheme has been in operation for more than 20 years, but the status of salt accumulation in the soil has yet to be determined. At present the DWAF has advised that the irrigation system does meet the standard required and has the capacity to cater for likely growth (Pim Goldby, 1990).

4.2.3 *Agriculture*

Agricultural irrigation return flows have only a minor impact on the water quality since only ± 31 ha are under irrigation (Mike Copelan, *pers. comm.*, 1991), and these are restricted to the relatively unimpacted upper/middle reaches above King William's Town. Palmer and O'Keeffe (1990) measured increases in nitrates in these reaches of the river, and suspected that these might have been a consequence of fertilisers in irrigation return flows.

5. WATER QUALITY SITUATION IN THE BUFFALO RIVER

For more detail on the water quality in the Buffalo River see Appendix D.

5.1 Historic and present water quality

The harnessing of the Buffalo River began in 1910 with the building of the Maden Dam in the upper catchment, but the serious exploitation of the river did not begin until the 1950's with the building of Laing and Rooikrans Dams in 1951 and 1953 respectively. Bridle Drift Dam was not built until 1968. Concern was already being expressed about water quality issues by 1950 (eg the Buffalo Catchment Association, 1950), and organised water quality monitoring began in Laing Dam in 1959 by East London Municipality. Prior to this, some salinity measurements were taken in Laing, and these showed that salinity had doubled (from 20 to 40 mS/m) between 1951 and 1960, and had then increased to 60 mS/m by 1965 (Hart, 1982). Bridle Drift Dam showed no such initial increase in salinity, but Tow (1981) reported that algal blooms had occurred annually since 1973 - a few years after the dam was built. Perhaps this provides some perspective on the blooms that have been experienced in the last two years.

5.1.1 *Summary of spatial trends*

Water quality problems are not yet a cause for concern in the upper and upper/middle reaches of the Buffalo River upstream of King William's Town. Palmer and O'Keeffe (1990) report some increase in nitrate concentrations downstream of Rooikrans Dam, and they ascribe this to the use of fertilisers, but concentrations are always within acceptable limits (see chapter 7). This is not to say there will not be problems in the future, if the present rate of increase in informal rural settlement continues.

The information collected during this study has shown that the major variables of concern (salinization, nutrient enrichment and faecal bacteria) are mainly a problem in the King William's Town area upstream of Laing Dam and in Bridle Drift Dam where the algal blooms as a result of nutrient enrichment and bacterial contamination are a major concern to the East London Municipality. Figures 5.1 and 5.2 illustrate the downstream trends in salinity (as TDS) and nutrients (as PO_4-P) in the Buffalo River and clearly show the sites where the highest inputs and increases of both variables occur. For both variables the highest concentrations occur in the middle reaches of the catchment (Sites 12 - 18) and for PO_4-P streams flowing into the Bridle Drift Dam from Mdanstane (Sites 22-25) are causing eutrophication problems.

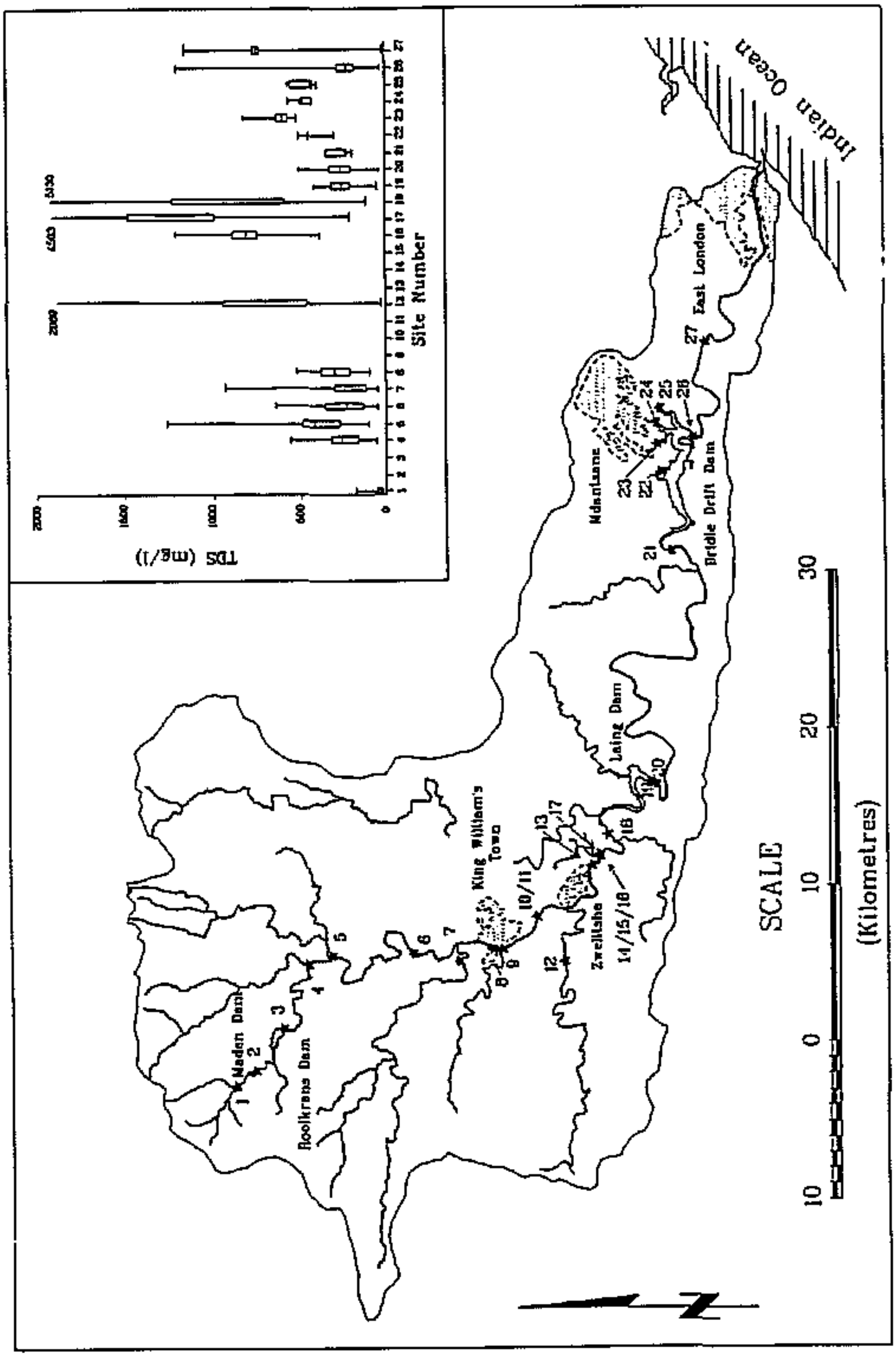


Figure 5.1 Boxplots showing medians, twenty-five and seventy-fifth percentiles and ranges of the TDS concentrations at sites indicated in the Buffalo River from 1960 to 1992.

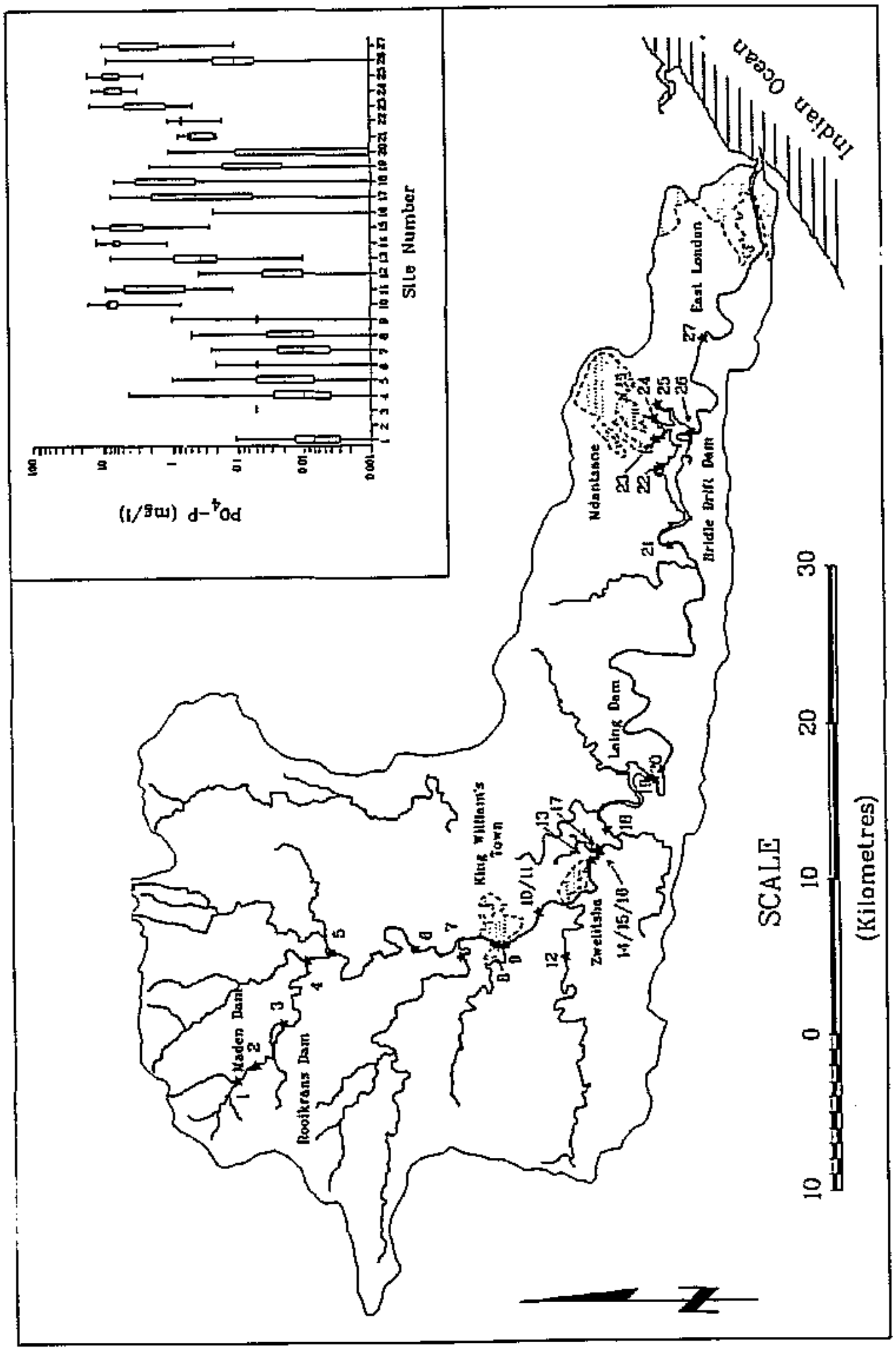


Figure 5.2 Boxplots showing the median, twenty-fifth and seventy-fifth percentiles and ranges of PO_4 concentrations at sites indicated in the Buffalo River from 1968 to 1992.

Since this project began (and at least partly as a result of the preliminary findings), there has been an improvement in conditions in some parts of the river. The latest data incorporated into this analysis was collected in September 1992. According to Mr Kahn of Ciskei Public Works (*pers. comm.*, 1993) the Zwelitsha sewage treatment works has been complying with the conditions of the special phosphate standard since October 1992. This has been confirmed by the latest analysis of samples at the Zwelitsha sewage treatment works outflow. Mr Kahn is also working on the diversion of any runoff caused by spills from the sewer and reticulation systems of Mdanstane. These actions should alleviate the problems of pollution in the Bridle Drift Dam in the near future.

For the third main variable of concern, faecal bacteria, there has been less extensive data collection, and an analysis of spatial trends down the river is not possible. East London Municipality has been collecting samples from Bridle Drift Dam since 1987 (figure 5.3) and samples were collected from the middle reaches (King William's Town to Laing Dam) during this project (figure 5.4). More details are given in Appendix E, and site locations are shown in figure 5 of Appendix E. Concentrations of faecal bacteria are often unacceptably high in parts of Bridle Drift Dam, but the year's sampling in the middle reaches revealed only one instance (at site 5) when concentrations exceeded the 2000 mpn/100 ml standard for recreation.

5.1.2 *Summary of temporal trends*

Although there were initial increases in salinity at low concentrations in Laing Dam during the first 15 years of operation (see section 5.1 above), the more recent records do not show long term increases either in the upper, middle or lower reaches (figure 5.5), despite fears expressed by Hart (1982). Similarly, although phosphate concentrations in Laing Dam prior to 1967 were rarely greater than 0.01 mg/l (Hart 1982), and have subsequently risen to between 0.1 and 1 mg/l, there is again no evidence from the more recent record of long term increases (figure 5.6). It is not unusual in an impoundment for there to be an initial increase in concentrations, as the organics in the basic decompose, and as initial flows transport matter into the dam from upstream. Once the dam equilibrates, and enters a regular cycle of lowering water levels and flushing floods, concentrations should rise over drought periods, but are then reset during floods. The fears of gradually increasing concentrations in Laing Dam during the 1980's were a consequence of the severe droughts of those years, and concentrations have reduced since then. Although no long-term trends are apparent in the main Buffalo River, phosphate concentrations in the Yellowwoods River have increased markedly since the mid-seventies (figure 7, Appendix D), most probably as a result of the development of Bisho and particularly its sewage treatment works.

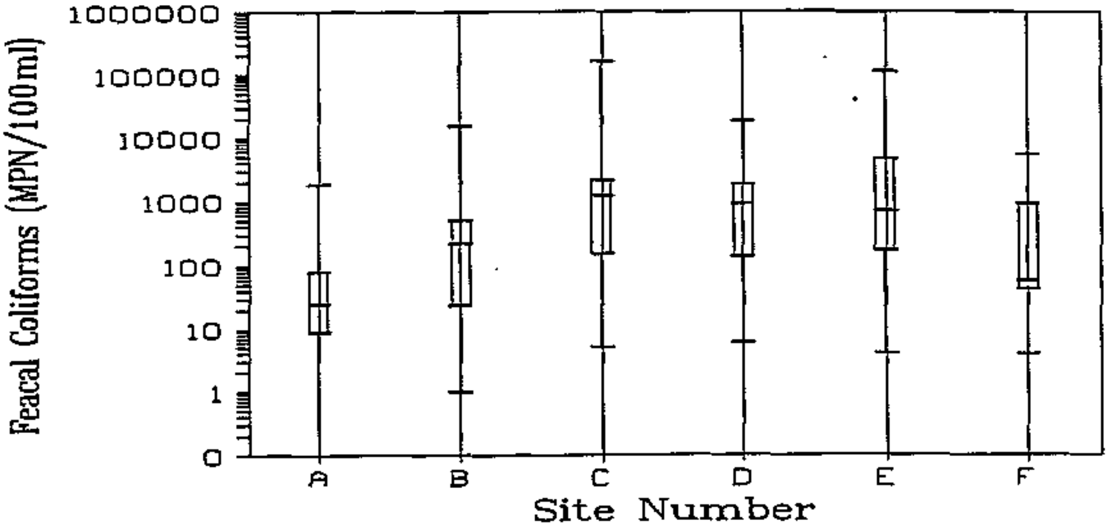


Figure 5.3 The geometrical mean twenty-fifth and seventy-fifth percentiles, and ranges of faecal coliform bacterial counts (MPN/100ml) at the inflowing streams and in the Bridle Drift Dam near the dam wall from 1987 to 1992.

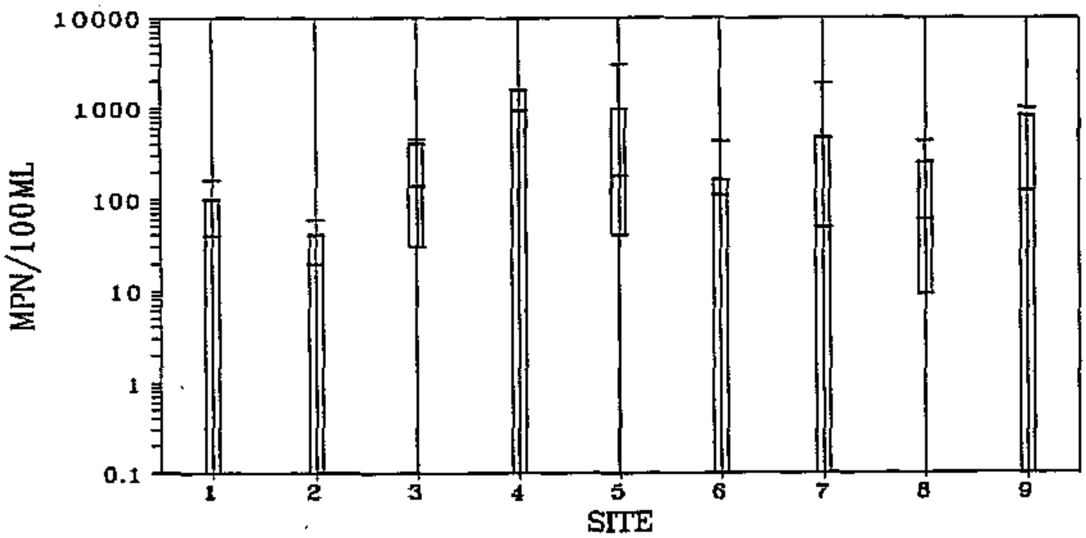


Figure 5.4 The geometrical mean twenty-fifth and seventy-fifth percentiles, and ranges of faecal coliform bacterial counts (MPN/100ml) at the sites in the King William's Town area from 1991 to 1992.

In the years since 1987 when East London Municipality started regular sampling for bacteria in the Bridle Drift Dam, it is not possible to identify any increasing trends in faecal pollution over time, but this is a very short period of record (figure 5.7). Thornton *et al.* (1967) did some sampling in Bridle Drift Dam, and the mean numbers of bacteria appear to have increased since then (see table 1 Appendix E).

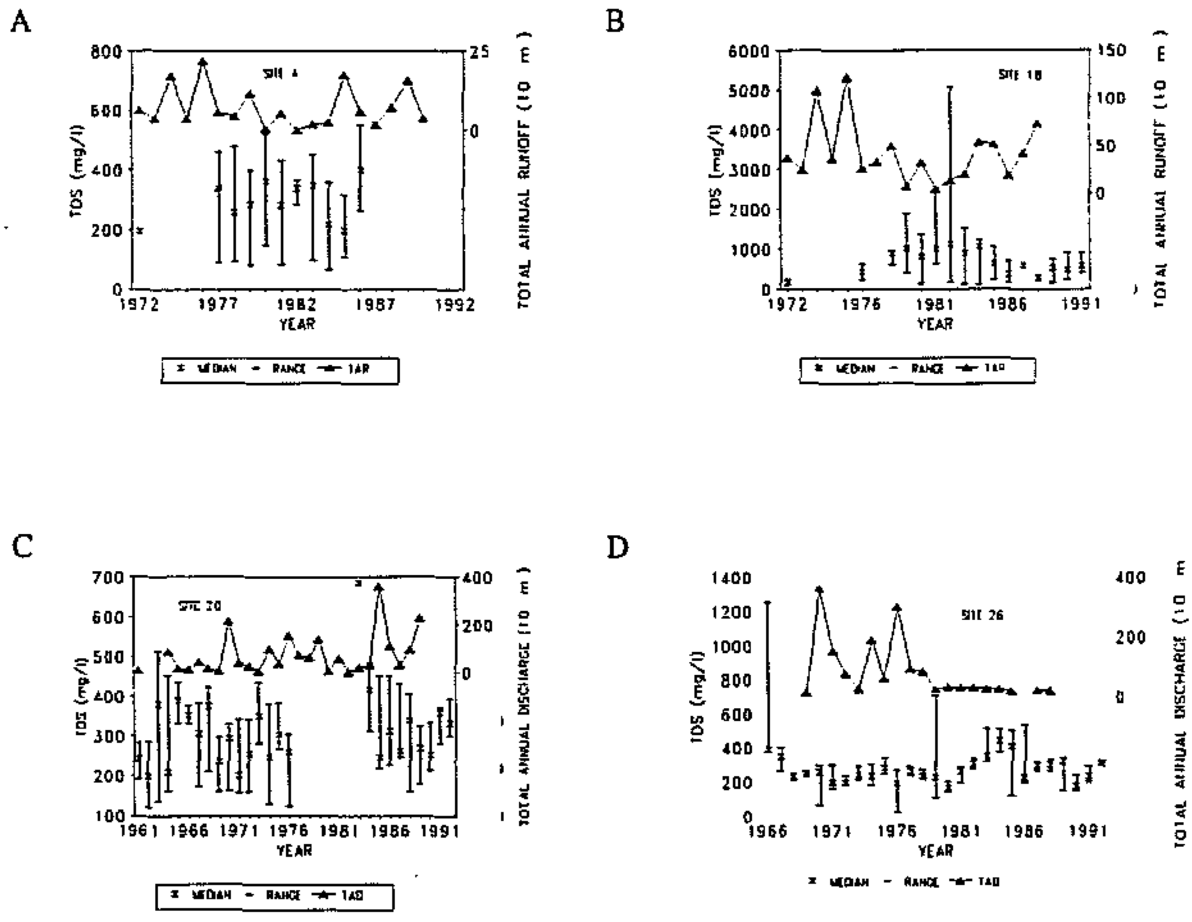


Figure 5.5 The temporal trends in median, minimum and maximum TDS concentrations in the upper (A - Site 4), middle (B and C - Site 18 and 20) and lower reaches (D - Site 26) of the Buffalo River.

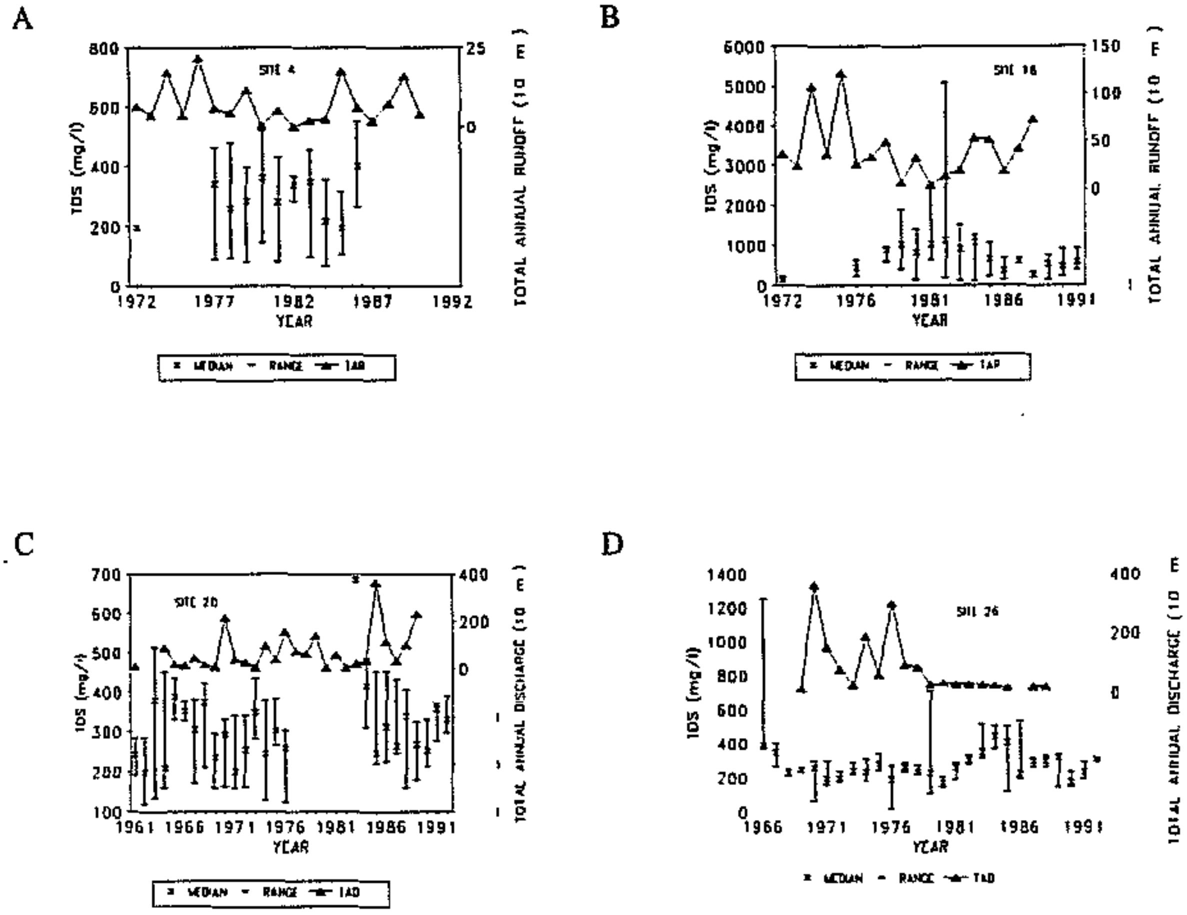


Figure 5.6 The temporal trends in median, minimum and maximum PO_4 concentrations in the upper (A), middle (B and C) and lower reaches (D) of the Buffalo River.

5.1.3 *TDS loads*

Salinization has been identified as one of the main variables of concern in the middle and lower reaches of the Buffalo River catchment (see chapter 6). It is therefore important to know what the contributions of the catchment as a non-point diffuse source is, as well as the contribution of the point sources to the total TDS load into the supply reservoirs in the catchment.

In order to assess the relative importance of different sources, a simulation was run using discharge and concentration data from the DWAF gauging weirs. Because the concentration data is only sporadic, and is seldom collected during high flow events, it is difficult to provide confidence limits for these results. However, from figures 5.8 and 5.9 it is evident that the catchment contributes the greatest proportion to the total load into Laing Dam for almost 90%

of the time. Over the 45 year period of the simulation the catchment contributed 65% of the total load and the point sources 35%. The catchment contributions to Bridle Drift Dam varied considerably during the 45 year period of simulation and contributed 45% to the toal load. Laing Dam outflows were also variable and contributed 30% to the total load entering Bridle Drift Dam. The point source contributions, which amount to 25% of the total load , are spills from the Mdantsane sewers and reticulation systems, and there are no other point sources flowing into Bridle Drift Dam.

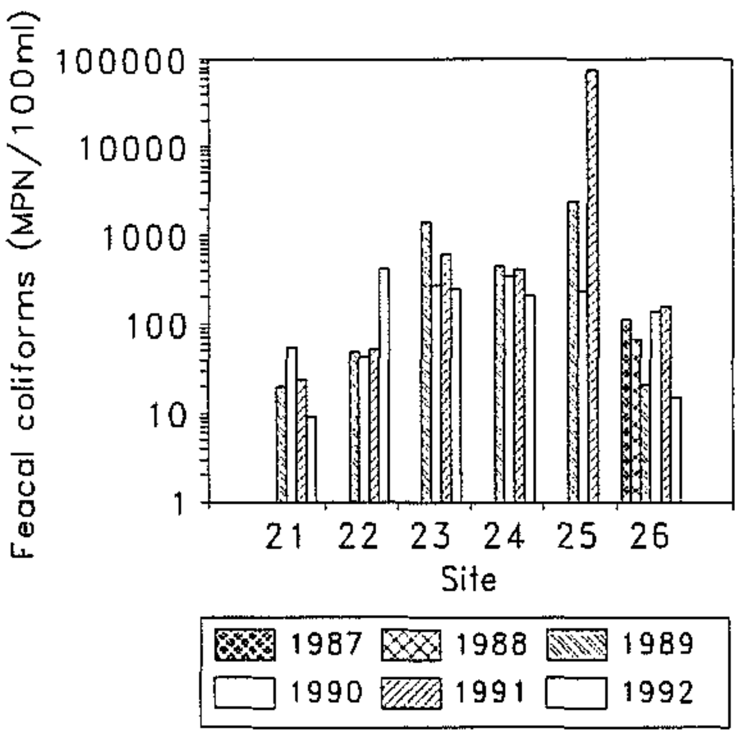


Figure 5.7 The temporal changes in geometrical mean feacal coliform counts (MPN/100ml) in the Bridle Drift Dam area of the Buffalo River catchment from 1987 to 1992.

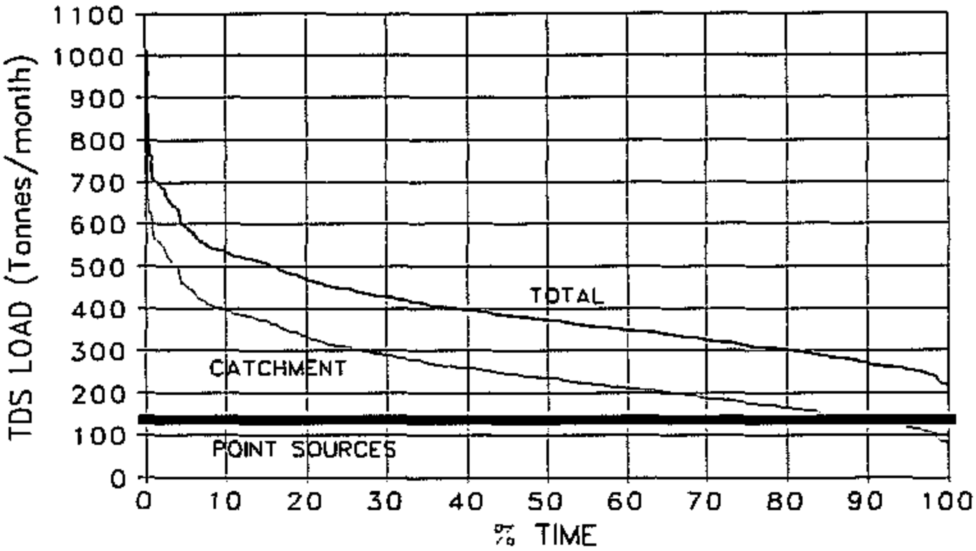


Figure 5.8 A simulated distribution curve showing the contributions of the catchment and point sources to the total TDS load entering Laing Dam for a 45 year period.

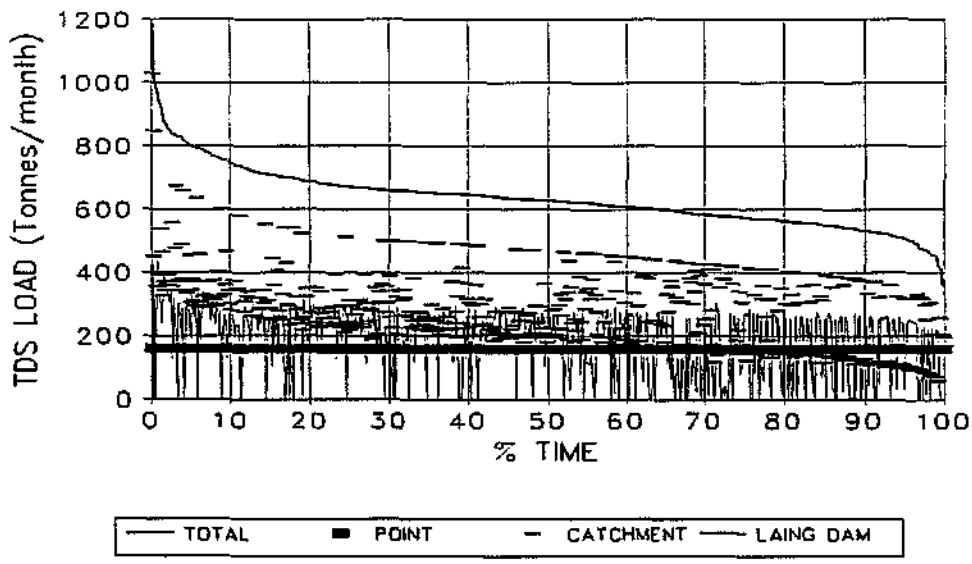


Figure 5.9 A simulated distribution curve showing the contributions of Laing Dam, the catchment and point sources to the total TDS load entering Bridle Drift Dam over a 45 year period.

5.1.4 *Total Phosphorus loads*

(This section is discussed in more detail in Appendix H)

In the middle reaches of the river the urban contributions to the total P load are important during high runoff events and form the dominant contribution to the total P load for ±27% of the time (figures 5.10 and 5.11). Urban washoff contributed 62% of the total P load to

Laing Dam during the 45 year period of the simulation. During low flow events (which persisted for ± 73% of the time) the point source P loads dominated contributions to the total P load entering Laing Dam, but contributed only 30% to the total load over the 45 year period. Diffuse catchment contributions to the total P load entering Laing Dam made up only 8% over the 45 year period.

In the catchment of Bridle Drift Dam phosphorus from diffuse urban runoff formed the dominant contribution to the total P load entering the dam for almost 70% of the time (figure 5.12 and 5.13), and contributed 73% to the total P load over thew 45 year period of simulation. The point sources (spills from the sewage and reticulation systems in Mdantsane) were the main contributors to the total P load for 30% of the time during low flows and contributed 8% of the total P load. The catchment ocntributions were a negligible 0.13% and Laing Dam contributed 19% to the total P load over the 45 year period.

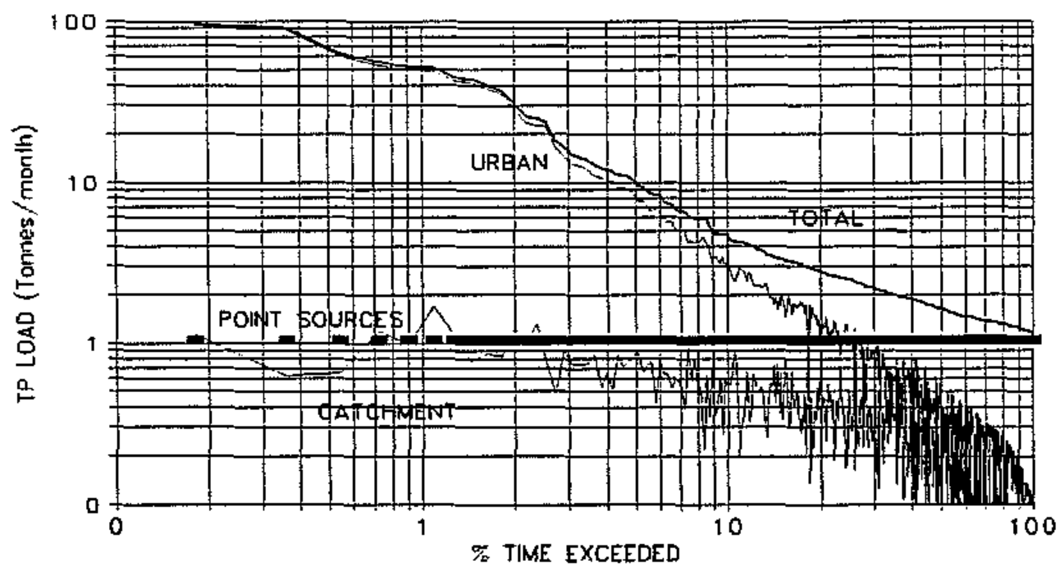


Figure 5.10 A simulated distribution curve showing the contributions of the urban, catchment and point sources to the total P load entering Laing Dam for a 45 year period.

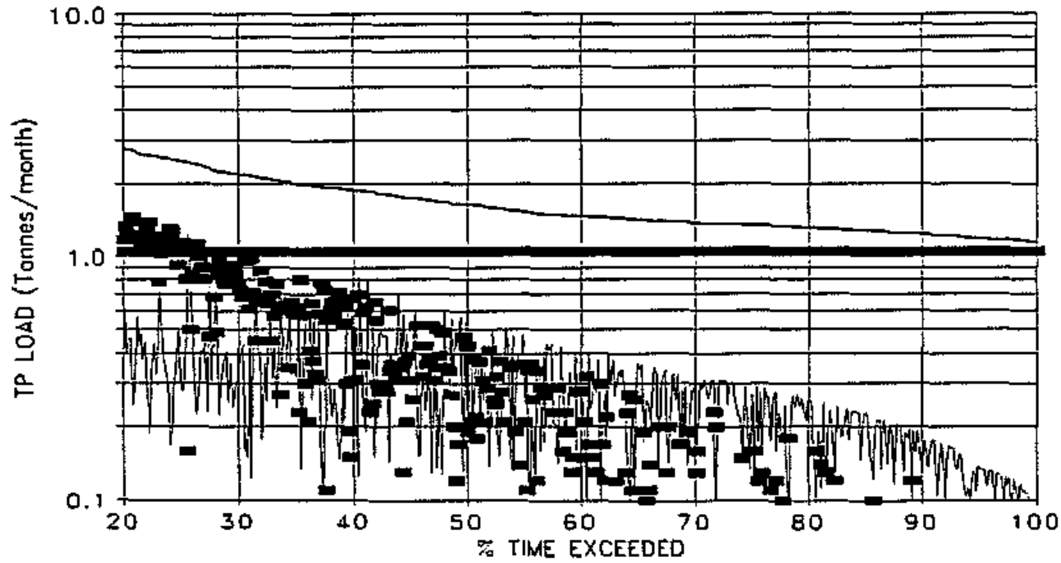


Figure 5.11 A simulated distribution curve showing the contributions of urban, catchment and point sources to the total P load (zoomed in to 20 - 100%) entering Laing Dam over a 45 year period.

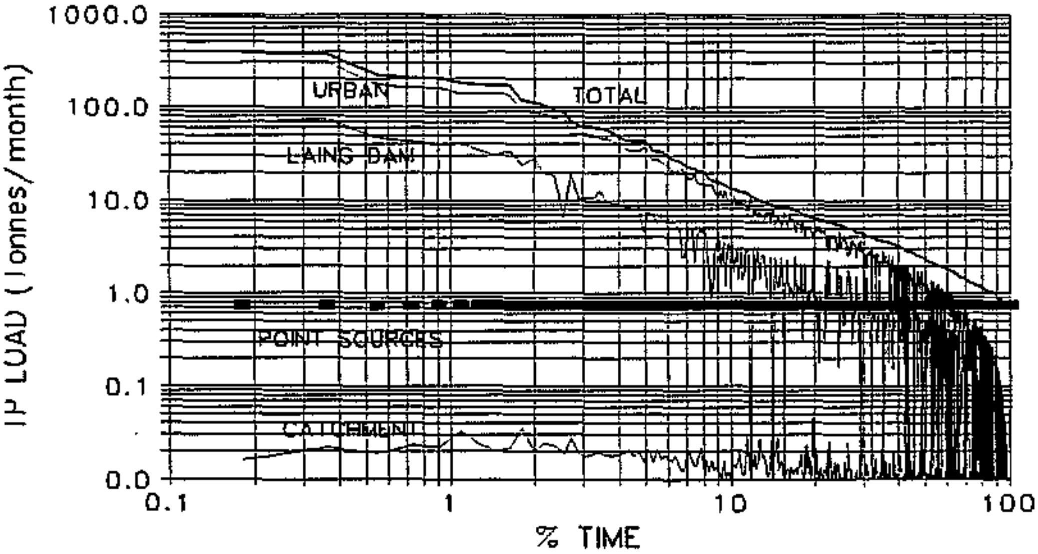


Figure 5.12 A simulated distribution curve showing the contributions of Laing Dam, urban, catchment and point sources to the total P load entering Bridle Drift Dam for a 45 year period.

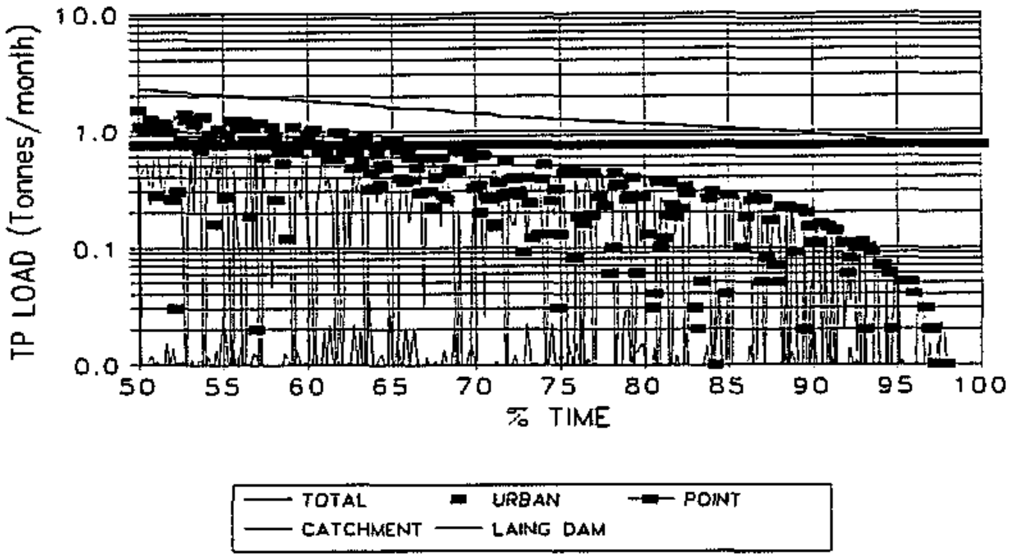


Figure 5.13 A simulated distribution curve showing the contributions of Laing Dam, urban, catchment and point sources to the total P load (zoomed in to 50 - 100%) entering Bridle Drift Dam over a 45 year period.

5.2 Summary of the present water quality, and comparisons with user requirements

The remainder of this chapter is a summary presentation of the data available for all water quality variables, compared to the stated user requirements and the DWAF guidelines. Tables 5.1 to 5.26 summarise each variable in terms of the median, minimum, maximum, fifth and ninety-fifth percentile concentrations and indicate what sector of user acceptability each concentration falls within (from ideal to unacceptable). Each table is accompanied by a figure (eg figure 5.14, 5.16 etc.) which compares the median concentrations down the river with the most stringent user requirements for each section of the river, and with the DWAF guidelines (either general or specific for appropriate industries). Further figures (5.15, 5.17, 5.19 etc. to 5.65) describe the seasonal changes in median and ninety-fifth percentile concentrations of each variable, in different sections of the river, in comparison to the user requirements and/or DWAF guidelines.

Very few of the variables remain within the no impact/ideal limits throughout the river at all times. However, it is encouraging to see that, except for the inflow to Laing Dam (site 18), the salinity levels are well within acceptable limits (table 5.22, figures5.56 and 5.57). Total phosphate concentrations are also within acceptable limits for most of the time (table 5.24, figures 5.60 and 5.61), but this is more a function of the very high limit set by users for unacceptable conditions (55 mg/l). This limit was set in relation to the direct effects of phosphates in the water, which are mild, rather than its indirect effects in promoting algal blooms, which take effect at much lower concentrations. The ortho-phosphate concentrations (table 5.17, figures 5.46 and 5.47) are perhaps more revealing, showing median values at the inflow to Laing Dam (site 18) in excess of the 1 mg/l special standard for most of the time.

Although extreme concentrations of many variables exceed unacceptable levels, these are relatively rare events. Median concentrations of calcium, chloride, electrical conductivity, total alkalinity and turbidity all exceed tolerable limits for the most stringent user requirements in the middle reaches. In the upper and lower reaches meadian concentrations for all variables are within tolerable limits (where data are available and users have defined their requirements).

Tables 7.1 and 7.2 in chapter 7 on assimilative capacity provide a clear overview of conditions in the river, relative to user requirements and the DWAF guidelines. They indicate that, while conditions are seldom ideal except in the upper river, many variables persist at concentrations well below the unacceptable/major impact levels.

Table 5.1 The minimum, median and maximum boron concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requiremnts.

B	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc *mg/l*	User require ments	Conc *mg/l*	User require ments	Conc *mg/l*	User require ments	Conc *mg/l*	User require ments
Min	-	-	0.00	-	-	-	-	-
5 Percentile	-	-	0.00	-	-	-	-	-
Med	-	-	0.01	-	-	-	-	-
95 Percentile	-	-	0.017	-	-	-	-	-
Max	-	-	0.02	-	-	-	-	-

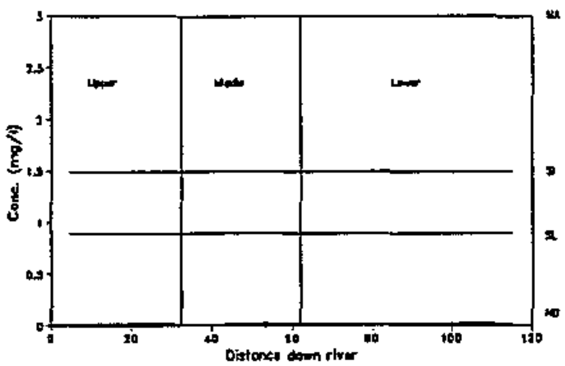


Figure 5.14 The median boron concentrations down the Buffalo River compared to the water quality guidelines as set by DWAF for irrigation and livestock (MA = major impact, SI = significant impact, SL = slight impact, NO = no impact).

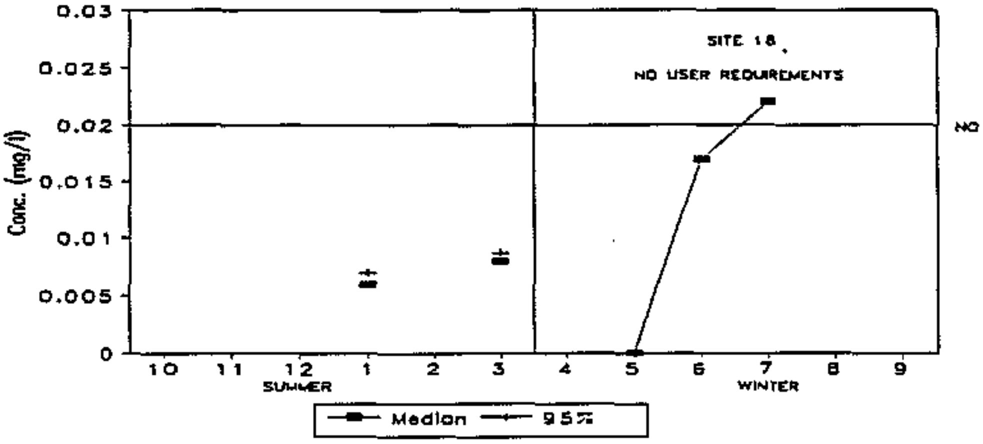


Figure 5.15 The median and 95 percentile seasonal boron concentrations at Site 18 in the Buffalo River compared to the water quality guidelines as set by DWAF for irrigation and livestock (MA = major impact, SI = significant impact, SL = slight impact, NO = no impact).

Table 5.2 The minimum, median and maximum calcium concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable

Ca	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20			
	Conc *mg/l*	User requirements	Conc *mg/l*	User requirements	Conc *mg/l*	User requirements	Conc *mg/l*	User requirements
Min	5.1	TO	7.0	ID	6.8	ID	4.4	ID
5 Percentile	8.7	TO	11	AC	9.4	ID	8.8	ID
Med	23.6	TO	31.2	UN	17.2	TO	16.2	TO
95 Percentile	40.7	TO	51.4	UN	24.4	TO	21.8	UN
Max	52.6	TO	106.7	UN	34.8	UN	186.0	UN

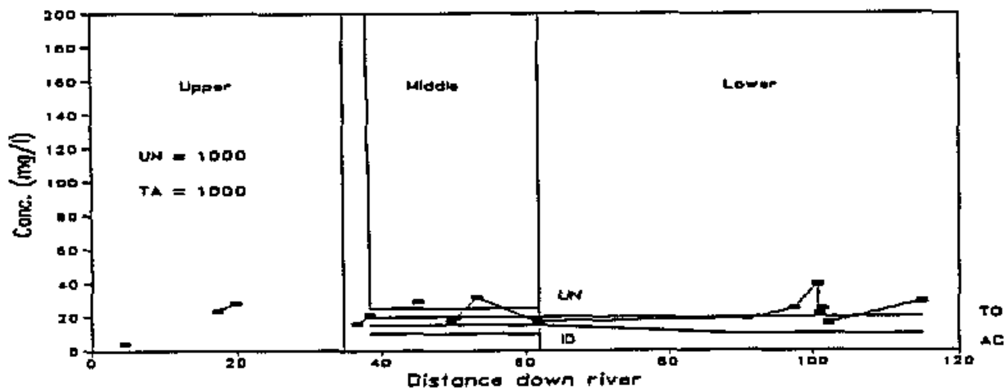
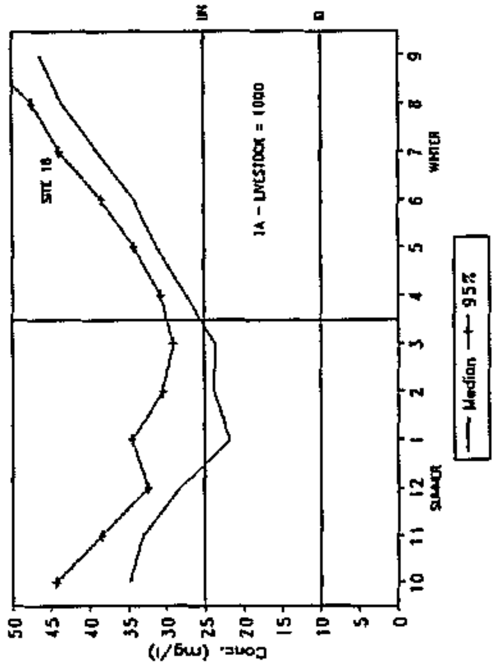


Figure 5.16 The median calcium concentrations (■) down the Buffalo River compared to the user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and the water quality guidelines upper target (TA) for livestock as set by DWAF.



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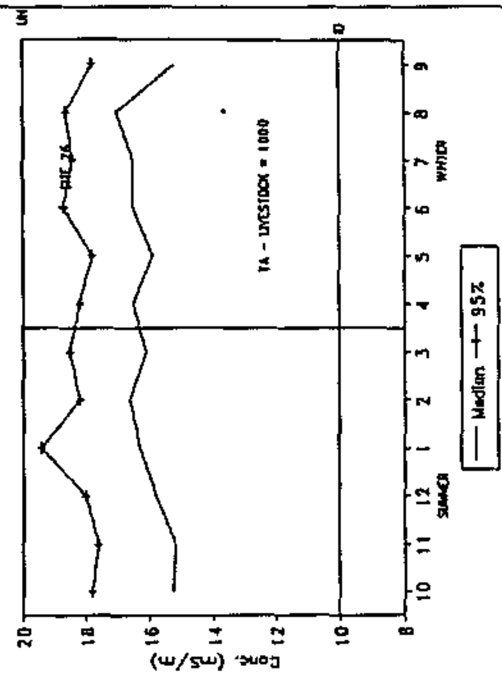

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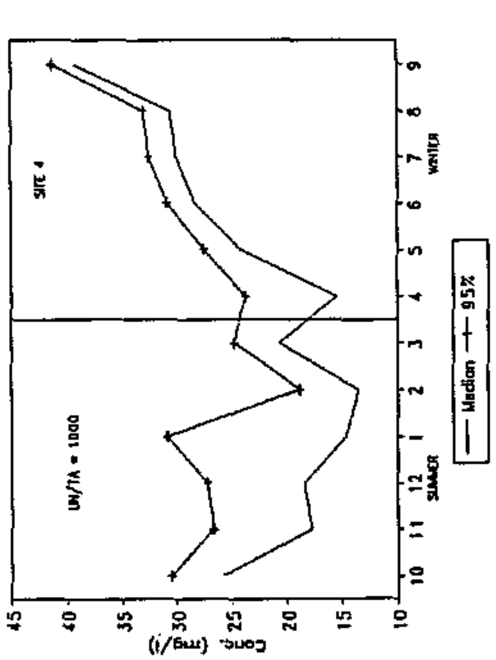

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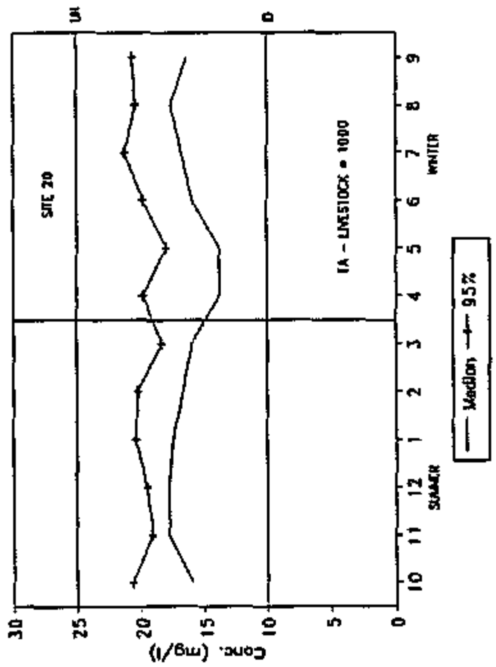

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Figure 5.17 The median and 95 percentile calcium concentrations at four sites on the Buffalo River compared to the user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and the water quality guidelines upper target (TA) for livestock as set by DWAF.

Table 4.3 The minimum, median and maximum chloride concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent users requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

Cl	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc *mg/l*	User requirements	Conc *mg/l*	User requirements	Conc *mg/l*	User requirements	Conc *mg/l*	User requirements
Min	17.7	ID	31.2	ID	18.0	ID	7.8	AC
5 Percentile	27.5	ID	48.3	ID	46	ID	45	AC
Med	66.6	AC-TO	203.7	UN	84.0	AC	83.0	AC
95 Percentile	117.8	AC-TO	393.4	UN	130	TO	132	TO
Max	142.9	AC-TO	2469.7	UN	158.0	TO	558.0	UN

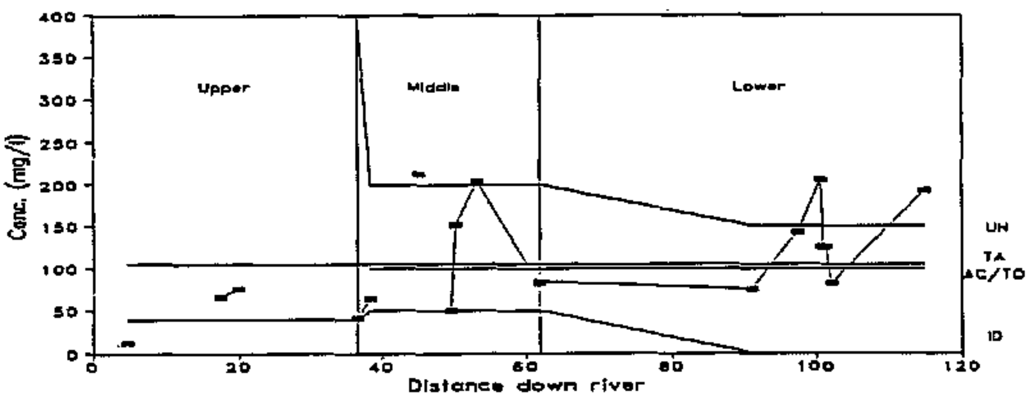
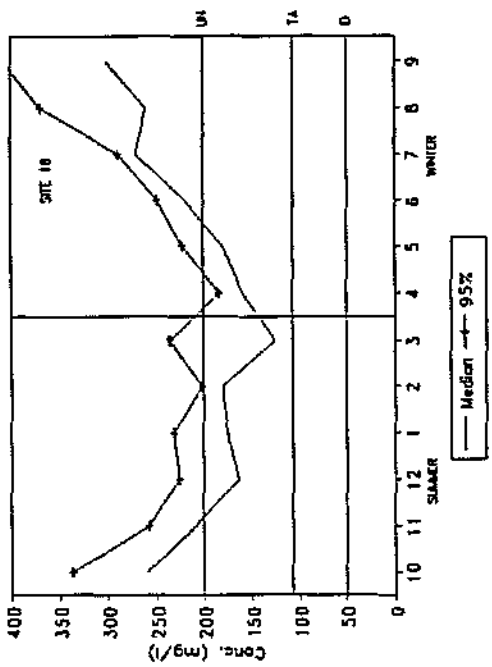


Figure 5.18 The median chloride concentrations down the Buffalo River compared to the user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and the water quality guidelines maximum target (TA) as set by DWAF for irrigation.



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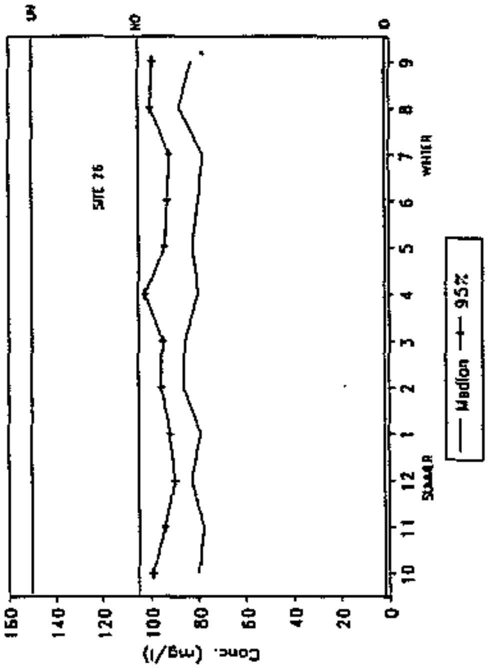

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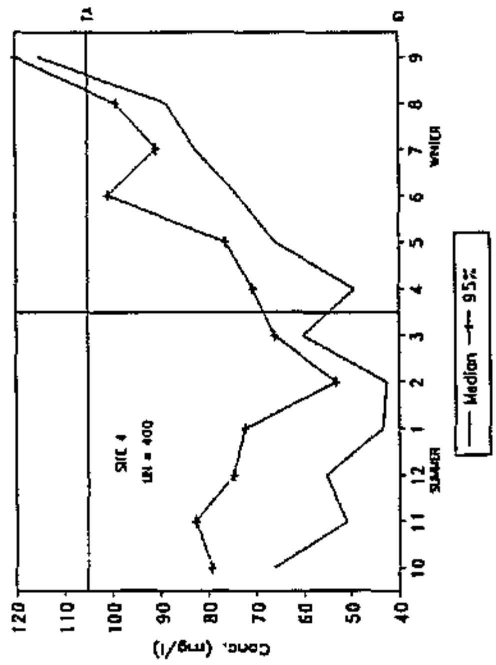

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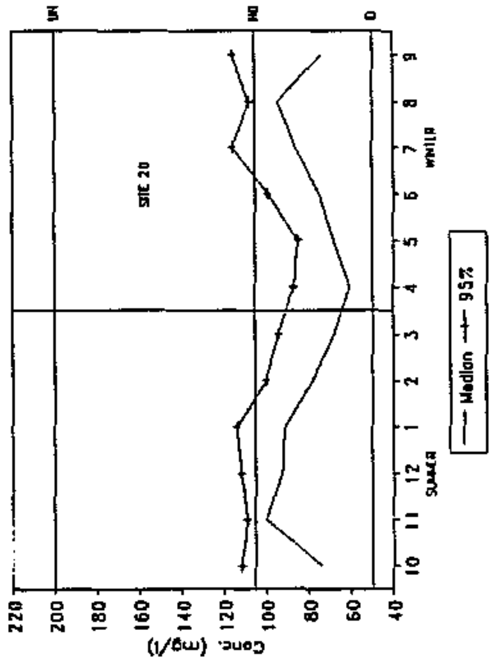

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Figure 5.19 The median and 95 percentile chloride concentrations at four sites on the Buffalo River compared to the user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and the water quality guidelines maximum target (TA) for irrigation as set by DWAF.

Table 5.4 The minimum, median and maximum Chemical Oxygen Demand concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. NR = no requirements

COD	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	conc (*mg/l*)	User requirements
Min	-	NR	4.0	NR	4.0	NR	0.0	NR
5 Percentile	_	NR	24.6	NR	10	NR	0.049	NR
Med	-	NR	52.0	NR	24.0	NR	17.0	NR
95 Percentile	_	NR	104	NR	45	NR	40.0	NR
Max	-	NR	187.0	NR	145.0	NR	242.0	NR

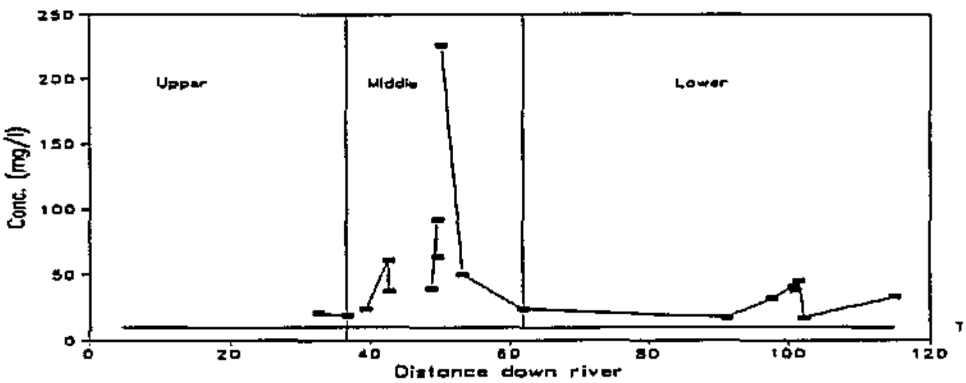
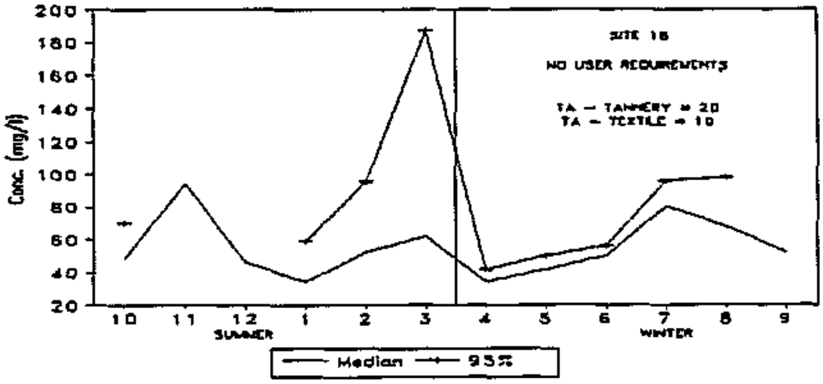


Figure 5.20 The median COD concentrations down the Buffalo River compared to the water quality guidelines maximum target (TA) as set by DWAF for the textile industry.



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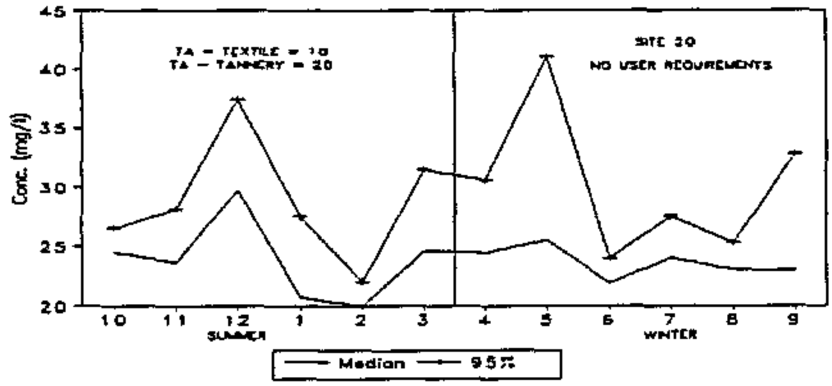

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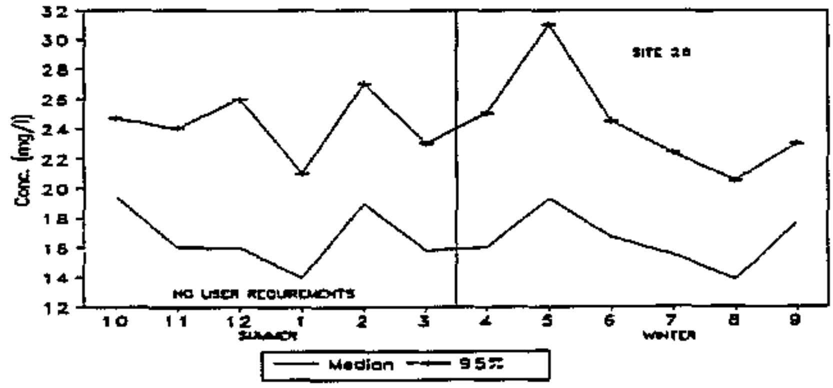

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Figure 5.21 The 95 percentile and median COD concentrations in the Buffalo River compared to the water quality guidelines maximum target (TA) as set by DWAF for the textile industry.

Table 5.5 The minimum, median and maximum DOC concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. NR = no requirements.

DOC	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	-	NR	0.00	NR	-	-	-	-
5 Percentile	-	NR	0	NR	-	-	-	-
Med	3.64	NR	8.42	NR	-	-	-	-
95 Percentile	-	NR	17.46	NR	-	-	-	-
Max	-	NR	27.12	NR	-	-	-	-

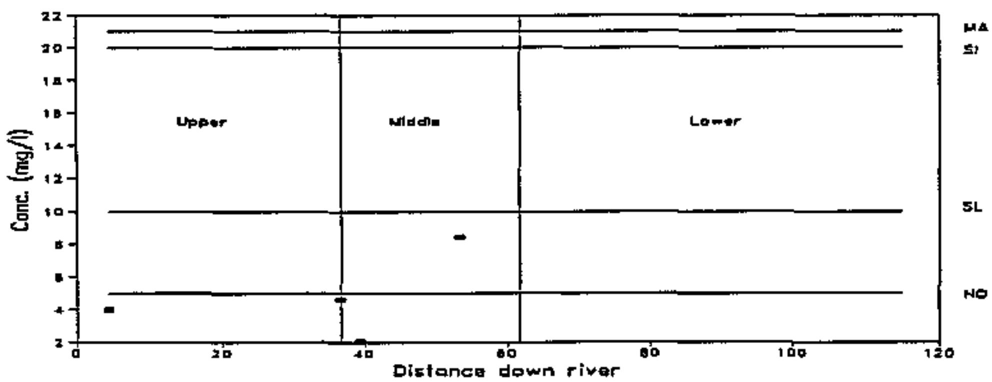


Figure 5.22 The median DOC concentrations down the Buffalo River compared to the water quality guidelines (MA = major impact, SI = significant impact, SL = slight impact, NO = no impact) as ser by DWAF for domestic uses.

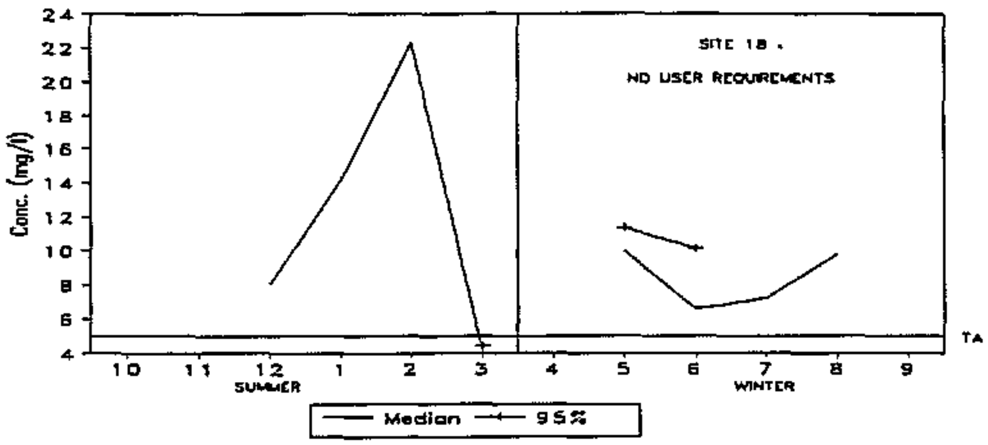


Figure 5.23 The 95 percentile and median DOC concentrations at Site 18 in the Buffalo River compared to the water quality guidelines (MA = major impact, SI = significant impact, SL = slight impact, NO = no impact) as ser by DWAF for domestic uses.

Table 5.6 The minimum, median and maximum electrical conductivity in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

EC	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mS/m*)	User requirements	Conc (*mS/m*)	User requirements	Conc (*mS/m*)	User requirements	Conc (*mS/m*)	User requirements
Min	11.0	ID	15.6	ID	11.3	ID	2.5	ID
5 Percentile	17.2	ID	32.7	AC	24.5	AC	24.8	ID
Med	43.3	ID	117.5	TO	45.0	UN	42.1	AC
95 Percentile	74	AC	224.6	UN	64	UN	68.9	TO
Max	91.0	AC	770.0	UN	755.0	UN	199.7	UN

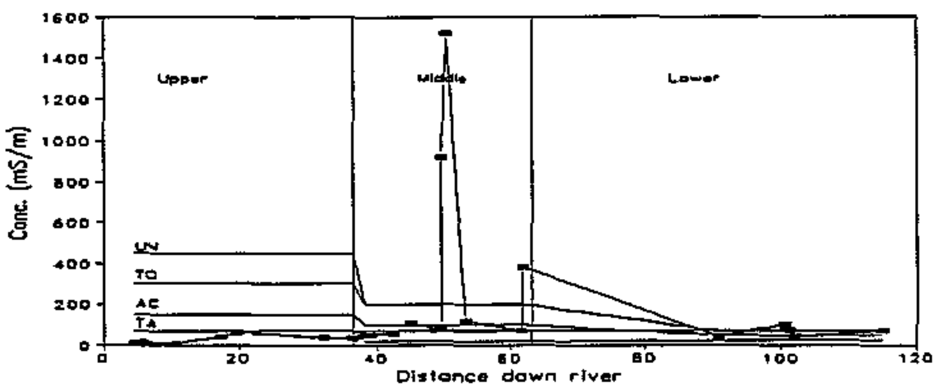


Figure 5.24 The median EC concentrations down the Buffalo River compared ot the user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and the water quality guidelines maximum target (TA) as set by DWAF for textile and tannery industrial uses as well as domestic uses.

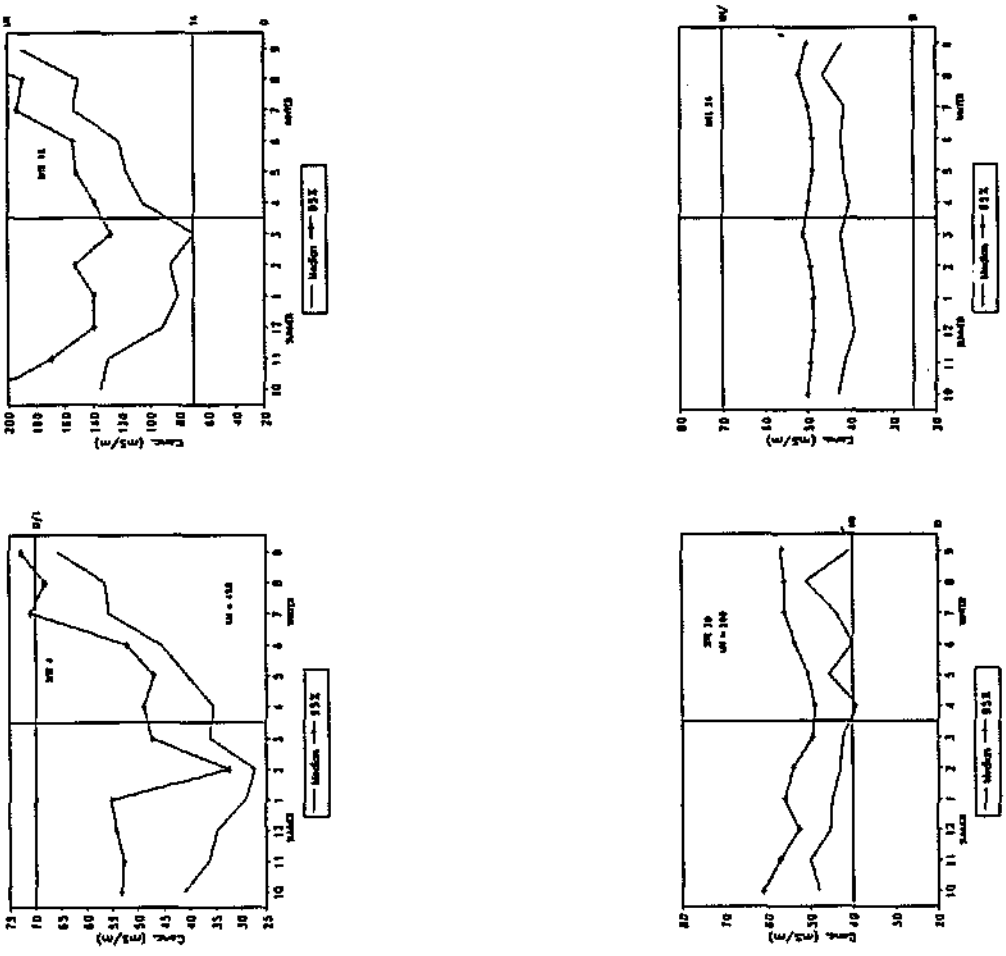


Figure 5.25 The 95 percentile and median EC concentrations at the four sites in the Buffalo River compared to the user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and the water quality guidelines maximum target (TA) as set by DWAF for textile and tannery uses as well as domestic uses.

Table 5.7 The minimum, median and maximum fluoride concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. NR = no requirements.

F	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	0.00	NR	0.00	NR	0.20	NR	0.00	NR
5 Percentile	0.03	NR	0.09	NR	0.2	NR	0.2	NR
Med	0.16	NR	0.32	NR	0.3	NR	2.60	NR
95 Percentile	0.34	NR	0.55	NR	0.30	NR	6.6	NR
Max	0.58	NR	1.22	NR	0.40	NR	16.80	NR

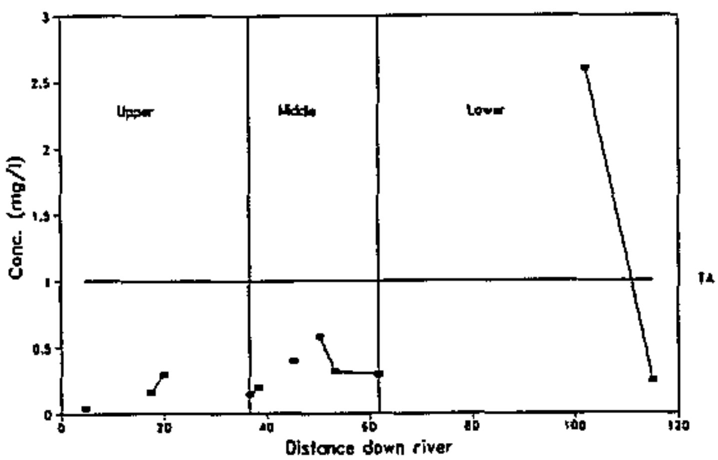
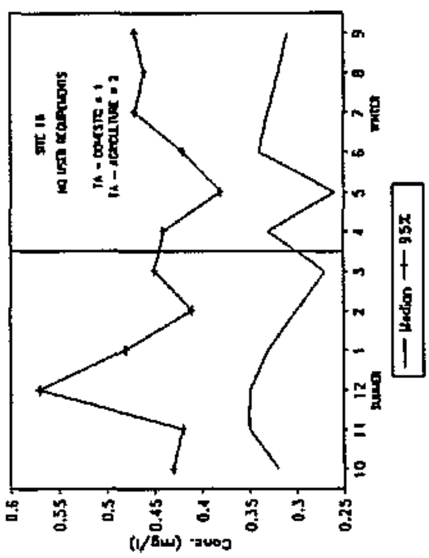


Figure 5.26 The median flouride concentrations down the Buffalo River compared to water quality guidelines maximum target (TA) as set by DWAF for domestic use.



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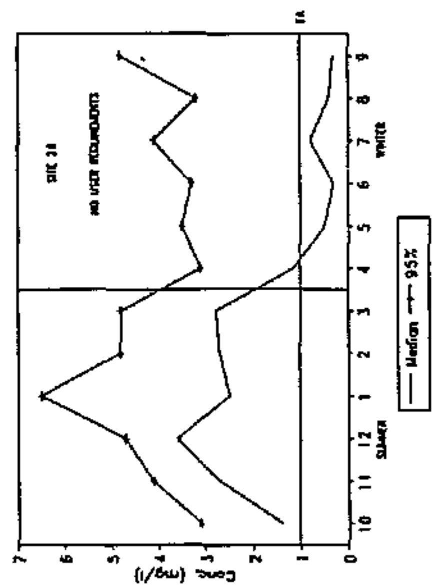

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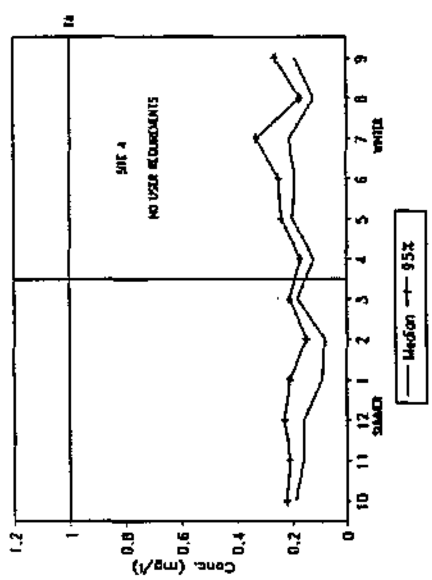

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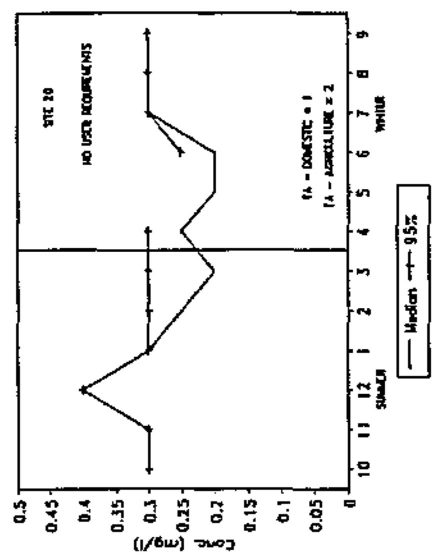

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Figure 5.27 The 95 percentile and median flouride concentrations at the four sites in the Buffalo River compared to water quality guidelines maximum target (TA) as set by DWAF for domestic uses.

Table 5.8 The minimum, median and maximum potassium concentrations (*mg/l*) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

K	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User require ments	Conc (*mg/l*)	User require ments	Conc (*mg/l*)	User require ments	Conc (*mg/l*)	User require ments
Min	0.00	ID	0.00	ID	1.00	ID	1.00	ID
5 Percentile	0.75	ID	2.47	ID	1.00	ID	2.5	ID
Med	1.83	ID	9.30	ID	4.00	ID	5.20	AC
95 Percentile	3.88	ID	19.44	AC	6.5	ID	7.8	TO
Max	8.23	ID	29.99	TO	15.50	AC	47.00	UN

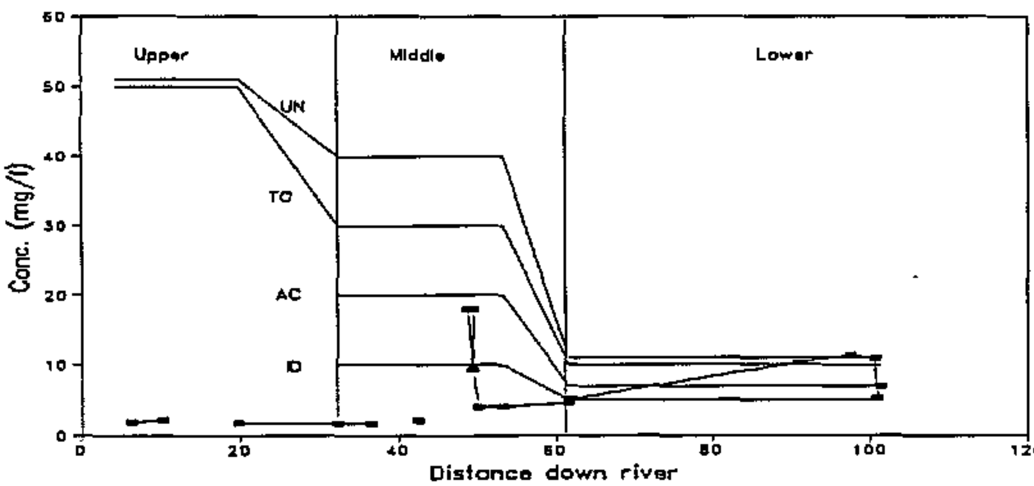


Figure 5.28 The median potassium concentrations down the Buffalo River compared to user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN).

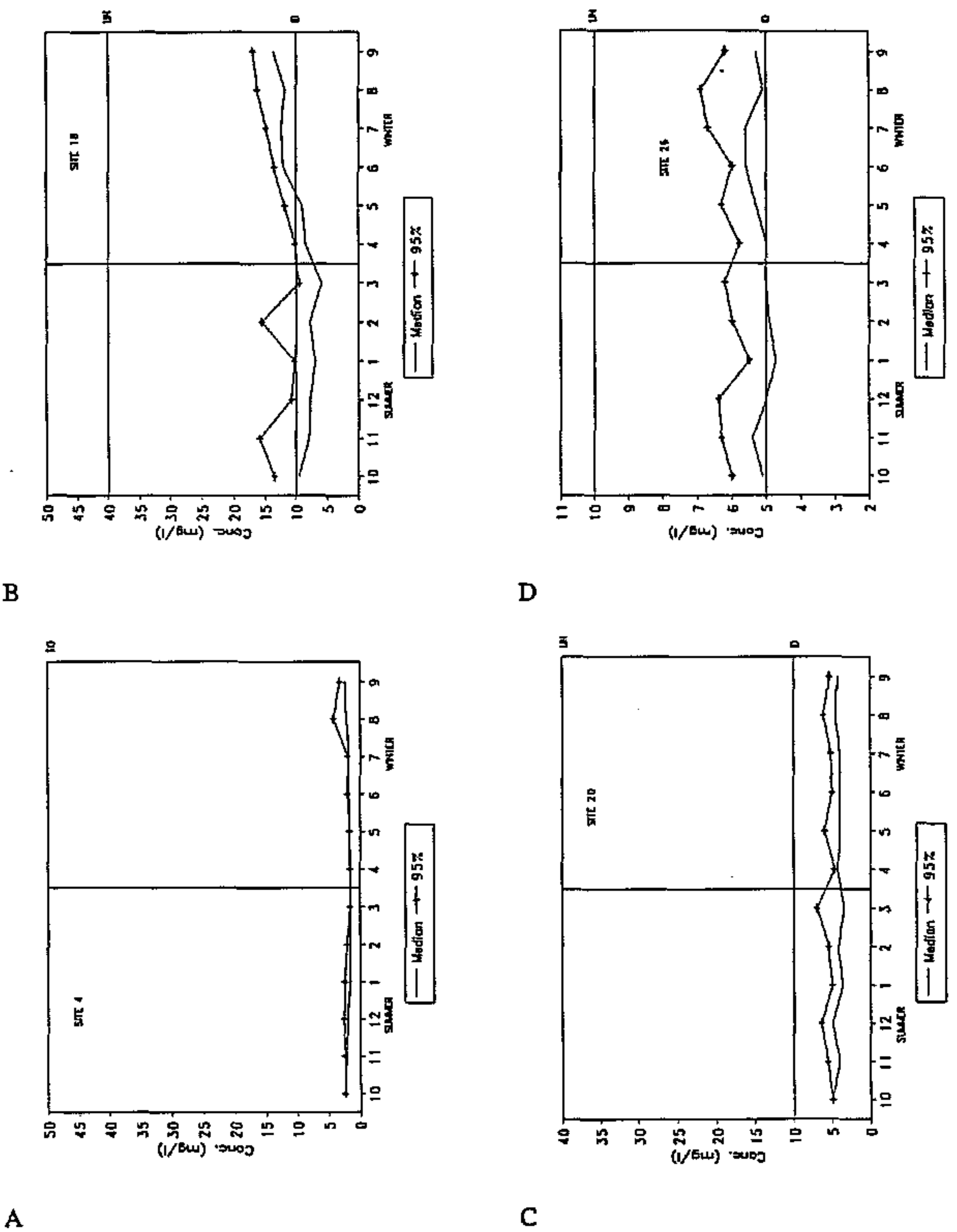


Figure 5.29 The 95 percentile and median potassium concentrations at the four sites in the Buffalo River compared to user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN).

Table 5.9 The minimum, median and maximum total nitrogen concentrations in the upper, middle and lower reaches of the Buffalo River catchment compared to the most stringent user requirements. NR = no requirements.

TN	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements
Min	0.13	NR	0.44	NR	0.08	NR	0.20	NR
5 Percentile	0.226	NR	0.718	NR	0.900	NR	0.80	NR
Med	0.47	NR	3.13	NR	2.03	NR	1.73	NR
95 Percentile	1.129	NR	19.250	NR	3.27	NR	3.6	NR
Max	2.30	NR	35.36	NR	7.65	NR	64.50	NR

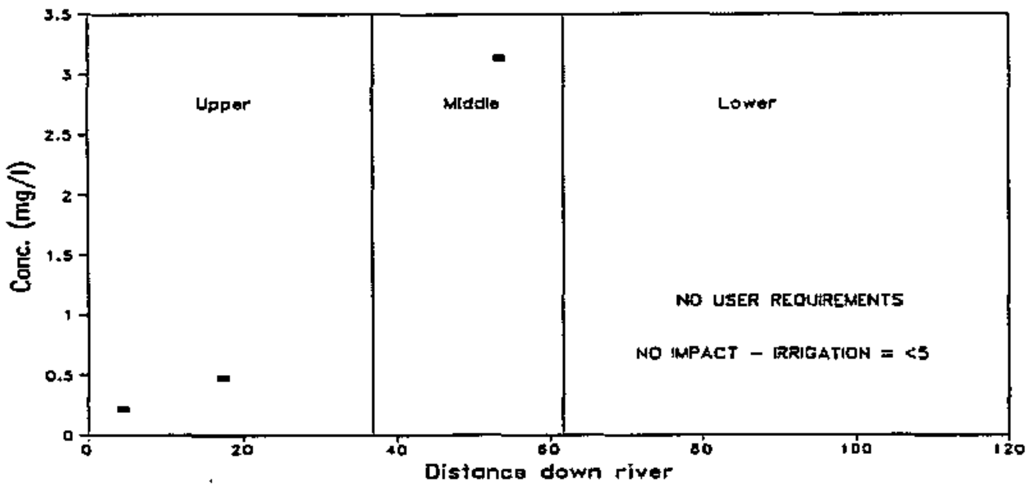
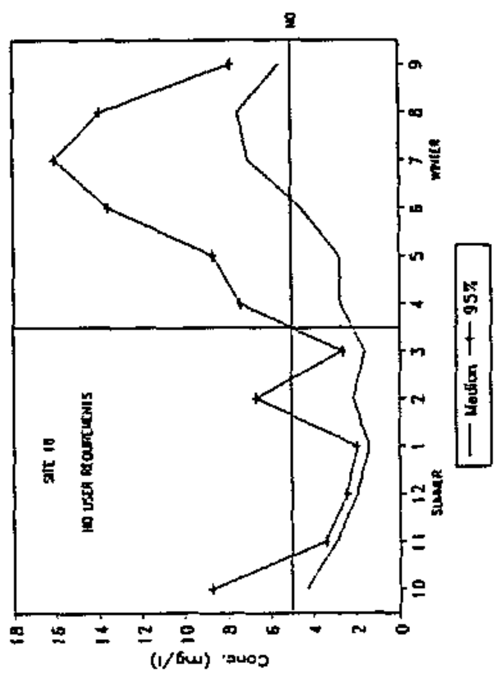
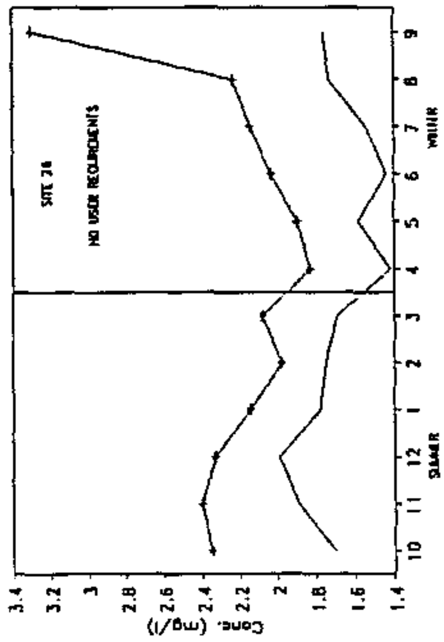


Figure 5.30 The median and total nitrogen concentrations down the Buffalo River compared to water quality guidelines no impact target (NO) for irrigation as set by DWAF. No user requirements are available.





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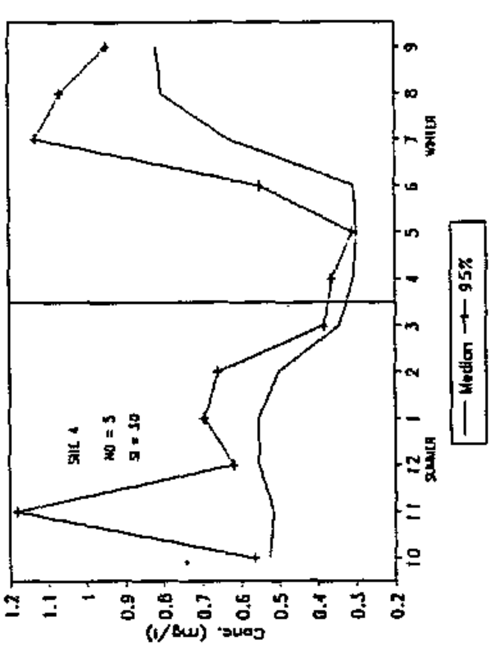

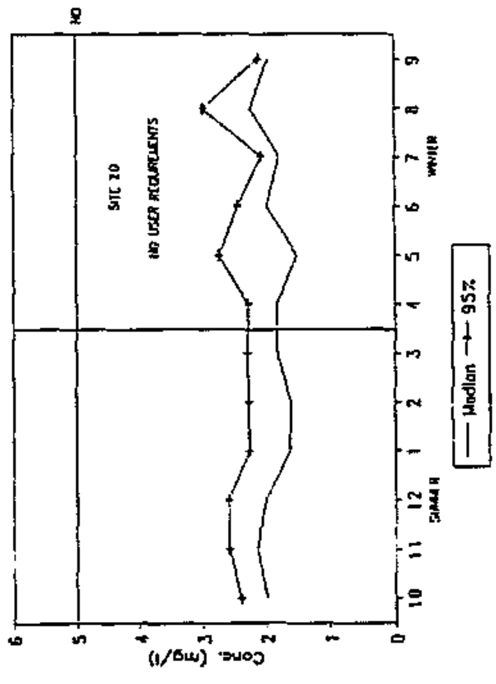

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Figure 5.31 The 95 percentile and median total nitrogen concentrations at the four sites in the Buffalo River. No user requirements are available.

Table 5.10 The minimum, median and maximum magnesium concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

Mg	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	3.50	TO	2.70	ID	0.30	ID	1.20	ID
5 Percentile	5.4	TO	6.9	ID	6.4	ID	8.3	AC
Med	14.15	TO	21.80	AC	13.00	AC	14.60	AC
95 Percentile	24.5	TO	34.9	TO	19.8	AC	20.2	UN
Max	31.60	TO	162.70	UN	36.00	TO	170.00	UN

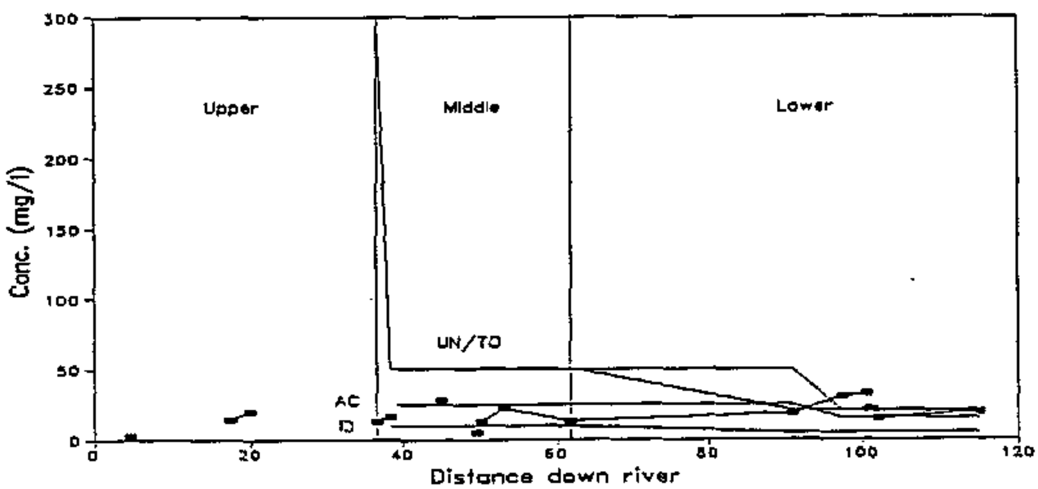
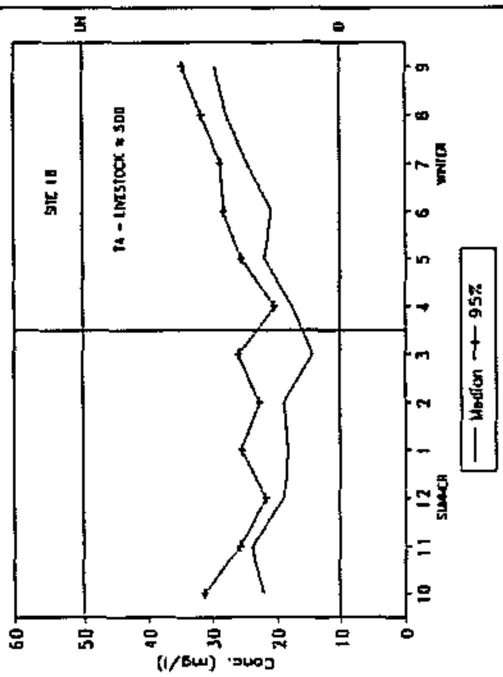


Figure 5.32 The median magnesium concentrations down the Buffalo River compared to user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN).



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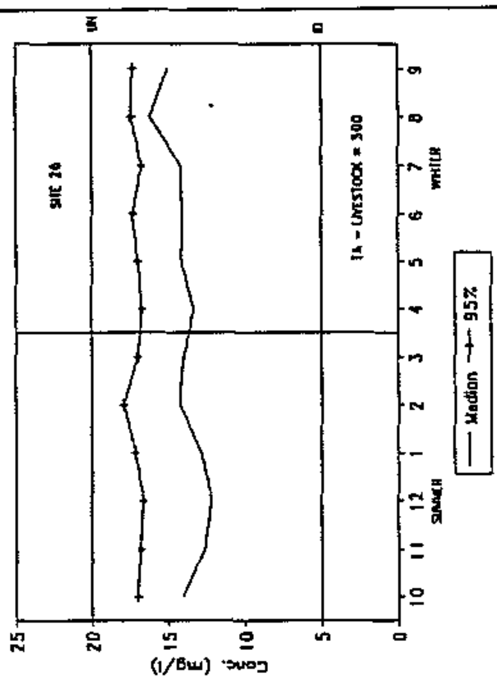

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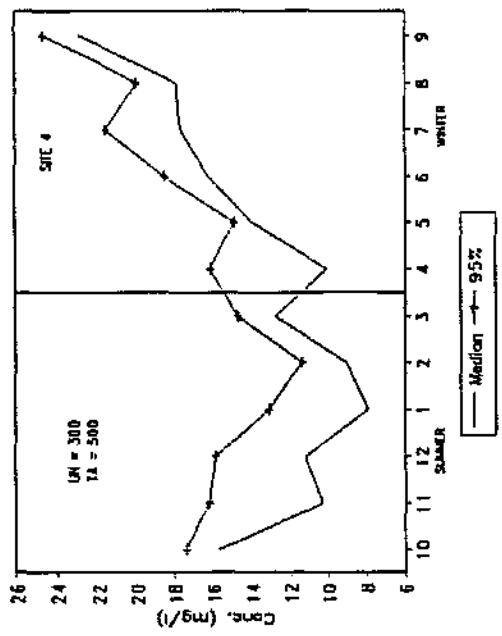

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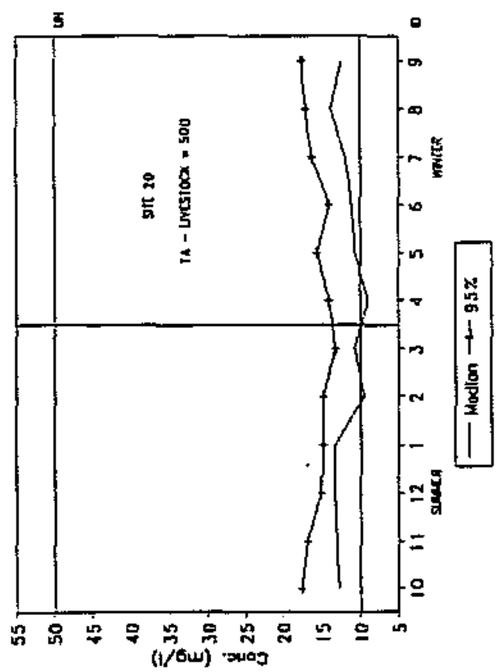

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Figure 5.33 The 95 percentile and median magnesium concentrations at four sites in the Buffalo River compared to user requirements as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN).

Table 5.11 The minimum, median and maximum sodium concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

Na	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	3.8	ID	7.7	ID	15.0	ID	5.0	ID
5 Percentile	16.9	ID	37.0	ID	34.0	ID	33.0	ID
Med	39.1	ID	214.0	TO	71.0	AC	58.0	TO
95 Percentile	68.5	ID	455.2	UN	94	AC	112.0	UN
Max	95.4	ID	1424.3	UN	114.0	AC	265.0	UN

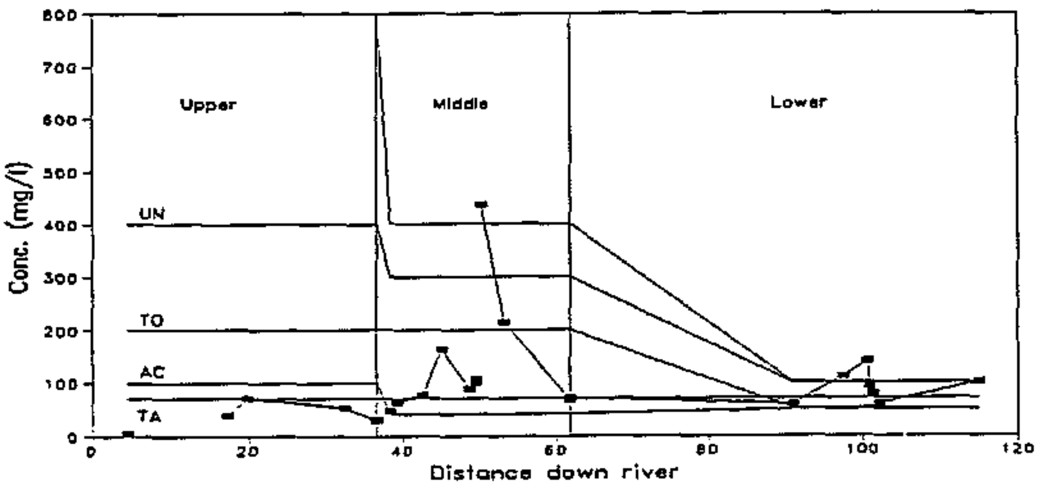
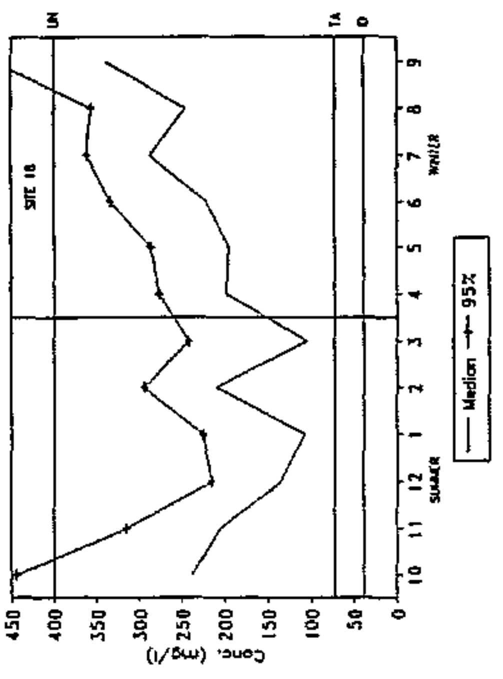
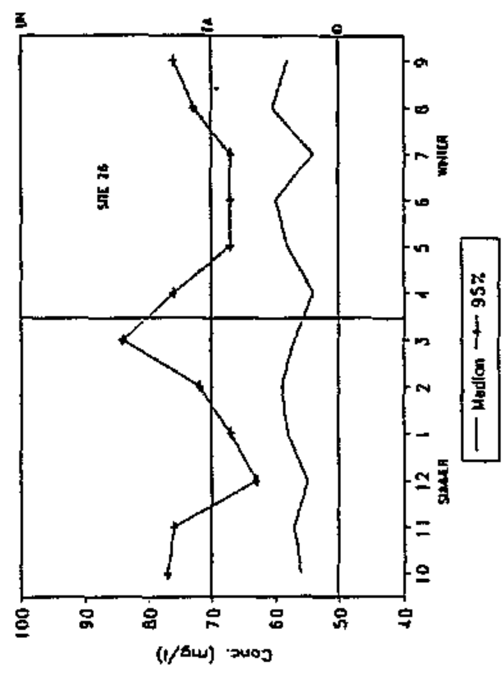


Figure 5.34 The median sodium concentrations down the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN)) and water quality guidelines maximum target (TA) as set by DWAF for irrigation.





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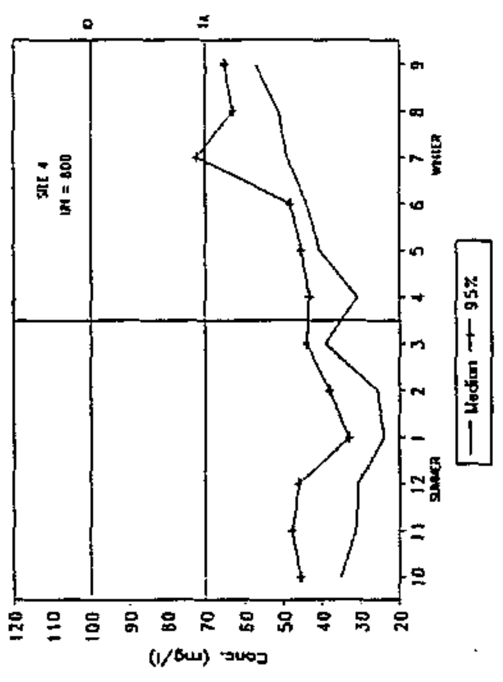

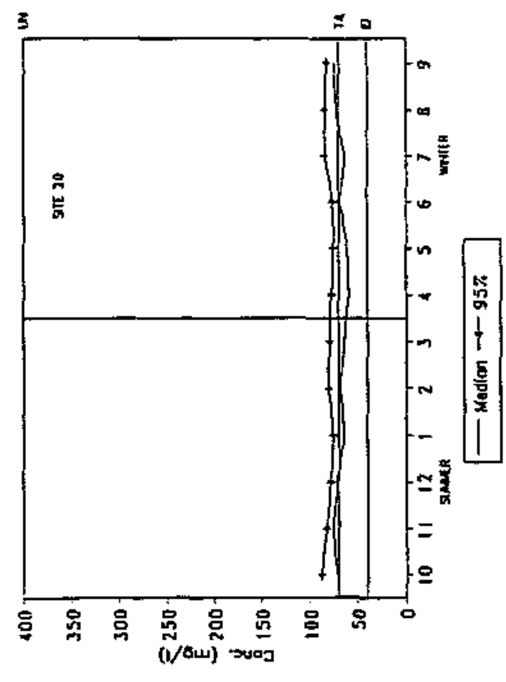

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Figure 5.35 The 95 percentile and median sodium concentrations at four sites in the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN)) and water quality guidelines maximum target (TA) as set by DWAF for irrigation.

Table 5.12 The minimum, median and maximum ammonium nitrogen concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. NR = no requirements.

NH_4	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	0.00	NR	0.00	NR	0.01	NR	0.00	NR
5 Percentile	0.01	NR	0.02	NR	0.01	NR	0.01	NR
Med	0.05	NR	0.10	NR	0.07	NR	0.10	NR
95 Percentile	0.16	NR	7.89	NR	0.41	NR	0.30	NR
Max	1.33	NR	14.25	NR	0.78	NR	2.90	NR

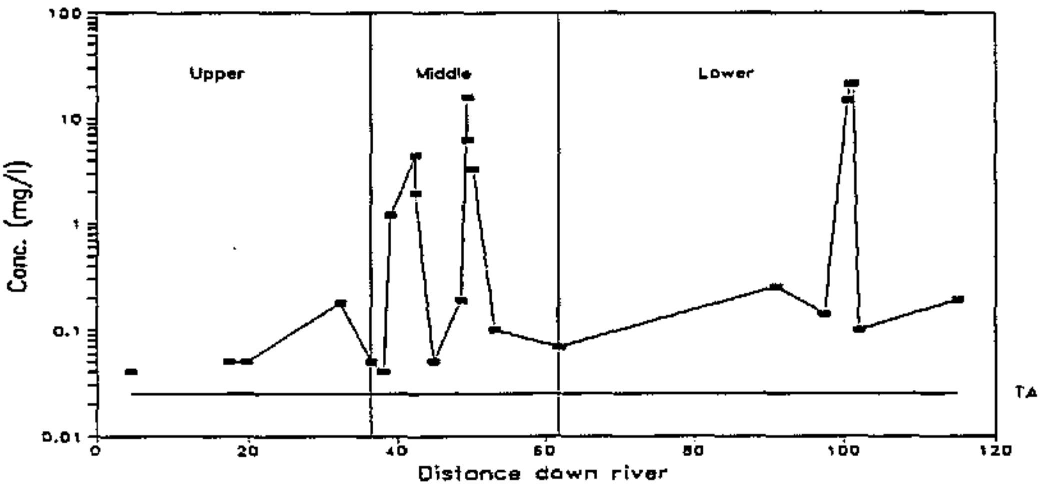
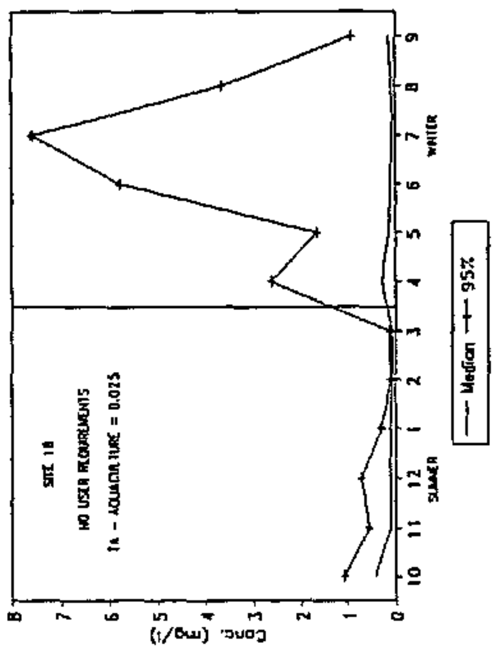


Figure 5.36 The median ammonium concentrations down the Buffalo River compared to water quality guidelines maximum target (TA) as set by DWAF for aquaculture.



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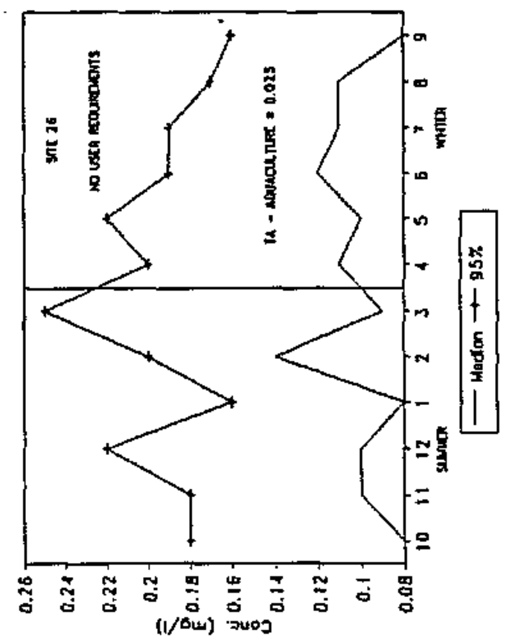

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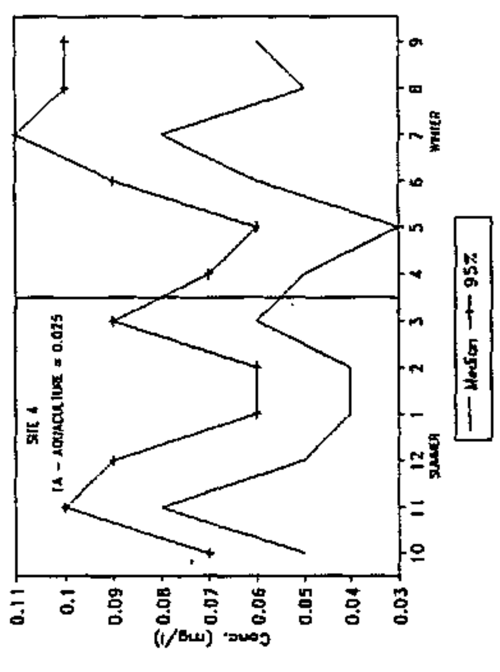

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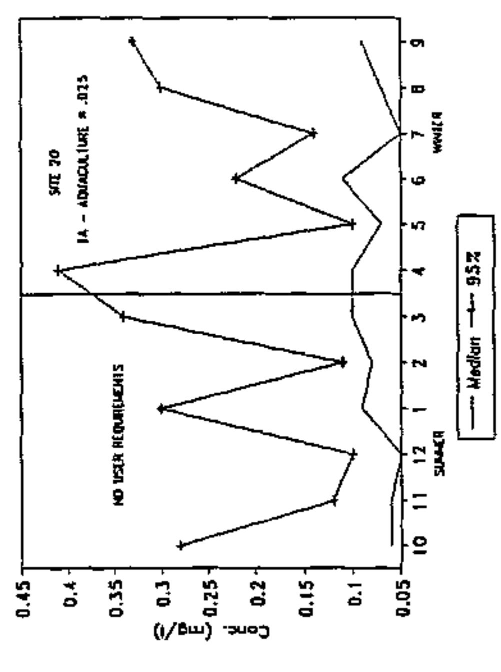

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Figure 5.37 The 95 percentile and median ammonium concentrations at four sites in the Buffalo River compared to water quality guidelines maximum target (TA) as set by DWAF for aquaculture.

Table 5.13 The minimum, median and maximum nitrites and nitrates concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable and NR = no requirement.

	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
$NO_2 + NO_3$	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	0.00	NR	0.00	NR	0.01	NR	0.05	ID
5 Percentile	0.01	NR	0.06	NR	0.09	NR	0.24	ID
Med	0.18	NR	7.00	NR	0.88	NR	0.90	ID
95 Percentile	0.99	NR	12.81	NR	1.61	NR	2.05	TO
Max	2.04	NR	46.44	NR	10.00	NR	3.26	TO

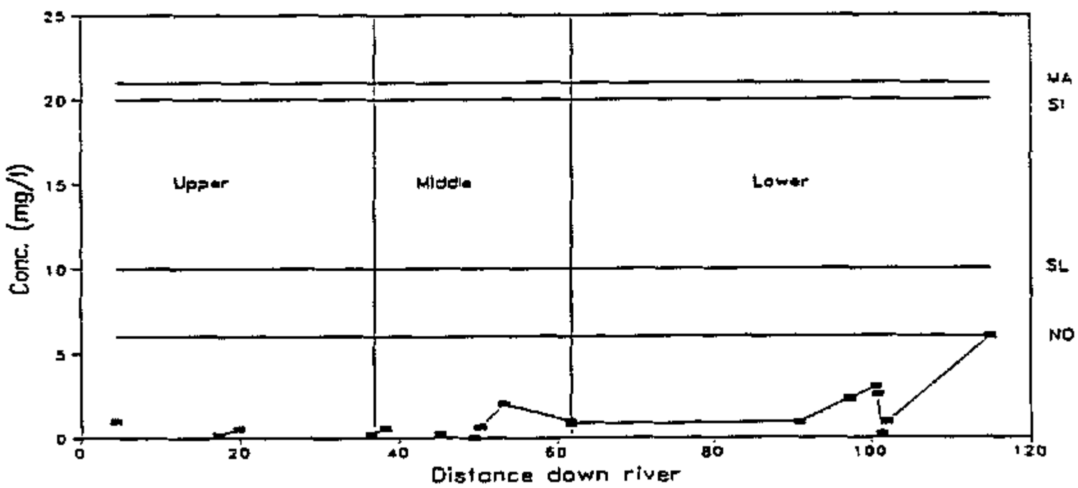
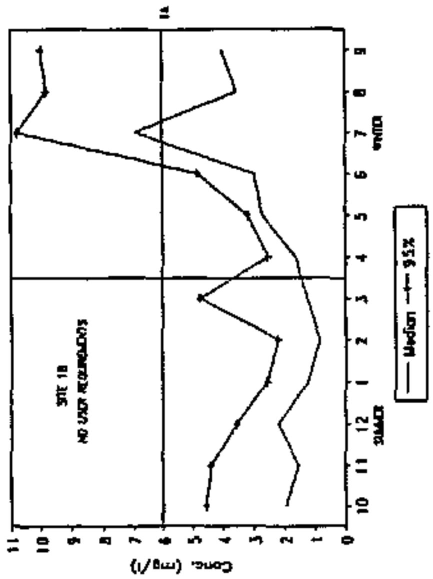


Figure 5.38 The median nitrite and nitrate concentrations down the Buffalo River compared to water quality guidelines (MA = major impact, SI = significant impact, SL = slight impact and NO = no impact) as set by DWAF for domestic uses.



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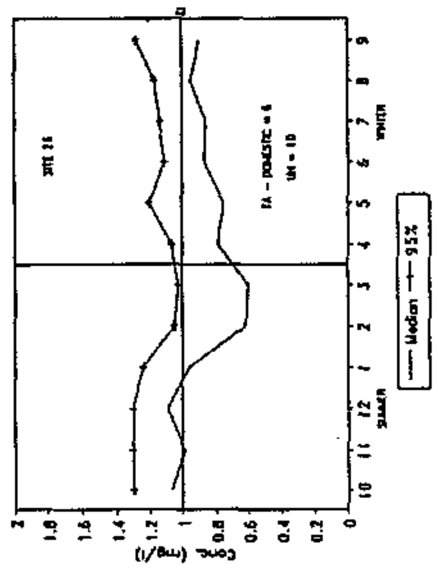

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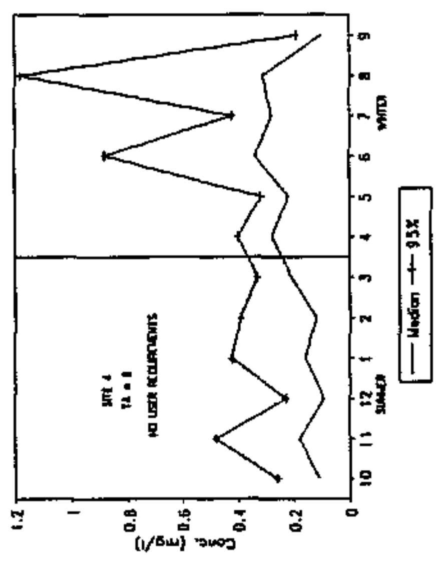

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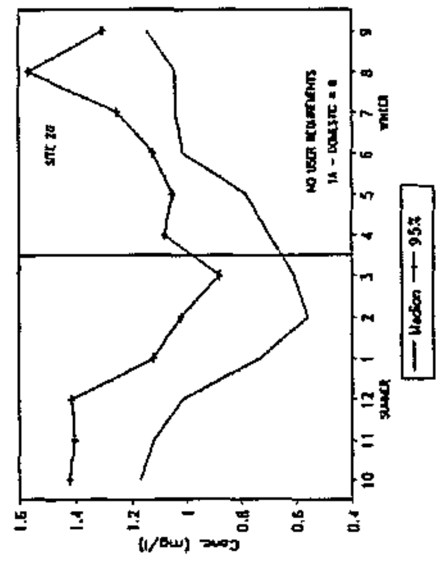

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Figure 5.39 The 95 percentile and median nitrite and nitrate concentrations at four sites in the Buffalo River compared to water quality guidelines (MA = major impact, SI = significant impact, SL = slight impact and NO = no impact) as set by DWAF for domestic uses.

Table 5.14 The minimum, median and maximum oxygen concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable and NR = no requirement.

O_2	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements
Min	-	-	3.4	NR	1.80	NR	-	-
5 Percentile	-	-	2	NR	2.60	NR	-	-
Med	-	-	5.8	NR	4.10	NR	-	-
95 Percentile	-	-	11	NR	7.50	NR	-	-
Max	-	-	12.5	NR	16.20	NR	-	-

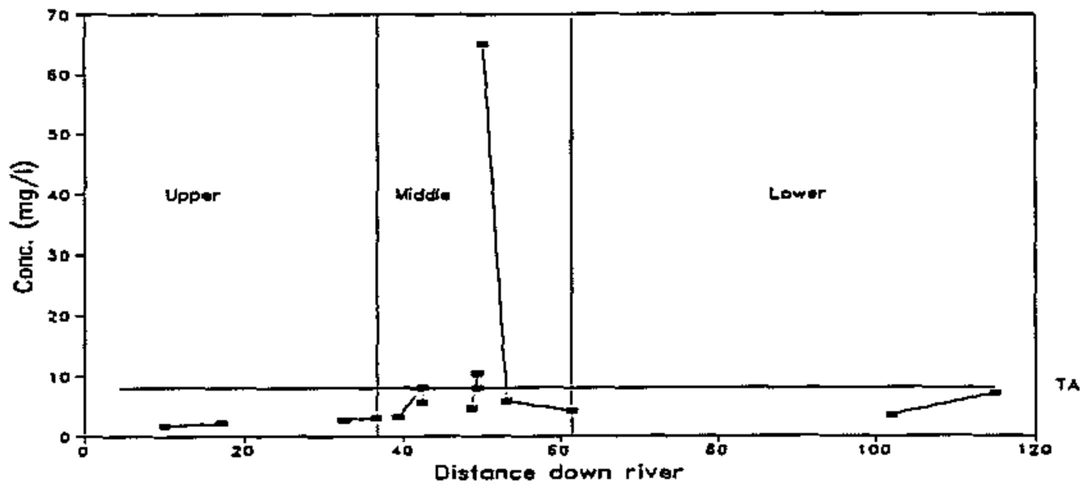
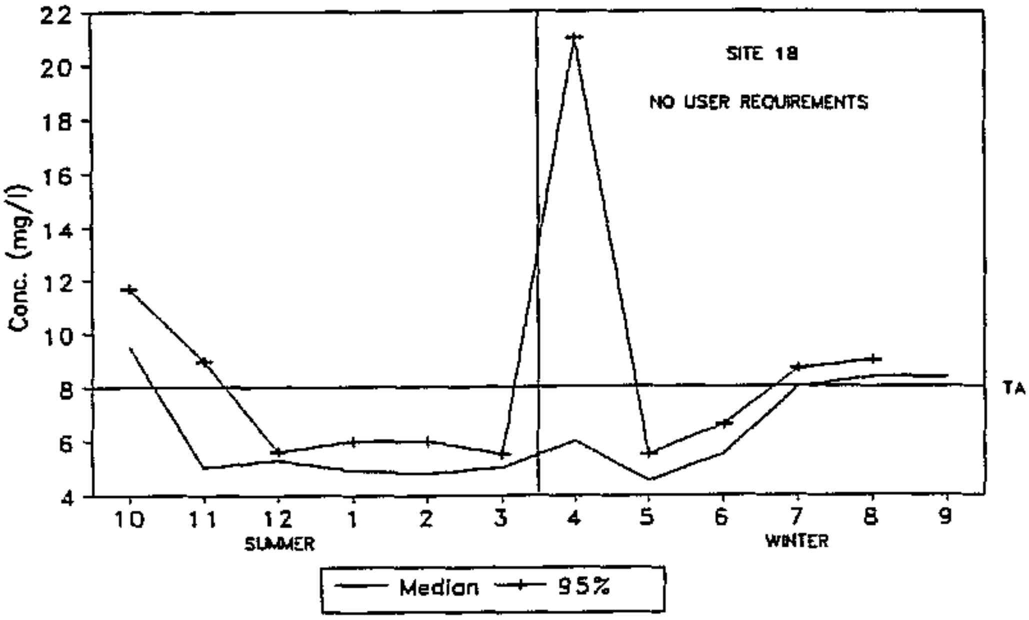


Figure 5.40 The median dissolved oxygen concentrations down the Buffalo River compared to water quality guidelines maximum target (TA) as set by DWAF for aquaculture.



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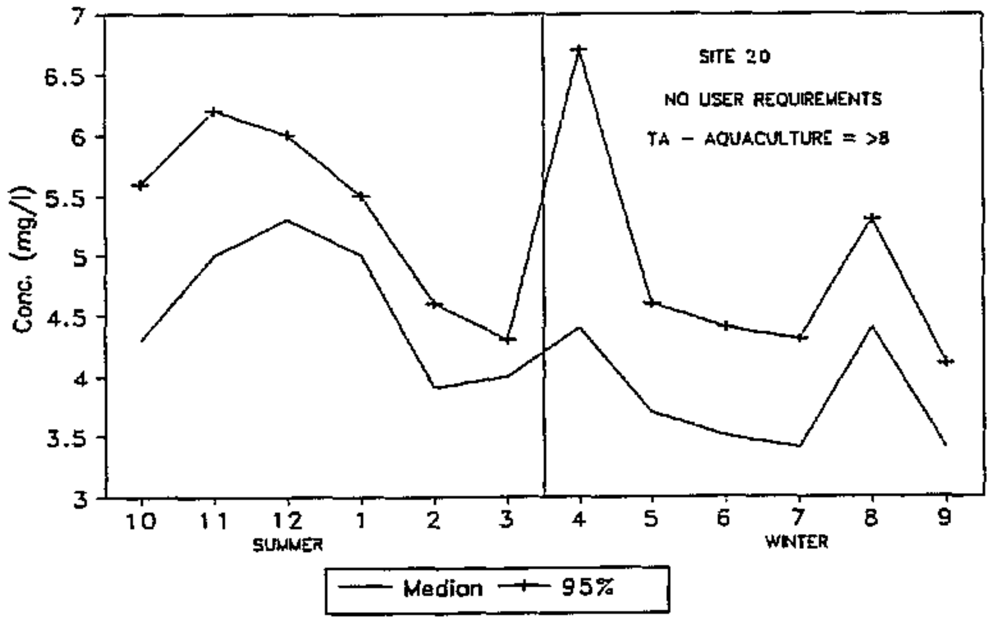

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Figure 5.41 The 95 percentile and median dissolved oxygen concentrations at site 18 (A) and Site 20 (B) in the Buffalo River compared to water quality guidelines maximum target (TA) as set by DWAF for aquaculture.

Table 5.15 The minimum, median and maximum pH values in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

pH	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	5.84	TO	5.77	UN	6.70	UN	6.80	ID
5 Percentile	6.59	TO	6.90	UN	7.20	AC	7.3	TO
Med	7.37	AC	8.00	TO	7.70	AC	7.90	TO
95 Percentile	7.59	AC	8.95	UN	8.40	TO	8.6	UN
Max	8.77	TO	10.22	UN	8.60	UN	9.50	UN

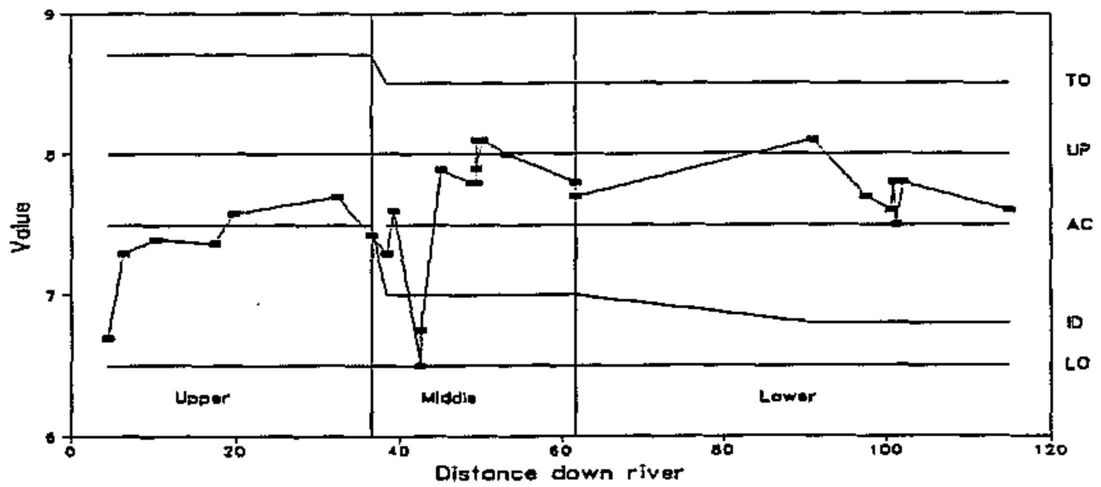
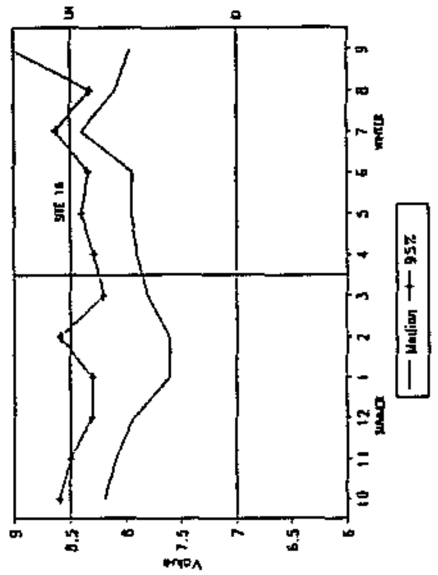


Figure 5.42 The median pH values down the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC) and tolerable (TO)) and water quality guidelines upper (UP) and lower (LO) targets as set by DWAF for most uses.



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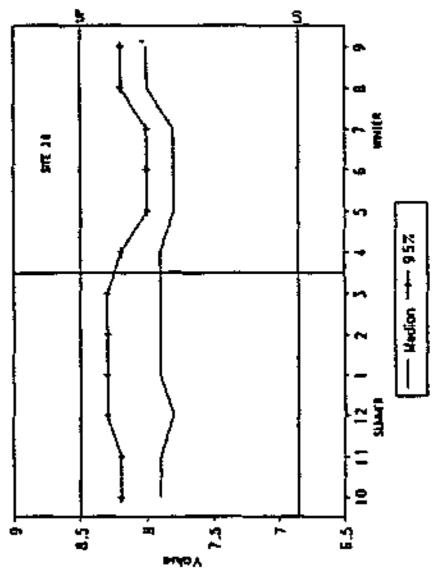

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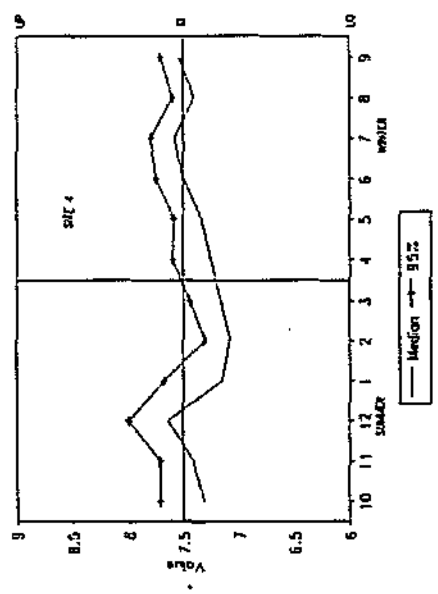
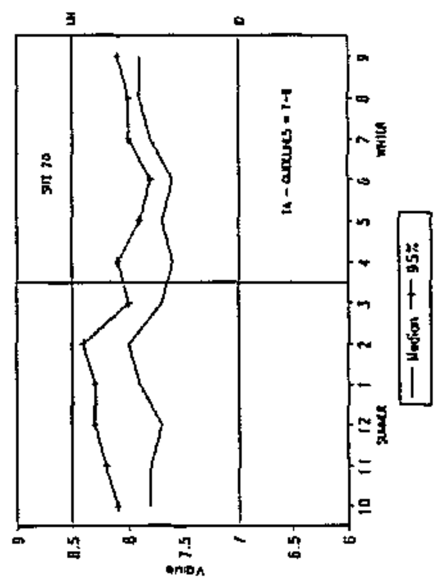


A



C

Figure 5.43 The 95 percentile and median pH values at four sties in the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC) and tolerable (TO)) and water quality guidelines upper (UP) and lower (LO) targets as set by DWAF for most uses.

Table 5.16 The minimum, median and maximum permanganate values (P.V.) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. NR = no requirements.

P.V.	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	-	-	-	-	1.40	NR	0.00	NR
5 Percentile	-	-	-	-	2.40	NR	2.00	NR
Med	-	-	-	-	4.40	NR	3.40	NR
95 Percentile	-	-	-	-	8.40	NR	8.30	NR
Max	-	-	-	-	17.20	NR	48.40	NR

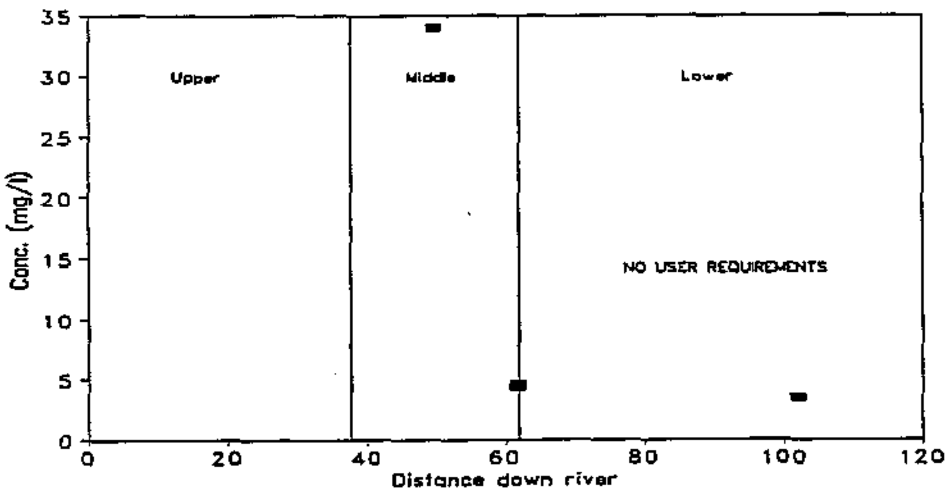


Figure 5.44 The median Permanganate value concentrations down the Buffalo River. There were no user requirements or water quality guidelines.

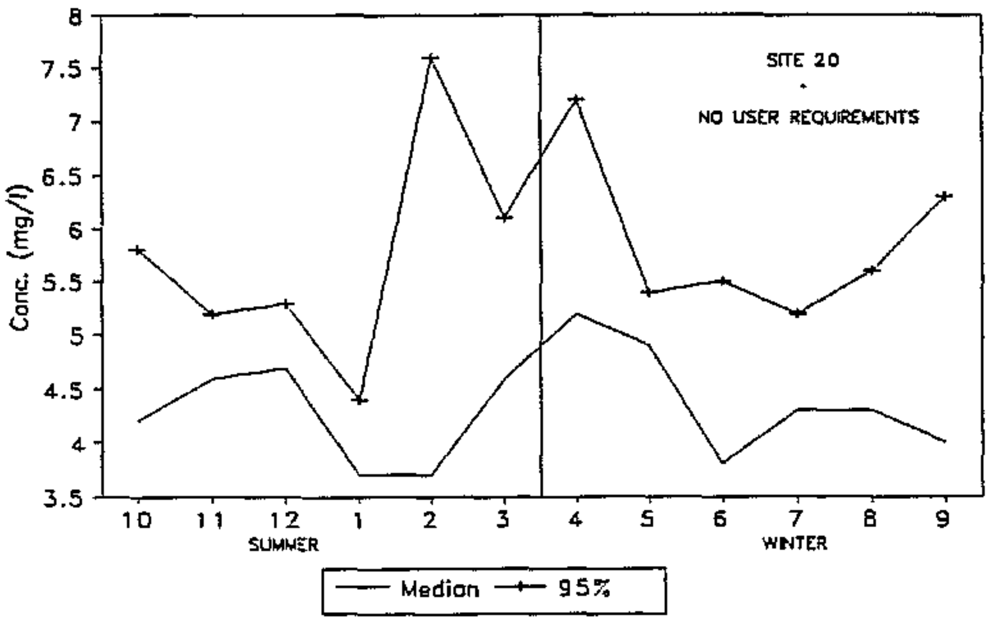


Figure 5.45 The 95 percentile and median permanganate value concentrations at Site 20 in the Buffalo River. No water quality guidelines are set for this parameter.

Table 5.17 The minimum, median and maximum ortho-phosphate concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirement.

PO_4	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User require ments	Conc (*mg/l*)	User require ments	Conc (*mg/l*)	User require ments	Conc (*mg/l*)	User require ments
Min	0.00	ID	0.00	NR	0.00	NR	0.00	ID
5 Percentile	0.00	ID	0.046	NR	0.00	NR	0.030	AC
Med	0.01	ID	1.40	NR	0.05	NR	0.10	TO
95 Percentile	0.079	TO	5.000	NR	0.35	NR	0.600	UN
Max	4.27	UN	6.50	NR	1.00	NR	8.00	UN

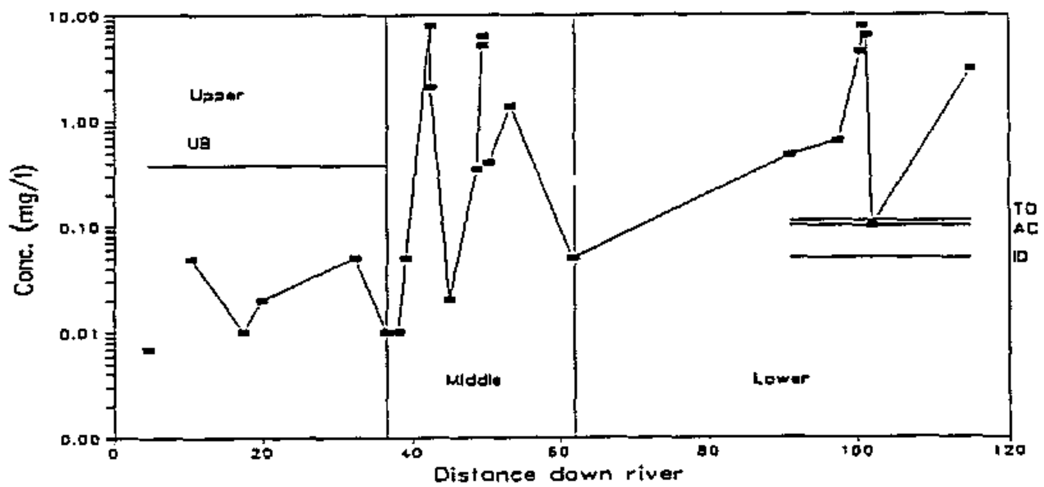
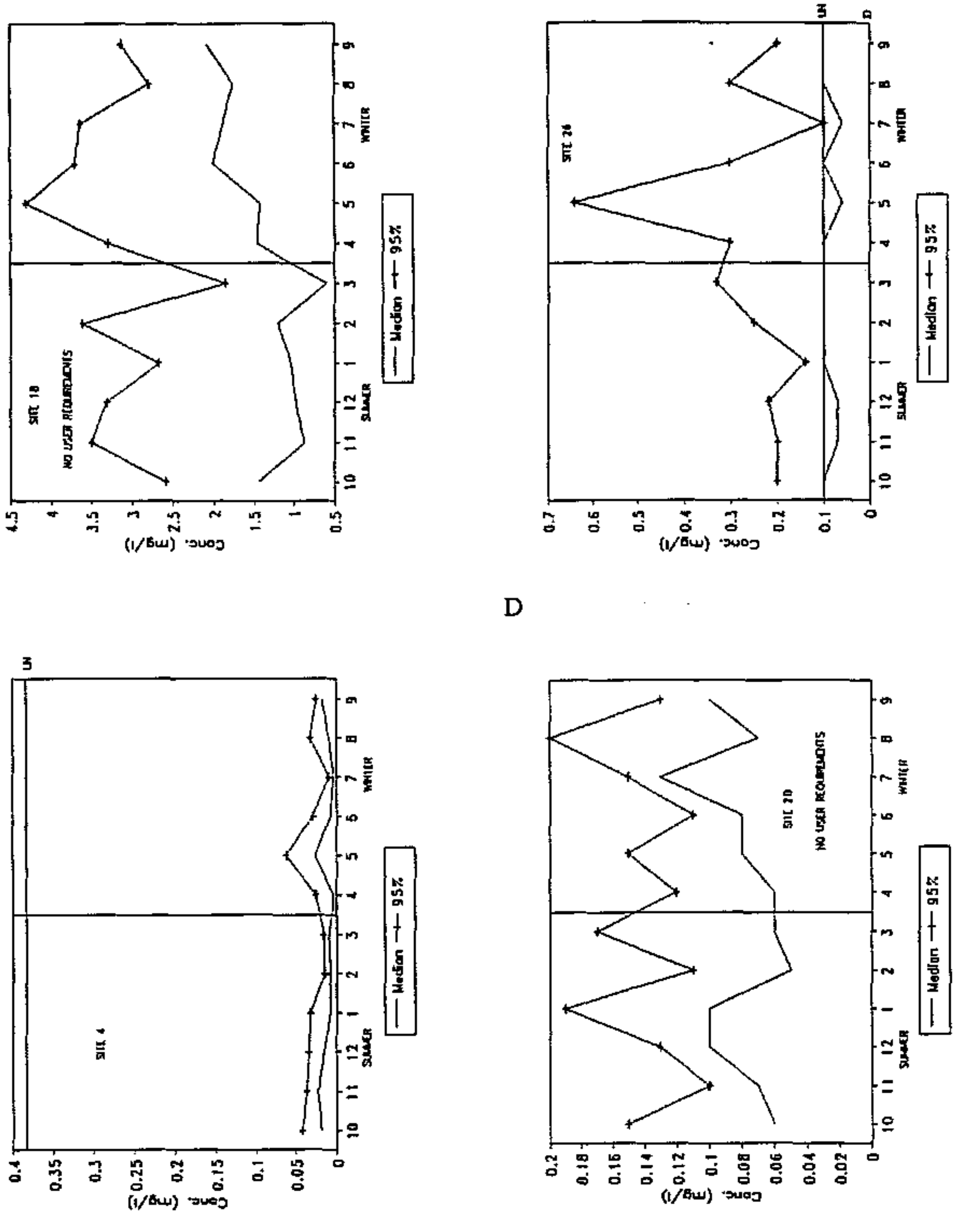


Figure 5.46 The median ortho-phosphate concentrations down the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable.



B D

A C

Figure 5.47 The 95 percentile and median ortho-phosphate concentrations at four sites in the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable.

Table 5.18 The minimum, median and maximum silica concentrtions in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

SI	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements	Conc (mg/l)	User requirements
Min	0.00	TO	0.00	ID	-	-	-	-
5 Percentile	5.95	TO	2.86	AC	-	-	-	-
Med	9.73	TO	6.00	AC	-	-	-	-
95 Percentile	11.97	TO	8.93	TO	-	-	-	-
Max	14.30	TO	17.52	UN	-	-	-	-

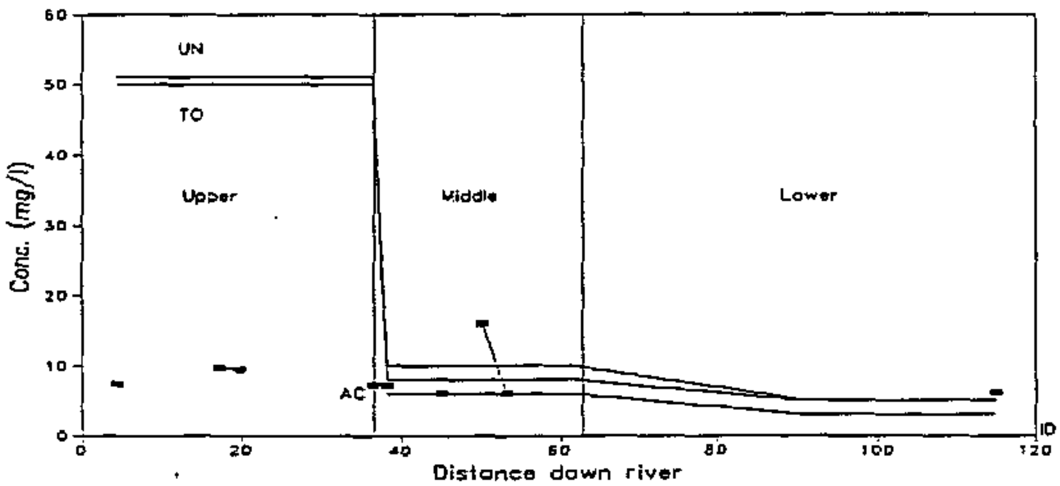
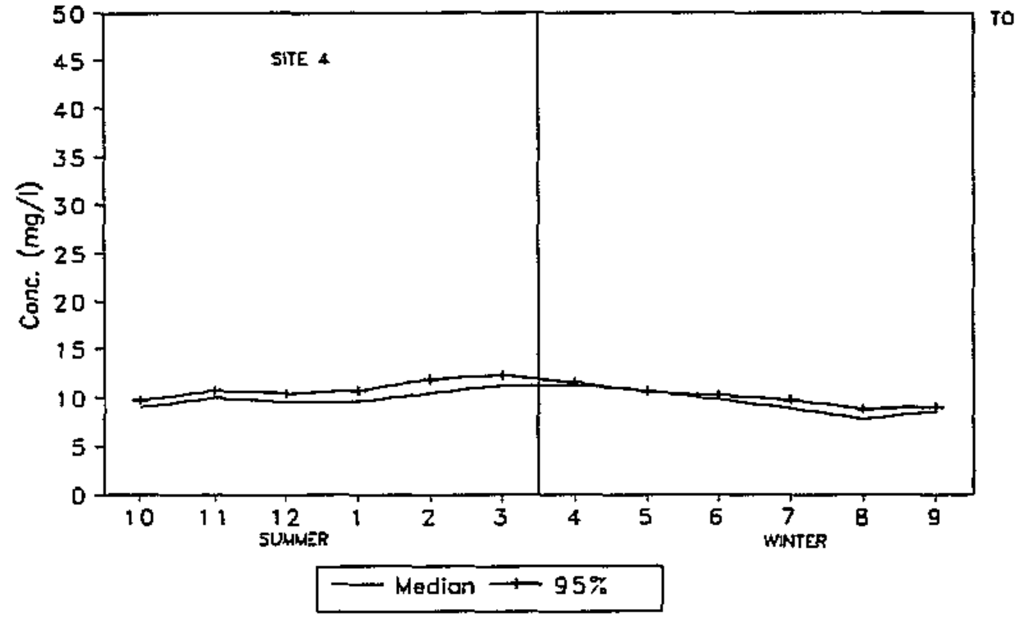
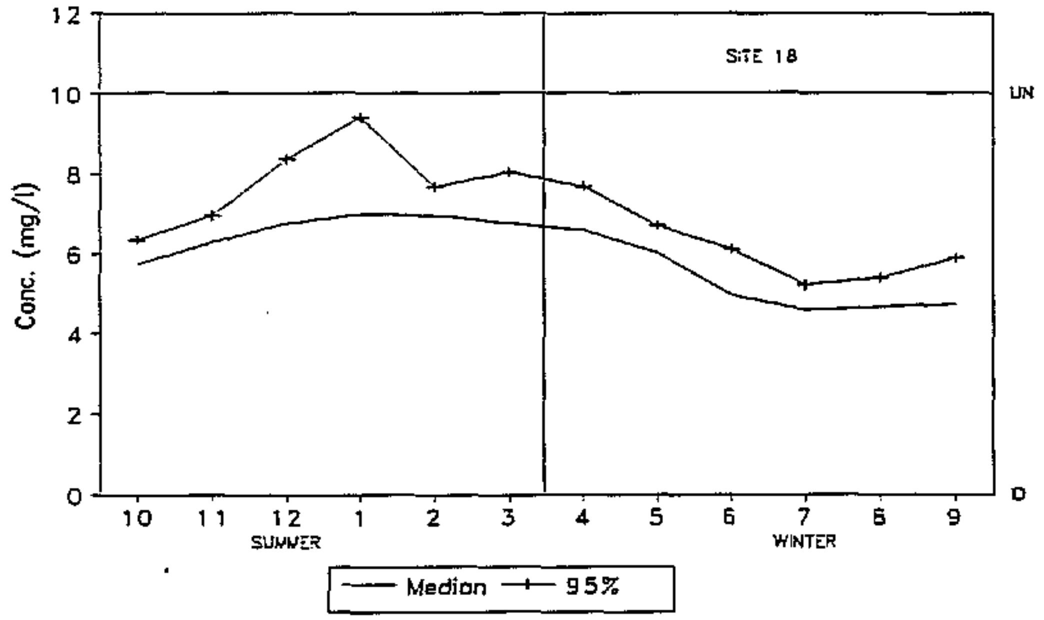


Figure 5.48 The median silica concentrations down the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable.



A



B

Figure 5.49 The 95 percentile and median silica concentrations at Site 4 (A) and Site 18 (B) in the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable.

Table 5.19 The minimum, median and maximum sulphate concentrations in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

SO_4	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirments	Conc (*mg/l*)	User requirments	Conc (*mg/l*)	User requirments	Conc (*mg/l*)	User requirments
Min	0.00	ID	3.30	ID	4.10	ID	0.10	AC
5 Percentile	0.9	ID	15.3	ID	9.4	ID	10.9	AC
Med	11.10	ID	85.10	AC	20.40	ID	19.20	AC
95 Percentile	47.6	ID	199.9	AC	31.0	ID	39.3	TO
Max	105.20	ID	294.10	TO	36.60	ID	61.10	UN

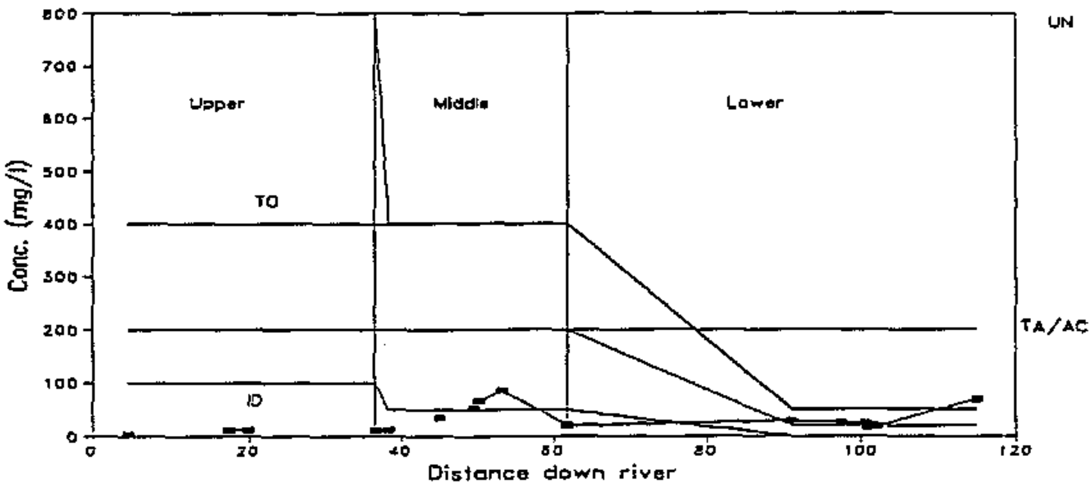
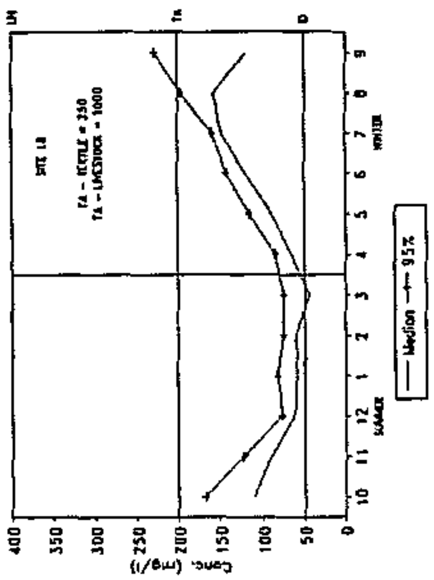


Figure 5.50 The median sulphate concentrations down the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN)) and water quality guidelines maximum target (TA) set by DWAF for the textile industry.



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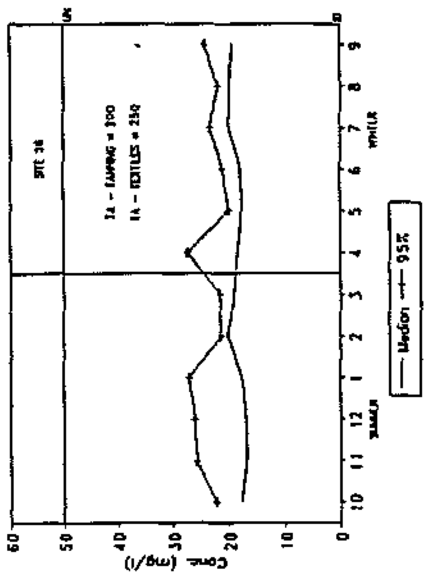

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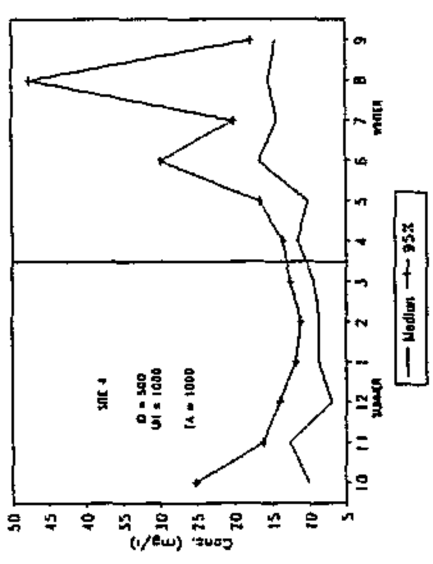

A

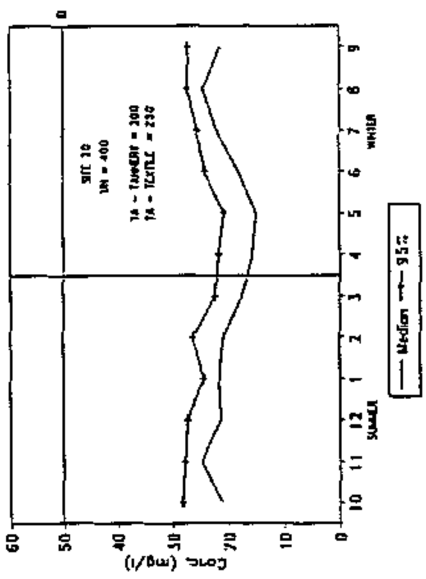

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Figure 5.51 The 95 percentile and median sulphate concentrations at four sites in the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN)) and water quality guidelines maximum target (TA) set by DWAF for the textile industry.

Table 5.20 The minimum, median and maximum suspended solids concentrations (*mg/l*) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable and UN = unacceptable.

SS	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	-	-	9.9	TO	-	-	-	-
5 Percentile	-	-	9.9	TO	-	-	-	-
Med	-	-	38.0	TO	-	-	-	-
95 Percentile	-	-	71	TO	-	-	-	-
Max	-	-	71.0	TO	-	-	-	-

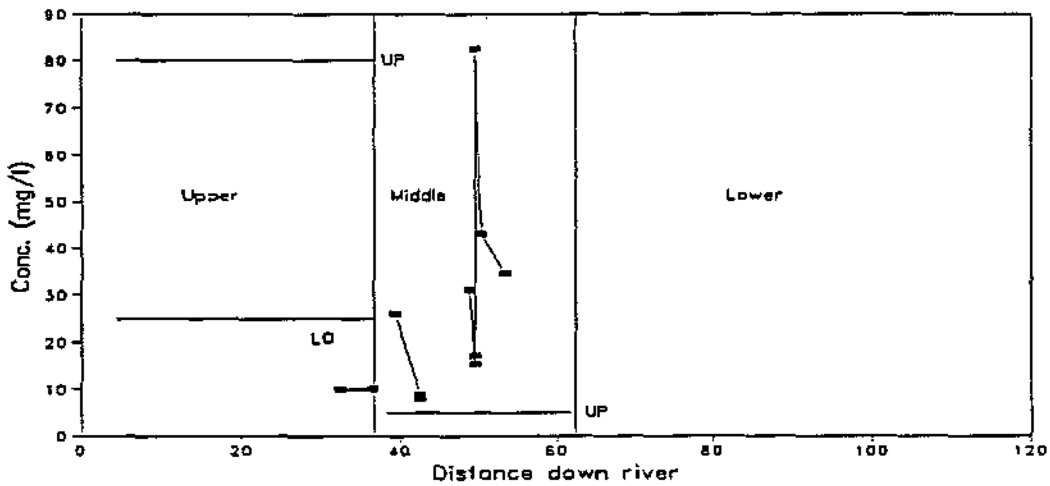


Figure 5.52 The median suspended solids concentrations down the Buffalo River compared to the water quality guidelines upper (UP) and lower (LO) targets set by DWAF for aquaculture in the upper reaches and the tannery and textile industries in the middle reaches.

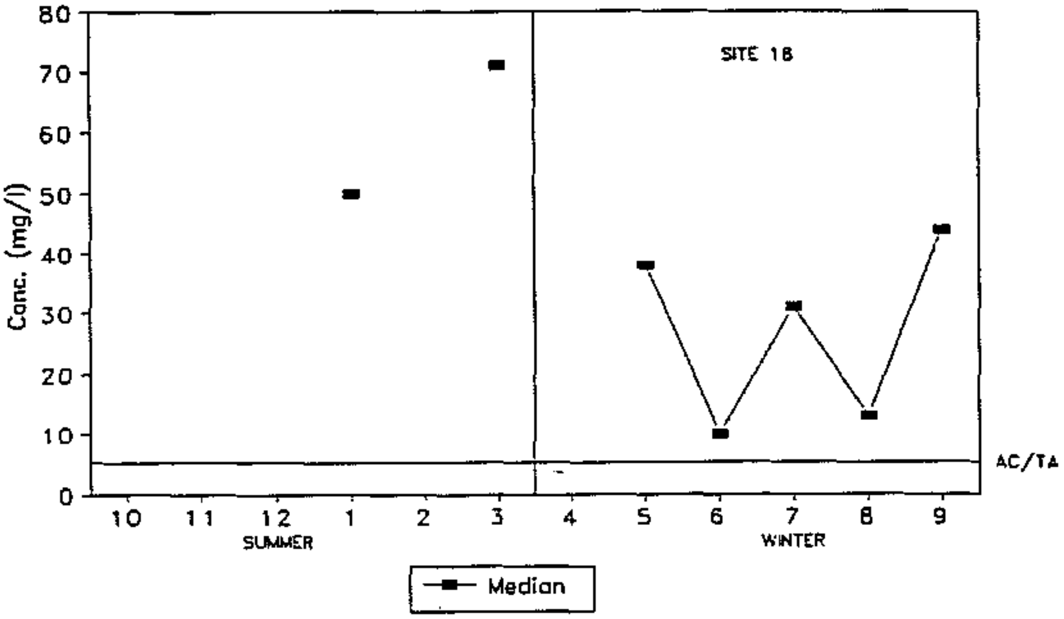


Figure 5.53 The seasonal median suspended solids concentrations at Site 18 in the Buffalo River compared to the water quality guidelines upper (UP) and lower (LO) targets set by DWAF for aquaculture in the upper reaches and the tannery and textile industries in the middle reaches.

Table 5.21 The minimum, median and maximum total alkalinity concentrations (*mg/l*) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

TAL	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	0.00	NR	0.0	ID	24.0	ID	15.0	ID
5 Percentile	25.4	NR	44.7	AC	47.0	AC	45	AC
Med	83.50	NR	240.5	UN	88.0	TO	83.0	TO
95 Percentile	153	NR	529	UN	124	UN	144	UN
Max	209.60	NR	1440.0	UN	157.0	UN	611.0	UN

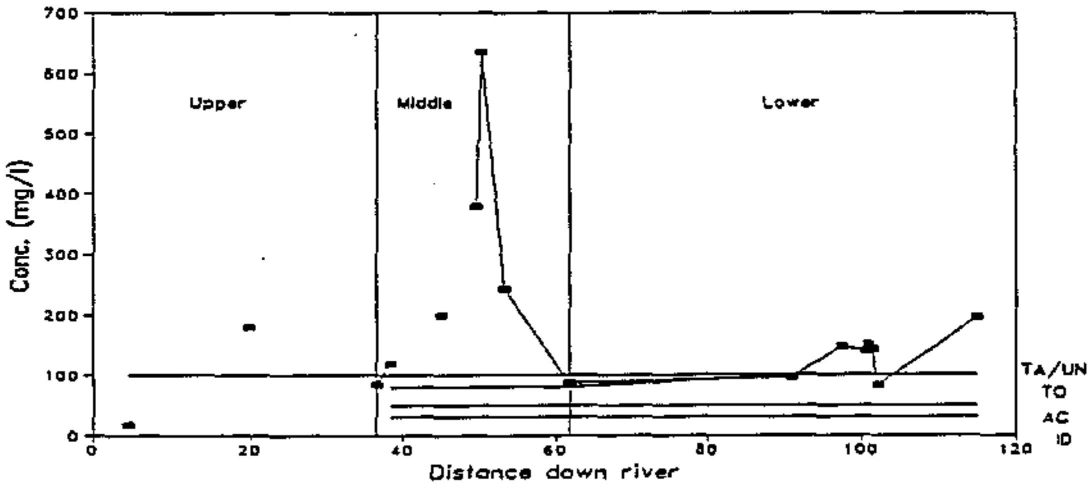


Figure 5.54 The median total alkalinity concentrations down the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN))and water quality guidelines maximum target (TA) set by DWAF for the textile industry.

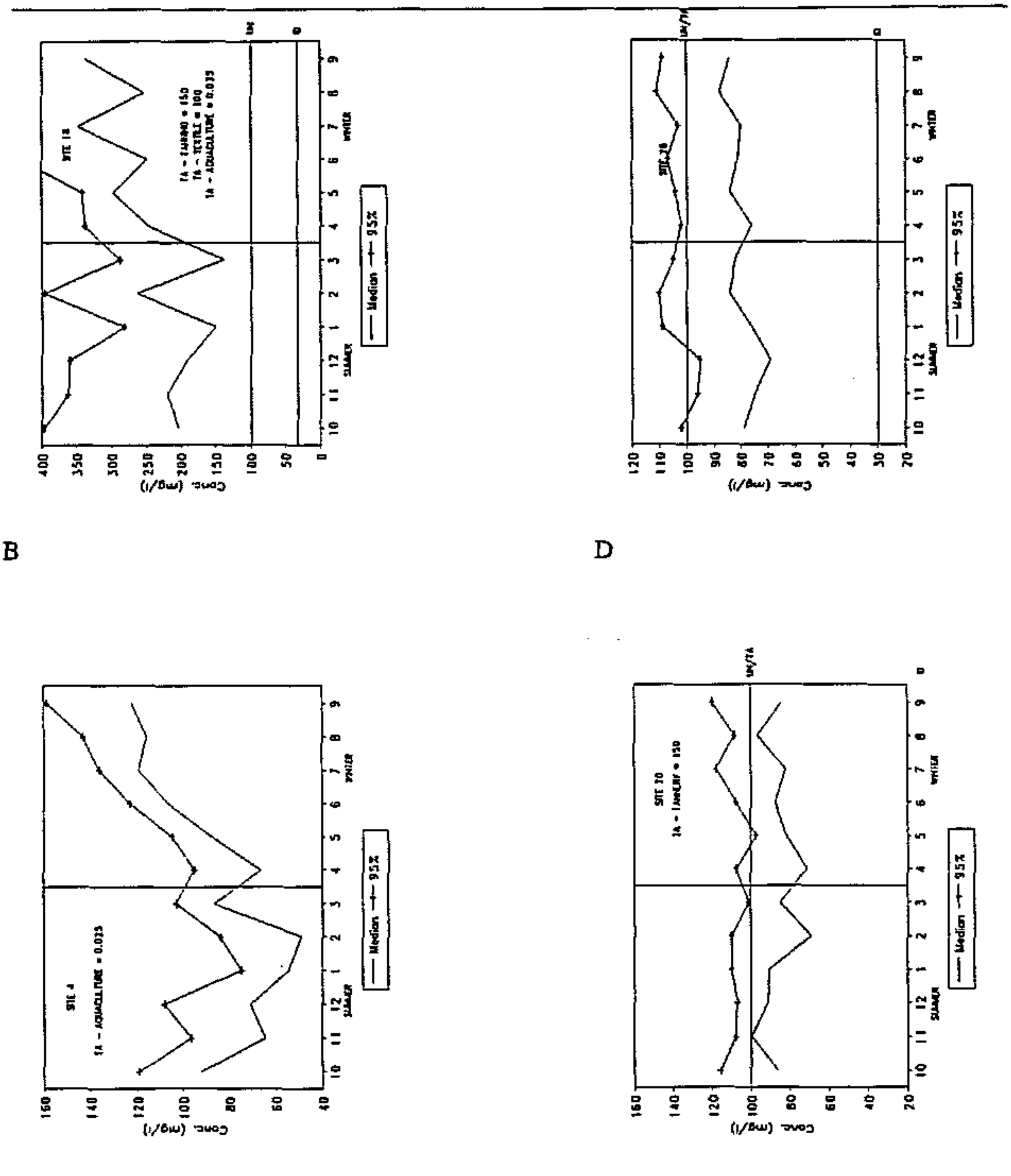


Figure 5.55 The 95 percentile and median total alkalinity concentrations at four sites in the Buffalo River compared to the user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN))and water quality guidelines maximum target (TA) set by DWAF for the textile industry.

Table 5.22 The minimum, median and maximum total dissolved salts concentrations (*mg/l*) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

TDS	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	68.7	NR	113.9	AC	7.0	AC	61	NR
5 Percentile	105	NR	202	AC	150	AC	150	NR
Med	266.7	NR	960.0	TO	289.5	AC	264	NR
95 Percentile	477	NR	1775	UN	404	AC	422	NR
Max	577.8	NR	5130.3	UN	536.0	AC	1242	NR

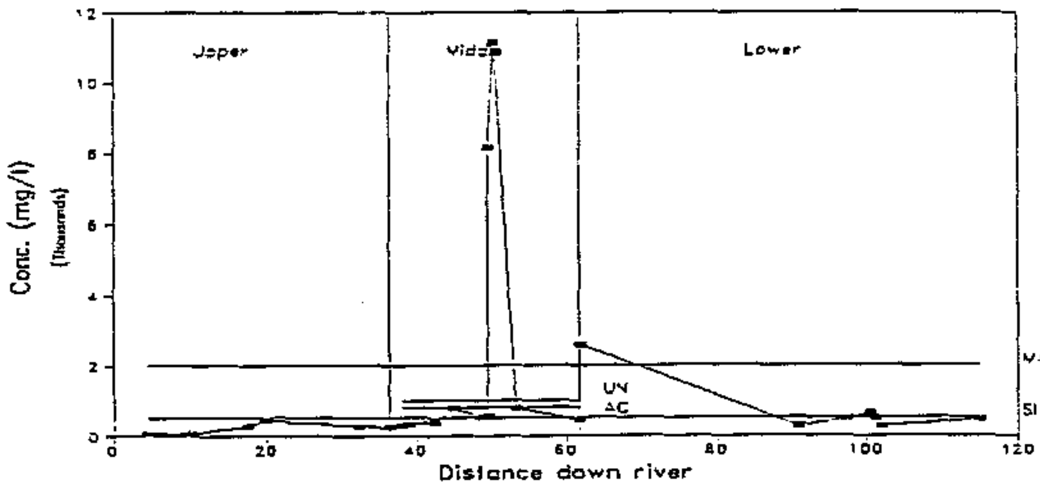
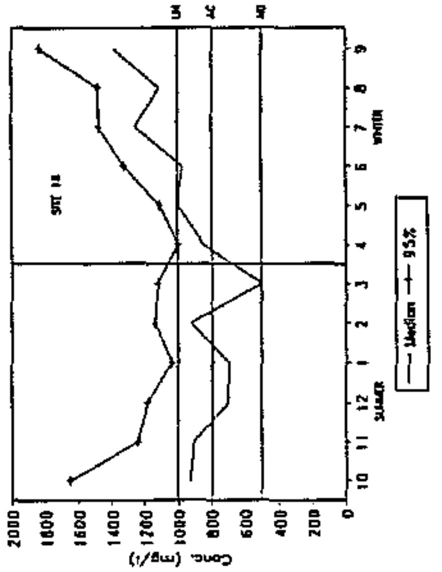


Figure 5.56 The median total dissolved salts concentrations down the Buffalo River compared to the user requirements (as acceptable (AC) and unacceptable (UN)) and water quality guidelines (MA = major impact and SI = significant impact) set by DWAF for the irrigation.



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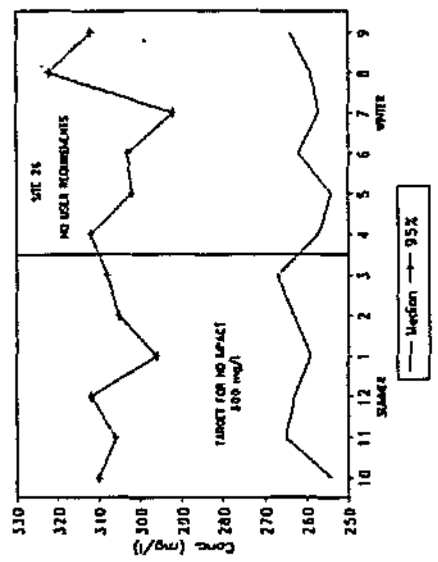

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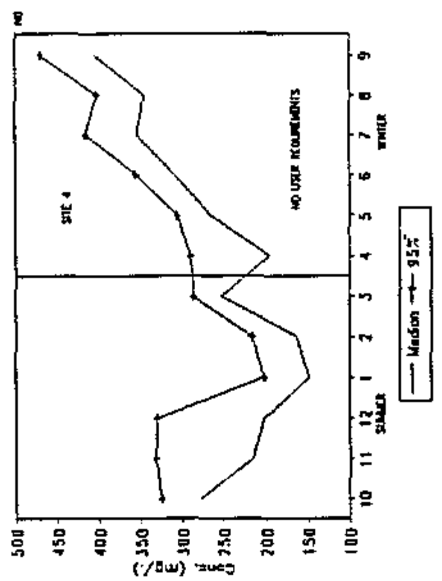

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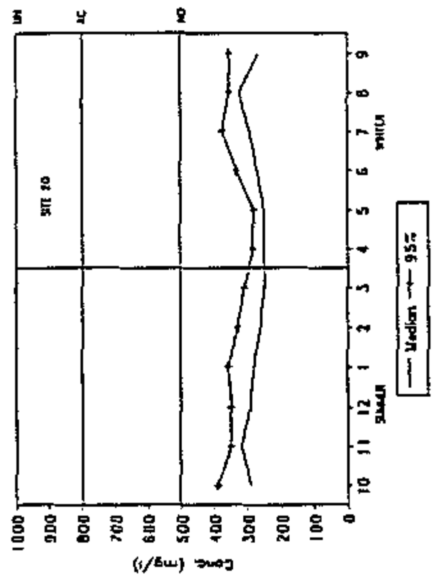

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Figure 5.57 The 95 percentile and median total dissolved salts concentrations at four sites in the Buffalo River compared to the user requirements (as acceptable (AC) and unacceptable (UN)) and water quality guidelines (MA = major impact and SI = significant impact) set by DWAF for the irrigation.

Table 5.23 The minimum, median and maximum temperatures (°C) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

TEMP	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	°C	User requirements	°C	User requirements	°C	User requirements	°C	User requirements
Min	4.0	AC	9.0	NR	-	NR	-	NR
5 Percentile	8.0	AC	13.0	NR	-	NR	-	NR
Med	18.0	AC	18.0	NR	-	NR	-	NR
95 Percentile	23.0	AC	24.0	NR	-	NR	-	NR
Max	25.0	UN	28.0	NR	-	NR	-	NR

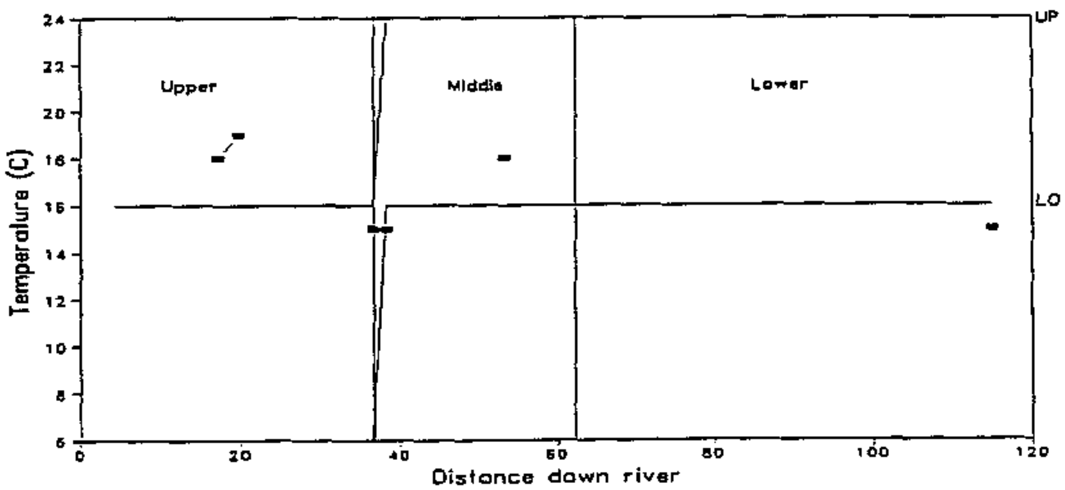
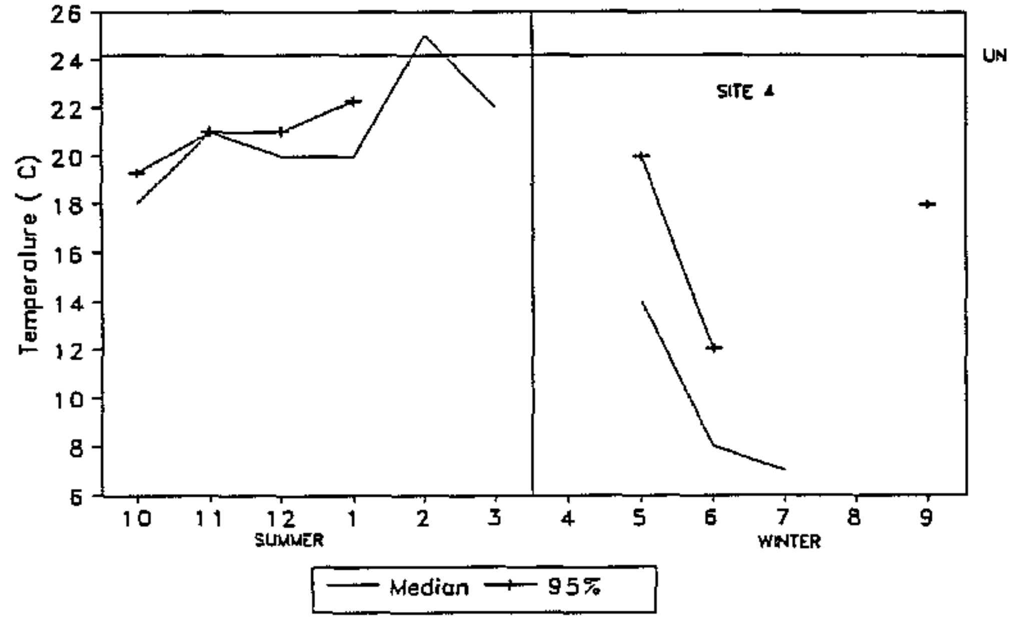


Figure 5.58 The median temperatures down the Buffalo River compared to water quality guidelines (UP = upper target and LO = lower target) set by DWAF for aquaculture.



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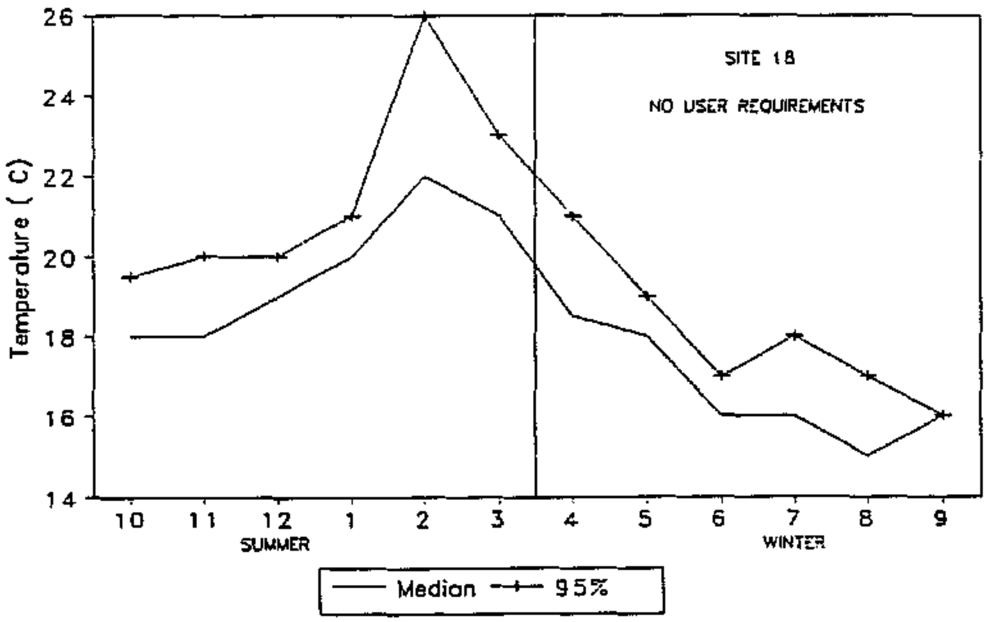


Figure 5.59 The 95 percentile and median temperatures at Site 4 (A) and Site 18 (B) in the Buffalo River compared to water quality guidelines (UP = upper target and LO = lower target) set by DWAF for aquaculture.

Table 5.24 The minimum, median and maximum total phosphate concentrations (*mg/l*) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

TP	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	0.01	NR	0.08	ID	-	-	-	-
5 Percentile	0.014	NR	0.12	ID	-	-	-	-
Med	0.03	NR	1.50	AC	-	-	-	-
95 Percentile	0.088	NR	5.70	AC	-	-	-	-
Max	0.28	NR	7.09	AC	-	-	-	-

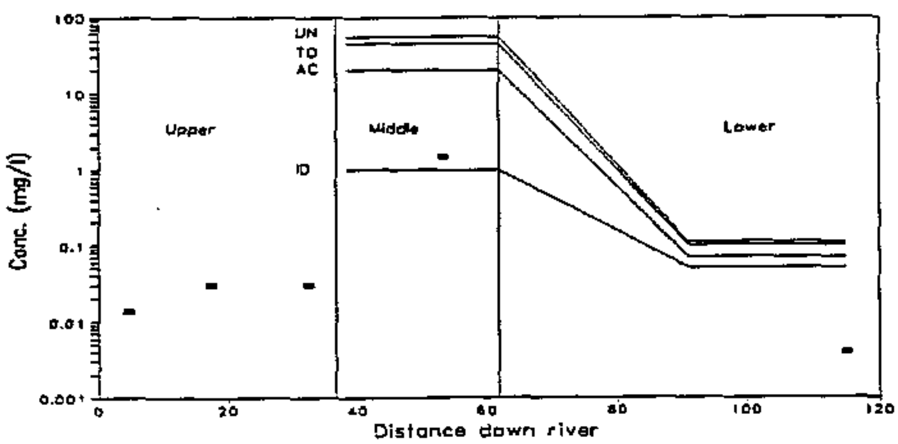
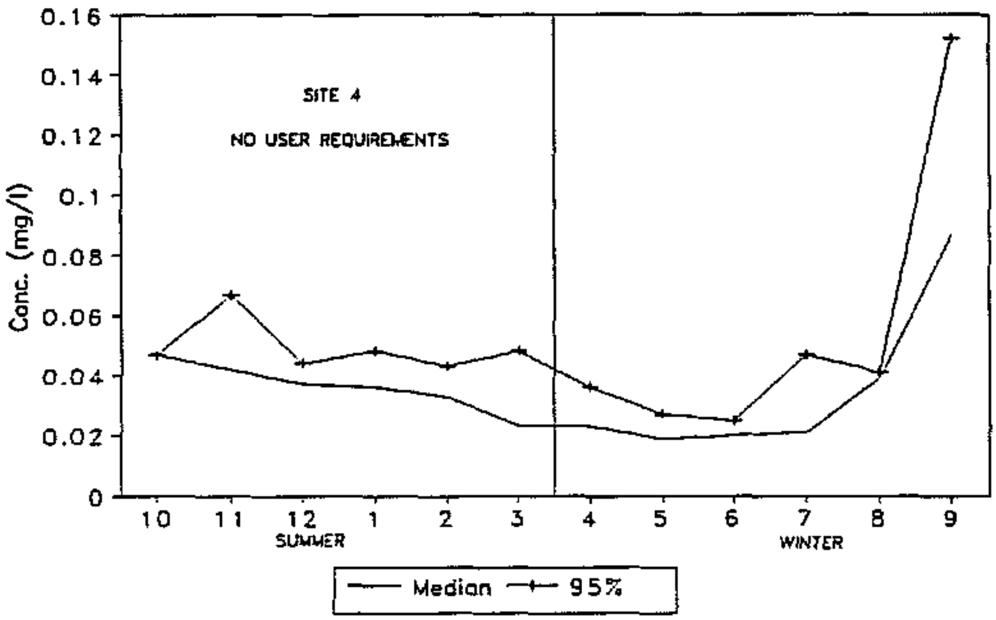


Figure 5.60 The median total phosphate concentrations down the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN).



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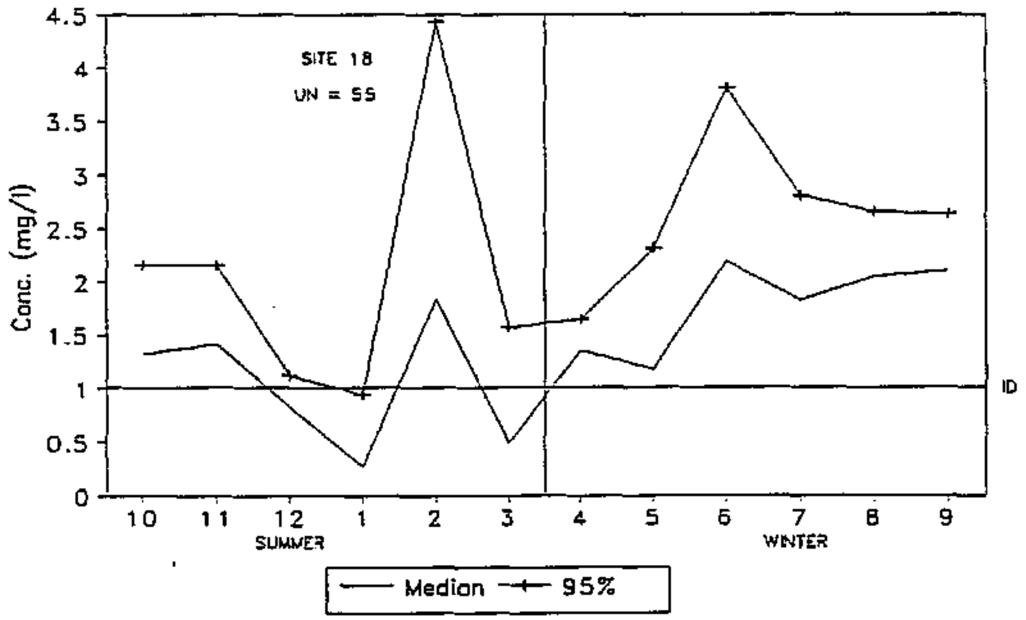

B

Figure 5.61 The 95 percentile and median total phosphate concentrations at four sites in the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN).

Table 5.25 The minimum, median and maximum total hardness (*mg/l*) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

Total hardness	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	-	-	-	-	31.23	ID	-	-
5 Percentile	-	-	-	-	51.9	AC	-	-
Med	-	-	-	-	98.2	AC	-	-
95 Percentile	-	-	-	-	141.3	TO	-	-
Max	-	-	-	-	196.82	TO	-	-

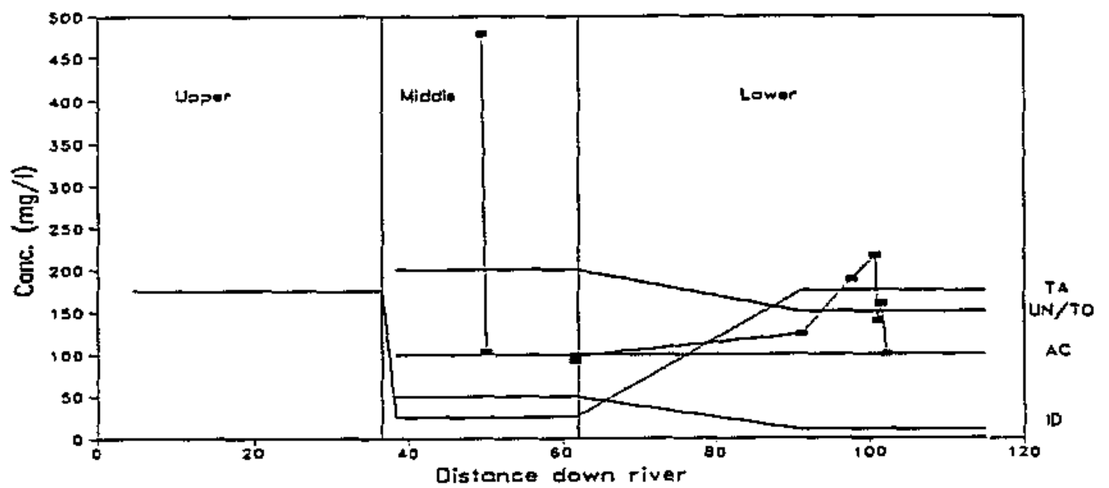

Figure 5.62 The median hardness as $CaCO_3$ concentrations down the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and water quality guidelines as set by DWAF for aquaculture and the textile industry.

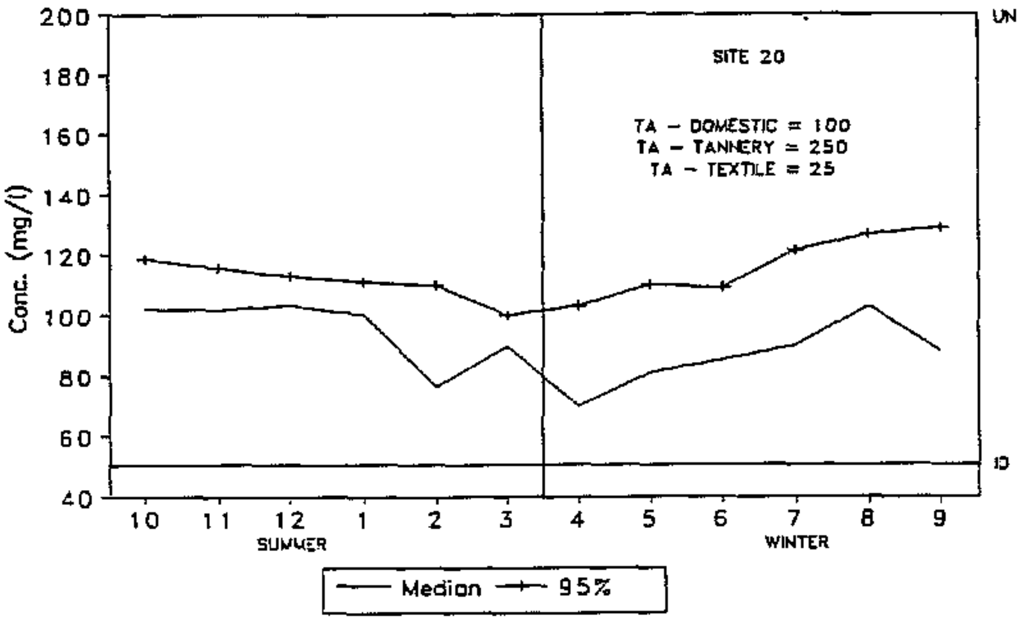

Figure 5.63 The 95 percentile and median hardness as $CaCO_3$ concentrations at Site 20 in the Buffalo River compared to user requirements (as ideal (ID), acceptable (AC), tolerable (TO) and unacceptable (UN) and water quality guidelines as set by DWAF for aquaculture and the textile industry.

Table 5.26 The minimum, median and maximum turbidity units (NTU) in the upper, middle and lower reaches of the Buffalo River catchment as compared to the most stringent user requirements. ID = ideal, AC = acceptable, TO = tolerable, UN = unacceptable and NR = no requirements.

Turbidity	Upper reaches		Middle reaches				Lower reaches	
	Site 4		Site 18		Site 20		Site 26	
	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements	Conc (*mg/l*)	User requirements
Min	-	-	3.0	AC	5.2	TO	2.5	NR
5 Percentile	-	-	3.0	AC	10.0	TO	5.8	NR
Med	-	-	5.1	UN	160.0	TO	57.0	NR
95 Percentile	-	-	70.0	UN	380.0	UN	344.0	NR
Max	-	-	90.0	UN	1200.0	UN	792.0	NR

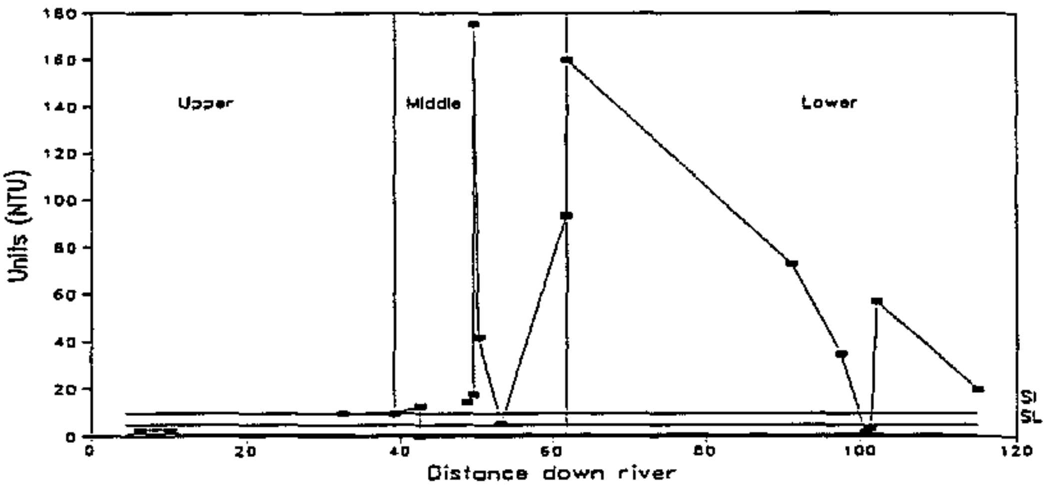

Figure 5.64 The median turbidity units down the Buffalo River compared to water quality guidelines (SI = significant impact, SL = slight impact) as set by DWAF for domestic uses.

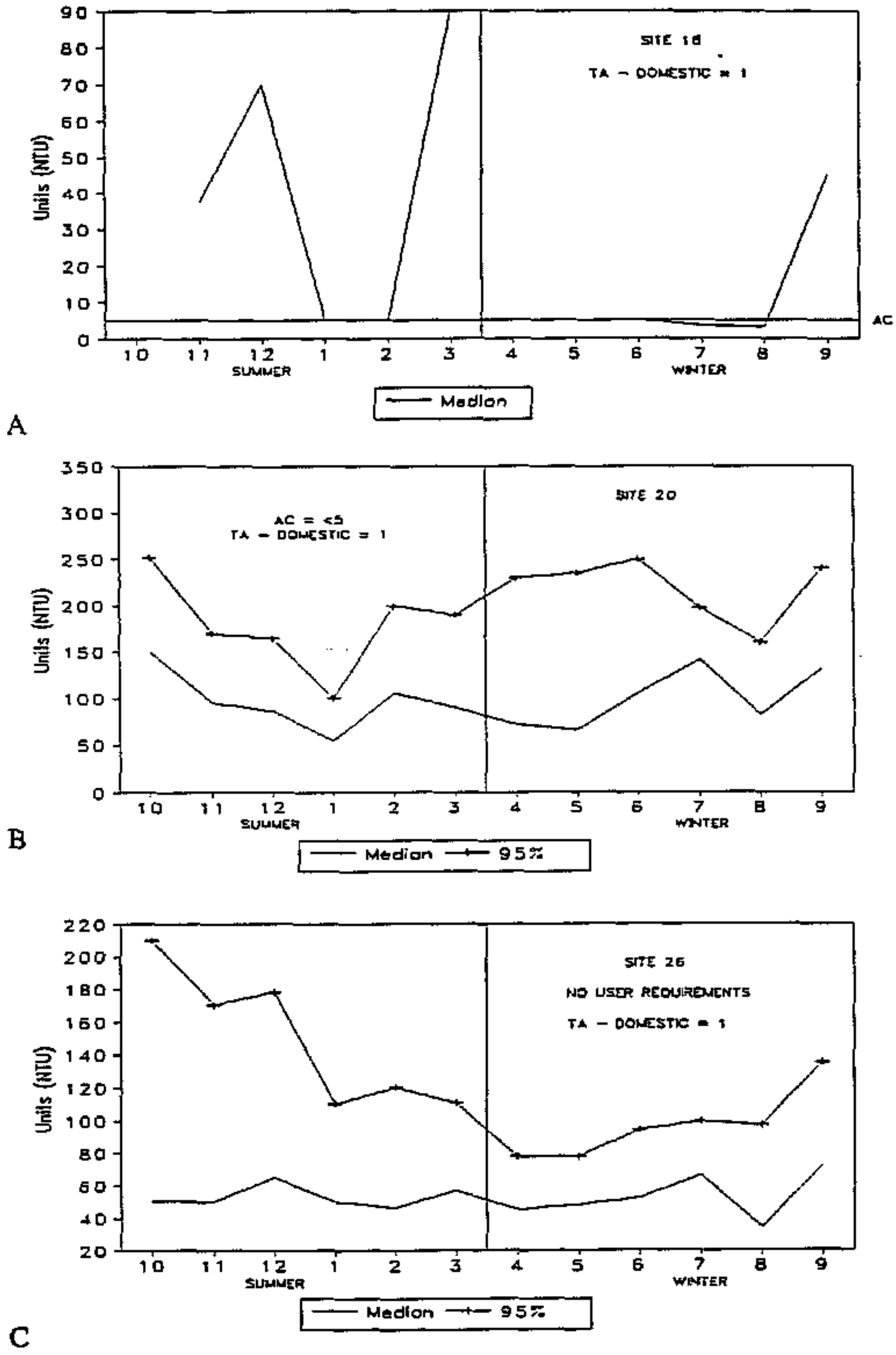

Figure 5.65 The 95 percentile and median turbidity units at Site 18 (A), Site 20 (B) and Site 26 (C) in the Buffalo River compared to water quality guidelines (SI = significant impact, SL = slight impact) as set by DWAF for domestic uses.

6. VARIABLES OF CONCERN

6.1 Definition of variables of concern

Variables of concern are those aspects of water quality in the river, either natural or anthropogenic, which actually or potentially exceed the regional water quality guidelines and/or the users' requirements, and therefore need to be managed if water quality requirements are to be met (F.C. van Zyl, DWAF, *pers. comm.*). These variables of concern need to be prioritised, since some have more serious effects than others, and some exceed the guidelines/requirements by more than others.

In this study, variables of concern have been defined in two categories: Those about which most concern has been expressed, both by the users canvassed during this study and historically in previous reports. These are designated as the main variables of concern. The second category includes those about which no specific concern has been expressed, but for which the user requirements or guidelines are not met in the river. These are designated simply as variables of concern. All the variables of concern have been defined at two levels: The no impact level: and the major impact or unacceptable level.

6.2 Main variables of concern in the Buffalo River

The main variables of concern were indicated by previous studies and identified by the users and the research team as salinization (expressed as Total Dissolved Salts or in terms of electrical conductivity), nutrient enrichment (measured as ortho-phosphate in mg/l) and faecal coliforms (expressed as the Most Probable Number of bacteria (MPN)/100ml).

Salinization is a problem both because of natural background levels which originate from wash-off from the marine shales which dominate the geology of the catchment, and the highly saline effluents from Da Gama Textiles and King Tanning in the King William's Town area. Table 5.6 in chapter 5 defines the status of salinity in the river in relation to the user requirements. In the upper reaches, concentrations are within the ideal to acceptable range at all times, while in the middle and lower sections concentrations reach unacceptable levels for up to 50% of the time.

Phosphate concentrations increase in the middle reaches of the Buffalo River catchment, mainly because of urban effluents from the STW's, and diffuse runoff from urban catchments. Phosphate appears to be the main limiting nutrient for algal growth in the Buffalo River (Selkirk and Hart, 1984) and is therefore the variable that needs to be managed as the main priority in order to limit eutrophication. Table 5.17 in chapter 5 summarises phosphate concentrations in relation to user requirements: In the upper reaches, concentrations are mostly within ideal to tolerable, but maximum concentrations exceed acceptable levels. In the middle reaches no user requirements were expressed, but concentrations at the inflow to Laing Dam exceed 1 mg/l for most of the time, and these concentrations are more than adequate to generate nuisance algal scums. In the lower reaches, concentrations exceed acceptable levels for more than 5% of the time.

East London Municipality has expressed great concern at the presence of raw sewage in Bridle Drift Dam, which appears to originate from broken pipes in Mdantsane. These spills carry high concentrations of faecal bacteria which render parts of the dam unfit for recreational purposes, and have raised widespread (though unjustified) doubts about the safety of Bridle Drift water as a potable supply. The doubts are unjustified because treatment of the water before it is supplied renders it quite safe to drink. There are fewer data for bacterial concentrations in the Buffalo River than for the other main variables of concern. Samples collected during this project from the middle reaches (figure 5.4 in chapter 5) showed reasonable cell counts, with only one sample exceeding the recreational standard of 2000 MPN/100ml. In Bridle Drift Dam, however, counts from samples collected by East London Municipality often exceeded 10 000, and on occasion 100 000 MPN/100ml.

6.3 Other variables of concern

According to the definition in 6.1 above, all aspects of water quality in the Buffalo River qualify are variables of concern, since all of those measured are sometimes at concentrations which exceed no impact limits. Those which are not measured, or for which there are insufficient data, or where there are no specified user requirements/guidelines, must also be variables of concern until information is available to demonstrate otherwise.

Table 6.1a lists those variables which exceed user requirements/ guidelines at the major impact or unacceptable level, and which are therefore variables of concern at all levels. Table 6.1b lists those variables about which not enough is known, either because of a lack of data or a lack of guidelines, to make an assessment. It should be noted that many of these variables can be assessed for some parts of the river but not for others.

Table 6.1 Variables of concern in the Upper, Middle, and Lower Buffalo River. Those in A. are defined as the variables which are measured in the river, and which at some time exceed the acceptable or major impact concentrations defined by users and by the DWAF guidelines.

A.

Variable	Upper	Middle	Lower
Chloride		*	
C.O.D.		*	*
D.O.C.		*	
Salinity		*	
Fluoride			*
Sodium		*	
Ammonium	*	*	*
Nitrates + Nitrites		*	
pH		*	
T.S.S.		*	
Turbidity		*	*
Tot. Alkalin.	*	*	*

B. Water quality variables for which there are no or insufficient data (D), and/or no known user requirements/guidelines (NG). For these variables in the sections of the river indicated, it is not possible to assess their status as variables of concern.

Variable	Upper	Middle	Lower
Boron	D	D	D
C.O.D.	D		
D.O.C.	D		
PO4 (SRP)		NG	
Silicon		D	D
T.S.S.	D		D
Temp.		NG	NG
Tot. PO4	NG		D
Hardness	D		D
Turbidity	D		

Further aspects of water quality that are not at present variables of concern at the major impact/unacceptable level can be identified. These are the variables which are always within acceptable user requirements/DWAF guidelines, and include Calcium, total Nitrogen, Magnesium, and Sulphates.

Other variables which could be of concern, but for which there is insufficient information, include: heavy metals such as copper, lead, zinc, manganese, cobalt, nickel, cadmium, strontium, chromium and mercury; and complex chemicals such as pesticides and herbicides. For all of these variables, any significant concentrations in the river would be evident in terms of an absence of benthic invertebrates. Although there have been occasional incidents of fish and invertebrate kills in the middle reaches of the river, these have been the short-term results of particular spills. There has been no evidence to date of the disappearance of the invertebrate fauna from any part of the river over the long term, and it therefore seems unlikely that they are yet a cause for concern. The main priority for these variables is to institute a monitoring programme to check whether they become a problem.

7. ASSIMILATIVE CAPACITY

The assimilative capacity of a water body is the ability of the water body to receive a pollutant without serious detriment to the water quality requirements of the recognised users. In its simplest conceptual form, it is the difference between the concentration of a water quality variable in the receiving water and the concentration at which the water becomes less fit or unfit for use. A river will therefore have an assimilative capacity for each water quality variable, and the capacity may be different for different seasons. The assimilative capacity may be defined at many different levels, depending on the priority aims for the river, and the potential management options. For the purposes of this analysis, the following protocol has been used :

- Two levels of assimilative capacity have been calculated, based on the most stringent of the user requirements or DWAF guidelines (no impact/ideal conditions), and on the least stringent (major impact/unacceptable limits). The results (tables 7.1 and 7.2) provide a range of assimilative capacities from those which would ensure that concentrations in the river would be low enough to have no effect on any user, to those which would maintain the river as near as possible to the limits of its carrying capacity within conditions that are still acceptable to the users.

- The assimilative capacities have been calculated for each of the upper, middle and lower zones of the river, and for summer and winter.

- The median and ninety-fifth percentile values for each variable in each zone during each month were calculated and plotted in relation to all the available values for user requirements and DWAF guidelines (figures 5.17 to 5.65).

- The calculations of assimilative capacity were made by subtracting the highest monthly ninety-fifth percentile value for a variable in the summer or winter months, from the relevant value of the user requirement/guideline.

- The assimilative capacities are presented as concentrations, since the effect in the river and on the water users is felt in terms of concentrations. To calculate Waste Load Allocations for effluent producers so as to make best use of the available assimilative capacity, would require a combination of discharge and concentration (eg an assimilative capacity of 50 mg/l of TDS at a discharge in the river of 2 m^3/s, would allow 50 x 2000 mg/s = 100g/s or 8.64 tonnes/day of TDS to be discharged to the river without exceeding the assimilative capacity.

Table 7.1 The "major impact" assimilative capacities of water quality variables measured in the Buffalo River at Sites 4 (upper river), 18 (inflow to Laing Dam), 20 (Laing Dam wall), and 26 (Bridle Drift Dam wall). These values are based on the unacceptable or maximum target limits defined in figures 5.15 to 5.65. Figures for assimilative capacities are expressed as concentrations in mg/l, except for EC (in mS/m), pH (in pH units), temperature (in °C), and turbidity (in turbidity units). Dom. = domestic, Agric. = agricultural, Tex. = textile, and liv. = livestock.

Variable	Site 4		Site 18		Site 20		Site 26	
	Sum	Win	Sum	Win	Sum	Win	Sum	Win
B	-	-	-	-	-	-	-	-
Ca	969	959	955	950	979	978	980.5	981
Cl	295	280	0	0	85	82	50	50
COD	-	-	-	0	0	0	0	0
DOC	-	-	0	0	-	-	-	-
EC	395	377	0	0	139	143	19	18
F	0.76	0.64	0.43 - dom. 1.43 - agric.	0.52 - dom. 1.52 - agric.	0.6 1.6	-	0	0
K	47	45	24	23	33	34	3.5	3
Total N	28.8	28.85	21	14	27.5	27	27.6	26.7
Mg	482.5	475.5	469	465	482	482	482	483
Na	752	727	0	0	310	311	15	25
NH_4	0	0	0	0	0	0	0	0
NO_2+NO_3	5.5	4.82	1.2	0	4.59	4.42	8.7	8.7
O_2	-	-	0	0	1.7	1.2	-	-
pH	1	1.2	0	0	0.1	0.9	0.2	0.3
P.V.	-	-	-	-	-	-	-	-
PO_4	0.34	0.32	-	-	-	-	0	0
Si	38	38.5	0.5	2.3	-	-	-	-
SO_4	975	952	80 - tex. 830 - liv.	20 - tex. 770 - liv.	371	372	173 tan. 223 tex.	173 tan. 223 tex.
TSS	-	-	0	0	-	-	-	-
TDS	1650	1530	0	0	600	620	188	180
Temp.(°C)	0	4	-	-	-	-	-	-
TP	-	-	50.6	51.2	-	-	-	-
Hardness	-	-	-	-	130	122	-	-
Turbidity	-	-	-	-	0	0	0	0
Total alkalinity	0	0	0	0	32	30	0	0

Table 7.2 The "no impact" assimilative capacities of water quality variables measured in the Buffalo River at Sites 4 (upper river), 18 (inflow to Laing Dam), 20 (Laing Dam wall), and 26 (Bridle Drift Dam wall). These values are based on the ideal or no impact limits defined in figures 5.15 to 5.65. Figures for assimilative capacities are expressed as concentrations in mg/l, except for EC (in mS/m), pH (in pH units), temperature (in °C), and turbidity (in turbidity units).

Variable	Site 4		Site 18		Site 20		Site 26	
	Sum	Win	Sum	Win	Sum	Win	Sum	Win
B	-	-	-	0	-	-	-	-
Ca	-	-	0	0	0	0	0	0
Cl	0	0	0	0	0	0	0	0
COD	-	-	-	0	0	0	-	-
DOC	-	-	-	-	-	-	-	-
EC	15	0	0	0	0	0	0	0
F	-	-	-	-	-	-	0	0
K	-	-	0	0	3	4	0	0
Total N	3.82	3.85	0	0	2.5	2	-	-
Mg	282.5	275	0	0	0	0	0	0
Na	22	0	0	0	0	0	0	0
NH_4	-	-	-	-	-	-	-	-
NO_2+NO_3	-	-	-	-	-	-	0	0
O_2	-	-	-	-	-	-	-	-
pH	0	0	0	0	0	0	0	0
P.V.	-	-	-	-	-	-	-	-
PO_4	-	-	-	-	-	-	0	0
Si	-	-	0	0	-	-	-	-
SO_4	475	452	0	0	22	23	0	0
TSS	-	-	-	-	-	-	-	-
TDS	-	-	0	0	100	120	-	-
Temp.	-	-	-	-	-	-	-	-
TP	-	-	0	0	0.1	-	-	-
Hardness	-	-	-	-	0	0	-	-
Turbidity	-	-	-	-	0	0	0	0
Total alkalinity	0	0	0	0	0	0	0	0

8. THE IMPORTANCE OF LOW-COST, HIGH-DENSITY HOUSING IN THE BUFFALO RIVER CATCHMENT

See Appendix F for a more detailed account

As South Africa develops in the future, it is only natural that more and more people will wish to upgrade their living conditions, and a central aspect of such upgrading is the desire for piped water and water-borne sanitation in every home. At present many of the low-cost houses in the Buffalo catchment are reliant on stand-pipes serving a number of houses, and have no water-borne sanitation. Any plan to upgrade these facilities will obviously put a considerable strain on the already stretched water resources of the Buffalo River. It is therefore important to collect reliable data about the types of sanitation and water supply in the catchment. It is equally important to assess the effects of wastes from different types of towns on the water quality of the river.

One of the aims of this project was therefore to identify representative low-cost high-density urban developments in different parts of the catchment, and to assess the effect of diffuse runoff on the water quality of the Buffalo River. It was also initially hoped to assess the effects of different climatic regimes on the transport of wastes from the catchment to the river, but this was not feasible because all the main urban areas in the catchment are situated in the middle and lower sections, where the climate is relatively homogeneous.

To assess the effects of these townships it was decided to carry out a demographic survey by means of in-depth interviews with residents, asking a series of questions about numbers of people, water use and waste disposal. The questions were designed to provide information from which to model the amounts of water used, and waste produced, in different kinds of townships. Phosphorus, as the limiting nutrient for primary production in the river, was chosen as the currency for the model.

The following sections of this chapter summarise the results of the attempt to calculate phosphorus budgets (Appendix H) for selected townships (figure 1.1 and Appendix F) and extrapolate the phosphorus input from the rest of the catchment to determine the potential annual phosphate loads in the catchment.

8.1 The demographic survey design

The 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, founded 1948, 3646 plots.
Urban:	Mdantsane, founded 1963, 27011 plots
Urban:	Ilitha, founded 1980, 1061 plots
Rural:	Needs Camp (a resettlement camp), founded 1987, 2102 plots
Rural:	Mlakalaka, (a traditional village), 311 plots.

The infrastructure in the urban areas is slightly better than in the rural areas, and this influences the provision of social services in these communities. Needs Camp is a representative case of a resettlement camp and Mlakalaka is a typical Ciskei village. A squatter area in Zwelitsha was included in the survey. Since the households in these communities vary a great deal in terms of their total income, eight different types of households were identified for investigation (the number of each type of house surveyed is indicated in brackets):

Elite houses (20 cases)
Improved township houses (42 cases)
Typical township houses (76 cases)
Elite village houses (6 cases)
Typical village houses (16 cases)
Humble village houses (16 cases)
Backyard houses (54 cases)
Squatter shacks (70 cases)

8.1.1 *Sanitation facilities*

The types of sanitation facilities available to these communities vary significantly. In the sample 56.3 % of the households used waterborne toilets, 28 % used pit latrines, 6.3 % used bucket toilets and 9.4 % had no toilets at all. Most of those who have no toilets are people who reside in the squatter area. Many of those who use bucket toilets complained about the fact that the buckets were not emptied regularly, and the contents had to be disposed of by the residents.

8.1.2 *Water*

Households 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 the people living in the smaller townships and villages obtained their water from communal taps and some supplemented this with water from tanks collecting water from their roofs.

8.1.3 *Rubbish Disposal*

Rubbish disposal is a problem in all the communities which were studied. Only 15 % of the households were fully dependent on the use of a refuse removal service. Others had to find means of disposing of their refuse. Some took rubbish to any dumping site they could find and some of the rubbish was burnt or buried in the yard. This problem is caused by the failure of the municipal authorities to remove the rubbish regularly. Thirty-six percent of the households do not have access to a refuse removal service and these are people living either in the rural areas or in the squatter areas. Forty-three percent of those who do not have this service said they would like to have it and would be prepared to pay for it.

8.1.4 *Livestock*

Fifty percent of the households kept livestock and/or domestic animals such as dogs and cats. However, there were large discrepancies between the different types of townships. No one in the survey in Mdantsane or Zwelitsha kept cattle, goats or pigs, but many did keep chickens and domestic pets. In Mlakalaka each household had an average of 1.6 cattle, 1.3 goats, and 1 pig, as well as chickens and domestic pets. In Needs Camp, a poorer community, there were 0.4 cattle, 0.8 goats, and 0.9 pigs per household, while in Ilitha there were 0.1, 0.2, and 0 respectively.

Cattle, goats, and pigs are therefore kept mostly by people living in the rural areas, and this discrepancy has a large effect on the amount of phosphorus produced per household (see table 8.1).

8.1.5 *Fuel*

Most households used a variety of fuels. Well over 80 % of the households used paraffin for cooking and/or light, especially in the poorer houses, while the better-off 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. In most cases ash was disposed of on the ground.

8.1.6 *Administrative constraints*

Many of the problems which cause dissatisfaction with sanitation facilities and waste disposal are a result of administrative failures in the poorer municipal areas, particularly in Ciskei. These communities often lack the resources and trained manpower to maintain efficient services, and the dissatisfaction caused by poor services combines with the general political unrest to cause further disruption of services.

8.2 Population

In the Ciskei it is very difficult to obtain reliable population estimates, mainly because no recent census has been taken. The 1991 census failed because of political opposition to it, but there have been a number of estimates which are in broad agreement, and have been used in this study, together with the figures from the interview survey. We have used data from Ciskei Public Works (Mr Landilli, *pers. comm.*, 1993) and the data analysed by Calitz and Grove (1991) to augment the figures collected in the survey. These data have been extrapolated to the sub-catchments of the Buffalo River to provide a picture of population densities in the catchment as a whole (figure 8.1).

The latest official population estimate for the whole of the Buffalo catchment is 311 000 people, but the distribution is very uneven, with
high population densities of more than 1000 persons per km^2 in the urban centres of King William's Town-Zwelitsha and Mdantsane-Potsdam, but densities of less than 10 people per km^2 in some parts of the upper catchment.

8.3 Phosphorus loads

The information from the demographic survey has been used to determine phosphate budgets for the five townships studied (Appendix H). The phosphate loads were calculated from total amounts of sewage, soap and detergents, ash, animal wastes, and food wastes produced in each township. A storage/runoff model was then used to route these components through processes such as sewage treatment, groundwater seepage, soil uptake, and surface runoff, as appropriate, to predict how much of the phosphate reached the river. It is important to realise that these simulations are as yet unverified, and it will be necessary to measure the processes involved in phosphate storage and runoff from urban catchments before confidence limits can be attached to these estimates.

Table 8.1 shows the results of the phosphate budgets for the five townships surveyed. Obviously, the larger urban areas produce much larger phosphate loads than the smaller rural areas, but it is interesting to see that the production per 1000 people is more than 2.5 times as high in the traditional village (Malakalaka), as it is in the large townships. This is almost entirely a function of the animal wastes produced by livestock in the rural traditional villages, compared with the more urban style of life in the bigger towns.

Table 8.1 Phosphorus budgets for five townships in the Buffalo catchment.

TOWNSHIP	TOTAL POTENTIAL ANNUAL P INPUT TO THE CATCHMENT	POTENTIAL ANNUAL P INPUT PER 1000 PERSONS	TOTAL POPULATION	% OF P REACHING THE RIVER
Ilitha	11.21	1.59	7 063	41.5
Mdantsane	235.83	1.41	167 004	40.1
Zwelitsha	47.95	2.01	23 900	41.0
Mlakalaka	11.06	4.20	2 631	90.3
Needs Camp	41.8	2.97	14 077	75.4

The % of the total phosphorus on the catchment which reaches the river is also very variable, ranging from around 40% for the typical townships, to 90% for Malakalaka. This is a consequence of the different pathways of disposal in different townships. In the typical urban areas, where most houses have water-borne sanitation, a much lower proportion of the wastes end up on the catchment, and therefore much less reaches the river, whereas in the rural settlements almost all the human and animal wastes are disposed of onto the catchment.

The above budgets for the five townships were combined with population figures of all the rural villages and townships to extrapolate the phosphorus budget data to the rest of the catchment, and the patterns of phosphate production for the whole catchment are shown in figure 8.2.
As might be expected, the areas of highest phosphate production coincide with the highly populated areas.

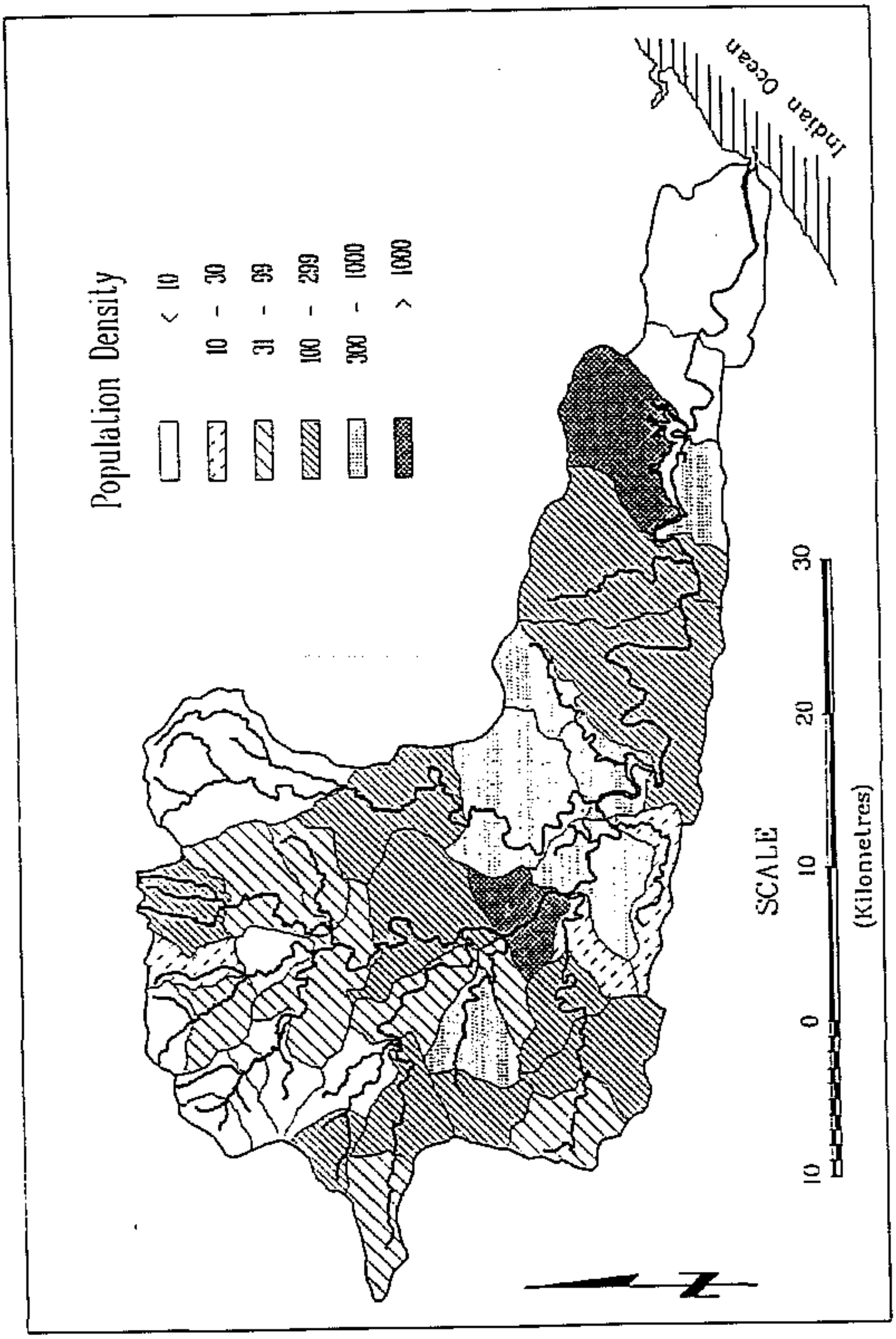

Figure 8.1 Population Densities throughout the Buffalo River Catchment.

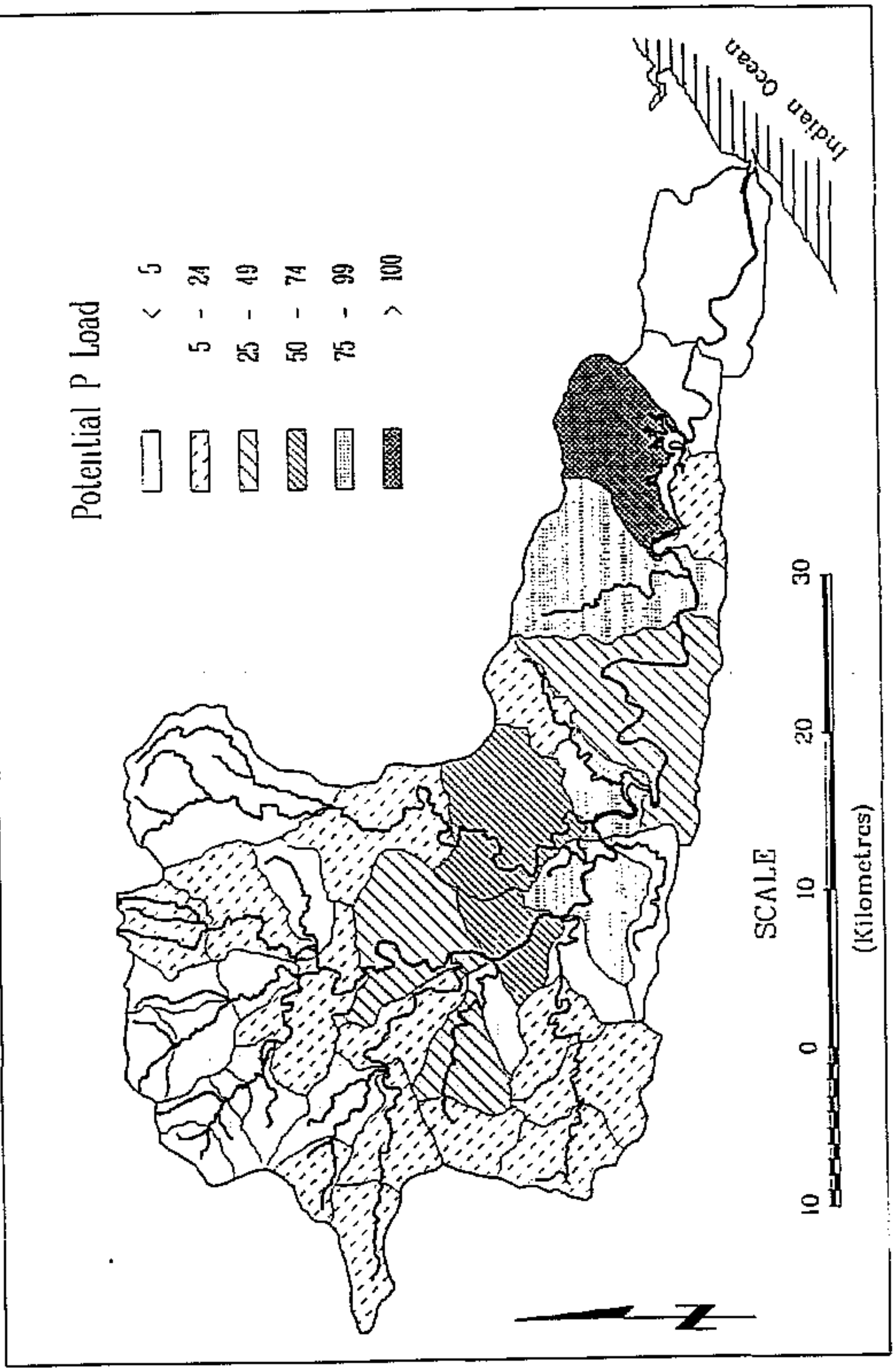

Figure 8.2 Patterns of Phosphate production for the Buffalo River Catchment.

9. WATER QUALITY MONITORING SYSTEM FOR THE BUFFALO RIVER CATCHMENT

9.1 Introduction

Good information is the cornerstone for effective management. It is therefore vitally important that in the design and implementation of a water quality monitoring system, the information gathering process is appropriate to the management needs. The monitoring programme must ensure that the right kinds of information are collected, processed, analyzed and presented in a way that allows the success or failure of a particular action or decision to be evaluated objectively. If required, timely decisions can then be taken on the choice of any corrective action that might be needed.

In the Receiving Water Quality Objectives approach to water quality management which has been implemented by the Department of Water Affairs & Forestry, attention is focused on maintaining the fitness for use of all water resources. Most river systems or surface water resources possess a natural "assimilative capacity" for non-toxic substances. An effluent discharger must be able to convince the Department that a particular effluent can be discharged safely at all times, without reducing the water's fitness for use by downstream users. In the context of effluent discharged to the Buffalo River and its tributaries, a clearly-defined and cost-effective water quality monitoring programme which addresses all these aspects will form a key component of any effective management system.

Much of the generalized background information and design criteria for a water quality monitoring programme in the Buffalo River system have been adapted from a detailed report prepared for the mines and industries of the Phalaborwa complex in the Eastern Transvaal (CSIR-WMB, 1993).

9.2 Objectives of a water quality monitoring system

In the description that follows, it has been assumed that those organizations which are currently responsible for conducting individual monitoring programmes would continue these activities. Ideally, however, the monitoring of river and effluent quality in the Buffalo River catchment should be conducted by a single organization to ensure uniformity of sample collection, chemical analysis, data transformation and reporting procedures.

Any monitoring system for the Buffalo River catchment should address four main objectives:

- describe the overall water quality in the Buffalo River, to determine whether or not its fitness for use has been maintained over time,
- determine the degree to which the different effluent dischargers comply with the conditions specified in their discharge permits,
- indicate any trends of change in the concentration of each water quality variable of concern, and
- indicate the source and timing of any additional salt loads contributed to the Buffalo River.

Where the principles of effluent flow and water quality monitoring differ from those required for river flow and quality, the principles of each are described separately.

9.3 Flow measurements

As part of a routine compliance monitoring programme, an industry is required to monitor both the quantity and quality of any effluent that is discharged to the aquatic environment. Accurate measurements of river and effluent floes are essential for the calculation of loads of the different water quality variables of concern.

Statistical analysis of flow data for a particular effluent stream often shows that most flows lie within a relatively narrow range though high and low flows are also recorded. The frequency distribution of effluent flows should be examined to evaluate the distribution of flow patterns whilst time series data of effluent flows would reveal the presence of any cyclical changes. The presence of cyclical changes in effluent flows usually indicates the existence of regular process changes within the industrial facility.

9.4 Water quality variables of concern

A detailed evaluation of the individual chemical components present in an effluent will provide a sound basis for decisions to be made as to the need for particular water quality variables to be monitored. On this basis, any future long-term compliance monitoring programme should focus on regular measurements of the main water quality variables of concern.

The Department of Water Affairs & Forestry routinely analyzes for the following water quality variables in samples collected from its monitoring sites along the Buffalo River:

- electrical conductivity,
- pH,
- sodium,
- magnesium,
- calcium,
- fluoride,
- chloride,
- nitrate-nitrogen,
- sulphate,
- orthophosphate-phosphorus,
- total alkalinity,
- reactive silica,
- potassium, and
- ammonium-nitrogen.

Not all of these water quality variables are directly relevant to the water quality concerns identified in the present study. For example, fluoride and magnesium are not considered to be water quality variables of concern since their concentrations are always below the guideline values or below any concentration level which signifies loss of fitness for use to any of the identified water users in the Buffalo River.

In addition, it would be important to include additional variable that are not presently monitored on a routine basis. In particular, trace metals which are associated with the textile and tanning industries should be included. These additional water quality variables would then include:

- chromium,
- cadmium,
- lead,
- iron,
- mercury,
- zinc, and
- copper.

Another series of water quality problems are concerned with bacterial contamination and the oxygen demand caused by bacterial degradation of organic matter. Additional water quality variables which should be included to cater for these issues are:

- total organic carbon,
- dissolved oxygen,
- turbidity,
- total bacterial numbers, and
- total faecal coliform bacteria.

All effluent producers/dischargers must be required to conduct routine (preferably daily) monitoring on their effluent, measuring variables which are appropriate to the type of effluent produced. These data must be provided to the Department of Water Affairs & Forestry.

It is clear that the inclusion of additional water quality variables into a water quality monitoring programme can require a major increase in both time and cost. It is recommended that the inclusion of any water quality variable which has not been specifically selected as a water quality variable of concern should be evaluated according to the protocol listed in Section 9.5, below.

9.5 Procedure to evaluate the inclusion of additional water quality variables in the routine sampling programme

The procedures suggested here to determine the need for the inclusion of additional water quality variables in the routine monitoring programme are based on a comparison of analytical results in the river with the proposed water quality guideline values. The procedures also compare results obtained from samples collected upstream and downstream of an effluent discharge to determine whether or not the effluent discharge is likely to be the source of the observed differences. In this procedure, action steps are highlighted.

The procedures are:

- Collect suitable water samples from the Buffalo River upstream and downstream of a defined point-source effluent discharge (or a poorly-defined, non-point source seepage). Analyze for all the water quality variables for which guidelines have been suggested but are not currently part of the existing sampling and analysis programme.

- For those results which are greater than 90 % of the guideline value for a particular water quality variable:

    - repeat the measurements two weeks later.

    - for those case(s) where both measurements for the downstream samples are larger than the upstream samples, by an amount which is considered to be large compared to the precision of the analytical procedure, the effluent discharge is likely to be the cause of the increase. In such cases, the river's fitness for use may be impaired.

    Add the variable to the list of water quality variables which are analyzed routinely in the river samples each week.

    Add the variable to the list of water quality variables which are analyzed routinely in the effluent samples each week.

    Consult with the Department of Water Affairs & Forestry on appropriate action;

e.g. changing the management objective, further investigation of the site of the effluent discharge, etc.

- for those case(s) where at least one of the measurements is larger at the upstream site than the downstream site, the river's fitness for use my be impaired by sources other than the specific effluent discharge under investigation.

Suggest that the Department of Water Affairs & Forestry adds the variable(s) to their routine analyses of samples collected each week.

- for those results which are less than 90 % of the water quality guideline value, or less than the limit of detection for those variables with a guideline specified at the detection limit, fitness for use is unlikely to be impaired. However, monitoring should be continued on an infrequent basis, e.g. at monthly or two-monthly intervals, with particular attention being paid during the driest months to ensure that the water quality is maintained.

Measure as needed to ensure continued acceptability.

9.6 Analytical procedures

During the development of a monitoring programme, a comparison should be made between the analytical results obtained by the industry's analytical laboratory and that used by the regulatory authority. Such an evaluation will revel whether or not the results obtained by an in-house laboratory will be acceptable to the regulatory authority. Where there are unacceptably large discrepancies between the results from different laboratories, the techniques used should be carefully examined to ensure that they are appropriate for the type of analysis performed. Where necessary, techniques should be adapted to match those preferred by the regulatory authority. It is also important to ensure that the accuracy and precision requirements of the regulatory authority are met.

9.7 Choice of appropriate river sampling sites

An extremely important requirement of any compliance monitoring programme is that any water sample collected at a particular sampling site should provide a reliable estimate of the water quality at that site for the time period in question. It is therefore important, for example, that a compliance point located downstream of an effluent discharge should not be affected by incomplete mixing of the effluent stream with the receiving river water. Typically, such a compliance point should be located beyond the minimum distance required for complete mixing to take place.

This mixing distance can be calculated using the equation of Thomann and Mueller (1987) to derive an approximation of the minimum distance from the effluent outfall to the point of complete mixing, for a range of river flow and dimension scenarios:

$$L_m = 8.6 * \frac{U * B^2}{H} \qquad \text{Equation 9.1}$$

Where:

L_m = distance to complete mixing (metres),
U = average stream velocity (metres/second),
B = average stream width (metres), and
H = average stream depth (metres).

This equation can be used to derive a matrix of values of the minimum distance required for complete mixing to take place in the receiving river. A range of possible flow rates, river widths and depths has been chosen to span the likely range of variations in a typical receiving river downstream of an effluent discharge. The calculated values for mixing lengths are listed in table 9.1.

This aspect can also be checked during a field survey. If field measurements do not show any significant differences between four sites spread across the width of the river and samples collected at two different depths at these sites, it can safely be assumed that complete mixing has occurred. Care must still be exercised where the physical features of the receiving river are likely to prevent physical mixing, for example the presence of an island which separates the river into two longitudinal portions would cause a dramatic increase in the distance required for full mixing to take place.

There is also considerable uncertainty surrounding the possible extent of diffuse contributions of salts to the Buffalo River. In particular, it is suspected that seepage from rubbish dumps and sites where effluents are irrigated could cause adverse effects on water quality in the Buffalo River. It is recommended that appropriate sampling sites be located upstream and downstream of these possible sites of diffuse pollution. Sampling at these sites can be stopped if no significant water quality deterioration occurs during a full annual cycle.

9.8 Choice of appropriate effluent sampling sites

Sampling sites should be located on every effluent stream at the point where the effluent is discharged to the Buffalo River or any of its tributaries. Ideally, both the effluent flow and quality should be measured at each site to allow the calculation of salt loads contributed by each effluent stream. This will require the installation and maintenance of flow-gauging structures at each sampling site.

Table 9.1 Matrix of calculated distances from effluent outfall to complete mixing, for four different combinations of river width, five river depths and four velocities of flow.

River Depth (m)	Average Velocity (m/sec)	River Width (metres)			
		5	10	15	20
0.5	0.1	43	172	387	688
	0.2	86	344	774	1376
	0.4	172	688	1548	2752
	0.8	344	1376	3096	5504
1.0	0.1	21.5	86	193.5	344
	0.2	43	172	387	688
	0.4	86	344	774	1376
	0.8	172	688	1548	2752
1.5	0.1	14.3	57.3	129	229.3
	0.2	28.6	114.6	258	458.7
	0.4	57.2	229.2	516	917.3
	0.8	114.4	458.4	1032	1834.6
2.0	0.1	10.8	43	96.8	172
	0.2	21.6	86	193.6	344
	0.4	43.2	172	387.2	688
	0.8	86.4	344	774.4	1376
2.5	0.1	8.6	34.4	77.4	137.6
	0.2	17.2	68.8	154.8	275.2
	0.4	34.4	137.6	309.6	550.4
	0.8	68.8	275.2	619.2	1100.8

Where periodic discharges are released to a receiving stream or river, the flow and quality of these discharges should also be monitored. This monitoring should take place at the same intervals as the normal (continuous) monitoring programme.

Table 9.2 A list of the present water quality and quantity monitoring stations on the Buffalo River (DWAF = Department of Water Affairs and Forestry; CPW = Ciskei Public Works)

Organization	Site	Variables	Dates	Detection limits	Interval
Department of Water Affairs and Forestry	Pirie Main Bos Res., Buffalo River R2H001	Flow	Water quality		
	Ploas 830, Buffalo River R2HOO2	Flow Water Quality	1980 - 1889 1972 - 1982		
	Fort Murray, Buffalo River R2H003	Flow	1938/10/01 - 1950/02/28		
	Tyusha Loc 7, Thyusha River R2H004	Flow	1941/06/01 - 1952/01/31		
	King Williams Town, Buffalo River R2H005	Flow Water quality	1977/01/06 - 1980/01/16 1977 - 1989		
	Msenge Ridge, Mgqakwebe River R2H006	Flow Water quality	1957/02/01 - 1964/11/18 1971 - 1986		
	Braunsweig, Zele River R2H007	Flow Water quality	1947/11/01 - 1981/12/22 1977/09/16		
	Braunsweig, Edendale, Cwencwe River R2H008	Water quality	1972/01/26 1972 - 1989		
	Sheshegu, Ngzokweni Loc 19 R2H009	Flow Water quality	1947/06/01 1972 - 1989		
	135 KWT Q, Macintyre Bridge, Buffalo R2H010	Flow Water quality	1950 - 1990 1972 - 1986		
	Fort Murray, Yellowwoods R2H011	Flow Water quality	1957 - 1985 1972 - 1986		
	Jelta's Loc 29 Mgqakwebe River R2H012	Flow Water Quality	1961 - 1990 1971 - 1986		
	Umnxesha, Mngqesha River, R2H013	Flow	1960/02/12		
	Tshabo Loc Sewage works, Buffalo, R2H014	Water quality	1979/06/13 - 1987/05/08		
	Fort Murray uitspan, Yellowwoods R2H015 - new weir	Flow Water quality	1988 1988		
	Mlakalaka, Zwelitsha Sloot R2H016	Flow Water quality	1988 - 1990 1988 - 1989		
Department of Water Affairs and Forestry	Laing Dam, R2R001	Water quality	1968/04/10		
	Rooikrantz Dam, R2R002	Water quality	1968/07/11		
	Bridle Drift Dam, R2R003	Water quality	1972/02/07		

Organization	Site	Variables	Dates	Detection limits	Interval
Water Quality Management (DWAF)	1. Maden Dam (damwall)	pH	1985/02/04-1987/06/16	None	monthly
	2. Rooikrantz Dam	Conductivity	1985/02/04-1987/06/16	0.1	
	3. Horseshoe bend above KWT	Suspended solids	1085/2/04-1991/06/13	10	
	4. Rail Bridge KWT	Free and saline ammonia	1085/2/04-1991/06/13	0.2	
	5. KWT Sewage Treatment Works, old	Oxygen absorbed	1984/09/17-1991/06/13	0.5	
	5A. KWT Sewage Treatment Works, new	Chemical oxygen demand	1987/10/01-1991/06/13	20	
	6. Denis Radue Bridge	Sodium	1985/02/04-1991/06/13	1.0	
	7. Zwelitsha STW, old	Ortho-phosphate	1984/09/17-1988/12/13	0.05	
	8. Mlakalaka Stream		1983/11/21-1991/06/13		
	9. Zwelitsha STW, New		1984/09/17-1991/06/13		
	10. MacIntyre Bridge		1983/11/21-1989/11/08		
	10A. R2M10 Weir		1987/02/18-1987/04/13		
	11. Laing Dam slipway				
	12. Bridle Drift Dam				
	13. Buffalo Pass				
	13. Yellowwoods, Lonsdale Bridge				
	14. Bisho Sewage Treatment Works				
	15. Yellowwoods below Bisho				
	16. Yellowwoods below Breidbach				
Water Quality Management (DWAF)	17. Yellowwoods R2M11 weir				
East London Municipality	Laing Dam		1959-1978		Daily
	Above Mlakalaka		1959-1976		Daily
	Mlakalaka Stream		1959-1976		Daily
	Fort Murray		1959-1976		Daily
	Good Hope effluent (Da Gama)		1962-1976		Weekly
	Zwelitsha effluent		1959-1960		Daily/monthly composites
	Upstream of Green River		1962-1963		Daily
	Downstream of Green River		1976-1978 8/1989-1991		Daily
	Bridle Drift Dam Streams		11/1967-1978 1979-1991 1/1987-1991 Bacterial		Daily
	Bridle Drift Dam site (Before construction)		4/1966-1967		Daily
	Mdantsane Stream		1966		Daily
CISKEI PUBLIC WORKS	Mdantsane Sewage Treatment Works	pH	Oct 1988 - Apr 1991		Weekly
	Potsdam Sewage Treatment Works	COD (mg/lO)	Oct 1988 - Apr 1991		Weekly
	Zwelitsha Sewage Treatment Works	Oxygen absorbed (mg/lO)	"		Weekly
	Laing Dam	Ammonia (mg/lN)	"		Weekly
	Rooikrantz Dam	Nitrates (mg/lN)	"		Monthly
	Buffalo River, Denis Radue bridge	Phosphates (mg/lP)	"		Weekly
	Buffalo River, R2M10	Faecal forms *E. coli*	"		Weekly
	Mlakalaka Spruit		"		Weekly
	Yellowwoods River		"		Weekly

Organization	Site	Variables	Dates	Detection limits	Interval
CISKEI PUBLIC WORKS	Mdantsane Stream		"		Fortnightly
	Tindelli Stream		"		
	Sitotona Stream		"		
	Shungani Stream		"		
Da Gama textiles		pH COD Coliform organisms E. coli Res Chlorine Total viable organisms colonies			
First National Battery		pH Lead			
Nestle		Sugar content Permanganate value			
Sanachem	At operation plant	pH EC $CaCO_3$			Daily

Where it is thought that contaminated groundwater could be flowing into the Buffalo River, it will be necessary to conduct a groundwater monitoring campaign. If possible, this should include estimates of flow rates and directions, as well as measurements of chemical quality.

9.9 Location of sampling sites in the Buffalo river catchment

Sampling points in the Buffalo River catchment should be located in those areas which are vulnerable to the inflow of undesirable effluents. These sites should also be coupled to reference sites upstream of sources of pollution, against which the level of deterioration can be judged. Sampling sites located in dams or reservoirs cannot easily be compared with those located on rivers and effluent outfalls. Nevertheless, both types of sampling sites are required to obtain sufficient water quality information for effective management of the Buffalo River system.

On the basis of the results obtained in this study, the minimum number of suitable water quality monitoring sites would be:

- in Maden Dam (surface water or integrated sample from near the dam wall),
- in Rooikrans Dam (surface water or integrated sample from near the dam wall),
- upstream of the Buffalo River/Mgqakwebe River confluence (as a background or "unimpacted" reference point),
- between King William's Town and Zwelitsha,
- in the Malakalaka Stream at the Zwelitsha Sewage Treatment Works,
- downstream of Zwelitsha, before the Buffalo River flows into Laing Dam,
- on the Yellowwoods River, downstream of Bisho,
- in Laing Dam (surface water or integrated sample from near the dam wall),
- at the inflow of the Buffalo River in Bridle Drift Dam,
- in Bridle Drift Dam (surface water or integrated sample from near the dam wall), and
- at the downstream portions of each of the tributary streams flowing out of Mdantsane into Bridle Drift Dam, namely: the Shangani, Sitotona, Tindelli and Umdanzani Streams).

Additional sampling sites can be added to the above list as and when the need arises. The sampling sites used in the existing water quality monitoring programmes and the organizations responsible are listed in Table 9.2.

9.10 Measurement of effluent flows

Daily flow measurements should be taken of all effluent streams discharged to the Buffalo River or its tributaries. Where shift-to-shift variations in flow are known to occur, the measurement frequency should be increased to match this. All flow gauging devices should be calibrated according to the directions given by the Department of Water Affairs & Forestry. If possible, automatic flow gauging equipment should be installed and calibrated. This would greatly improve the estimates of total effluent flow and allow far greater control over effluent discharges.

The flows of the effluent streams discharged by sewage treatment works should be measured on a daily basis. If required, appropriate automatic flow-gauging equipment should be installed at these locations.

9.11 Choice of an appropriate sampling frequency for both river and effluent samples

An important consideration of any monitoring programme is the need to optimize the expenditure of time and money for the information required. Therefore it is important to specify at an early stage the precise information requirements that the monitoring programme is designed to satisfy. In the case of an effluent compliance monitoring programme, several different scales of information are required. For example, it is important to understand the variability in quality of the effluent stream with time, as well as the degree to which the effluent meets allowable discharge limits, and the scale and duration of any effects on the receiving aquatic system. The choice of an appropriate frequency for sample collection therefore becomes a critical issue in the design of an effective monitoring programme.

Where very little information is available on the variability of an effluent stream, an initial (or pilot) monitoring programme should be designed to obtain as much information as possible on the variability of the effluent quality and its impact on the receiving river system. Statistical analysis of the data will allow evaluation of the most suitable sampling frequency to obtain the information required to monitor the degree of compliance of the effluent with discharge limits set by the Department of Water Affairs & Forestry.

Industrial effluent discharged to the Buffalo River and its tributaries should be analyzed on a daily basis. This should be based on a single grab sample taken at a standard time each day. If there are significant differences in the effluent quality during a single day, consideration should be given to analysing one grab sample in each working shift.

If the day-to-day (or shift-to-shift) variation in the chemical composition of each effluent stream is relatively minor, selected key analyses (e.g. pH, electrical conductivity, sulphate:chloride ratio) can be used to calculate the concentrations of other water quality variables in the effluent stream. This is based on the assumption that the relative proportions of each of the chemical components or characteristics remains relatively constant. This procedure will help to minimize cost and effort expended whilst maximizing the information gained.

9.12 Data analysis procedures

Three data sets are important in any compliance monitoring programme, namely: the effluent data, upstream data for an unaffected site, and downstream data at a specific compliance point.

All raw data should be stored in a suitable database (e.g. LOTUS, QUATTRO, PARADOX) on a personal computer. The personal computer should preferably be at least a 386-AT model with at least 80 MB of memory available and a maths co-processor to increase the efficiency of operation. At least one back-up copy should be kept of each data file, in a secure location and separated from the location where the data is routinely analyzed.

A routine check should be made for the presence of possible computer viruses each time the data files are examined or manipulated.

Data analysis procedures should incorporate accepted routine statistical techniques for determining the mean, 95th percentile and standard deviation values for each water quality variable at each sampling site.

Wherever possible, the data should be examined to assess whether or not there are any cyclical variations in effluent concentrations, as well as a distinct trend of increase or decrease with time.

In an analysis of possible concentration trends with time it is important to determine the seasonality of the data set. If a distinct seasonal cycle exists, the seasonal components of the data set should be removed before statistical analysis of any trends is conducted. This can be

accomplished by using any one of a number of commercially available statistical software packages, for example SAS, SPSS, Statgraphics and Systat. Once the seasonal components have been removed, the residual values should be examined to ensure that there is an even spread of values either side of the residual index.

Subsequently, the seasonal components are removed from the original data set to produce a seasonally-adjusted data set. This seasonally-adjusted data set is then plotted. With the seasonal components removed, it is now possible to evaluate any trend in concentration with time. This trend is then evaluated using a line/formula fitting technique to evaluate the rate of change with time. Where the rate of change with time is very variable, it may be more appropriate to split the de-seasonalized data set into smaller (shorter) sets and evaluate each set of changes separately.

An auto-correlation analysis of the original data set can indicate whether or not there was auto-correlation between any data point and those collected at specified time intervals either before or afterwards. Taken on its own, this information will indicate what time interval must elapse between the collection of successive samples to ensure that an independent sample is collected. An independent sample is one where the concentration of any specific water quality variable is unrelated to (or not influenced by) the concentration of that variable in either a preceding or a subsequent water sample.

If this exercise is repeated with the de-seasonalized data set, a different picture could emerge. The auto-correlation analysis will reveal whether or not there are any cyclical changes in concentration, which increase the variability of the effluent quality. Such cyclical changes could, for example, be caused by a particular pattern of operations within the particular industry or facility. Such an observation will allow management to develop and implement appropriate corrective measures to reduce this variability.

The most appropriate sampling frequency for compliance monitoring of a factory effluent stream will ultimately be determined by the particular water quality variable which requires the shortest time interval between samples. For example, in a case where one water quality variable should be sampled at weekly intervals and another at fortnightly intervals, it would be appropriate to sample both variables simultaneously at the shorter (weekly) time interval.

The second important component of a compliance monitoring programme is the receiving water body. Again, similar seasonality analysis should be conducted for each water quality variable of concern as a basis for deciding on the most appropriate sampling interval and statistical treatment of the data.

Subsequently, the seasonal components should once again be subtracted from the original data set and a seasonally-adjusted data set plotted. With the seasonal components removed, it will now be possible to evaluate any trend in concentration with time. Once again, any trend analysis must consider whether or not the data set should be split into shorter sets to examine different portions of the pattern of change.

Against the background of the required sampling frequency for the effluent stream (for example, once per week), it would be inappropriate for compliance monitoring at the downstream river site to occur less frequently than that required for the effluent. Therefore, an overall sampling frequency should be selected that will reduce the expenditure of time and effort to a minimum and still provide reliable results.

9.13 Reporting formats and frequencies

The format of reports on a compliance monitoring programme should be such that both industry management and the regulatory authority (in this case the Department of Water Affairs & Forestry) should be able to evaluate the information quickly and implement any corrective action as rapidly as possible. Therefore, the reports should be as concise as possible and yet contain all the relevant information on the characteristics of the effluent stream and its effect on the Buffalo River. The information presented should, if possible, include an evaluation of any trends of change. Where appropriate, any corrective action that have been taken should also be listed.

It is difficult to define precisely the types of statistical routines which could be used to demonstrate trends of change in a data set, before the data set is available. Therefore, it would be better to make sure that all the individual data points for the preceding twelve-month period of sampling are shown in each report that is submitted to the Department of Water Affairs & Forestry. This will allow rapid comparisons to be made between data for the same month from the previous year and allow evaluation of possible seasonal effects during an annual cycle. Where necessary, a "t" test can be run to compare the means of different months to evaluate the significance of any differences between the means. In addition, the number of data points which exceed the allowable limits set for the river (or effluent) should also be clearly shown.

Ideally, any report to the Department of Water Affairs & Forestry should include information covering a reasonable period of time. It is felt that a period of twelve months is reasonable and would eliminate the bias of seasonality. If reports are submitted to the Department of Water Affairs & Forestry every three to six months, and each report contains the data for the last twelve months, these reports will provide a better overview of the effluent quality, its impacts on the receiving river and any trends in concentration over time. If such a reporting arrangement is considered suitable by the Department of Water Affairs & Forestry, it is relatively straightforward for the industry concerned to customize an effluent quality database for this purpose and to automate most of the report writing procedures.

The reports submitted to the Department of Water Affairs & Forestry should contain the following information for each of the variables for each of the river and effluent sampling sites:

- the dates and sites at which samples were collected,
- measured results for the previous twelve months,
- mean and median values for each month's results for the previous twelve months,
- standard deviation of each month's results for the previous twelve months,
- mean of each of the twelve month's results for the previous five years,
- standard deviation of each of the twelve month's results for the previous five years, and
- 95th percentile values for each water quality variable of concern, for the preceding twelve months.

9.14 Identification of sources of any toxicity

It is important to ensure that effluent streams discharged to natural rivers do not contain any compounds at potentially toxic concentrations. Conventional analytical techniques usually do not reflect this type of information and cannot indicate the possibility of synergistic or antagonistic effects between compounds or substances. It is recommended that any effluent streams that are discharged to a natural river system should be tested for possible toxic effects on aquatic ecosystem components. This testing should be repeated whenever process changes result in significant changes to the quality of the final effluent that is discharged.

The toxicity testing should preferably consist of a simplified series of screening tests in the first instance. These tests should be carried out on all effluent streams to demonstrate whether or not there is any toxicity in these effluent streams and, where one or more toxic effects are present, the type of toxic effect (e.g. mutagenic, carcinogenic, etc.). Screening toxicity tests are normally carried out on batch samples of effluent, either undiluted or diluted with the receiving water. This approach ensures that possible synergistic or antagonistic between effluent components and the receiving water are also evaluated.

The strictest criterion, i.e. nil test organism deaths (or other effects) in undiluted effluent samples, signifies that the effluent can be discharged safely to the receiving river. If the effluent causes significant effects in terms of lethality, mutations, etc., further testing should be conducted to determine what degree of dilution is required to reduce these effects to some pre-determined "acceptable level". The choice of an "acceptable level of effect" will depend on the type of effect caused and the public sensitivity around the issue.

All toxicity testing should be conducted using internationally accepted testing procedures and appropriate test organisms or groups of organisms.

9.15 Auditing system

Auditing of a water quality management system as described above can be defined as:

A basic management tool comprising a systematic, documented, periodic and objective evaluation of how well the organizational/management systems and equipment are performing with the aim of helping to safeguard the water environment by:

- facilitating management control of water quality management practices, and
- assessing compliance with agreed policies, which would include meeting regulatory requirements.

Some of the more common objectives of an audit system include:

- to identify areas where costs can be saved through minimizing waste, conserving energy and utilizing by-products,
- to determine whether or not there is compliance with the relevant legislation and regulations and, if necessary, international standards as well,
- to identify major areas of risk,
- to determine the degree to which an organization is complying with its own corporate environmental policies and guidelines,
- to identify gaps or weaknesses in the water quality management systems with the aim of improving these systems,
- to establish yardsticks or benchmarks against which future performance can be assessed,
- to evaluate the effectiveness of emergency response plans,
- to assist with the maintenance of good relationships with the authorities by being able to demonstrate responsible management of water quality, and
- to improve environmental performance and thereby protect the environment in general.

Successful audits depend largely on the following four factors:

- systematic and well-structured questionnaires, interview procedures and protocols to be able to identify key problems quickly and effectively,
- the ability to access background information rapidly, for instance, information on legal requirements, toxicity information, etc.,
- good interviewing techniques and the ability to put interviewees at ease, and
- careful scheduling.

There are two basic approaches which can be used to carry out the kind of audit which is envisaged. These are:

- to audit only one or two aspects of a large number of sites or facilities, i.e. a "narrow and deep" approach, or
- to audit several aspects of a limited number of sites or facilities, i.e. a "broad and shallow" approach.

It is improbable that an audit of the water quality management system would examine every aspect of that system. A sampling and scoping process usually takes place, determined by the system's particular needs and objectives. Three main baseline levels of auditing are generally adhered to:

- policies,
- management systems, and
- compliance audits.

Once a monitoring system has been implemented and has functioned for a reasonable period of time, an assessment can be made of the auditing approach to use and a final decision made. The auditing of the water quality monitoring and management systems is a process which will evolve naturally over time. The elements in the process and the priorities which must be attached to each, should only be clearly defined or fixed once the process has been tried and tested in practise for a reasonable period of time.

10. POTENTIAL WATER QUALITY MANAGEMENT OPTIONS

Different management options are appropriate for different zones of the Buffalo River. The rest of this chapter defines the existing and potential water quality problems in each zone of the river, and suggests possible management strategies to prevent, repair, or minimise the problems.

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. Much of the upper catchment is under natural montane forest, with areas of commercial forestry. In our opinion, it is the largely undisturbed nature of the natural forest which maintains the quality of the water, and buffers the rainfall/runoff regime to ensure a gradual constant supply of water to the upper dams. Any increase in commercial forestry, or clear-felling of the natural forest, will inevitably lead to increases in sediment loads and a flashier flow regime, with larger shorter floods and lower or non-existent base flows. It is also likely that the nutrient loads into the upper dams would increase, if the nutrient retention capacity of the natural forest is lost. Maden Dam is becoming more popular as a recreation area, and there is at present very little control over numbers of visitors or their behaviour. Unrestricted cooking fires, swimming, and waste disposal could threaten the present very high quality status of the water in the dam.

The management options for this section of the catchment are therefore 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.

10.1 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. A potential problem is the increase in the rural population, many without properly planned water supplies. This could lead to localised water quality problems at low flows due to increased direct use of the river for washing, laundry, and waste disposal.

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.

10.2 The middle reaches (to Laing Dam):

The area from the inflow of the Mgqakwebe tributary (just upstream of King William's Town) to the upstream end of Laing Dam is one of the major foci of water quality deterioration. It is here that the main concentration of urban and industrial effluents enters the river (see chapters 4 and 5), as well as the more diffuse effluents from urban runoff, squatter settlements, and seepage from rubbish dumps. One of the major tributaries, the Yellowwoods, also contributes its load of pollution, including Bisho's sewage effluent, into the upper reaches of 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.
  It appears that this measure is already in progress, and the King William's Town STW now generally conforms to the Standard (Mr. W. Selkirk, pers. comm.). The Zwelitsha STW has also been upgraded, and has conformed to the Standard since October 1992 (Mr. R. Kahn, pers. comm.). Since these STW's have been the main contributors of phosphates entering Laing Dam for 73% of the time, an improvement in their performance should alleviate conditions in Laing Dam considerably.

- Extension of the existing Cyril Lord pipeline to Berlin or King William's Town (Kapp Prestedge Retief, 1992; Mallory *et al.*, 1989).
  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. Feasibility studies have been carried out on extending the existing pipeline, which serves the textile factory at Arnoldton, either to Berlin or all the way to King William's Town (Pim Goldby, 1990). The advantages of such a pipeline would be a reduced risk to the environment, and improved water quality in the river, and the possible attraction of new industries to the region. However, the disadvantages include the loss of water to the river, and the costs of building and maintaining the pipeline, which might be as much as twice the costs of upgrading the conventional treatment facilities and disposing of the treated effluent in the river (Pim Goldby, 1990). 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. One dump is situated upstream of King William's Town in a small valley which leads for

300 m into the river. Two others are situated on the river banks between Zwelitsha and the inflow to Laing Dam (see Figure 3.1). There is at present no information on the effect of these dumps on water quality in the river, so the first priority is to monitor any seepage during rainfall events. Depending on the results of such monitoring, it may be necessary to remove or in some way seal off the dumps from the river.

- 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 (R. Kahn, pers. comm.).

- 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. However, it is very well established in Laing Dam, and would be extremely expensive to eradicate. The plants do take up excess nutrients, and may have an important role in the reduction in available nutrients which occurs in Laing Dam. There is some uncertainty as to the rate of nutrient retention by the plants, which obviously die and decompose, re-releasing the nutrients. How much of the nutrients becomes available, and how much becomes incorporated in the sediments, are at present unresolved questions.

- Use water from Wriggleswade Dam on the Kubusi River to improve conditions in the Yellowwoods River and to dilute saline water in Laing Dam.
  One of the options from the Amatole Water Scheme is to release water from Wriggleswade Dam into the Yellowwoods Tributary to flow into Laing Dam. The Yellowwoods River is a temporary stream, with no natural flow for most of the year, and with high densities of rural settlements as well as Bisho in its catchment. As a result, the water quality is often very poor in the pools along the river bed. The addition of high quality water from the Kubusi River would improve the water quality by flushing out the pools. The water could also serve to dilute poor quality Laing Dam water, if sufficient quantities were made available. The disadvantage would be that the quality of the transferred water would deteriorate both in the Yellowwoods River and in Laing Dam. It may therefore be more beneficial to take advantage of the high quality water by piping it directly to a treatment works rather than using it to dilute low quality water, and this now appears to be the most likely option.

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

Water quality improves in Laing Dam, both in terms of salinity and nutrients, due to the dilution effect of stored flood water low in dissolved salts, to algal and plant uptake of nutrients, and to sedimentation of nutrients. Between Laing dam and Bridle Drift the river is relatively inaccessible. catchment land-use is mainly extensive unirrigated agriculture, population levels near to the river are fairly low, and there are therefore few threats to the water quality in this section. However, the immediate catchment of Bridle Drift Dam is dominated by large urban areas and settlements, including Mdantsane, Potsdam, and Needs Camp. Problems here are mainly caused by sewage effluent leaking into the Dam down the small tributaries which drain Mdantsane (chapter 5).

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

- Control and mend the breakages in the sewer and reticulation systems in Mdantsane. Raw and partially treated sewage effluent periodically leaks into Bridle Drift Dam from broken sewage pipes in Mdantsane. It appears that the breakages are the result of vandalism or sabotage.

- Divert low flows from the four streams in Mdantsane to the sewage works. Low flows in the four small tributaries draining Mdantsane often carry very high concentrations of sewage effluent. It would be possible to build small holding dams at the bottom end of these tributaries to intercept the low flows and divert the water back through the Mdantsane STW. In this way the effluent would not reach Bridle Drift Dam in an untreated state. This would only be effective at low flows, but it appears (chapter 11 below) that it is these low flow conditions which lead to high concentrations of faecal bacteria, and promote the formation of algal scums which cause the main concerns, both for recreational use of the dam and for potable water treatment.

- 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 action.
  Perhaps information days organised by peoples' representatives to inform Mdantsane representatives of the consequences and the financial implications of such vandalism might help in the prevention rather than the 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 inherent problems have been compounded by the political division of the catchment between Ciskei and South Africa, and by the placement of storage reservoirs downstream of the sources of pollution, resulting in the accumulation and recirculation of effluents between the dams and their supply centres. The geology of the catchment, being largely marine shales, also contributes to the inherent water quality problems, causing high concentrations of background salinity in the river.

The political division of the catchment should soon be a thing of the past, with the proposed reincorporation of Ciskei into South Africa, and this should help to streamline the management of the water resources of the river. The other inherent problems, of population growth, the unfortunate positioning of the dams, and naturally high levels of salinity, are much less likely to be solved in the foreseeable future, and have to be managed in order to limit the problems, rather than resolve them. The conclusions and recommendations in this report have to be seen within the context of these intractable problems.

11.1 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).

11.2 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. Upstream of King William's Town there is a slight increase in nutrients, probably due to fertiliser runoff downstream of Rooikrans Dam. Downstream of Bridle Drift Dam, below the Mdantsane sewage outlet, nutrient concentrations are often very high (Palmer and O'Keeffe, 1990), but there is practically no water abstraction below this point.

The role of Laing Dam in diluting saline effluent and as a sink for nutrients is very important. Water quality at the dam wall is considerably improved compared with inflowing water, and not only does this affect the water supply to King William's Town and Zwelitsha, but it helps to protect water quality downstream to Bridle Drift Dam.

11.3 Temporal water quality trends:

Despite fears expressed during the 1980's (eg Hart, 1982), 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). There are periods of several years when concentrations of salinity in particular rise, such as the period during the early 1980's in Laing Dam, but these events are associated with droughts, and concentrations reduce dramatically when the dam is flushed out by floods. It is extremely difficult to assess whether loads entering the dams are increasing over time, but even if they are, the flushing effects of floods will continue to reset the river periodically.

11.4 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). In the immediate future, it is possible that saline effluents in the Zwelitsha area may increase, with the move of the Da Gama operation in East London to their main plant in Zwelitsha. There is no growth predicted for agriculture in the catchment.

11.5 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.

Two intensities of variables of concern were identified: At the ideal or no impact limit, and at the major impact or unacceptable limit. In the former case, all variables exceeded the limits at some time, but in the latter case, Calcium, Total Nitrogen, Magnesium, and Sulphates were consistently at concentrations within the limits.

11.6 Sources of pollution:

Natural background sources of salinity from the local geology contribute 65% of the dissolved salt load entering Laing Dam, and Da Gama Textiles contributes a further 21%. Other unquantified contributions come from wash-off from the irrigation lands used by Da Gama and King Tanning, and from seepage from the rubbish dumps next to the river. 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. The remainder of the salt load emanates from run-off from the surrounding townships during rainfall events, or as seepage from the Mdantsane tributaries during dry periods. 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 driving the algal blooms which are the main cause of concern in Bridle Drift Dam. The high loads entering the dam during flood events are accompanied by large sediment loads, high turbidity and therefore low light penetration. As a result, conditions are unsuitable for the formation of algal blooms, nutrients become adsorbed onto the sediment particles, and are therefore unavailable to algal cells. During dry periods, on the other hand, the water is usually clear and less turbulent, conditions ideal for the growth of algae such as *Microcystis aeruginosa*, so that a much smaller phosphate load is sufficient to inoculate and sustain nuisance blooms. We would therefore conclude that high phosphorus inputs during low flow conditions when there is good light penetration, combined with the *adaptations of Microcystis aeruginosa* (buoyancy and an affinity to strong light intensities, Zohary and Robarts, 1989) are causing the algal blooms that have been experienced in Bridle Drift Dam since early 1991 and have persisted for most of 1992 (except during June to August - A. Lucas *pers. comm.*, 1993).

11.7 Effects of low-cost, high-density housing:

It is evident from chapter 8 and from figures 5.10 to 5.13 that large phosphorus loads are generated within the different types of townships in the catchment, and that these loads form the main contribution to the middle and lower reaches of the river. 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. Because of the nature of run-off from the catchment, these nutrients tend to reach the river intermittently and in large amounts, associated with high flows and large sediment loads. It is unfortunate that the main supply dams are situated immediately downstream of the largest townships in the catchment, and therefore receive and often store the intermittent flushes of nutrient washing off from these townships.

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. In the smaller and more traditional townships people tended to keep more animals, which substantially increased the nutrient loads onto the catchment.

11.8 An assessment of the RWQO approach:

The Receiving Water Quality Objectives (RWQO) approach has been a considerable step forward compared to the uniform effluent standard approach previously adopted by DWAF. It is aimed at the identification and implementation of catchment and variable specific standards related to the users' requirements, and is therefore much more likely to achieve a happy compromise between the maintenance of the functioning of the river and the need to dispose of wastes. However, some problems have emerged in the assessment of RWQO's during the course of this investigation.

Chief amongst these problems is that RWQO's are set in terms of concentrations for each variable from which acceptable waste loads can be calculated. This would work well if the undesirable effects of any variable were directly related to the concentration in the water. In the case of nutrients in particular, there are many other important governing factors which confuse the consequences of the inflowing loads and resulting concentrations in the receiving water. We have seen that nuisance algal blooms have been the main water quality problem in Bridle Drift Dam over 1991 and 1992, and that these are mediated by organically-enriched effluents from the

Mdantsane tributaries during dry periods. Nutrient run-off simulations have indicated that these loads are small relative to the other sources of inflow during high flows. Concentrations in the dam as a whole resulting from the dry period contributions are low, and are certainly well within the acceptable limits defined by users. The algal blooms 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 this case, 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 unacceptable conditions.

For salinity, which chiefly consists of conservative elements, less affected by outside factors, concentrations in receiving waters are generally related to the influent loads diluted by the volume of water in the river. In this case, the RWQO approach is likely to be more successful in predicting the limits of acceptable conditions. It must therefore be concluded that the RWQO approach should be applied with caution, and may be a necessary process for the assessment of acceptable limits, but is not sufficient for the understanding of the consequences of the more reactive variables in the river.

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.).

12.1 Improvements to the infrastructure in the catchment

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

12.1.2 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.

12.1.3 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.

12.1.4 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.

12.2 Water Management

12.2.1 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).

12.3 Monitoring

12.3.1 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.

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

12.3.3 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.

12.4 Information and education

12.4.1 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.

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