FINAL REPORT

WATER QUALITY FOR AQUATIC ECOSYSTEMS:

TOOLS FOR EVALUATING REGIONAL GUIDELINES

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EXECUTIVE SUMMARY

E 1. BACKGROUND AND MOTIVATION

This project began in July 1994 subsequent to the previous Water Research Commission Project No. K5/351 (Final Report 351/1/94 "The effects of water quality variables on riverine biotas": Dallas *et al.* 1994). During the latter half of the previous project and in the initial stages of the current one, the South African Department of Water Affairs and Forestry (DWAF) began developing guidelines for water quality for the five identified categories of "user": industry, domestic supply, agriculture, recreation and aesthetics, and aquatic ecosystems. Subsequently, (DWAF 1997) have recognised ecosystems as the resource from which users are supplied, and guidelines for aquatic ecosystems therefore aim to "protect" the resource so that sustainable use is possible.

Water quality requirements for most of these users are more or less universal. Water quality guidelines for aquatic ecosystems are not universally applicable, however, varying from continent to continent and from region to region; further, very little local information is available (Hart & Jones 1992, Dallas & Day 1993). These regional differences provided motivation for investigating the development of regional guidelines for variables likely to change geographically, while certain components of the previous project, such as the Biological and Chemical Database, required additional development. The current project has also facilitated refinement of the geographical extent of the Water Quality Management Regions proposed in the previous project.

E 2. TERMS OF REFERENCE

E 2.1 General

The overall objective of the project was to increase our knowledge of water quality requirements of riverine organisms with a view to developing and/or verifying regional water quality guidelines for aquatic ecosystems. The overall aims of the project, as agreed at various Steering Committee Meetings, are detailed below.

E 2.2 Aims

1a) To continue the development and refinement of the biological/chemical database (BCD),
b) to investigate potential custodians of the BCD, and
c) to produce a user manual for querying the BCD.

The development of the BCD has taken the project team far longer than originally envisaged. Approval to focus on the BCD was given at the Steering Committee meeting of 23 March 1995. Extensive development has taken place on the BCD (Chapter 2) and a user manual has been written (Dallas & Janssens 1997). Both the BCD and the manual have been demonstrated to a number of potential user organisations including DWAF, Cape Nature Conservation, Rhodes University, the

Water Research Commission and members of the Freshwater Research Unit, UCT, in addition to groups such as Ninham Shand and Iscor, which may wish to access the BCD. Investigation into the final custodianship and accessibility of the BCD is continuing, and funding for capturing of new data, further querying of the BCD and investigation into accessing data, e.g. via the Internet, has been incorporated into a new project proposal to the WRC.

2a) Either,
to produce interim site-specific guidelines (where these have not already been produced by DWAF) for all variables of concern,
or,
if these interim guidelines have already been produced, to determine to what extent these guidelines compare with information extracted from the review and the BCD.

b) In either case, to attempt to develop regional values for these variables.

The variables focused on in the current project are all non-toxic inorganic constituents or attributes such as conductivity and total dissolved solids (TDS), total suspended solids (TSS) and turbidity, and pH. Some of these may cause toxic effects at extreme concentrations, but are generally 'system characteristics' because natural concentrations depend on localised geochemical, physical and hydrological processes. It is therefore necessary to assess their guidelines at a regional and not a national level.

Interim national water quality guidelines for aquatic ecosystems were developed for South Africa in 1996 (DWAF 1996a). Ms Dallas formed part of the Project Team responsible for the compilation of background information on selected variables and Dr Day acted as one of the reviewers. Criteria for 'system characteristics' in the guidelines are given as numerical ranges or as proportional changes from local background conditions because of natural geographical variations.

This project has focused on the extent to which these interim national guidelines are appropriate at regional level. In this regard, a *region* with respect to *regional water quality guidelines* includes both regional (or geographic) and sub-regional (or longitudinal riverine) divisions. Regional water quality guidelines have been developed within this spatial framework for the Southern and Western Coast Water Quality Management Region (WQMR) using the BCD supplemented with data collected in the current project (Chapter 3) and preliminary regional guidelines have been proposed for other WQMRs, although scarcity of data in the BCD for certain regions has prevented detailed analysis.

3a) To select suitable sites on three representative rivers that vary widely geographically and in terms of their intrinsic water quality,

b) to determine the extent to which the actual water quality in these rivers (extracted from DWAF records, local authorities, etc) corresponds with the values set by the interim guidelines, and

c) to examine the responses of riverine biotas in regard to three or four site-specific variables (probably turbidity/suspensoids, pH and TDS, and possibly one or more nutrients).

With the agreement of the Steering Committee (23 March 1995) it was agreed to change the methodology such that more detailed assessments would be undertaken within a single catchment but would include a number of sites in different subregions. It was initially envisaged that a similar undertaking could be done in a further two catchments within different WQMRs. However, the additional time devoted to the development and refinement of the BCD prevented this,. Funding has therefore been requested as part of the follow-on WRC proposal for verification of the methodology within a second WQMR.

4 To develop protocols for:

a) verification of interim guidelines, and

b) monitoring the effectiveness of guidelines.

A protocol for the verification of regional guidelines has been developed (Chapter 3). Subsequent to this project's proposal, there has been considerable interest in and development of a national aquatic ecosystem biomonitoring programme (NAEBP). SASS is the proposed method for monitoring the effectiveness of the guidelines and this biomonitoring method is likely to also form an integral component of the NBP. The use of SASS as a tool for testing the effectiveness of the water quality guidelines has been tested within a single DWAF drainage area, namely H, which includes the Breede and Duiwenshoek catchments (Chapter 4). The SASS assessments undertaken in these catchments, together with additional SASS assessments from rivers in the southern and western coast water quality management region, have enabled SASS reference sites to be identified and preliminary categories of water quality impairment to be developed for this WQMR on the basis of these SASS Scores. This aspect of the study is reported on in Chapter 5. These will facilitate future monitoring of the effectiveness of the guidelines within this WQMR. The technique with which these reference sites were identified and water quality categories established can be applied to other regions in South Africa.

5 To undertake pre-construction monitoring of the biota of the upper Berg River.

The opportunity to undertake monitoring of the biota of a river, prior to the construction of a dam, is an unusual but fortunate one. The project team has undertaken quarterly assessments of the macroinvertebrate fauna and water chemistry over a two year period (mid-1995 to early-1997). This will form the baseline information against which future monitoring programmes can be compared. The results of this study are reported in Chapter 7.

6 To begin to address the question, "to what extent does water quality determine the distribution of local south-western Cape endemics?

The development of the Biological and Chemical Database and the extensive SASS assessments undertaken within this region have enabled characteristic communities associated with the mineral poor, acidic and poorly buffered south-western Cape waters to be identified. One such organism is the amphipod, *Paramelita nigroculus*. A detailed toxicological study of the combined effect of aluminium, copper and manganese on this organism has been undertaken as a doctoral thesis by a

part-time member of the research team, D. Musibono. This study uses the South African water quality guidelines for toxic constituents as criteria for toxicity testing. A synthesis of this study has been documented in Chapter 6 of this report.

E 3. SUMMARY OF MAJOR RESULTS

E 3.1 Biological and Chemical Database (Chapter 2)

Development of the Biological and Chemical Database (BCD) was initiated during the course of a previous project (K5/351) on the effects of water quality variables on riverine biotas, and has been further enlarged and refined during the present project. It contains approximately 140 000 biological and 34 000 chemical records and includes data from virtually all of the ecological studies on South African rivers in which both taxonomic and chemical data have been collected concurrently, as well as a few that consist of taxonomic data only.

Data are available for 684 sites on various rivers within South Africa and can be accessed within water quality management regions (WQMRs), bioregions, political regions and subregions. Using drop-down menus it is possible to find and sort information about taxonomy, biotope, region, date, study reference, SASS (a biomonitoring procedure) and chemical constituents. Some simple summary statistics are also available.

In essence, the BCD allows one to investigate the geographical localities at which various taxa have been found and the numerical ranges of a variety of physical and chemical constituents measured concurrently with the collection of the biological data. This means that one can ascertain the recorded tolerance ranges of numerous invertebrates and use this information to assess the validity of water quality guidelines, among other things.

The database was created using *Microsoft Access* (Ver 2.0), which is a relational database operating on IBM compatible PCs in the Windows environment. Querying has been streamlined using *Microsoft Excel* and data analysis is possible using *Statistica*. Minimum requirements for running the database are a 486 PC with at least 16 MB RAM (although a pentium PC with 32MB RAM is preferable), Microsoft Access 2.0 and Microsoft Excel 5.0 or higher. Technical support was provided by Soft Craft Systems cc. A user manual has been developed (Dallas & Janssens 1997). The database is currently housed in the Freshwater Research Unit, University of Cape Town. Further custodianship is still being investigated. The BCD will ultimately be accessed via the Water Research Commissions Internet site.

E 3.2 Development of regional water quality guidelines for non-toxic inorganic constituents and a protocol for the verification of guidelines (Chapter 3)

Chapter 3 provides a synthesis of the characteristics of three constituents, namely total dissolved solids (TDS) and conductivity; total suspended solids (TSS) and turbidity; and pH, and outlines the

occurrence and interactions of each variable, in addition to elaborating on the effects of, and guideline criteria proposed for, each variable. A method for deriving regional water quality guidelines, which takes account of spatial, seasonal and diel variations, is proposed and developed for the south and western coastal Water Quality Management Region (WQMR).

Using the BCD, background concentrations were ascertained for TDS and TSS, and background ranges for conductivity and pH for rivers within selected WQMRs. A screening method was developed whereby sites with impaired water quality were excluded by referring to their SASS scores. SASS (the South African Scoring System, described in detail in previous WRC Final Reports and more briefly in Appendix 3.1) is a rapid bioassessment method developed to assess impairment of water quality in riverine ecosystems. It uses the presence or absence of benthic macroinvertebrates, each taxon being assigned a score related to its sensitivity to or tolerance of pollution. The higher the score, the greater the sensitivity of the taxon to pollutants. Interpretation is based on two values: the SASS score and the average score per taxon (ASPT), which is the SASS score divided by the number of taxa found.

Application of SASS scores to historical data, although not ideal, provides a crude means of ranking or identifying the extent of impairment of water quality at each site on each sampling occasion. In this way, SASS scores and ASPTs were used to identify impacted sites within each subregion in the WQMR. SASS scores for sampling occasions for the remaining 'least-impacted' sites could then be used to examine temporal and spatial variations in the constituents of interest. A hundred and twenty-nine 'least-impacted' sampling occasions were identified from mountain streams, 72 from foothill streams, 56 from transitional zones and 35 from sites in lower rivers.

It should be noted that the screening method developed is a preliminary one which needs to be subject to additional testing and verification. The actual SASS Scores used to separate 'least-impacted' from 'impacted' sites for the southern and western Coast WQMR were derived subjectively on the basis of knowledge of exposure and proximity to pollutants. A more robust method which adopts statistically sound, multivariate analysis techniques needs to be used to verify the derivation of scores. The following assumptions are also made: sites within a subregion within a single WQMR have similar characteristics with respect to water chemistry; SASS is assumed to reflect water quality at a site, based on individual taxon's sensitivity or tolerance to water quality impairment, and water quantity has not been taken into account. Biotope availability has been incorporated in the screening process using the quadrat method, but again results are preliminary and the hypothesis proposed needs to be tested. In summary, additional testing of the SASS method needs to be undertaken in order to ensure that the screening method proposed is based on a firm foundation.

In order to ascertain the extent to which the selected variables fluctuate in response to seasonal changes in factors such as discharge and temperature, four sites were selected in mountain stream, four in foothill, three in transitional and two in lowland subregions, and subjected to statistical analyses. Diel (short-term) fluctuations in conductivity, turbidity and pH were measured for periods of about a week each in three mountain stream and three foothill sites.

The summarised results on background concentrations or ranges, seasonal and diel variation for each of the selected variables is given below.

TDS and conductivity

There were subregional differences in TDS concentrations and conductivity, and mountain streams and foothills were significantly different from transitional and from lowland sites.

- *Mountain Stream*: Median TDS concentration and conductivity were 26.3 mg l^{-1} and 3.0 mS m^{-1} respectively. Seasonal variation was significant for conductivity, which was generally highest in summer, lowest in winter and most variable in autumn. There was no diel pattern in conductivity, although conductivity rose from 2.0 to 4.0 mS m^{-1} during a high-flow event.
- *Foothill*: Median TDS concentration and conductivity were 32.0 mg l^{-1} and 3.1 mS m^{-1} respectively. Seasonal variation in TDS concentration and conductivity was significant for two and all of the four sites respectively. Both were highest in summer and lowest in winter. There was no diel pattern in conductivity.
- *Transitional*: Median TDS concentration and conductivity were 83.6 mg l^{-1} and 9.6 mS m^{-1} respectively. Seasonal variation in TDS concentration and conductivity was significant at all three sites. Generally both were highest in summer and lowest in winter. They were most variable in autumn or winter. Diel variation was not assessed.
- *Lowland*: Median TDS concentration and conductivity were 183.0 mg l^{-1} and 21.0 mS m^{-1} respectively. Seasonal variation in TDS concentration and conductivity was significant and concentrations and values were highest in summer, lowest in winter and most variable in autumn. Diel variation was not assessed.

TSS and turbidity

There were subregional differences in TSS concentrations, and sites in mountain stream, foothill and transitional subregions were significantly different from lowland sites. Verification of these results is necessary because of the relative paucity of data, which also prevented the examination of seasonal variation for either TSS or turbidity.

- *Mountain Stream*: Median TSS concentration and turbidity were 0.66 mg l^{-1} and <1 NTU respectively. There was no diel pattern in turbidity, although turbidity rose from $\leq$ 1 NTU to 4 NTU during a high-flow event.
- *Foothill*: Median TSS concentration and turbidity were 0.78 mg l^{-1} and 1 NTU respectively. There was no diel pattern in turbidity, although turbidity rose from approximately 1 NTU to 22 NTU during a high-flow event.
- *Transitional*: Median TSS concentration was 1.70 mg l^{-1}. Diel variation was not assessed.
- *Lowland*: Median TSS concentration and turbidity were 9.57 mg l^{-1} and 3 NTU respectively. Diel variation was not assessed.

pH

There were subregional differences in pH and all subregions were significantly different from one another.

- *Mountain Stream*: Median pH was 5.5, and there was no seasonal variation. There was a distinct diel pattern in pH values, with highest values occurring during daylight hours. Diel variation was in the order of 1 pH unit. pH decreased and was less variable following a high-flow event.
- *Foothill*: Median pH was 6.0, and there was minimal seasonal variation in values. When present, pH values were higher in summer and lower in winter. There was a distinct diel pattern in pH values, with highest values occurring during daylight hours. Diel variation was in the order of 1.3 pH units. pH was less variable following a high-flow event.
- *Transitional*: Median pH was 6.5 and pH varied seasonally. pH values were generally highest in summer, most variable in autumn and lowest in winter. Diel variation was not assessed.
- *Lowland* Median pH was 7.3, and pH values tended to be higher in summer and lower in winter. Diel variation was not assessed.

Protocol for the establishment of regional water quality guidelines for non-toxic inorganic constituents

A method is described for examining the appropriateness of water quality guidelines for aquatic ecosystems. Background concentrations for TDS and TSS, and ranges for conductivity and pH, were established for 'least-impacted' sites in each subregion within each WQMR, using data extracted from the BCD. (Such sites may also be considered as 'reference sites' with respect to water chemistry variables assessed). SASS scores were used to differentiate between least-impacted and other sites. Suitable time periods were chosen for analysis and all data assigned to a season. Median concentrations or ranges were calculated for each season and 'test ranges' were formulated in relation to the provisions of the interim guidelines. The percentage of observed data within each 'test range' was calculated and the data were also plotted for visual inspection. Finally, the percentage of observed data that fell within and outside of the Target Water Quality Range (TWQR), i.e. a management objective derived from numerical or narrative criteria aimed at maintaining the water quality within the No Effect Range, were assessed. If the observed data fell outside the TWQR, it can be modified according to a specified percentage (a hypothetical percentage of 80% is given in the protocol). The results in relation to the interim guidelines are as follows.

TDS and conductivity

The national water quality guidelines recommend that the TDS concentration not change by >15% from that of the water body under unimpacted conditions at any time of the year and that the amplitude and frequency of natural cycles be maintained. For both TDS and conductivity, it is the higher concentrations or values which are of concern in the aquatic ecosystem.

- *Mountain Stream* : between 69% and 85% of the TDS concentrations and between 75% and 90% of the conductivity values were either within or below the TWQR. Examination of the plot of observed data over time, suggest that short duration peaks in conductivity occurred periodically throughout the year.

- *Foothill* : between 72% and 85% of the TDS concentrations and between 60% and 90% of conductivity values were either within or below the TWQR. The observed conductivity plotted for Site H1H018 show that most of the values exceeding the TWQR are short duration peaks.
- *Transitional*, : between 61% and 79% of the TDS concentrations and between 61% and 77% of conductivity values were either within or below the TWQR. Observed data exhibited considerable fluctuation, particularly in winter, when 30% of the observed data exceeded the "Test Range" (median + 30%).
- *Lowland* : between 58% and 72% of the TDS concentrations and between 57% and 71% of conductivity values were either within or below the TWQR. Observed data exhibited considerable fluctuation, particularly in summer and autumn, when 29 to 39% of the observed data exceeded the "Test Range" (median + 30%).

There was no distinct seasonal pattern in the percentage observed data within each "Test Range" for any of the subregions, although seasonal medians were generally higher in summer. In comparison to mountain stream and foothill subregions, sites in transitional and lowland subregions exhibited a greater fluctuation in both TDS concentration and conductivity, with more of the observed data exceeding the TWQR. This may indicate that at such sites the TWQR would need to be modified.

pH

The national water quality guidelines recommend that pH values should not be allowed to vary from the background pH values for a specific site and time of day, by > 0.5 of a pH unit, or by > 5%, and should be assessed by whichever estimate is more conservative.

- *Mountain Stream* : between 37% and 65% of the pH values were within the TWQR. A relatively large percentage of observed data had pH values between 0.5 and 1.0 of a pH unit above or below the TWQR.
- *Foothill :* between 43% and 70% of the pH values were within the TWQR. Again a relatively large percentage of observed data had pH values between 0.5 and 1.0 of a pH unit above or below the TWQR.
- *Transitional :* between 76% and 92% of the pH values were within the TWQR. In 1990 and 1991 there were periodic decreases in pH possible in response to rainfall events although this would need to be verified.
- *Lowland :* between 59% and 94% of the pH values were within the TWQR.

There was no distinct seasonal pattern in the percentage observed data within each "Test Range" for any of the subregions, although seasonal medians were generally lower in autumn or winter. Upper catchments in the western and southern coast region are often poorly buffered and therefore exhibit considerable fluctuation in pH. Sites lower in the catchment are more buffered and pH is relatively more stable. On this basis, the TWQR may need to be modified for mountain stream and foothill subregions which exhibit considerable fluctuation in pH, both with respect to the percentage observed data exceeding the TWQR and diel variation in pH values. A protocol is described for establishing refined regional water quality guidelines for non-toxic inorganic constituents.

E 3.3 Breede River Catchment Assessment (Chapter 4)

This chapter describes the physical, chemical and biological conditions at 50 riverine sites within DWAF Drainage Region H, the Breede and Duiwenshoek catchments. These data were collected so as to expand the geographical extent of our knowledge on water quality requirements of invertebrates in the southern and western Coast WQMR. The study also provided an opportunity to assess the biological integrity or 'health' of the rivers of this drainage region as a basis for later developing reference sites for long-term biological monitoring.

Using SASS scores, 19% of mountain stream sites, 67% of foothill sites, 50% of transitional sites and 60% of lowland sites were categorised as 'impacted'. "Least impacted" or reference sites in the mountain stream and foothill subregions had SASS4 Scores>140 or ASPTs>7.5 suggesting that differentiation between these subregions with respect to SASS4 Scores is not necessary. Similarly, transitional and lowland reference sites all had SASS4 Scores>85 and ASPTs>6.5. Cluster and ordination analysis of biological communities generally supported the SASS groupings with the exception of a few sites. Conplots of SASS4 Scores and ASPTs overlaid on the Multi-dimensional Scaling ordination also supported the groups. Interestingly, HABS1, developed to aid in the interpretation of SASS scores, showed little correlation with either SASS4 Score or ASPT.

Examination of the frequency of occurrence of each macroinvertebrate taxon at reference sites, supported the observed similarity between mountain stream and foothill subregions. Eight of the most frequently recorded taxa were common to reference sites in both subregions, with an additional taxon, Heptageniidae, also important at foothill reference sites. Most of these taxa were highlighted as important in differentiating Group 1 (i.e. mostly mountain stream and foothill reference sites) from Groups 2 and 3. On this basis it should be possible to establish reference conditions for SASS Scores. This aspect is examined in more detail in Chapter 5.

Principal Components Analysis of the physical attributes and chemical constituents measured at each site, including both data from the current study and long term DWAF data, showed that the primary gradient corresponded to conductivity, pH and $(NO_2^- + NO_3^-)$-N. TSS, which was only measured in the current study, was also included as a factor in the respective analysis. There was a distinct gradient with mountain stream and foothill reference sites at the lower end of the gradient, with transitional and lowland reference sites and impacted mountain stream and foothill sites progressively moving along the gradient towards the higher values or concentrations. A second gradient corresponded to the anion or cation ratio, with mountain stream and foothill reference sites with high anion or low cation ratios, and transitional or lowland sites and impacted mountain stream and foothill sites with low anion or high cation ratios. Of these chemical constituents, conductivity and pH were most highly correlated with the biological community data.

Examination of land use, physical modifications and water quality impacts at each site, and relating these to the physical attributes, chemical constituents and biological communities recorded at the sites, revealed the effects that the former have on the latter. Activities in the catchment clearly affect water quality which is in turn reflected in SASS Scores. Sites below urban areas and/or in

high intensity agricultural areas, particularly those which have livestock watering points adjacent to the river, were identifiable on the basis of both chemical characteristics of the water, particularly conductivity, pH, (NO_2^-+NO_3^-)-N and TSS, and with respect to the biological community, both in terms of SASS Scores and community composition. As a site becomes impacted with respect to water quality, it assumes the characteristics of sites lower in the catchment, such that mountain streams resemble foothills, transitional or lowland sites and foothills resemble transitional or lowland sites.

E3.4 Monitoring the effectiveness of the water quality guidelines: reference scores (Chapter 5)

Since SASS provides an "invertebrates' eye view" of water quality, then the higher the SASS score at any site, the higher the water quality and the more suitable the site as a habitat for riverine organisms. Thus SASS scores can be used to indicate which sites are least-impacted, and therefore represent useful reference sites for later long-term biomonitoring activities. This chapter briefly explores the development of SASS reference scores.

Techniques that might be suitable for calculating these scores include the use of median values for all reference sites, maximal (i.e. 'best attainable') scores, and scores based on the taxa occurring most frequently at reference sites. In this case, the decision was made that 'best attainable' scores are most useful. Each site score (SASS and ASPT) was divided by the 'best attainable' score and expressed as a percentage.

The 'best attainable' scores for mountain stream and foothill subregions were SASS4 score = 239 and ASPT = 10.42, and for transitional and lowland subregions SASS4 score = 182 and ASPT = 9.6. These will enable new sites to be categorised on the basis of the differences between observed scores at these sites and the 'expected' (i.e. 'best attainable') scores at reference sites. Common taxa associated with reference sites have also been identified.

E3.5 Toxicological studies of aluminium, copper and manganese on an endemic freshwater amphipod in acid waters (Chapter 6)

This chapter describes some of the effects of acidic, aqueous solutions of aluminium, copper and manganese on *Paramelita nigroculus*, a mountain stream amphipod (a type of shrimp) from the south-western Cape. The aims were to examine the antagonistic and/or synergistic effects of the metals in aqueous mixtures and to investigate the adequacy of the interim South African water quality guidelines for aquatic ecosystems, all of which describe criteria only for individual elements.

Effects of the metals on survival, growth and reproductive output (measured as increase in numbers) were examined, as were interactions between the three metals, and the processes of uptake and bioaccumulation of each. The experiments on survival, growth and reproductive output are reported in Chapter 6. The entire body of work has been submitted as a PhD thesis to the

University of Cape Town.

Survival of adult amphipods was 70% after 21-day exposures to combinations of all three metals in stream water at Acute Effect Values + 50% (i.e. Al 1388µg l^{-1}, Cu 17.5µg l^{-1}, Mn 13993µg l^{-1}), and 62% when Mn was omitted from the solutions. Under the same circumstances, survival of juveniles was 69% in solutions including Mn and 62% in solutions without Mn. Thus Mn appears to act as an antagonist to the toxic effects of combinations of Al+Cu.

South African guidelines appear to be adequate for all three metals in that LT_{50}s were >21 days at concentrations at least ten times the guideline values. Furthermore, concentrations measured in the natural stream from which amphipods were collected were relatively high: 221 µg l^{-1} Al, 9µg l^{-1} Cu and 323 µg l^{-1} Mn; and in natural systems the presence of dissolved organics and suspended solids will reduce bioavailability of the metals.

Animals in solutions containing Al+Cu+Mn showed faster growth rates and higher reproductive outputs than did those in solutions without Mn.

Juveniles seem to be good test organisms for long-term (chronic) and bioaccumulation experiments (and routine bioassays) because they are relatively tolerant of a range of toxins, including heavy metals.

E 3.6 Pre-construction monitoring of the upper Berg River

One of the aims of the present project was to provide some baseline data on the upper reaches of the Berg River in anticipation of the construction of the proposed Skuifraam Dam. When the project began, the stated intention of DWAF was that construction would begin in about 1997. In fact, at the time of writing (September 1997), a firm decision about whether or not to build the dam has yet to be made. Nonetheless, the data generated in this part of the project are valuable as they have allowed us to develop a better understanding of long-term variations in both abiotic and biotic features of the upper Berg River, and to provide an assessment of the 'state of the river'.

The Berg River is the best studied of all the rivers of South Africa, beginning with a pioneering investigation of the water chemistry and invertebrates in the early 1950s.

The monitoring programme that is reported here was initiated in September 1994 and ran until August 1996. Three sites were examined, one above and two below the site of the proposed dam wall. The two lower sites are on a stretch of the river that is presently affected by afforestation by pine trees, the unnatural provision of water from the Theewaterskloof Dam in summer, effluents from a trout farm, and the growth of extensive stands of alien acacia trees. Thus even in its upper reaches it suffers from major anthropogenic influences.

Physical, chemical and biological data were collected and subjected to a variety of analytical techniques. Multivariate analyses of the chemical data provided further circumstantial evidence for

the effects of the aseasonal discharges of water on the downstream riverine environment. Seasonal data showed that the river is moderately impacted at the two lower sites and that the impacts are most severe in summer, when water is unnaturally transferred into the river. Differences in species composition observed between sites when the interbasin transfers were not occurring may be attributable to the impact of other influences such as the trout farm. Comparisons of ordinations for different sites show that, downstream of the releases, summer communities are more similar to winter communities than are those subjected to naturally low summer flows. This is compounded by the fact that such sites are out of synchrony with the life cycles of re-colonising adult insects. In summer, even though flows may resemble winter flows, the winter fauna is not present. Impacted sites thus have communities that represent neither high-flow winter nor low-flow summer conditions but show a tendency to group with either autumn or spring communities.

E 3.6 Other products: Literature Database, SASS (South African Scoring System) Database

In addition to the BCD, two other databases have been developed and maintained in *Microsoft Access.* The first is a literature database comprising approximately 1300 references from local and international sources. The second is a SASS database which consists of all SASS data collected over the last six years in the south-western Cape. It is structured in a similar manner to the BCD, in that a spatial framework has been adopted and associated chemical data are incorporated.

E 4. SUMMARY OF MAJOR CONCLUSIONS

E 4.1

The BCD has already proved useful in assessing various aspects of water chemistry and should continue to provide valuable data.

E 4.2

Methods have been developed for assessing and updating non-toxic water quality guidelines for aquatic ecosystems.

E 4.3

The data collected in the Breede River catchment will provide the basis for further biomonitoring initiatives. The upper reaches of the river are generally in fairly good condition, while water quality in the lower reaches is impaired as a result of agricultural activities and abstraction of water.

E 4.4

A method has been developed for comparing water quality at any site against a 'best attainable' condition, and thus for identifying suitable reference sites for further biomonitoring initiatives.

E 4.5

Examination of the effects in combination of three heavy metals on various aspects of the biology of an endemic amphipod indicates that the present interim water quality guidelines for aluminium, copper and manganese are adequate for the protection of aquatic ecosystems.

E 4.6

Adequate data are available to act as a baseline against which to examine the effects of the dam proposed for the upper Berg River.

E 5. RECOMMENDATIONS

1. The approach proposed for the development of regional water quality guidelines for non-toxic inorganic constituents needs to be used by DWAF to establish guidelines for other Water Quality Management Regions.

2. A biomonitoring programme for the southern and western WQMR and which is suitably linked to the national initiative, needs to be established. The many studies undertaken by members of the Freshwater Research Unit, UCT, provide an ideal backbone for the future development of this very important programme. Ultimately regional DWAF should be responsible for the routine monitoring of our aquatic resources but members of FRU are ideally placed to assist in the developmental phases. The techniques documented in this report should also feed into the national initiative and be compared to other techniques or methodologies currently being used.

3. It is recommended that continual low-intensity sampling be undertaken on the Berg River until a decision is reached on the construction of Skuifraam dam. It would be advisable for this to be conducted by regional DWAF personnel who are becoming familiar with the SASS technique, but who could receive additional field supervision by members of FRU if required.

4. The synergistic and antagonistic effects of toxins needs to be further examined with a view to revising the interim water quality guidelines if appropriate, including other combinations of metals and using other invertebrate taxa.

5. The BCD has already proved to be most useful in establishing both chemical and biological characteristics of riverine ecosystems. Further interrogation should enhance our understanding of both aspects. It is therefore important that the BCD be maintained through the incorporation of new studies, and its use be encouraged, albeit it a controlled manner.

6. Additional testing and development of the SASS method needs to be undertaken.

APPENDIX E1. CONTRIBUTIONS AND ACTIVITIES OF RESEARCH TEAM DURING THE PROJECT

Project Leader: Jenny Day (JAD), Full-time Researcher: Helen Dallas (HFD), Temporary researcher: Liz Day (ED), Part-time Researcher: Dieudonne Musibono (DEM), Part-time Consultant: Pierre Janssens (MPJ)

1994

ED Attended Southern African Society of Aquatic Scientists Annual Congress, University of Port Elizabeth, July 1994.

JAD Visiting lecturer, University of Adelaide, Australia

JAD Invited participant, DWAF Workshop on water requirements for the Wilderness Lakes

JAD Member, numerous Water Research Commission Steering Committees

1995

JAD Invited speaker, Women's Symposium on environmental issues

JAD Invited participant and Workshop Chairperson, DWAF/Cape Town Metropolitan Council symposium on water resources

HFD attended Water Research Commission Steering Committee meeting: *Rapid biological assessment of water quality impacts in stream and rivers* (Afridev).

HFD consultant to Cape Nature Conservation (CNC), Jonkershoek. Conducted an assessment of the effects of an alcohol spill by KWV on the macroinvertebrates of the Berg River.

HFD consultant to Council for Scientific and Industrial Research (CSIR), Pretoria. Responsible for assisting in the compilation of background information for South African Water Quality Guidelines: Aquatic Ecosystem.

HFD consultant to CSIR, Stellenbosch. Conducted a situation assessment of the riverine ecosystem of the Eerste River

HFD consultant to CNC. Involved in the analysis and interpretation of SASS data.

HFD attended and presented a paper at the South African Society of Aquatic Scientists Annual Congress July 1995 (Dallas 1995)

HFD attended a conference hosted by the Scottish Natural Heritage : "Freshwater quality: defining the indefinable?" at Stirling University, September 1995. During the follow-on two week study tour HFD visited the Institute of Aquaculture, Stirling; National Rivers Authority in Bristol and Reading;

and the Institute of Freshwater Ecology in Wareham, United Kingdom.

DEM attended a workshop on "Water resources and wetlands management for sustainable development in Africa", held at Makerere University (Kampala, Uganda) and sponsored by Dutch Government and the International Institute for Infra-structural, Hydraulic and Environmental Engineering (Delft, The Netherlands). DEM presented a paper on "Drinking Water quality in Africa" (Musibono 1995).

DEM paid a 3-day scientific visit to Rhodes University in October 1995 to discuss invertebrates used in their studies.

DEM gave a series of lectures on Drinking Water quality Management in Africa. This formed part of a short course organised by the Medical Department, University of Cape Town and which was sponsored by World Health Organisation (These lectures were repeated in 1996 and will probably be repeated in1997)

1996

JAD Invited speaker, US AID symposium on Namibia's natural resources, Windhoek

JAD Member, WRC Consultative Committee on Water Ecosystems Research

HFD team member of the Caledon Resort Project (Planning Partnership)

HFD consultant to Steenberg Estate: SASS assessment of Steenberg artificial stream

HFD consultant to Stanford Municipality: Assessment of the potential effects of sewage discharge into the Klein River at Stanford

HFD member of Steering Committee for WRC Project: *Water quality and aquatic faunal studies in the Umzimvubu catchment, Eastern Cape* (University of Transkei)

HFD attended WRC Steering Committee meeting: *The application of an artificial stream system to investigate macroinvertebrate water quality tolerances* (Rhodes University)

HFD assisted in a limited capacity with the development of a National Biomonitoring Programme

HFD gave a lecture on biomonitoring as part of the Limnology course for the 3rd year students in the Zoology Department, University of Cape Town

HFD participant in the Berg River (Skuifraam) Instream Flow Requirement Workshop as the water quality and invertebrate specialist

DEM attended "Afriwater Conference " (including the Aquatic Toxicology session) at Midrand (South Africa). DEM presented a paper on the preliminary results of his doctoral research (Musibono 1996a).

DEM attended the third autumn mathematical ecology workshop (core group: Ecotoxicology & Water Quality Management) at the International Centre for Theoretical Physics- Trieste (Italy), sponsored by UNESCO. DEM presented two papers on Bioaccumulation of heavy metals (Musibono 1996b) and Urban rivers pollution by heavy metals in Kinshasa (Zaire, actual Democratic Republic of Congo) (Musibono

1996c). DEM was appointed chairperson of the Bioaccumulation process working group.

DEM gave a series of lectures on ecotoxicology and water quality management as part of the Limnology course for the 3rd year students in the Zoology Department, University of Cape Town.

1997

JAD Invited participant, DWAF/SA/USA Binational Agreement: Water Demand Management (Hermanus, Western Cape)

JAD Invited participant, national workshop on Risk Assessment, Pretoria

JAD and HFD National initiative to re-examine interim water quality guidelines

HFD gave a lecture on SASS4 bioassessment method for the Biomonitoring course organised by Institute for Water Quality Studies (Department of Water Affairs & Forestry) and Environmentek

HFD consultant to ISCOR: comments on biomonitoring proposal for assessing the potential effects of mining in the Kwazulu-Natal Region (ISCOR)

HFD team member of Lourens River situation assessment

HFD (and MPJ) gave a demonstration on the Biological and Chemical Database to members of the Freshwater Research Unit, UCT, Cape Nature Conservation, Department of Water Affairs & Forestry, Ninham Shand and other interested groups.

Refereed Publications

Day J. A., Dallas H. F. & Wackernagel A. *Delineation of management regions for South African rivers based on water chemistry*. (in press.) Journal of Ecosystem Health.

Publications submitted or in preparation

Dallas H. F. & Day J. A. Small-scale patchiness in the distribution of stream invertebrates: effects on sampling strategy. Submitted to Archiv für Hydrobiologie.

Dallas H. F. A preliminary evaluation of aspects of SASS (South African Scoring System) for the rapid bioassessment of water quality in rivers, with particular reference to the incorporation of SASS in a national biomonitoring programme. Submitted to the Southern African Journal of Aquatic Sciences.

Dallas H. F. Variability of benthic macroinvertebrates in mountain streams of the south-western Cape, South Africa, as assessed using SASS (South African Scoring System). In Prep.

Dallas H. F. Seasonal variability in SASS4 Scores for rivers in the south-western Cape, South Africa. In Prep.

Dallas H. F. & Janssens M. P. E. In Prep. The Biological and Chemical Database: User Manual. Report for the Water Research Commission, Pretoria.

Musibono D. E. & Day J. A. Mortality, survival and growth of the amphipods *Paramelita nigroculus* (B.) exposed to aluminium, copper and manganese mixtures in acidic waters. (In Prep.)

Musibono D. E. & Day J. A. Notes on the active uptake of aluminium, copper and manganese by *Paramelita nigroculus* (B.) in acidic waters. (In Prep.)

Musibono D. E., Day J. A. & Juritz J. Reproduction of *Paramelita nigroculus* (B.) exposed to aluminium, copper and manganese mixtures in acidic waters. (In Prep.)

Musibono D. E., Day J. A. & Juritz J. Bioaccumulation and regulation of aluminium, copper and manganese by *Paramelita nigroculus* (B.) in acidic waters. (In Prep.)

Musibono D. E., Day J. A. & Juritz J. Risk and regression analysis applied to the survival, growth, reproduction and bioaccumulation process with *Paramelita nigroculus* (B.) as test organism. (In Prep.)

Musibono D. E., Day J. A. & Pretorius J. Interactions between aluminium, copper and manganese, chemical speciation and toxicity modelling in freshwater environments at low pH. (In Prep.)

Consultancy Reports

Brown C. A. & Dallas H. F. 1995. Eerste River, Western Cape: Situation Assessment of the riverine ecosystem. Southern Waters Ecological Research and Consulting, Cape Town.

Brown C. A., Dallas H. F. & Harding W. R. 1996. Caledon Resort. Southern Waters Ecological Research and Consulting, Cape Town.

Dallas H. F. 1996. The effect of an alcohol spill from KWV on the aquatic invertebrates of the Berg River. Southern Waters Ecological Research and Consulting, Cape Town.

Dallas H. F. 1996. The potential effects of discharging purified sewage effluent into the Klein River at Stanford. Southern Waters Ecological Research and Consulting, Cape Town.

Dallas H. F. 1997. Comments on the proposal for biomonitoring at the proposed Iscor mines (Hellendale and Fairbreeze) and smelter complex. Southern Waters Ecological Research and Consulting, Cape Town.

Dallas H. F. & Day J. A. 1996. Aquatic invertebrates of the Berg River: status and flow requirements. Instream Flow Requirements Starter Document. Berg River IFR Refinement Workshop.

Day J. A. & Dallas H. F. 1996. Water quality of the Berg River. Instream Flow Requirements Starter Document. Berg River IFR Refinement Workshop.

Other Publications and presentations

Dallas H. F. 1995. An evaluation of SASS as a tool for the rapid bioassessment of water quality. Paper presented at the South African Society of Aquatic Scientists Annual Congress.

Musibono D. E. 1995. Environment and drinking water quality in Africa. Paper presented at the workshop on Water Resources and Wetlands management for a sustainable development in Africa. Kampala (Uganda). Sponsored by Dutch Government and the International Institute for Infra-structural, Hydraulic and Environmental Engineering (Delft, The Netherlands).

Musibono D. E. 1996a. (Eco)Toxicological studies of the combined effects of aluminium, copper and manganese on the endemic freshwater amphipod *Paramelita nigroculus* in acidic waters. Paper presented at the Afriwater Conference, Midrand (South Africa).

Musibono D. E. 1996b. Mathematical model of the bioaccumulation process in aquatic environments (i.e. fresh waters). Paper presented at the Third Autumn college on Mathematical Ecology. International Centre for Theoretical Physics, Trieste (Italy).

Musibono D. E. 1996c. Urban rivers pollution by heavy metals in Kinshasa (Zaire). Paper presented at the Third Autumn college on Mathematical Ecology. International Centre for Theoretical Physics, Trieste (Italy).

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TERMS OF REFERENCE

The overall objective of the project was to increase our knowledge of water quality requirements of riverine organisms with a view to developing and/or verifying regional water quality guidelines for aquatic ecosystems. The overall aims of the project, as agreed at various Steering Committee Meetings, are detailed below.

AIMS OF THE PROJECT

1a) To continue the development and refinement of the biological/chemical database (BCD),
b) to investigate potential custodians of the BCD,
c) and to produce a user-guide for interrogation of the BCD.

The development of the BCD has taken the project team far longer than originally envisaged. Approval to focus on the BCD was given at the Steering Committee meeting of 23 March 1995. Extensive development has taken place on the BCD (Chapter 2), user manual has been written (Dallas & Janssens 1997) and the BCD has been demonstrated to a number of potential user organisations.

2a) Either,
to produce interim site-specific guidelines (where these have not already been produced by DWAF) for all variables of concern,
or,
if these interim guidelines have already been produced, to determine to what extent these guidelines compare with information extracted from the review and the BCD.
b) In either case, to attempt to develop regional values for these variables.

Interim national water quality guidelines for aquatic ecosystems have been developed for South Africa (DWAF 1995). Ms Dallas formed part of the Project Team responsible for the compilation of background information on selected variables and Dr Day acted as one of the external reviewers. Regional water quality guidelines for non-toxic inorganic constituents such as total dissolved solids, pH and total suspended solids, have been developed within a spatial framework, incorporating a geographic and subregional component, for the southern and western coast water quality management region (WQMR) using the BCD and supplemented with data collected in the current project (Chapter 3). Preliminary regional guidelines have been proposed for other WQMRs although scarcity of data in the BCD for certain regions has prevented detailed analysis.

3a) To select suitable sites on three representative rivers that vary widely geographically and in terms of their intrinsic water quality,
b) to determine the extent to which the actual water quality in these rivers (extracted from DWAF records, local authorities, etc) corresponds with the values set by the interim guidelines, and
c) to examine the responses of riverine biotas in regard to three or four site-specific variables (probably turbidity/suspensoids, pH and TDS, and possibly one or more nutrients).

With the agreement of the Steering Committee (23 March 1995) it was decided to change the methodology such that more detailed assessments were undertaken within a single catchment and hence WQMR but which included a number of sites on different rivers within each subregion. SASS

(South African Scoring System) assessments and measurements of water quality parameters were collected simultaneously (Chapter 4). It was initially envisaged that a similar undertaking could be done in a further two catchments within different WQMRs. The additional time devoted to the development and refinement of the BCD, however, prevented this from happening. Funding has therefore been requested as part of the follow-on WRC proposal for verification of the methodology within a second WQMR.

4a) To develop a protocols for the verification of interim guidelines, and for
b) monitoring the effectiveness of guidelines.

A protocol for the verification of regional guidelines has been developed (Chapter 3) and an established method for the assessment of water quality, namely SASS, advanced to facilitate monitoring of water quality guidelines. Reference sites have been identified and preliminary water quality categories proposed for the southern and western coast water quality management region (Chapter 5). The technique with which these reference sites were identified and water quality categories established can be applied to other regions in South Africa.

6 To begin to address the question, "to what extent does water quality determine the distribution of local south-western Cape endemics?

This aim does not have a specific programme associated with it, but rather becomes a question that may be addressed as a result of the research undertaken within the south-western Cape. A detailed toxicological study of the combined effect of aluminium, copper and manganese on an amphipod, *Paramelita nigroculus* endemic to this region has been undertaken as a doctoral thesis by a part-time member of the research team, Mr Musibono. This study uses the South African water quality guidelines for toxic constituents as criteria for toxicity testing (Chapter 6).

5 To undertake pre-construction monitoring of the biota of the upper Berg River.

The project team has undertaken quarterly assessments of the macroinvertebrate fauna and water chemistry over a two year period (Chapter 7). This will form the baseline information against which future monitoring programmes can be compared.

CHAPTER 1. INTRODUCTION

This project began in July 1994 as a follow-on from the previous WRC project: "The effects of water quality variables on riverine biotas" (Dallas *et al.* 1994). The overall objective of the project was to increase our knowledge of water quality requirements of riverine organisms with a view to developing and/or verifying regional water quality guidelines for aquatic ecosystems. During the latter half of the previous project and in the initial stages of the current one, the South African Department of Water Affairs and Forestry (DWAF) began developing guidelines for water quality for the five identified categories of "user", namely industry, domestic supply, agriculture, recreation and aesthetics, and aquatic ecosystems. Subsequently, (DWAF 1997) have recognised ecosystems as the resource from which users are supplied, and guidelines for aquatic ecosystems therefore aim to "protect" the resource so that sustainable use is possible.

Water quality requirements for most of these users are more or less universal. Water quality guidelines for the aquatic ecosystem, are however, not universally applicable, varying from continent to continent and from region to region; further, very little local information is available (Hart & Jones 1992, Dallas & Day 1993).

This regional variation provided motivation to investigate the development of regional guidelines for variables likely to vary geographically. Interim national water quality guidelines for aquatic ecosystems were developed for South Africa by CSIR Environmental Services on behalf of DWAF in 1995. Ms Dallas formed part of the Project Team responsible for the compilation of background information on selected variables and Dr Day acted as one of the external reviewers. The variables focused on in the current project are the non-toxic inorganic constituents. These variables may cause toxic effects at extreme concentrations, but are generally "system characteristics" because natural concentrations depend on localised geochemical, physical and hydrological processes. Criteria are given as numerical ranges or as proportional changes from local background conditions for constituents such as Total Dissolved Solids, pH and Total Suspended Solids. It is appropriate therefore not to assess these guidelines at a national level, but rather to focus on developing regional guidelines. These need to take into account both geographic variation (as dictated by differences in geology and climate, and in the nature of the terrestrial vegetation) and longitudinal zonation of rivers (as dictated by altitude and slope). A *region* with respect to *regional water quality guidelines* therefore includes both regional (or geographic) and subregional (or longitudinal) divisions.

Regional water quality guidelines (Chapter 3) have been developed within this spatial framework for the southern and western coast water quality management region (WQMR) (Dallas *et al.* 1994) using the Biological and Chemical Database (BCD) and supplemented with data collected in the current project. Preliminary regional guidelines have been proposed for other WQMRs although scarcity of data in the BCD for certain regions has prevented detailed analysis. A protocol for the verification of regional guidelines has also been developed.

The BCD incorporates information on macroinvertebrates and water chemistry collected simultaneously within rivers in South Africa (Chapter 2). Extensive development has taken place of the BCD and a user manual has been written (Dallas & Janssens 1997). Both the BCD and the manual have been demonstrated to a number of potential user organisations including the Institute for Water Quality Studies, DWAF; Cape Nature Conservation; the Institute for Water Research, Rhodes University; the Water Research Commission and members of the Freshwater Research Unit, University of Cape Town, in addition to groups such as Ninham Shand and Iscor, who may wish to access the BCD. Investigation into the final custodianship and accessibility of the BCD is continuing, and funding for capturing of new data, further interrogation of the BCD and investigation into accessing and adding data, e.g. via the Internet, is likely to be provided as part of a new project funded by WRC.

Establishing water quality guidelines on a regional basis enables local conditions to be taken into account. In order to ensure that the guidelines are effective in protecting the aquatic ecosystems from degradation, monitoring also needs to be undertaken. Subsequent to the initiation of this project, there has been considerably interest in and development of a national biomonitoring programme (NBP) for riverine ecosystems of which SASS (South African Scoring System) is likely to form an integral component. The use of SASS as a tool for testing the effectiveness of the water quality guidelines has been tested within a single DWAF drainage area, namely H, which includes the Breede and Duiwenshoek catchments (Chapter 4). The SASS assessments undertaken in these catchments, together with additional SASS assessments from rivers in the southern and western coast water quality management region, have enabled SASS reference sites to be identified and preliminary categories of water quality impairment to be developed for this WQMR on the basis of these SASS Scores (Chapter 5). These categories and reference sites will facilitate future monitoring of the effectiveness of the guidelines within this WQMR. The technique with which these reference sites were identified and water quality categories established can be applied to other regions in South Africa.

The research components outlined above all relate directly to the establishment or monitoring of regional water quality guidelines for non-toxic inorganic constituents. Two additional studies have been undertaken as part of the separate aims of the research proposal. The first is to determine the extent to which water quality determines the distribution of local south-western Cape endemics. One such organism is the amphipod, *Paramelita nigroculus*. A detailed toxicological study of the combined effect of aluminium, copper and manganese on this organism has been undertaken. This study uses the interim South African water quality guidelines for toxic constituents as criteria for toxicity testing (Chapter 6).

The second component focused on the pre-construction monitoring of the upper Berg River. The opportunity to undertake monitoring of the biota of a river, prior to the construction of a dam, is an unusual but fortunate one. The project team has undertaken quarterly assessments of the macroinvertebrate fauna and water chemistry over a two year period (mid-1995 to early-1997). This study will form the baseline information against which future monitoring programmes can be compared (Chapter 7).

In summary, the report is structured as follows:

- description of the Biological and Chemical Database - Chapter 2
- development of regional water quality guidelines for non-toxic inorganic constituents, including a protocol for the verification of these guidelines - Chapter 3
- an assessment of the Breede River Catchment, which provides development opportunities for the SASS methodology - Chapter 4
- monitoring the effectiveness of the guidelines, and establishment of SASS Scores for reference sites and preliminary water quality categories - Chapter 5
- toxicological study of the combined effect of aluminium, copper and manganese on the endemic amphipod, *Paramelita nigroculus,* using the interim South Africa water quality guidelines - Chapter 6
- pre-construction monitoring of the upper Berg River as a baseline against which future monitoring during and after construction of Skuifraam Dam can be assessed - Chapter 7

CHAPTER 2. THE BIOLOGICAL AND CHEMICAL DATABASE

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2.1 INTRODUCTION

One of the most important aspects of the biological and chemical database (BCD) is that it enables the linking of biological and chemical variables on both spatial (data collected from the same place) and temporal (data collected at the same time) planes. The database has been constructed using data extracted from the available literature, and from unpublished reports pertaining to South African rivers, in which biological (invertebrates) and chemical data have been collected concurrently. Forty-three studies have contributed to the biological records of the database, of which forty had associated chemical data. It is intended that updating of the records from fresh sources will be an ongoing exercise (funding permitting). Details of the history and source information for the database have been previously documented (Dallas *et al.* 1994). A summary of source information and descriptions of additional studies are presented in Appendix 2.1. This chapter provides an overview of the database. More detailed information on the utilization of the database is documented in the manual which introduces the user to the database structure and outlines the types of queries that can be executed (Dallas & Janssens 1997).

The database has been created using *Microsoft Access* (Ver 2.0), which is a relational database operating on IBM compatible PCs, in the Windows environment. Querying has been streamlined using *Microsoft Excel* and data analysis is possible using *Statistica.*

2.2 STRUCTURE OF THE DATABASE

The database has been structured to take account of spatial and temporal variation in both invertebrate and chemical data. Information is viewed, edited and queried via the **Control Centre.** The options are:

	BUTTON	FUNCTION / ACTION
1	Sites	to display all sites
2	Biological and Chemical Data	data entry/viewing of site visits
3	Taxonomy	taxa used in the database
4	References	Study References (Author, Year, Title, Journal etc.) on which data is based
5	Picklist Options	to change various options (entries in drop-down lists)
6	Query Centre	to Query the database
7	Stop	to Exit the database

2.2.1 Sites

Biological and/or chemical data are available for 684 sites on various rivers within South Africa. The **Sites** option is the main data entry form for entering or viewing site information. It is divided into two tables, one which provides an overview of selected sites (Summary Site Table) and one which gives details of each site (Detailed Site Summary). The intrinsic variability of biotic and chemical

components of riverine ecosystems within South Africa has necessitated the differentiation of rivers into smaller units. Various spatial frameworks have been incorporated to facilitate useful manipulation of the available biological and chemical information. The primary level is the regional or geographic framework, the secondary level is at the longitudinal differentiation and the tertiary level is the site. Associated with each site is information on the spatial location of the site, including the following:

Primary level: geographic frameworks

Three frameworks have been incorporated to allow for selection of sites and hence biological and chemical data within the regions defined below.

- **Water Quality Management Regions** (*WQRegion*; Appendix 2.2), which are based on DWAF water chemistry data, were proposed at a secondary catchment level (Dallas *et al.* 1994). These have been refined using new information such as Bioregions (see below).
- **Bioregions** (Appendix 2.3) are a refinement of the Biogeographic Regions, which were based on the biological distribution of aquatic organisms (Eekhout *et al.* in prep.). The Bioregions were defined following a workshop with twenty specialists and take into account various physical factors such as altitude (Brown *et al.* 1996).
- **Political Regions** (*PolRegion*, Appendix 2.4) are the political regions within South Africa and were deemed important because of provincial management considerations.

Secondary level: longitudinal differentiation (Subregion)

In addition to the above geographic frameworks, it was considered important to incorporate a measure which takes account of the longitudinal zonation of rivers. This zonation has been based on the Biotic Subregions developed at the bioregion workshop (Brown *et al.* 1996). The subregions associated with each bioregion are given in Appendix 2.5. For example rivers in the Fynbos Bioregion have been divided into four subregions: namely Mountain Stream, Foothill, Transitional and Lowland. In some instances additional subregions have been incorporated (given in italics). Bioregions and/or subregions for which no biological or chemical data are available in the database are in parentheses.

Tertiary level: Site

Associated with each site is a description of the site and details of the River, Subregion, BioRegion, Political Region, Water Quality Region, latitude, longitude and altitude of the site. Groups of sites or single sites may be selected and site details viewed. Summarized information on the study reference, biological and chemical data available for each site is included.

2.2.2 Biological and Chemical Data

Approximately 140 000 biological and 34 000 chemical records are currently in the database. The main form for data entry and/or viewing is accessed via the "Biological and Chemical Data" option. Biological and chemical data for each site are linked to the site in a hierarchical manner as follows:

Biological data

CODE	DESCRIPTION
Site	Site Code for a specific site
SiteVisitBio	Site Code plus the BioDate at which the biological data was collected
SiteVisitBioBiotope	Site Code plus BioDate plus the Biotope at which the biological data was collected
SiteVisitBioBiotopeTaxon	Site Code plus BioDate plus Biotope plus the actual abundance of each taxon recorded

Chemical data

CODE	DESCRIPTION
Site	Site Code for a specific site
SiteVisitChem	Site Code plus the ChemDate at which the biological data was collected
SiteVisitChemValue	Site Code plus ChemDate plus value for each chemical component recorded

Information is selected and viewed in a sequential manner by choosing a site, biodate (date at which biological data were collected) and biotope. Biological data and associated chemical data are displayed and a site visit summary and SASS summary may be selected.

Explanation of terms and conventions used in biological and chemical data tables

a. Biodates and Chemdates

"Biodate" and "Chemdate" refer to the dates at which biological and chemical data were collected respectively. Sampling frequency was highly variable, with some records being one-off "spot" samples, while others are the means of weekly, monthly, seasonal or annual samples. To facilitate querying the bio- and chem -dates have been standardized (Year.Month.Day) and "Sort Month", "Sort Year" and "Sort Season" allocated to each. Details of the conventions used are given in Dallas *et al.* (1994). Some inaccuracies are inherent to such an hierarchical system and to counteract this to some degree, the following warning codes have been added.

CODE	TYPE	DESCRIPTION
Spot	Spot sample	Data based on a one-off survey
MP	Month Pool	Data were seasonal and Sort Month was deduced by convention
YP	Year Pool	Data taken in the same month were presented together, but as a mean over several years
BP	Both Pool	Both month and year sort dates are artificial and records are presented as seasonal means, over a number of years.

Linking biological and chemical data

One of the reasons for the development of this database was to facilitate a linking of biological and chemical data. Whilst acknowledging that there are inherent problems in doing this, there is sufficient utility in such a function. For example, one is able to ascertain the range of pHs at which a particular species or family have been recorded. It was therefore necessary to link the biological and chemical data. Problems arose due the inconsistent nature in which the data were reported, making it impossible to link the data in a straightforward manner. To overcome this problem, the sampling dates from each study have been assessed, and a subjective judgment made as to the best matched chemical and biological data, for each site. The linking of data within each study is documented in Dallas *et al.* (1994). When biological and chemical samples were taken at the same time matching was direct.

b. Biotopes

This is the level at which the biological information was collected. A hierarchical structure was adopted to take into account the numerous biotopes sampled and the variability in both terminology and methodology between studies. Each of the documented biotopes have also been assigned a SASS (South African Scoring System) biotope which provides a more uniform basis from which comparisons can be made (Appendix 2.6).

c. Taxa (Biological Data)

The presence or absence of each taxon has been included in a yes/no manner, and when present the abundance of the taxon is expressed as a percentage occurrence because of the semi-quantitative nature of much of the data. Abundances given as "p" in the study text, indicating that a taxon was present but in a very low abundance, have been reported as 0.01.

d. Chemical Data

Chemical data were recorded at forty of the forty-three sites documented in this database. The variables measured and units reported varied between studies. These units have been standardized into SI units where possible, and conversions made where applicable. Details of these changes are outlined in Appendix 4.2 of Dallas *et al.* (1994) and in Appendix 2.1 of this report. A full list of the chemical variables for which we have records is given in Appendix 4.3. of Dallas *et al.* (1994). In certain studies chemical values were given as "trace", "not detected" or "0.0". On the basis of reported chemical values for each variable, the following standardization was adopted:

VARIABLE	TRACE OR "NOT DETECTED" VALUE (in mg l^{-1})
Total Suspended Solids, anions and cations, total alkalinity, fluoride, free CO_2	0.01
Metals	0.001
Kjeldahl nitrogen, ammonium and phosphorus	0.001
Nitrite and nitrate	0.0001

e. Site Visit Summary

A summary of all the taxa present at a particular site on a particular date is tabulated by taxon name and biotope.

f. SASS Summary

The South African Scoring System (SASS) is a rapid bioassessment method, based on the sensitivity/tolerance of macroinvertebrates to water quality impairment. It is designed to assist in the detection and monitoring of water quality in riverine ecosystems. Application of SASS scores to historical data in the database provides a crude means of ranking or ascertaining the extent of water quality impairment at each site. It is limited in that certain studies were restricted to a single biotope whilst others incorporated numerous biotopes which are then considered collectively. Certain data are the result of a single site visit whilst others are more intensive and the grouping of months and/or years. These aspects need to be taken into consideration if SASS Summary information is used. Each SASS taxon recorded for each site visit is used to calculate Total Score, Number of Taxa and Average Score per Taxon (ASPT) for the site.

2.2.3 Taxonomy

Each species has been given a unique, numerical genus/species code. The state of flux of the taxonomy and inconsistent historic record of species names is to be noted, and caution is advised when querying at the lower taxonomic levels (e.g. species). Synonymous names and all taxonomic levels have been incorporated when known and the most recent name is used in querying. Selection may be made at any taxonomic level and groups of taxa or single taxa may be viewed.

2.2.4 Study References

Forty three studies have been captured in the database and details of the author, year, title and journal details are given for each study. Study references are numerically coded and linked to both the biological and chemical data.

2.2.5 Picklist Options

Modification and updating of the database is facilitated via the "Picklist" option.

2.3 QUERY CENTRE

The database has been designed to facilitate querying in a manner that only requires a basic knowledge of Microsoft Access and Excel. The Query Centre has three pre-defined query frameworks and within each it is possible to select the following. Operational details are not given here and the reader is referred to the User Manual.

2.3.1 Biology

Queries created from this form include only biological records. Using a series of drop-down lists and selection boxes within the following categories, queries can be streamlined.

- Taxonomy (Phylum, Class, Order, Family, Genus species etc., including wildcards as *)
- Biotope (SASS, broad, specific, substratum, description)
- Region (Bioregion, Water Quality region, Political region), subregion, river and site(s)
- Date (year, month, season)
- Study Reference
- SASS

2.3.2 Chemistry

Queries created from this form include only chemical records. Using a series of drop-down lists and selection boxes within the following categories, queries can be streamlined.

- Chemical parameter(s)
- Region (Bioregion, Water Quality region, Political region), subregion, river and site(s)
- Date (year, month, season)
- Study Reference

2.3.3 Chemical parameters linked to biology

Queries created from this form return chemical records that have been linked to biological records. Using a series of drop-down lists and selection boxes within the following categories, queries can be streamlined.

- Chemical parameter(s)
- Taxonomy (Phylum, Class, Order, Family, Genus species etc., including wildcards as *)
- Region (Bioregion, Water Quality region, Political region), subregion, river and site(s)
- Date (year, month, season)
- Study Reference
- SASS

2.3.4 Selecting Criteria and running queries in Microsoft Access

For each of the above queries it is possible to specify criteria such that a particular taxon and/or chemical variable, for a particular BioRegion, subregion and river, etc. is selected. By default these queries produce a Microsoft Excel PivotTable which allows complex manipulation and dynamic selection of information at all levels. The "Chemistry" and "Chemical parameters linked to biology" queries may also be queried within Microsoft Access by unselecting the Excel PivotTable. Statistical information is generated for each chemical parameter and summary information such as "Value Results Set", "Summary Results Set" and "Responsible Taxa" can be generated, manipulated and exported to Excel using the File/Output to command.

Each "Chemistry" and "Chemical parameters linked to biology" provides information on the average (Avg), standard deviation (SD), number of records (n), minimum (min), maximum (max), range and median values for each selected chemical variable. Additional features include:

- viewing of detailed data for each variable below the summary data by selecting the appropriate variable,
- the ability to exclude upper and lower 5% values (i.e. outliers) from the statistical analyses,
- viewing (and exporting to a geographical system such as GIS) of the "Values Results Set" which is a datasheet of all values used in the analyses, including information on the sitecode, chemdate, bioregion, subregion, and latitude and longitude co-ordinates,
- viewing and exporting of the "Summary Result Set" which is a datasheet summary of the statistical results for the selected chemical variables,
- viewing (and exporting to a geographical system such as GIS) the "Responsible Taxa" for the "Chemical parameters linked to biology" which is a datasheet of all taxa used in the analyses, including information on the presence/absence, abundance, sitecode, chemdate, bioregion, subregion, and latitude and longitude co-ordinates.

2.3.5 Selecting Criteria and running queries in Excel PivotTables

In addition to Microsoft Access queries, parameters may be selected within Access and/or data may be manipulated within Excel using PivotTables. By default all three pre-defined query frameworks produce PivotTables.

2.4 TECHNICAL INFORMATION

The database has been created using *Microsoft Access* (Ver 2.0) and querying has been streamlined using *Microsoft Excel.*

Installation: Hardware and Software requirements

- 486 PC with a minimum of 16 MB RAM.
- Microsoft Access 2.0 or run-time version of Access
- Microsoft Excel 5.0 or higher

Technical Support

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Appendix 2.1. Study references used in compiling the biological and chemical database and details of additional references not included in Dallas *et al.* 1994.

1. HARRISON A.D. & ELSWORTH J.F. 1958. *Hydrobiological studies of the Great Berg River; Part 1. General description of chemical studies and main features of the flora and fauna.* Transactions of the Royal Society of South Africa Vol 35. Part 3: pp.125-226.

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STUDY REFERENCE: 38

RIVER PALMIET RIVER, WESTERN CAPE PROVINCE
REFERENCE GALE B.A. 1992. THE EFFECT OF REGULATION BY TWO IMPOUNDMENTS ON AN ACID, BLACKWATER, CAPE MOUNTAIN STREAM. PHD THESIS. ZOOLOGY DEPARTMENT. UNIVERSITY OF CAPE TOWN, SOUTH AFRICA

BIOLOGICAL DATA
Biological sampling was conducted monthly. Mesh size = 80μm.

Biotopes sampled	Sampling devices
A. stony bottom: stone-in-current (riffle)	Box sampler

CHEMICAL DATA
Chemical samples were collected at the same time as biological samples. The following variables were measured:
temperature (TEMP), °C
pH (PH)
conductivity (COND), μS cm^{-1}, converted to mS m^{-1}
total dissolved solids (TDS), mg l^{-1}
percentage saturation dissolved oxygen (DOPER), %
total alkalinity (TAL), mg l^{-1} $CaCO_3$ and converted to meq l^{-1}
sulphate (SO4), mg l^{-1}
chloride (CHD), mg l^{-1}
nitrate (NO3-N), mg l^{-1}
nitrite (NO2-N), mg l^{-1}
ammonium (NH4-N), mg l^{-1}
Soluble Reactive Phosphorus (SRP), mg l^{-1}

MATCHING BIOLOGICAL AND CHEMICAL DATA
Biological and chemical data were matched directly.

STUDY REFERENCE: 39

RIVER LOURENS RIVER, WESTERN CAPE PROVINCE

REFERENCE RACTLIFFE G. 1991. THE EFFECTS OF SUSPENDED SEDIMENTS ON THE MACROINVERTEBRATE COMMUNITY STRUCTURE OF A RIVER ECOSYSTEM. HONOURS THESIS, ZOOLOGY DEPARTMENT, UNIVERSITY OF CAPE TOWN.

BIOLOGICAL DATA

Biotopes sampled	Sampling devices
A. stony bottom: stone-in-current (riffle)	Box sampler

Mesh size = 80μm.

CHEMICAL DATA
Chemical samples were collected at the same time as biological samples. The detection limit for the nutrients was 0.5 mg l^{-1}. The following variables were measured:
temperature (TEMP), °C
pH (PH)
conductivity (COND), μS cm^{-1}, converted to mS m^{-1}
percentage saturation dissolved oxygen (DOPER), %
total alkalinity (TAL), mg l^{-1} $CaCO_3$ and converted to meq l^{-1}
Nitrate-nitrogen (NO3-N), mg l^{-1}
Ammonium-nitrogen (NH4-N), mg l^{-1}
Orthophosphates (PO4-P), assumed equivalent to SRP, mg l^{-1}
Chemical Oxygen Demand (COD), mg l^{-1}

MATCHING BIOLOGICAL AND CHEMICAL DATA
Biological data for July and August were linked to chemical data for June.

STUDY REFERENCE: 40

RIVER EERSTE RIVER, WESTERN CAPE PROVINCE

REFERENCE KING J.M. 1983. ABUNDANCE, BIOMASS AND DIVERSITY OF BENTHIC MACRO-INVERTEBRATES IN A WESTERN CAPE RIVER, SOUTH AFRICA. TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTHERN AFRICA. 45: 11-33

BIOLOGICAL DATA
Sampling was conducted monthly between March 1975 and April 1976. Samples were however combined and data were presented seasonally for March-May, June-August, September-November and December-February. Mesh size = 0.6 mm.

Biotopes sampled	Sampling devices
A. stony bottom: stone-in-current (riffle)	Box sampler

CHEMICAL DATA
Chemical were collected simultaneously to biological data but are given as May-August and December-March means. The following variables were measured:
temperature (TEMP), °C
pH (PH)
percentage saturation dissolved oxygen (DOPER), %
dissolved oxygen (DO), mg l^{-1}
total alkalinity (TAL), mg l^{-1} $CaCO_3$ and converted to meq l^{-1}
Nitrite-nitrogen (NO2-N), mg l^{-1}
Nitrate-nitrogen (NO3-N), mg l^{-1}
Total phosphorus (TOT-P), mg l^{-1}

MATCHING BIOLOGICAL AND CHEMICAL DATA
Biological data for June-August have been linked to chemical data for May-August, and December-February to December-March.

STUDY REFERENCE: 41

RIVER VARIOUS RIVERS IN THE WESTERN CAPE (E.G. BERG AND TRIBUTARIES, KRAALSTROOM, EERSTE, MOLENAARS, PALMIET RIVER, OLIFANTS)

REFERENCE DALLAS H.F. 1994. AN EVALUATION OF SASS (SOUTH AFRICAN SCORING SYSTEM) AS A TOOL FOR THE RAPID ASSESSMENT OF WATER QUALITY. MSC THESIS. ZOOLOGY DEPARTMENT, UNIVERSITY OF CAPE TOWN, SOUTH AFRICA.

BIOLOGICAL DATA
SASS (South African Scoring System) sampling was conducted using a 950μm mesh. A mixture of biotopes were sampled and data pooled.

Biotopes sampled		Sampling devices
A. mixed	all available biotopes, (e.g. sic, sooc, mv, aqv, sand)	SASS Kick net

CHEMICAL DATA
Chemical samples were collected at the same time as biological samples. The following variables were measured:
temperature (TEMP), °C
conductivity (COND), μS cm^{-1}, converted to mS m^{-1}
pH (PH)

total dissolved solids (TDS), mg l^{-1}
total suspended solids (TSS), mg l^{-1}
total organics (TORGS), mg l^{-1}
dissolved oxygen (DO), mg l^{-1}
nitrate (NO3-N), mg l^{-1}
nitrite (NO2-N), mg l^{-1}
ammonium (NH4-N), mg l^{-1}
Soluble Reactive Phosphorus (SRP), mg l^{-1}
silica, mg l^{-1}
total alkalinity (TAL), meq l^{-1}
calcium (CA), mg l^{-1}
magnesium (MG), mg l^{-1}
sulphate (SO4), mg l^{-1}
sodium (NA), mg l^{-1}
potassium (K), mg l^{-1}
chloride (CHD), mg l^{-1}
aluminium, mg l^{-1}
iron, mg l^{-1}
lead, mg l^{-1}
Phenols, mg l^{-1}

MATCHING BIOLOGICAL AND CHEMICAL DATA
Biological and chemical data were matched directly.

STUDY REFERENCE: 42

RIVER PALMIET RIVER, WESTERN CAPE PROVINCE

REFERENCE DE DECKER H.P. 1981. CHANGES IN THE COMMUNITY STRUCTURE OF BENTHIC MACROINVERTEBRATES IN THE STONY-BED AREAS OF THE PALMIET RIVER, IN RELATION TO THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE RIVER. HONOURS THESIS, ZOOLOGY DEPARTMENT, UNIVERSITY OF CAPE TOWN, SOUTH AFRICA.

BIOLOGICAL DATA
Biological sampling was conducted in March and August 1981. Mesh size = 0.6 mm.

Biotopes sampled	Sampling devices
A. stony bottom: stone-in-current (riffle)	Box sampler

CHEMICAL DATA
Chemical samples were collected at the same time as biological samples. The following variables were measured:
temperature (TEMP), °C
pH (PH)
percentage saturation dissolved oxygen (DOPER), %
nitrate (NO3-N), mg l^{-1}
nitrite (NO2-N), mg l^{-1}
Soluble Reactive Phosphorus (SRP), mg l^{-1}
silica, mg l^{-1}

MATCHING BIOLOGICAL AND CHEMICAL DATA
Biological and chemical data were matched directly.

STUDY REFERENCE: 43

RIVER UMGENI RIVER, WESTERN CAPE PROVINCE

REFERENCE SCHOONBEE H.J. 1964. A HYDROBIOLOGICAL INVESTIGATION OF THE UMGENI RIVER SYSTEM, NATAL, AND ITS BEARING ON THE ECOLOGICAL INTERPRETATION OF FAUNAL COMMUNITIES IN SOUTH AFRICAN RIVERS. PHD THESIS. ZOOLOGY DEPARTMENT. POTCHEFSTROOM UNIVERSITY, SOUTH AFRICA

BIOLOGICAL DATA

Biological data are given for each season, with a further division into early and late in some instances. Mesh size approximately 500 μm.

Biotopes sampled		Sampling devices
A) stony bottom:	in stickles	Surbur sampler or hand net
	in run	Surbur sampler or hand net
	in cascade	hand net
	in flats	Surbur sampler or hand net
	in backwaters	hand net
	in pool	Surbur sampler or hand net
B) vegetation:	marginal vegetation	hand net
	stream bottom vegetation	hand net

CHEMICAL DATA

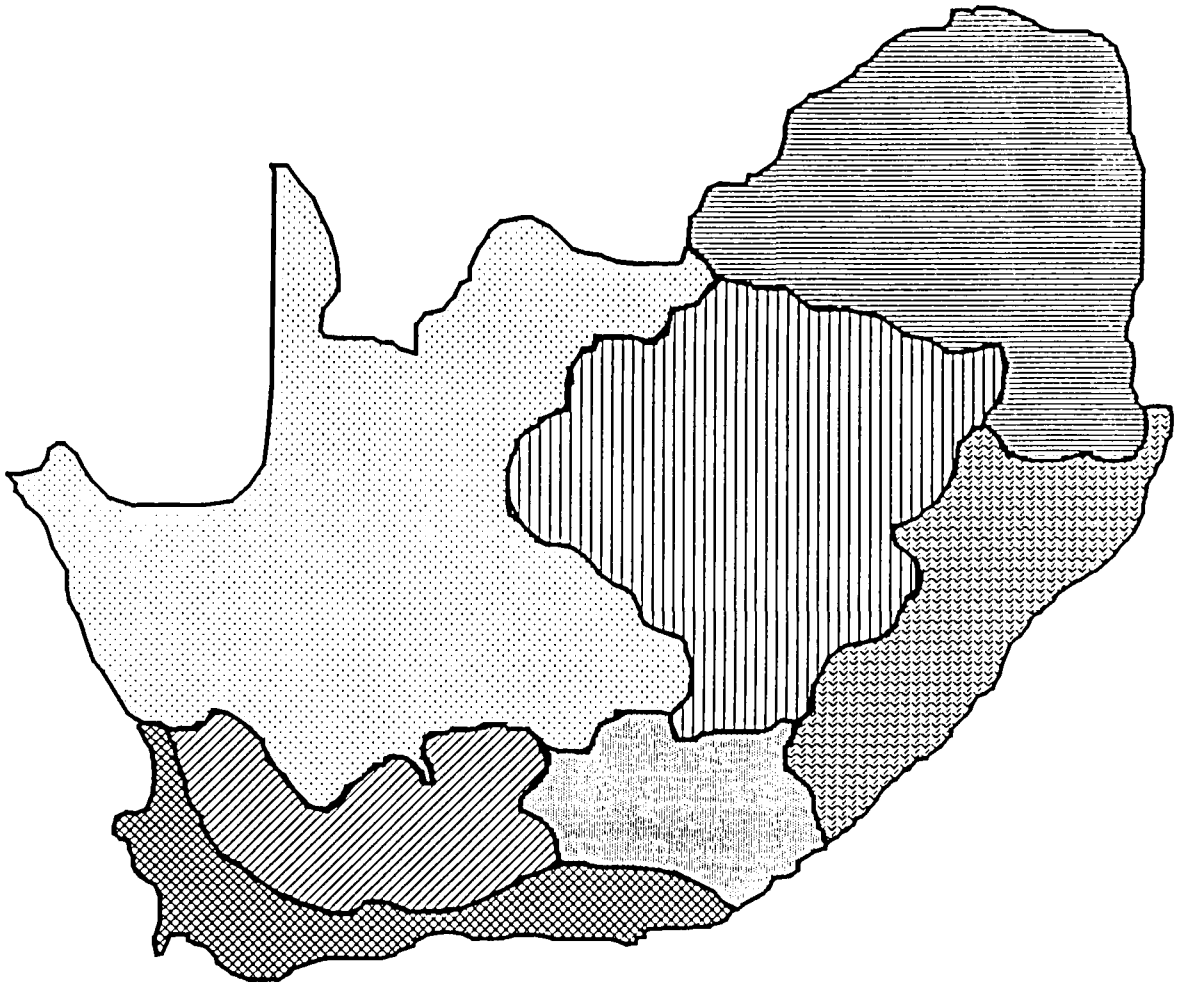
Composite and snap samples of water were taken throughout the period 1959 to 1960. Data are presented as mean, minimum and maximum values for the entire period. The following variables were measured:

pH (PH)
conductivity (COND), in micromho at 20 °C, converted to mS m^{-1}
total dissolved solids (TDS), mg l^{-1}
biological oxygen demand (BOD), 5 days at 20 °C, mg l^{-1}
total alkalinity (TAL), mg l^{-1} $CaCO_3$ and converted to meq l^{-1}
total hardness (CACO3), mg l^{-1} $CaCO_3$
calcium (CA), mg l^{-1}
magnesium (MG), mg l^{-1}
sulphate (SO4), mg l^{-1}
sodium (NA), mg l^{-1}
potassium (K), mg l^{-1}
chloride (CHD), mg l^{-1}
silica, mg l^{-1}
nitrate (NO3-N), mg l^{-1}
nitrite (NO2-N), mg l^{-1}
free and saline ammonia, assumed equivalent to ammonium (NH4-N), mg l^{-1}
phosphate, assumed equivalent to Soluble Reactive Phosphorus (SRP), mg l^{-1}
turbidity (TURB), as mg l^{-1} SiO_2

MATCHING BIOLOGICAL AND CHEMICAL DATA

Analysis of the chemical data by the author indicated minimal seasonal differences in physical and chemical variables. The seasonal biological data was therefore matched to the composite chemical data.

Appendix 2.2. Water Quality Management Regions



Southern and Western Coast

Arid Interior

Eastern Cape Drought Cooridor

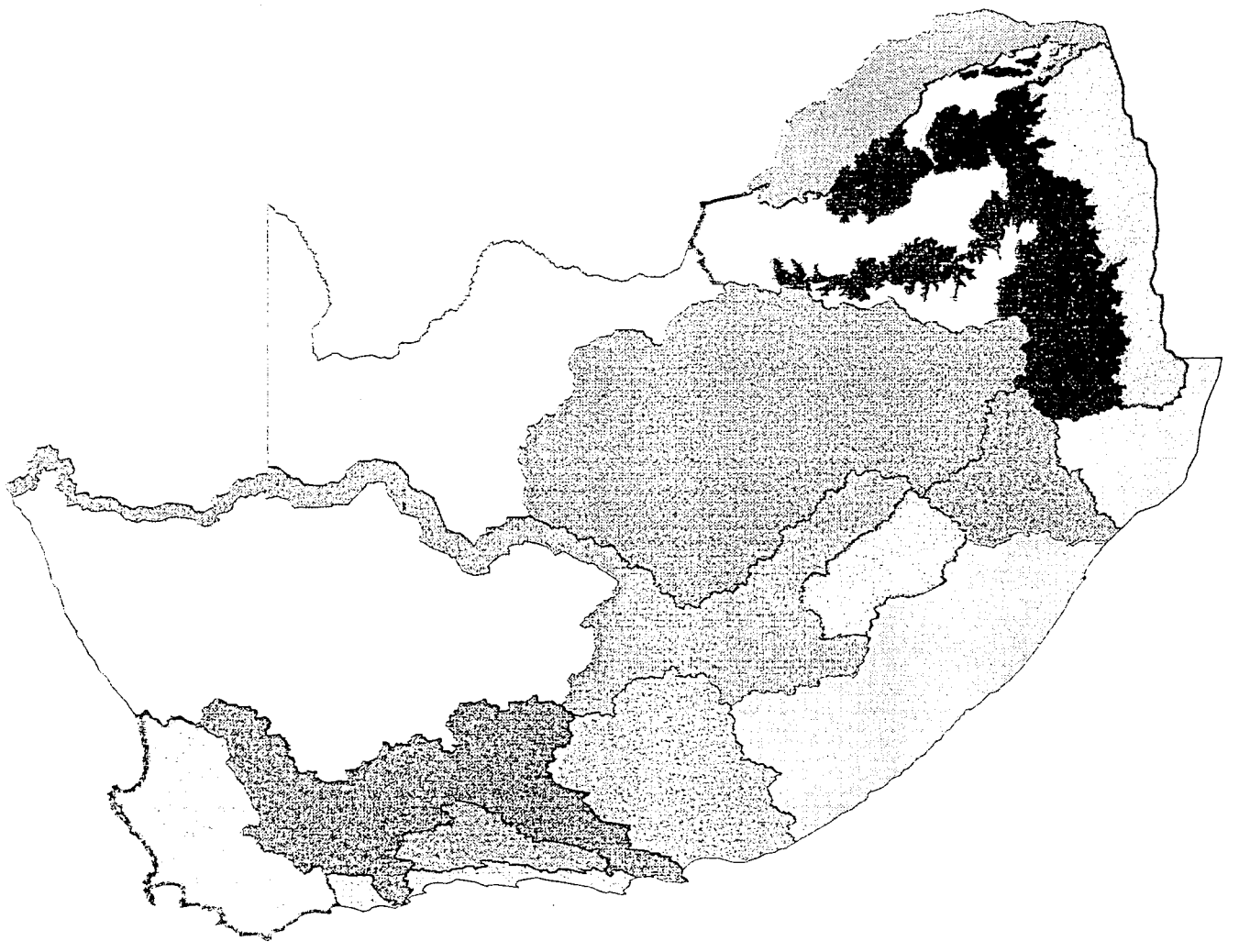
East Coast

Upper Orange/Vaal

North-east

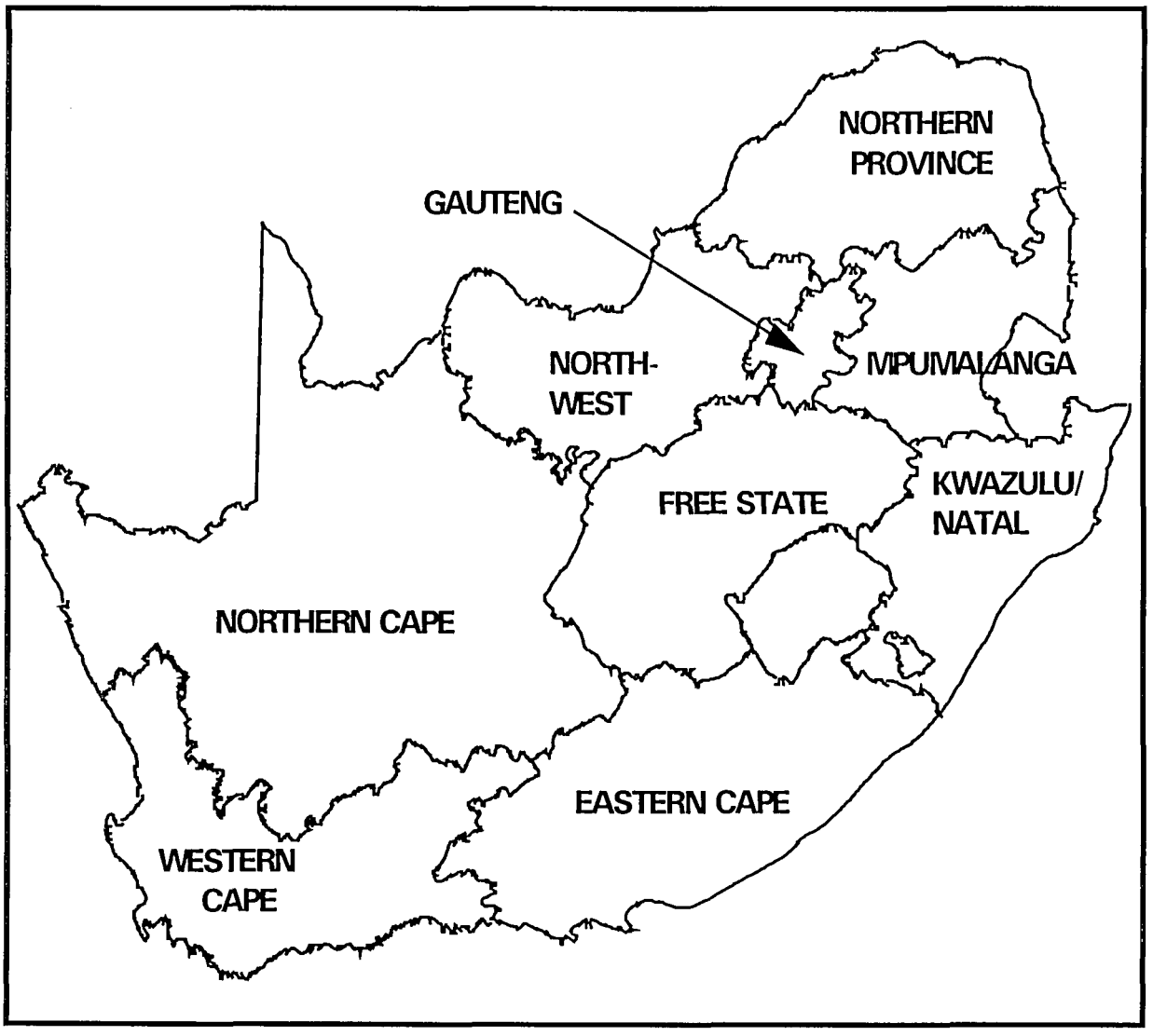
Karoo

Appendix 2.3. Bioregions (From Brown *et al.* 1996)



Fynbos
Alkaline Interior
Southern Coastal
Southern Inland
Arid Interior
Drought Corridor
Orange
Vaal
Montane
Eastern Seaboard
Tugela
St. Lucia Complex
Lowveld
Northern Uplands
Highveld Source
Northern Plateau
Bushveld Basin
Limpopo

Appendix 2.4. Political regions of South Africa.



Appendix 2.5. Bioregions and associated subregions for rivers within South Africa. Those in parenthesis are not represented by sites in the database.

BIOREGION	SUBREGION
(Limpopo)	(Rejuvenated Foothill) (Transitional) (Lowland) (Gorge)
(Northern Plateau)	(Upland Plateau)
Northern Uplands	Mountain Stream Foothill (Gorge) (Upland Plateau)
(Bushveld Basin)	(Lowland)
Highveld Source	Mountain Stream Transitional
Lowveld	Foothill Lowland
Vaal	Source Mountain Stream Foothill/Transitional
Orange	Foothill Transitional (Sandbed and Orange) Lowland (Lower Orange A, B, C, D and E)
Arid Interior	Mountain Stream Foothill
Fynbos	Source Mountain Stream Foothill Transitional Lowland (Rejuvenated)
Alkaline Interior	Mountain Stream Foothill Transitional (Lowland)
	(Coastal)
Southern Coastal	Mountain Stream
Southern Inland	Source Mountain Stream Foothill
Drought Corridor	*(Source)* Mountain Headwater Foothill Upland Transitional
Eastern Seaboard	Source Mountain Stream Foothill

BIOREGION	SUBREGION
	Transitional Lowland (Coastal) (Gorge and rejuvenated foothill)
Montane	Not assessed
Tugela	Mountain Stream Upland Plateau Lowland (Coastal)
St Lucia Complex	(Upland Plateau) Transitional Lowland (St. Lucia Coastal Floodplains) (Maputoland Sandplain)

Appendix 2.6. Hierarchical arrangement of biotope categories giving SASS, broad and specific biotopes, substratum and a description for each. Blank fields indicted unspecified details.

SASS BIOTOPE	BROAD BIOTOPE	SPECIFIC BIOTOPE	SUBSTRATUM	DESCRIPTION OF BIOTOPE
AQV	VEG	AQV	SCIRPUS	Aquatic vegetation: Scirpus beds
AQV	VEG	AQV		Aquatic vegetation: unspecified type
MV	VEG	MV		Marginal vegetation: unspecified type
SIC	WATERFALL	CAS		Waterfall: cascades
SIC	WATERFALL	MIT		Waterfall: mossy rocks
SIC	WATERFALL	SFR		Waterfall: perpetually sprayed rock regions flanking cascades
SIC	SIC	RIF		Riffles (in stones-in-current biotope), with no specified substrate
SIC	SIC	RIF	COB	Riffles (in stones-in-current biotope), with cobble substrate
SIC	SIC	RIF	BCOB	Riffles (in stones-in-current biotope), with mixed bedrock and cobble substrate
SIC	SIC	HIGH FLOW		High flow over stones, release phase (in stones-in-current biotope)
SIC	SIC	LOW FLOW		Low season trickle over stones, drying phase (in stones-in-current biotope)
SIC	SIC	RIC		Scrapings from large rock in current (in stones-in-current biotope)
SIC	SIC			Stones-in current biotope, specific biotope and substrate unspecified
SIC	SIC	RUN	BED	Run, over bedrock (in stones-in-current biotope)
SIC	SIC	RUN	BCOB	Run, over bedrock/cobble (in stones-in-current biotope)
SIC	SIC	RUN	COB	Run, over cobble (in stones-in-current biotope)
SIC	SIC	RUN	BBOLD	Run, over bedrock/boulder (in stones-in-current biotope)
SIC	SIC	RUN		Run, over unspecified substrate (in stones-in-current biotope)
SIC	SIC	RAPID	BED	Rapid, over bedrock (in stones-in-current biotope)
SIC	SIC	RAPID	BCOB	Rapid, over bedrock/cobble (in stones-in-current biotope)
SOOC	SOOC	BACK	COB	Stones-out-of-current, backwater, with cobble substrate
SOOC	SOOC	BACK	GCOB	Stones-out-of-current, backwater, with gravel and cobble mixed substrate
SOOC	SOOC	BACK		Stones-out-of-current, stony bottomed backwater, unspecified substrate
SAND	SAND	BACK	SAND	Stones-out-of-current, sand bottomed backwater

SASS BIOTOPE	BROAD BIOTOPE	SPECIFIC BIOTOPE	SUBSTRATUM	DESCRIPTION OF BIOTOPE
GRAVEL	GRAVEL	RUN	GSAND	Run, over gravel/sand (in stones-in-current biotope)
SAND	SAND	RUN	SAND	Run, over sand (in stones-in-current biotope)
SAND	SAND	BACK	MSAND	Stones-out-of-current, backwater, with mixed mud and sand
SAND	SAND	POOL	SAND	Pool, sand bottom
SAND	SAND	POOL	MSAND	Pool, mixed mud and sand bottom
SOOC	SOOC	POOL	BCOB	Pool, mixed bedrock and cobble bottom
SOOC	SOOC	POOL	BED	Stone bottomed pool, with bedrock substrate specified
MUD	MUD	POOL	MUD	Mud bottomed pool
SOOC	SOOC	POOL		Stone bottomed pool, no substrate specified
SOOC	SOOC	POOL		Pool, with no substrate type specified
SAND	SEDIMENT			Sediment bottom, with no substrate type specified
SAND	SAND		SAND	Sandy substrate, bioptope not specified
MIXED	MIXED	SAND AND VEG	SAND AND MV	Mixed biotopes: sand and marginal vegetation, unspecified type
MIXED	MIXED			Mixture of biotopes sampled, and data pooled
SIC	SIC	RUN	FLAT	Stones-in-current, slight to moderate current; smooth flow

CHAPTER 3. DEVELOPMENT OF REGIONAL WATER QUALITY GUIDELINES FOR AQUATIC ECOSYSTEMS: NON-TOXIC INORGANIC CONSTITUENTS

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3.1. INTRODUCTION

Water quality guidelines for certain constituents of water in aquatic ecosystems need to be developed on a regional or site-specific basis because of differences in intrinsic or background concentrations or ranges of these constituents. This chapter provides a synthesis of the characteristics of three constituents, namely total dissolved solids (TDS) and conductivity, total suspended solids (TSS) and turbidity, and pH and alkalinity, and outlines the occurrence and interactions of each variable, in addition to elaborating on the effects of, and criteria proposed for, each variable. A method for deriving regional water quality guidelines which takes account of spatial, seasonal and diel variation is proposed and developed for the southern and western coast water quality management regions (WQMR; Dallas *et al.* 1994). Background concentrations have also been derived for other WQMRs for which data were available.

3.2 NATIONAL WATER QUALITY GUIDELINES FOR AQUATIC ECOSYSTEMS

Interim national water quality guidelines for aquatic ecosystems have been developed for South Africa (DWAF 1995). A water quality guideline is a set of information provided for a specific water quality constituent. The guidelines are used in water quality management as the primary source of reference information and decision support for the management and protection of aquatic ecosystems. Constituent-specific criteria have been developed and divided into four categories based on the effects that the constituents have on aquatic biota, and on the methodologies of derivation used in the criteria. The four categories are:

- **Toxic constituents**
  It is generally accepted (although not yet proven) that data on the effects of toxins are more or less universally applicable and a single criterion is probably acceptable country-wide. Criteria may be given as single numerical values associated with a specific level of risk, or a value below which no adverse effect is expected. These constituents seldom occur in high concentrations in unimpacted systems.

- **System variables**
  These include those constituents such as temperature and dissolved oxygen which regulate essential processes within the aquatic ecosystem. The biota are usually adapted to the natural seasonal cycles of changing water quality which characterise particular systems.

- **Non-toxic inorganic constituents**
  These may cause toxic effects at extreme concentrations, but are generally "system characteristics" because natural concentrations depend on localised geochemical, physical and hydrological processes. Criteria are given as numerical ranges or as proportional changes from local background conditions for constituents such as TDS, TSS and pH.

- **Nutrients**
  These are generally not toxic, but may stimulate eutrophication if present in excess. Criteria are given as narrative or numerical, site-specific values or ranges for constituents such as inorganic nitrogen (nitrate, nitrite, ammonium) and inorganic phosphorus (ortho-phosphates).

Of these four categories it is the non-toxic inorganic constituents, in particular TDS and conductivity, pH and TSS and turbidity, which have been focused on within the present research project. The national water quality guidelines for each of these is given below, together with information on the occurrence of the constituent in the aquatic environment, the norms used to assess its effects on water uses, and the conditions for case-, site- and region-specific modifications. The guidelines for TDS and pH were written by Dallas (DWAF 1995).

3.2.1 Total Dissolved Solids (TDS) and conductivity

Introduction

TDS is a measure of all salts and organics dissolved in water. The TDS concentration is usually directly proportional to the electrical conductivity (EC) of water. Since EC is easier to measure, it is routinely used as an estimate of TDS concentration.

Occurrence

Virtually all natural waters contain varying levels of dissolved ions as a consequence of the dissolution of minerals in rocks, soils and decomposing plant material and the background or intrinsic TDS concentration is often dependent on the characteristics of the geological formations which the water has been in contact with. TDS concentrations may be <30 mg l^{-1} under certain geological conditions (e.g. granite) and in the range of 200 to 1100 mg l^{-1} in water in contact with palaeozoic and mesozoic sedimentary rock formations. Anthropogenic activities, such as discharge of industrial effluents and sewage, return flow irrigation water, and clear-felling of trees, result in elevated TDS levels.

Interactions

The effects of TDS are largely governed by the constituent inorganic salts and the proportional concentrations of the major ions affect the buffering capacity of the water. Most commonly, the relative concentrations of the major ions tends to be:

- Cations: sodium > calcium/magnesium > potassium
- Anions: chloride or bicarbonate > sulphate > carbonate

In waters with either very low or very high pH values, the hydrogen ion (H^+) and the hydroxyl ion (OH^-) respectively, also contribute to the total ionic charge.

Effects and criteria

The norms for assessing the effect of TDS on aquatic ecosystems are:

- chronic and acute physiological effects on aquatic biota; and
- changes in background site-specific TDS levels which cause changes in ecosystem structure and function.

Plants and animals possess a wide range of physiological mechanisms and adaptations to maintain the

necessary balance of water and dissolved ions in cells and tissues. This ability is extremely important in any consideration of the effects of changes in total dissolved solids on aquatic organisms. The individual ions also exert physiological effects on aquatic organisms. Changes in the concentration of TDS can affect aquatic organisms at three levels, namely:

- effects on, and adaptations of, individual species;
- effects on community structure; and
- effects on microbial and ecological processes such as rates of metabolism and nutrient cycling.

Very little information is available on the tolerances of aquatic organisms to elevated TDS concentrations, although a number of generalisations can be made:

- the rate of change of the TDS concentrations, and the duration of change, appears to be more important than absolute changes in TDS concentration, particularly in systems where the organisms may not be adapted to fluctuating levels of TDS;
- juvenile stages appear to be more sensitive;
- secondary effects (synergistic or antagonistic) often result from elevated TDS levels (e.g. alteration of the toxicity of trace metals); and
- organisms adapted to low-salinity habitats are generally sensitive to changes in TDS concentration.

Criteria and modifications

The Target Water Quality Range (TWQR), i.e. a management objective derived from numerical or narrative criteria aimed at maintaining the water quality within the No Effect Range, for TDS is stated in terms of case- or site-specific TDS concentrations. In all cases local water quality conditions need to be determined before water quality criteria are set. For all inland waters:

- the TDS concentration should not be changed by >15% from those of the water body under unimpacted conditions at any time of year, and
- the amplitude and frequency of natural cycles in TDS concentration should not be changed.

Modifications may be considered where case-, site-specific measurements indicate the TWQR to be too stringent or inappropriate. In particular:

- in naturally saline systems,
- if the site (or river or stream) has been subjected to increased TDS concentrations over a long period of time, such that the original biota have either adapted to the new conditions or have been replaced by more salt-tolerant species, and
- where endemic or introduced organisms might be more sensitive to changes in TDS concentrations and may therefore have more stringent TDS requirements, e.g. in unimpacted cold-water habitats.

The following conditions should be satisfied before the TWQR for TDS concentrations is altered:

- adequate site-specific analytical data, covering at least one annual cycle, are available; and
- site-specific studies demonstrate that there are no adverse effects on the ecosystem for the proposed changes in TDS concentration.

TWQRs have not been set for conductivity, but given that TDS concentration and conductivity are generally proportional to one another, the relationship between the two may be established on a case- or site-specific basis.

3.2.2 Total Suspended Solids (TSS) and turbidity

Introduction

The total suspended solids (TSS) concentration is a measure of the amount of material suspended in water. This definition includes a wide range of sizes of material, from colloids (0.1μm) through to large organic and inorganic particles. The concentration of suspended solids increases with the discharge of sediment washed into rivers due to rainfall and re-suspension of deposited sediment. As flow decreases the suspended solids settle out, the rate of which is dependent on particle size and the hydrodynamics of the water body.

Water turbidity in the southern hemisphere is generally considered to be equivalent to some measure of the concentration of suspended solids. Turbidity is an expression of the optical property that causes light to be scattered and adsorbed rather than transmitted in straight lines through a water sample. The scattering of light is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, plankton and other microscopic organisms, while the adsorbtion of light is caused by soluble coloured organic compounds, such as fulvic, humic and tannic acids.

Correlation of turbidity with the concentration of suspended solids (mass/unit volume) is difficult because the size, shape and refractive index of the particulates affects the light scattering properties of the suspension. The relationship between turbidity and suspended solids may however, be determined on a site-specific basis. A turbidimeter, calibrated with consideration of the site-specific characteristics, may then potentially be used to monitor suspended solids.

Occurrence

Natural variations in rivers often result in changes in TSS, the extent of which is governed by the basic hydrology and geomorphology of a particular region. In South Africa, all rivers, except some in the Natal foothills of the Drakensberg and in the south-western Cape, become highly turbid and laden with suspended solids during the rainy season. The major part of suspended material found in most natural waters is made up of soil particles derived from land surfaces. Erosion of land surfaces by wind and rain is a continuous and natural process. However, land use practices such as overgrazing, non-contour ploughing, removal of riparian vegetation and forestry operations accelerate erosion and result in increased loads of suspended solids in associated rivers.

Increases in total suspended solids may also result from other anthropogenic sources, including:

- discharge of domestic sewage,
- discharge of industrial effluents (such as the pulp/ papermill, china-clay, and brick and pottery industries),
- discharge from mining operations,
- fish-farm effluents (mostly organic suspended solids), and
- physical perturbations from road, bridge and dam construction.

Interactions

An increase in TSS may lead to a decrease in water temperature as more heat is reflected and less

absorbed by the water. This may affect temperature-sensitive organisms. Suspended inorganic material carries an electrical charge. The result is that a variety of dissolved substances, including nutrients, trace metal ions, and biocides, may become adsorbed onto the surfaces of these particles. Substances adsorbed onto particles are not available, and this may be advantageous in the case of toxic trace metal ions, but disadvantageous, in the cases of nutrients. If the suspended solids consist largely of organic solids, then the concentration of dissolved oxygen in the water body may decrease on oxidation of the solids by micro-organisms.

Effects and criteria

Changes in turbidity or TSS concentrations that are unrelated to natural variation (e.g. diel, i.e. over a 24-hour period, and seasonal patterns) may have effects on organisms, species and communities. Background TSS levels need to be established if deviation from such "natural" levels for a particular water body at a particular time are assessed. Elevated levels of turbidity and TSS will have a greater effect in areas which have lower background TSS levels, for example, upper mountain catchment regions.

The norms for assessing the effects of the TSS concentration on aquatic ecosystems are:

- acute and chronic physiological effects on aquatic organisms;
- changes from "natural" site-specific TSS levels that cause changes in ecosystem structure and functioning.

The significance to aquatic biota of changes in the TSS depends on the extent, duration, frequency and timing of these changes. If increases in TSS from anthropogenic causes result in the same amplitude as that of natural flooding, then these increases may well be tolerated by aquatic organisms. Continuous high-level inputs may, however, have serious consequences.

In turbid waters light penetration is reduced, leading to a decrease in photosynthesis. The resultant decrease in primary production reduces food availability for aquatic organisms higher up the food chain. Suspensoids may interfere with the feeding mechanisms of filter-feeding organisms such as certain macroinvertebrates, and the gill functioning, foraging efficiency (due to visual disturbances) and growth of fish. Suspended solids that settle out may smother or abrade benthic plants and animals, and may result in changes to the nature of the substratum. This may lead to changes in the structure of the biotic community by the decline of those organisms requiring "open" eroded substrata for attachment or feeding, and replacement with organisms which burrow in the soft sediments. Sensitive species may be permanently eliminated if the source of the suspended solids is not removed. The recovery of a stream from sediment deposition is dependent on the elimination of the sediment source and the potential for the deposited material to be flushed out by stream flow.

Criteria and modifications

According to the water quality guidelines all TSS measurements for a site should be within the Target Water Quality Range. The criteria for TSS in aquatic ecosystems are as follows:

- where background TSS concentrations are < 100 mgl^{-1}, any increase in TSS concentrations must be limited to < 10 mgl^{-1}, or

- where background TSS concentrations are > 100 mgl^{-1}, any increase in TSS concentrations must be limited to < 10 % of the background TSS concentration.

Modifications may be necessary under certain circumstances, for example:

- where locally important species may be very sensitive to TSS;
- where aquatic organisms are stressed by diseases, parasites, predators, other contaminants, contaminated or insufficient food, and fluctuating or extreme conditions of flow or water quality; and
- where natural background TSS concentrations are higher than the TWQR.

Before any TWQR is modified, a site-specific study must demonstrate that there will be no adverse effects on the ecosystem for the proposed changes in TSS concentrations. Adequate data, covering at least one annual cycle, will therefore needed to be analyzed or collected. The study must also establish that the particle size distribution of any additional TSS material will not significantly change the particle size distribution of the bed of the recipient system.

TWQRs have not been set for turbidity, but the relationship between TSS concentration and turbidity may be established on a case- or site-specific basis and TWQRs set .

3.2.3 pH

Introduction

The pH value is a measure of the hydrogen ion activity in a water sample. It is mathematically related to hydrogen ion activity according to the expression: $pH = - \log_{10} (H^+)$, where (H^+) is the hydrogen ion activity. The pH of pure water (i.e. water containing no solutes) at a temperature of 24°C is 7.0, the number of H^+ and OH^- ions are equal and the water is therefore electrochemically neutral. As $[H^+]$ increases, pH decreases and the solution becomes more acid. As $[H^+]$ decreases, pH increases and the solution becomes more alkaline. A change of 1 unit equals a ten-fold change in $[H^+]$. The equilibrium between H^+ and OH^- ions is influenced by reactions with acids and bases introduced into the aqueous system. In general, acidity is the number of OH^- ions that have reacted over a given pH range during a base titration, i.e. a measure of the water's ability to neutralise base. Similarly, alkalinity is a measure of the number of H^+ ions that have reacted over a given pH range during an acid titration, i.e. a measure of the water's ability to neutralise acid.

Alkalinity is primarily controlled by carbonate species and is therefore usually expressed in terms of equivalence to calcium carbonate ($CaCO_3$) or hardness. Briefly, carbon dioxide dissolves in water to form carbonic acid (H_2CO_3) which, depending on the pH, dissociates to form carbonate, bicarbonate and hydrogen ions:

$$CO_2 + H_2O \_ H_2CO_3 \_ HCO_3^- + H^+ \_ CO_3^{2-} + 2H^+$$

At a pH value below 4.0, carbonate species are mostly in the form of CO_2, and between a pH value of 6.4 and 8.6 in the form HCO_3^-. As the pH increases above 8.6, so the proportion of CO_3^{2-} increases, and above 10.3 only CO_3^{2-} is present.

The rate of change of pH, on addition of a given quantity of an acid or base, depends on the buffering capacity of the water. The most important buffering system in fresh waters is the carbonate-bicarbonate one, and between pH values of 6.4 and 10.3 the bicarbonate ion predominates. In naturally acid waters, complex polyphenolic organics and their salts may form the major buffering system, while aluminium and its salts become effective buffering agents in waters subject to acid precipitation.

Occurrence

For surface water, the pH range is typically 4 to 11. The relative proportions of the major ions, and in consequence the pH, of natural waters, are determined by geological and atmospheric influences. Most fresh waters, including most in South Africa, are relatively well buffered and more or less neutral, with pH ranges around 6-8. Very dilute sodium-chloride-dominated waters are poorly buffered because they contain virtually no bicarbonate or carbonate. If they drain catchments containing certain types of vegetation (e.g. fynbos), the pH may drop as low as 3.9 owing to the influence of organic acids (e.g. humic and fulvic acids). In South Africa such conditions are found in parts of the south-western and southern Cape and in the swamp forests of Natal.

The pH may also vary both diurnally and seasonally. Diurnal fluctuations occur primarily in productive systems where the relative rates of photosynthesis and respiration vary over a 24-hour period. Seasonal variability is largely related to the hydrological cycle, particularly in rivers draining catchments with vegetation such as fynbos. Humic material is flushed into the water during rainfall events, particularly the first flushes, and the concentration of organic acids in the water body increases, and pH decreases.

Industrial activities generally cause acidification rather than alkalinization of rivers. Acidification is normally the result of three different types of pollution, namely:

- low-pH point source effluents from industries, such as the pulp and paper industry, and the tanning and leather industry,
- mine drainage, which is nearly always acid, leading to the pH of receiving streams dropping to <2, and
- acid precipitation resulting largely from atmospheric pollution caused by the burning of coal (and subsequent production of sulphur dioxide) and the exhausts of combustion engines (nitrogen oxides). Both SO_2 and NO_xes form strong mineral acids when dissolved in water. When acid rain falls on a catchment, the strong acids leach calcium and magnesium from the soil and interfere with nutrient availability.

Elevated pH values can be caused by increased biological activity in eutrophic systems. The pH may fluctuate widely from <6 to >10 over a 24-hour period as a result of changing rates of photosynthesis and respiration.

Interactions

The pH is affected by factors such as temperature, calcium, sodium and chloride concentrations, and biological activity. Of these temperature is unlikely to be of any great significance in natural systems because the pH of fresh water only decreases by 0.1 unit for a temperature increase of 20°C. The toxic effects of acid pH values on fish increases as the concentrations of calcium, chloride and sodium

decrease.

Extreme rates of photosynthesis, whether natural or as a result of eutrophication, commonly cause very high pH values in standing waters. Very eutrophic systems may exhibit significant diel fluctuations in pH, through the high rates of consumption of CO_2 during photosynthesis (increase in pH), and release of CO_2 during respiration and decomposition (decrease in pH). Such extreme eutrophication is not common in rivers however, and they rarely exhibit these large fluctuations in pH. In relation to this, high concentrations of dissolved oxygen may decrease the effect of high pH values on fish, particularly if alkaline conditions are the result of intense photosynthetic activity of aquatic plants which is normally accompanied by high levels of dissolved oxygen.

The buffering capacity of the receiving water affects the rate of change of the pH in aquatic systems. In poorly buffered waters pH can change rapidly, and this may have severe effects on the aquatic biota. The pH may also effect other constituents of the water body, particularly in terms of availability and toxicity of constituents such as trace metals, non-metallic ions such as ammonium, and essential elements such as selenium.

The degree of dissociation of weak acids and bases is affected by changes in pH. The pH also determines the chemical species of many metals, and thereby alters the availability and toxicity of metals in the aquatic environment. The metals most likely to have increased detrimental environmental effects as a result of lowered pH are silver, aluminium, cadmium, cobalt, copper, mercury, manganese, nickel, lead and zinc. Non-metallic ions can be similarly affected by changes in pH. Ammonium ions (NH_4^+), which are not toxic, are the main form in which nitrogen is assimilated by most plants. At a pH above 8, however, they are converted to the highly toxic un-ionized ammonia (NH_3). A decrease in pH can also decrease the solubility of certain essential elements such as selenium. Human populations from areas polluted by acid rain may begin to suffer from selenium deficiency.

Since the adsorptive properties of large molecules (such as polyphenolics) and of particulate matter in water depend on their surface charges, altering the pH can also alter the degree to which nutrients such as PO_4^{3-}, trace metals and biocides adhere to these materials. This is of particular significance where lowered pH can lead to the release of toxics from sediments.

Effects and criteria

Background pH values, in addition to diel and seasonal variability, need to be established if deviation from natural pH values for a particular water body at a particular time is to be assessed. The significance of pH changes to aquatic biota depends on the extent, duration and timing of the changes. Small changes in pH often cause large changes in the concentration of available metallic complexes and can lead to significant increases in the availability and toxicity of certain metals.

The norms for assessing the effect of pH on the natural aquatic environment are:

- acute and chronic physiological effects on aquatic biota,
- changes from background site-specific pH values, which result in changes to ecosystem structure and function.

A change in pH from that normally encountered in unimpacted streams may have severe effects upon the biota. The extent of acidification or alkalinization is important in determining the degree of severity of the effects. When assessing the potential effect of a change in pH, it is important to note that some streams are naturally more acidic than others and their biotas are often adapted to these conditions. Direct effects of pH changes consist of alterations to the ionic and osmotic balance of individual organisms, in particular in the rate and type of ion exchange across body surfaces. This requires greater energy expenditure, with subsequent effects such as slow growth and reduced fecundity becoming apparent. Aquatic organisms, however, generally have well developed mechanisms to maintain ionic and osmotic balance. Indirect pH changes include changes in the availability of toxic substances such as aluminium and ammonia.

Acidic pH

Gradual reductions in pH may result in a change in community structure, with acid-tolerant organisms replacing less tolerant ones. Streams with acidic pH values have different periphyton (the microflora and fauna living on aquatic surfaces) communities and lower overall production in comparison to less acid streams. Acidic streams, with a mean pH<5.5, have been shown to have a lower invertebrate diversity than more alkaline streams. A specialised fauna and flora often develops in streams where the natural pH is <5.0. Certain invertebrates such as mosquito larvae and an amphipod, *Gammarus* sp., are tolerant of pH values approximately 2.4. The discharge of acid wastes into water containing bicarbonate alkalinity results in the formation of free carbon dioxide. If the water is alkaline, free CO_2 may be liberated and be toxic to fish even though the pH does not drop to a level normally considered toxic.

Alkaline pH

Limited information is available on the effects of elevated pH.

Criteria and modifications

For aquatic ecosystems:

- *pH values should not be allowed to vary from the background pH values for a specific site and time* of day, by > 0.5 of a pH unit, or by > 5%, and should be assessed by whichever estimate is more conservative.

The Target Water Quality Range for pH should be stated in terms of background site-specific pH regime. In all cases, local background conditions should be determined (including diel and seasonal variability where appropriate) before a water quality objective for a particular aquatic ecosystem is set.

Both spatial and temporal variability in pH need to be determined on a case-, site-specific basis.
Spatial variability includes:

- geographic differences, and
- longitudinal differences (upper, middle and lower reaches),

and temporal variability includes:

- diel differences, and
- seasonal differences.

Modifications may be necessary under certain circumstances, for example:

- where locally important species may be very sensitive to changes in pH;
- where aquatic organisms are stressed by diseases, parasites, predators, other contaminants, contaminated or insufficient food, and fluctuating or extreme conditions of flow or water quality; and
- where natural background pH values have a range of variation which is greater than that specified by the TWQR.

Before any TWQR is modified, a site-specific study must demonstrate that there will be no adverse effects on the ecosystem for the proposed changes in pH range. Adequate data, covering at least one annual cycle, will therefore need to be analyzed or collected.

3.3 REGIONAL WATER QUALITY GUIDELINES FOR AQUATIC ECOSYSTEMS

Regional guidelines are necessary because of the intrinsic variability in water chemistry between regions. There are different perceptions regarding the term "regional" and two spatial frameworks have been adopted with respect to "regional" water quality guidelines. The first is a geographic framework based on water chemistry (Day *et al.* 1997) and the second relates to longitudinal differences within river systems. Guidelines need to be developed within both a geographic and a longitudinal framework, and in some instances may need to be developed on a site-specific basis.

The geographic framework is designated by *Water Quality Management Regions* (see Appendix 2.2), based on Department of Water Affairs & Forestry (DWAF) water chemistry data, which were proposed at a secondary catchment level in the final report of the previous water quality project (Dallas *et al.* 1994). Subsequent production of Bioregions (Brown *et al.* 1996, see Appendix 2.3) during a workshop designed to facilitate the selection of monitoring and reference sites for a national biomonitoring programme, has enabled previously unknown areas to be incorporated into defined WQMRs. An additional WQMR, termed Karoo, has been added such that seven WQMRs (see Appendix 2.2) are proposed:

WQMR	Description
1	Southern and Western Coast
2A	Arid Interior
2B	Eastern Cape Drought Corridor
3	East Coast
4	Upper Orange/Vaal
5	North-east
6	Karoo

Longitudinal differences (e.g. mountain stream versus foothill versus lowland river) have been taken into account by incorporating Biotic Subregions (see Appendix 2.5), which were also delineated at the workshop (Brown *et al.* 1996).

3.3.1 Methodology for assessing regional water quality guidelines for selected variables

Diel and seasonal ranges in background concentrations need to be established for each spatial framework and compared with the interim Target Water Quality Ranges (TWQR).

Subregional variation

Using the Biological and Chemical Database (BCD) developed as part of this research project (see Chapter 2), background concentrations were determined for TDS and TSS, and background ranges for conductivity and pH for rivers within selected WQMRs. The quantity of information available in each WQMR and/or subregion varied considerably, with some WQMRs being very data-rich and others data-poor. Longitudinal differences were taken into consideration by ascertaining these background characteristics for each subregion within each WQMR. In some instances subregions were combined because of the scarcity of data. By restricting the analyses to one geographic region and dividing this into subregions, both geographic and longitudinal differences are taken into account. Both the parametric Analysis of Variance (ANOVA) and the non-parametric equivalent, Kruskal Wallis, which uses median values and not mean values, were applied to the data to test for significance. The results produced were very similar and results presented are for Kruskal Wallis analyses.

Exclusion of impacted sites

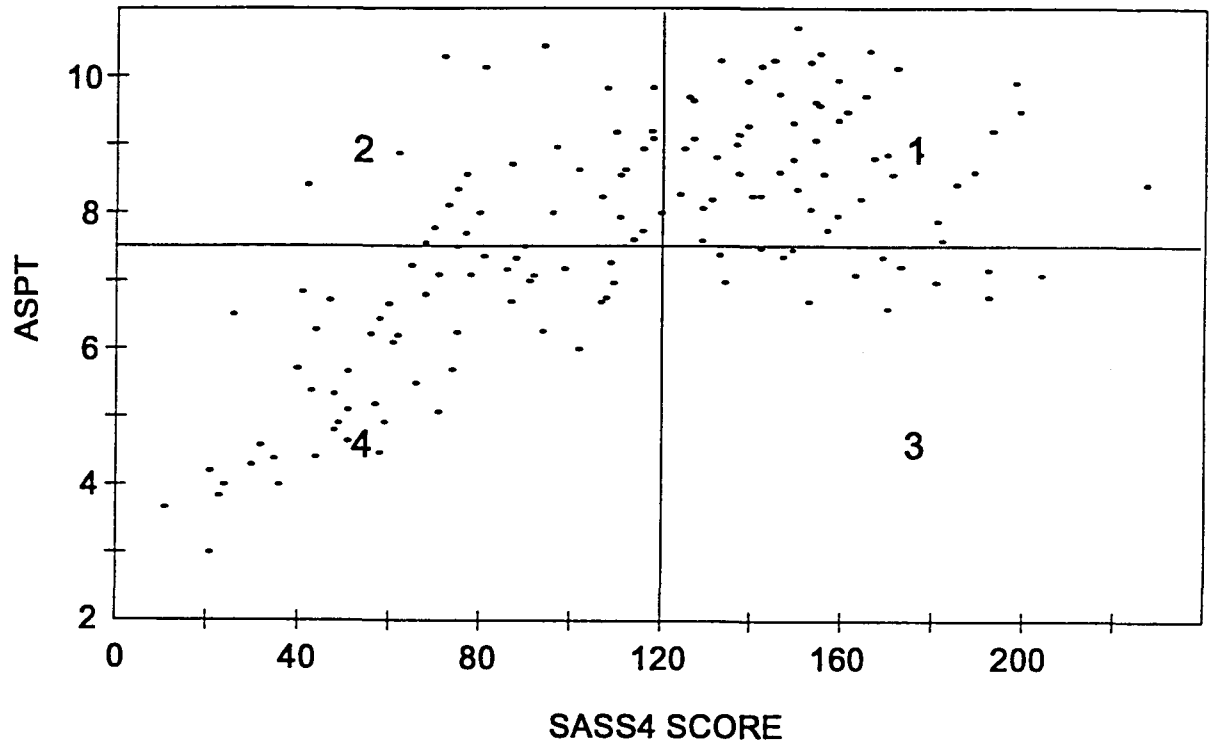
In order to establish background ranges reflective of least impacted conditions with respect to water quality, a screening method was developed whereby sites with impaired water quality were excluded. A feature included in the BCD is the ability to calculate SASS (South African Scoring System, Chutter 1994) scores for each site visit (a unique combination of site and sampling date) or sampling occasion. Briefly, SASS is a rapid bioassessment method which has been developed to assess water quality in riverine ecosystems. It is a scoring system based on benthic macroinvertebrates, whereby each taxon is allocated a sensitivity/tolerance score according to the water quality conditions it is known to tolerate (Dallas 1995). The higher the score the greater the organism's sensitivity and the lower its tolerance to pollution. A detailed explanation of SASS, including the recognised sampling methods, is presented in Chutter, (1994, 1995). Interpretation of scores is based on two calculated values, namely SASS4 Score, which is the sum of the taxon scores for taxa present at a site, and average score per taxon (ASPT), which is the SASS4 Score divided by the number of taxa. The method was not designed to enable the exact nature of the pollution to be determined, and it was intended that once an impairment of water quality had been established, it would be further assessed via intensive chemical and other studies. A more detailed explanation of SASS is given in Appendix 3.1.

Application of SASS scores to historical data in the database provides a crude means of ranking or ascertaining the extent of water quality impairment for each sampling occasion. It is limited in that certain data are the result of a single sampling occasion whilst others are more intensive and are grouped by month, season or year. On the basis of calculated SASS scores, the SASS4 Score was plotted against ASPT for each sampling occasion. This enabled impacted points to be excluded after which the least-impacted sites within each subregion were used to determined ranges of the selected water quality variables. For the southern and western coast WQMR data from the BCD were

supplemented with SASS data and water chemistry data collected during the present study.

Selection of sampling occasions for inclusion in analyses was based on a quadrat method generated using SASS4 Scores and ASPTs considered appropriate for each subregion. Biotope availability influences SASS Scores, since the greater the number of biotopes the greater the number of taxa and hence the higher the SASS4 Score. To counteract this effect and thereby ensure that biotope diversity does not affect the ranges calculated for water quality variables, an either/or relationship for SASS4 Score and ASPT was adopted. The following diagram (Figure 3.1) outlines the approach adopted.

Figure 3.1. Hypothetical diagram for identification of least-impacted sites based on SASS4 Scores and ASPTs.



Examination of data on biotope availability versus SASS4 Scores and ASPT suggest that if for example SASS4 Score and ASPT are hypothetically set as 120 and 7.5 respectively, the following would apply in each quadrat:

- sites in quadrat 1 have SASS4 Score > 120 and ASPT > 7.5, and biotope diversity is high;
- sites in quadrat 2 have SASS4 < 120 and ASPT > 7.5, and biotope diversity is low;
- sites in quadrat 3 have SASS4 Score > 120 and ASPT > 7.5, and biotope diversity is high;
- sites in quadrat 4 have SASS4 < 120 and ASPT < 7.5.

Points in quadrats 1, 2 and 3, i.e. with SASS4 Scores or ASPTs > 120 and 7.5 respectively, would therefore be included in analysis, and those in quadrat 4, i.e. with SASS4 Scores and ASPTs < 120 and 7.5 respectively, excluded. SASS4 Scores and ASPTs used to ascertain which sampling occasion would be included and which excluded are based on examination of box-and-whisker plots of median values, frequency histograms and knowledge of location and degree of water quality impairment for each

site. They were ascertained for each subregion in the southern and western coast region (Table 3.1) and are presented in Figures 3.2 to 3.5. The number of sampling occasions included and excluded in analyses are also given in Table 3.1.

It should be noted that the screening method developed is a preliminary one which needs to be subject to additional testing and verification. The actual SASS Scores used to separate 'least-impacted' from 'impacted' sites for the southern and western Coast WQMR were derived subjectively on the basis of knowledge of exposure and proximity to pollutants. A more robust method which adopts statistically sound, multivariate analysis techniques needs to be used to verify the derivation of scores. The following assumptions are also made: sites within a subregion within a single WQMR have similar characteristics with respect to water chemistry; SASS is assumed to reflect water quality at a site, based on individual taxon's sensitivity or tolerance to water quality impairment, and water quantity has not been taken into account. Biotope availability has been incorporated in the screening process using the quadrat method, but again results are preliminary and the hypothesis proposed needs to be tested. In summary, additional testing of the SASS method needs to be undertaken in order to ensure that the screening method proposed is based on a firm foundation.

Table 3.1. Minimum SASS4 Scores and ASPTs used to exclude impacted sites within each subregion in the southern and western coast WQMR. The number of included and excluded sampling occasions are tabulated.

Subregion	SASS4 Score	ASPT	Number of Sampling occasions	
			Included	Excluded
Mountain Stream	140	7.5	129	62
Foothill	120	7.5	72	135
Transitional	85	6.5	56	91
Lowland	50	5.0	35	34

Availability of sites in subregions lower in the catchment is limited in that many of the transitional and lowland rivers are already severely impacted with respect to water quality. Much of the data used in these subregions is therefore historical, representing conditions when lowland sites were less impacted. The background concentrations (TDS and TSS) and ranges (conductivity and pH) for each subregion were then calculated using water chemistry data from sampling occasions in quadrats 1, 2 and 3. Box-and-whisker plots of median values (Figure 3.6) and frequency histograms (Figure 3.7) for included sites are given for each variable within each subregion.

In addition to subregional variation, seasonal and diel variation were examined for sites within the southern and western coast WQMR.

Seasonal variation

Seasonal fluctuations in certain water quality variables may influence TWQRs established for sites or subregions. In order to ascertain the extent to which the selected variables fluctuate in response to

seasonal changes in factors such as discharge and temperature, sites representative of least impacted conditions were selected and concentrations and/or ranges of selected water quality variables ascertained for each month using water chemistry data from Department of Water Affairs & Forestry water quality monitoring stations. Four sites were selected each in mountain stream and foothill subregions, three in the transitional and two in the lowland subregions. Both the parametric Analysis of Variance (ANOVA) and the non-parametric equivalent, Kruskal Wallis, which uses median values and not mean values, were applied to the data to test for significance. The results produced were very similar and results presented are for Kruskal Wallis analyses.

Diel variation

Diel variation, i.e. variation over a 24 hour period, may occur in certain water quality variables such as pH, which is affected by photosynthesis and respiration within a water body. Hourly logging of water quality data including conductivity, pH and turbidity was conducted at sites selected to represent least impacted conditions within the mountain stream (Lang, Palmiet and Wit rivers) and foothill (Berg, Molenaars and Du Toits rivers) subregions of the rivers indicated in parentheses. All mountain stream sites were in unimpacted areas either in nature conservation or forestry reserves. The sites in the foothill subregion were exposed to impacts such as forestry, aquaculture and water abstraction but each site supported a diverse invertebrate fauna and were deemed representative of least impacted conditions within this subregion. Rainfall events occurring during the monitoring phase at certain sites provided information on changes in the variables during high-flow events.

3.3.2. Background concentrations or ranges, and seasonal and diel variations in, selected water quality variables in the southern and western coast Water Quality Management Region.

Chemical data associated with sampling occasions included in the analysis were extracted from the BCD and supplemented with chemical data collected simultaneously during SASS sampling in the southern and western coast WQMR. In some instances data were severely limited. Background concentrations, in the cases of TDS and TSS, and ranges, in the case of conductivity and pH, were calculated and are presented as a series of tables, box-and-whisker plots and frequency histograms for each subregion within the southern and western coast WQMR. Median concentrations or values are used in all cases although averages and standard deviations are also given for subregional variations. Median values are a measure of central tendency, and where one-half (50%) of the observations will lie below the median and one-half above the median. Median values therefore provide a more accurate reflection of the data than averages without being influenced by extreme values often related to seasonal events. Seasonal fluctuations were examined for TDS, conductivity and pH, and diel variation for conductivity, turbidity and pH.

A. TDS and conductivity

TDS concentration and electrical conductivity usually correlate closely for a particular type of water, except in waters rich in dissolved organic carbon, since conductivity does not measure un-ionized solutes. Because conductivity is easier to measure it is routinely used as a surrogate of TDS

Figure 3.2. Calculated ASPT and SASS4 Scores for sampling occasions within the mountain stream subregion of the southern and western coast WQMR.

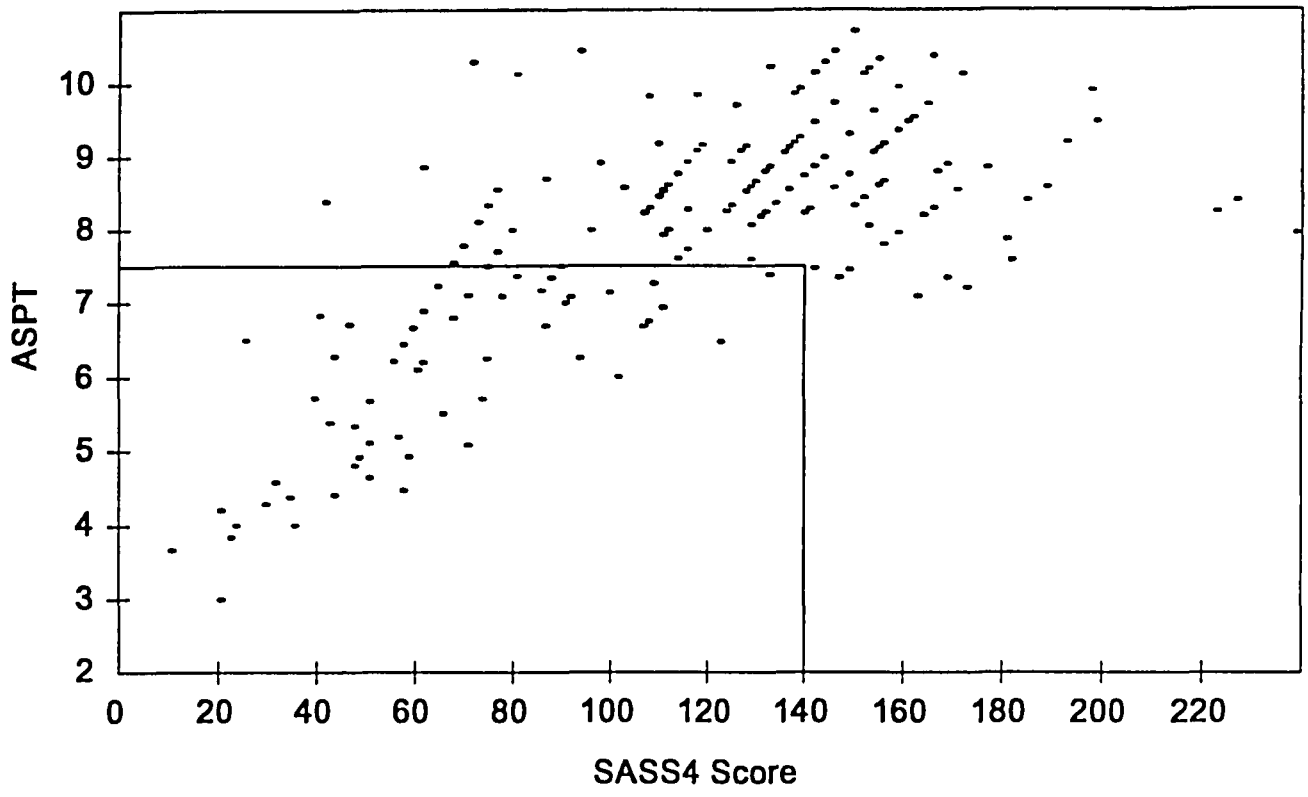


Figure 3.3 Calculated ASPT and SASS4 Scores for sampling occasions within the foothill subregion of the southern and western coast WQMR.

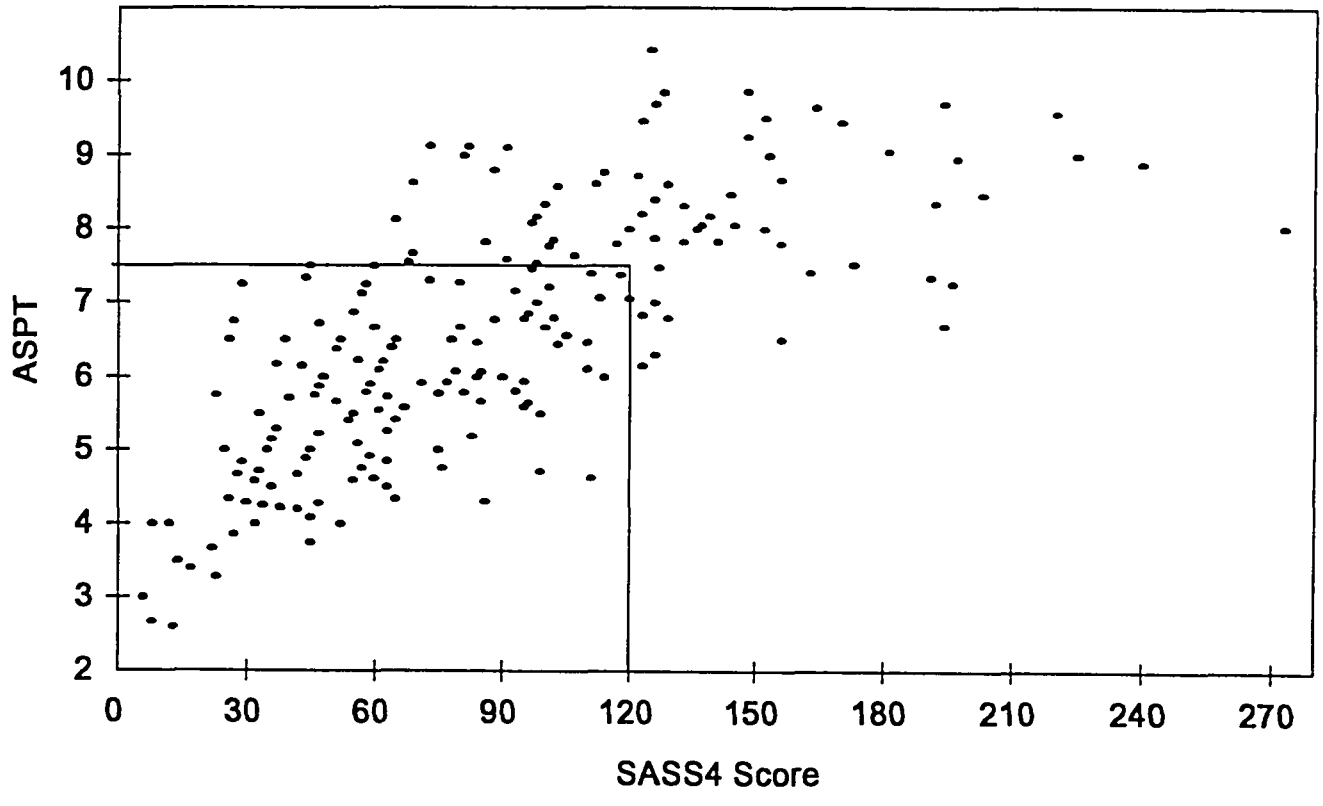


Figure 3.4. Calculated ASPT and SASS4 Scores for sampling occasions within the transitional subregion of the southern and western coast WQMR.

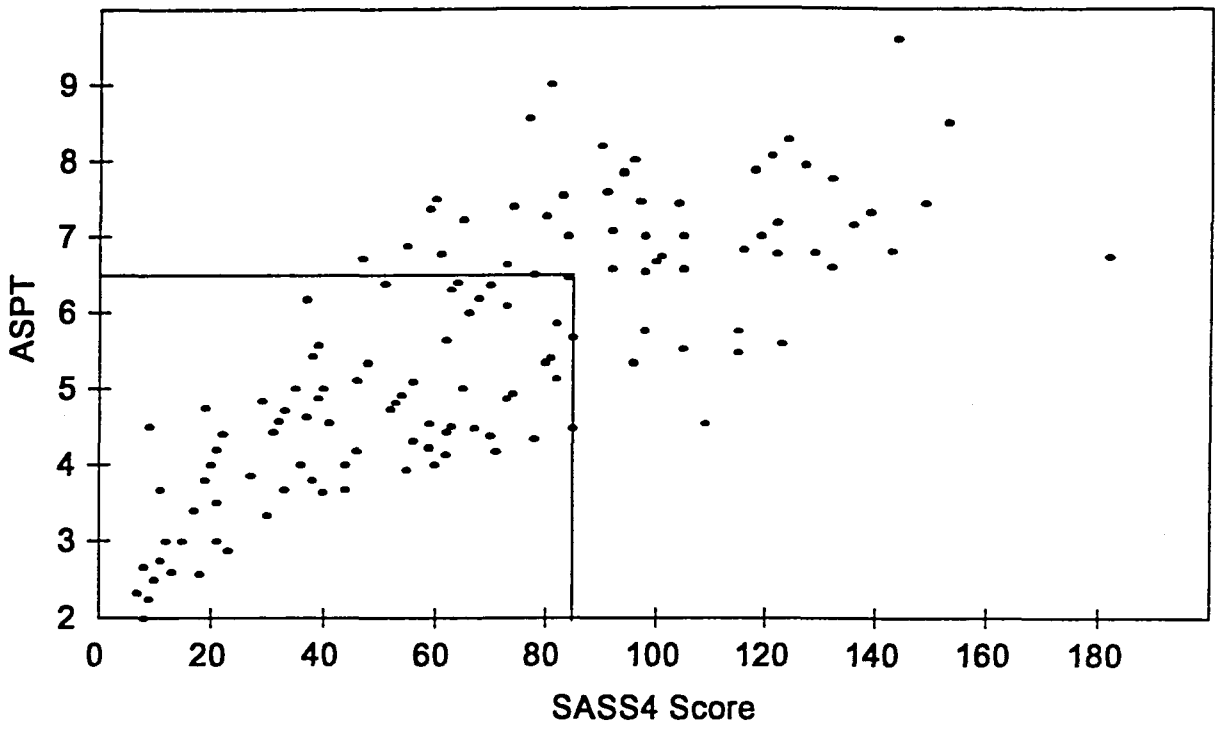


Figure 3.5. Calculated ASPT and SASS4 Scores for sampling occasions within the lowland subregion of the southern and western coast WQMR.

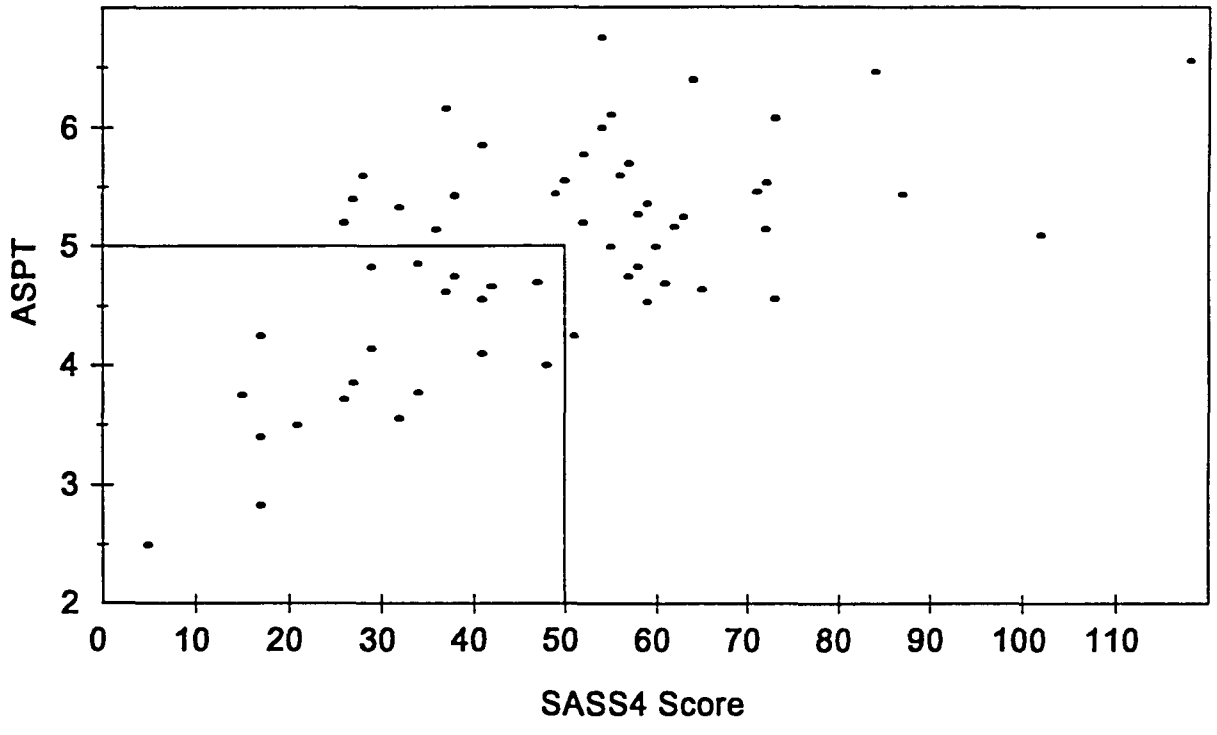


Figure 3.6. Box-and-whisker plots of SASS4 Score, ASPT and number of taxa for included sites in each subregion in the southern and western coast WQMR.

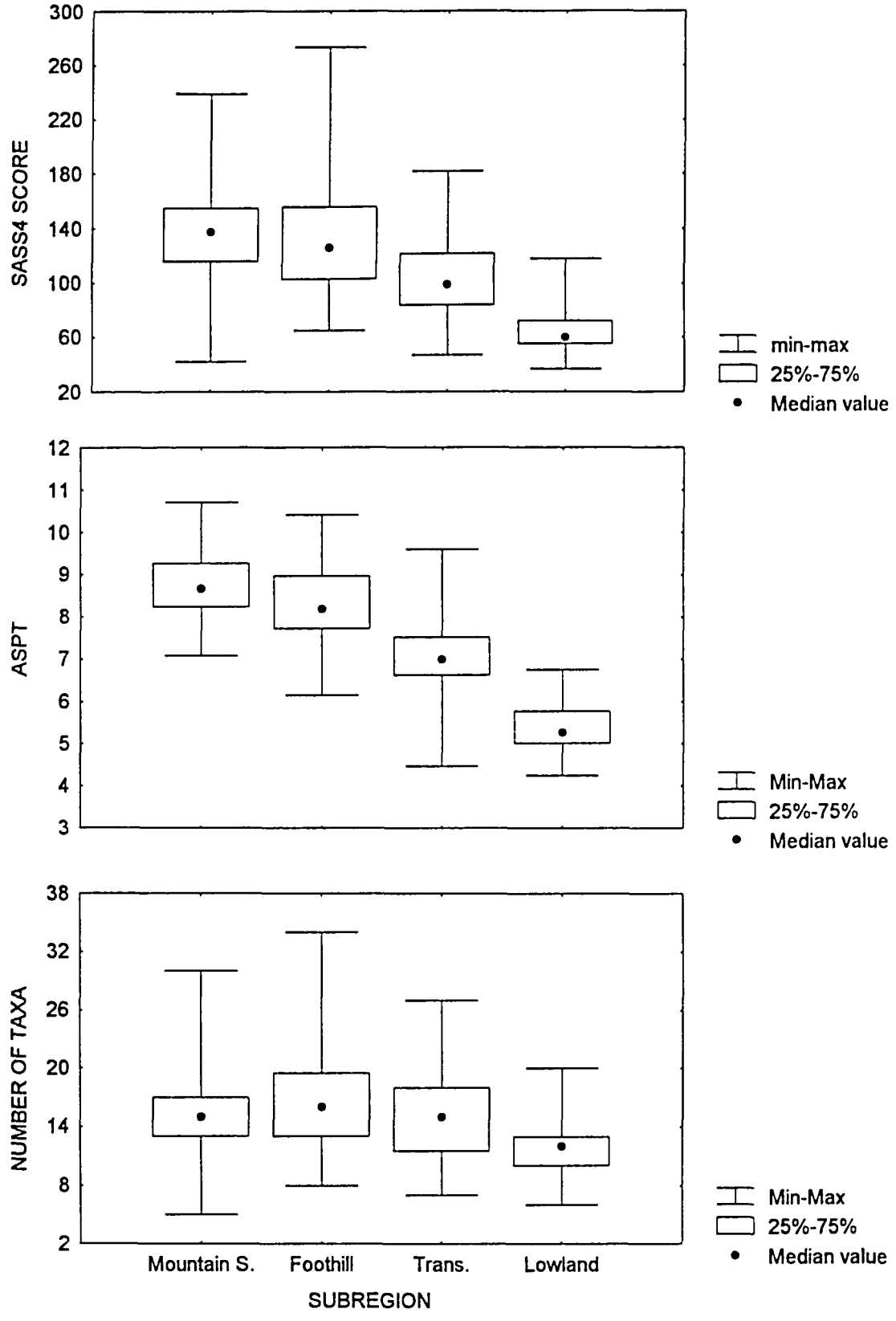
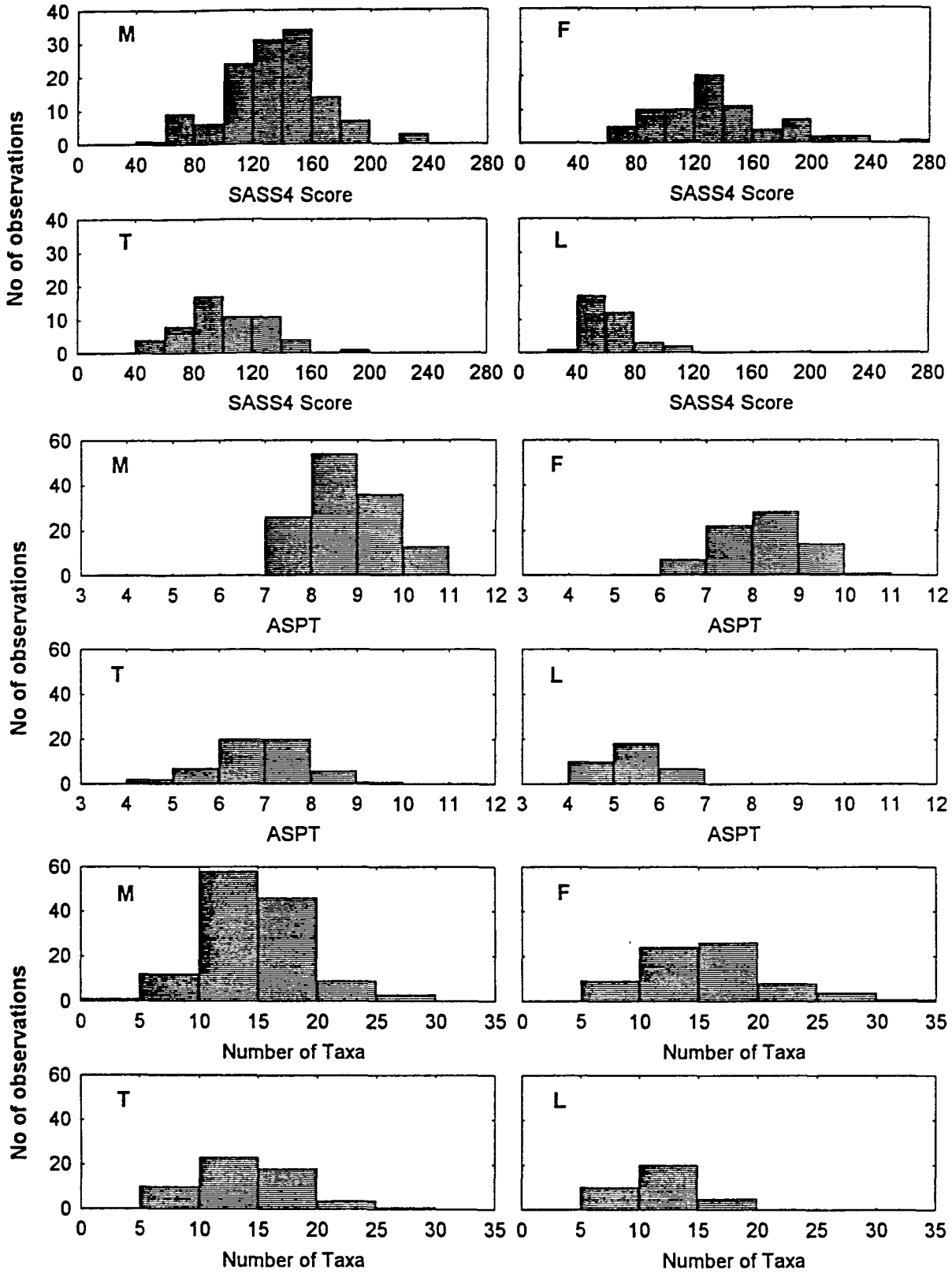


Figure 3.7. Frequency histograms of SASS4 Score, ASPT and number of taxa for included sites in each subregion in the southern and western coast WQMR. M = mountain stream, F = foothill, T = transitional and L = lowland.



concentration. It was however deemed important to examine both measures in ascertaining background concentrations when chemistry data permitted.

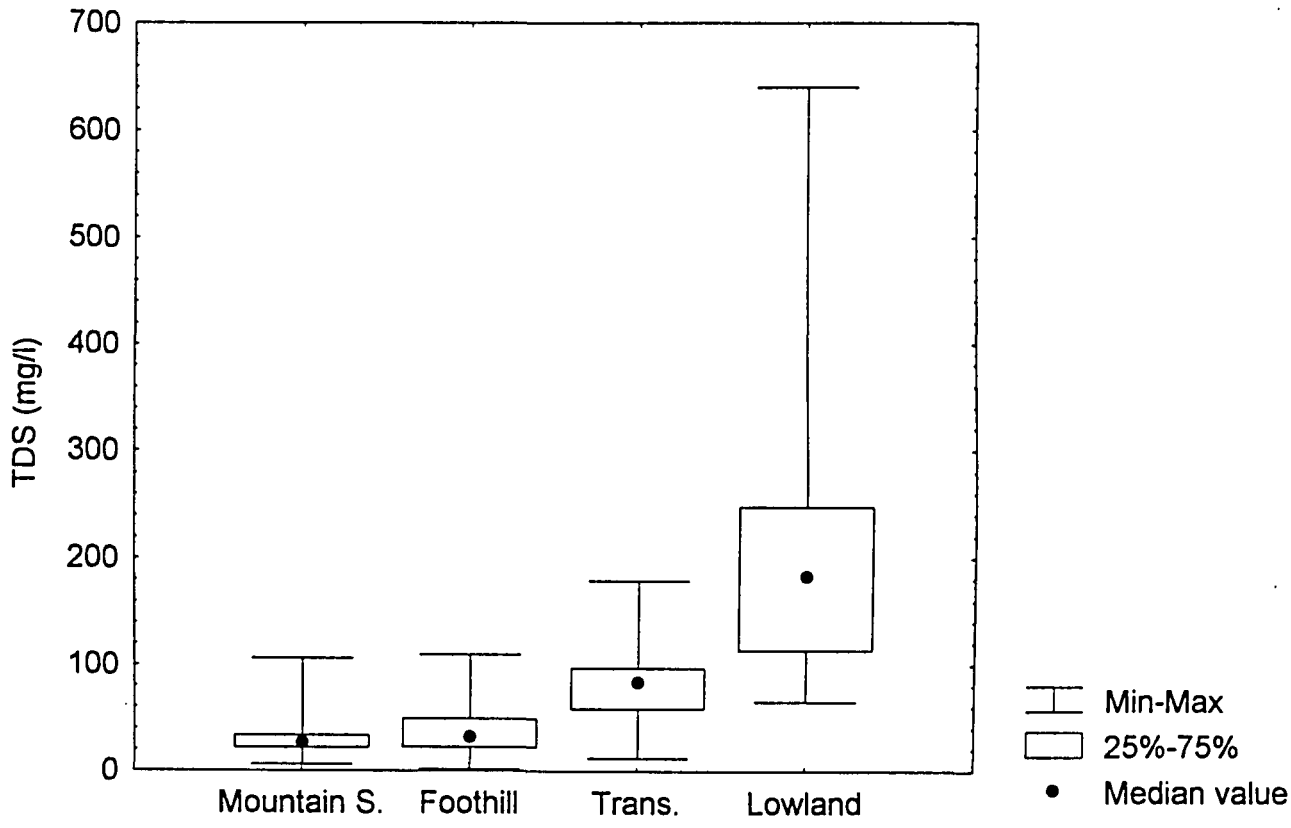
Subregional variation in TDS

Background concentrations of TDS for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR are given in Table 3.2 and Figure 3.8.

Table 3.2. Median, average ± standard deviation (SD), minimum and maximum concentrations of TDS (in mg/l) for each subregion within the southern and western coast WQMR. n = number of sampling occasions.

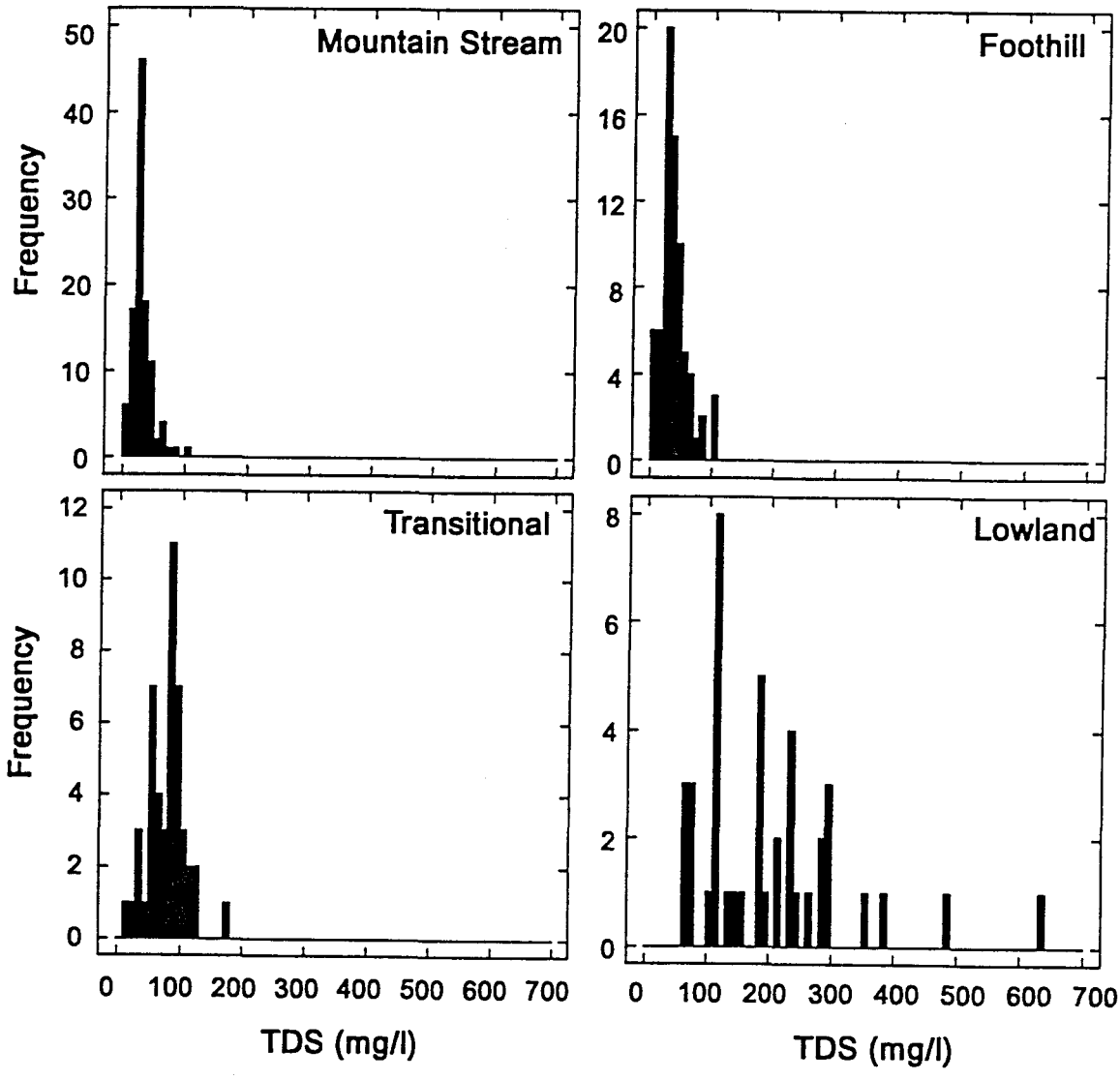
Subregion	Median	Average±SD	Minimum	Maximum	n	Sig.
Mountain Stream	26.3	29.7 ± 15.9	5.9	105.5	107 (30)	#
Foothill	32.0	37.5 ± 22.5	2.0	109.4	71 (19)	#
Transitional	83.6	78.8 ± 30.5	12.0	179.1	46 (7)	##
Lowland	183.0	201.0 ± 119.0	65	640	41 (9)	###

Figure 3.8. Background concentrations of TDS for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.



Lowland and transitional subregions were significantly different from one another and from the mountain stream and foothill subregions as indicated by asterisks in Table 3.2 ($p<0.01$; Kruskal Wallis). The number of observations i.e. sampling occasions, in addition to the number of sites (in parenthesis) included in the analyses are also given. In all cases, significantly different subregions are indicated with a distinct number of hash (#) symbols. For example, median TDS concentrations for mountain streams and foothills are not significantly different from one another (indicated by #), but are both significantly different from TDS concentrations in transitional (##) and lowland (###) subregions. A frequency histogram of TDS concentrations for each subregion is given in Figure 3.9.

Figure 3.9. Frequency histogram of background concentrations of TDS for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.



Seasonal variation in TDS

Mountain Stream: Of the four sites examined, one had a mixture of weekly and monthly data for the years 1985-1995 [Wit River at Drosterskloof (H1H007)], two had monthly data for the same years [Rooielskloof River at Roode Els Berg (H2H005) and Baviaans River at Genadendal Mission Station (H6H005)]

and one had monthly data for 1985-1992 [Riviersonderend at Nuweberg Forest Reserve (H6H008)]. Details of DWAF sites, data used and statistical results for all variables are tabulated in Appendix 3.2. Monthly concentrations of TDS were significantly different between months at one of the four sites ($P<0.01$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for the site with weekly data for a ten year period (Wit River: H1H007) are presented in Figure 3.10. Generally concentrations were more variable in late winter and spring and higher in summer and autumn.

Foothill: Of the four sites examined, one had a mixture of weekly and monthly data for the years 1985-1995 [Molenaars River at Hawequas Forest Reserve (H1H018)], one had a mixture of weekly and monthly data for 1981-1986 [Holsloot River at Daschbosch Rivier (H1H012)], one had a mixture of weekly and monthly data for 1980-1992 [Duiwenshok River at Broken Hill (H8H002)], and one had monthly data for 1980-1992 [Sanddrifskloof River at Zanddrifts Kloof (H2H004)]. Monthly concentrations of TDS were significantly different at two of the four sites ($P<0.05$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for the site with weekly data for a ten year period (Molenaars River: H1H018) are presented in Figure 3.11. There was a seasonal trend in mean concentration which was highest in summer, decreasing through autumn and lowest in winter.

Transitional: Of the three sites examined [Bree River at Secunda (H5H004), Bree River at La Chasseur (H4H017) and Bree River at Die Nekkies (H1H015)], all had weekly data for the years 1990-1995. Details of DWAF sites, data used and statistical results for all variables are tabulated in Appendix 3.2. Monthly concentrations of TDS were significantly different between months at all of the sites ($P<0.05$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for one of the sites (Bree River: H4H017) are presented in Figure 3.12. Generally median concentrations were highest in late summer, dropped and were most variable in autumn, and lowest in winter.

Lowland Of the two sites examined [Bree River at Swellendam (H7H006) and Riviersonderend River at Reenen (H6H009)], one showed seasonal trends which were significant ($P<0.01$; Kruskal Wallis). Both sites had weekly data for 1985-1995. Box-and-whisker plots of monthly median and mean values for the site which showed significant differences (Bree River: H7H006) are presented in Figure 3.13. Mean and median values were highest in late summer, decreased through autumn, were lowest in winter and increased in spring. Concentrations were most variable in autumn.

Figure 3.10. Box-and-whisker plots of monthly mean and median concentrations of TDS for a site on the Wit River (H1H007) representative of the mountain stream subregion.

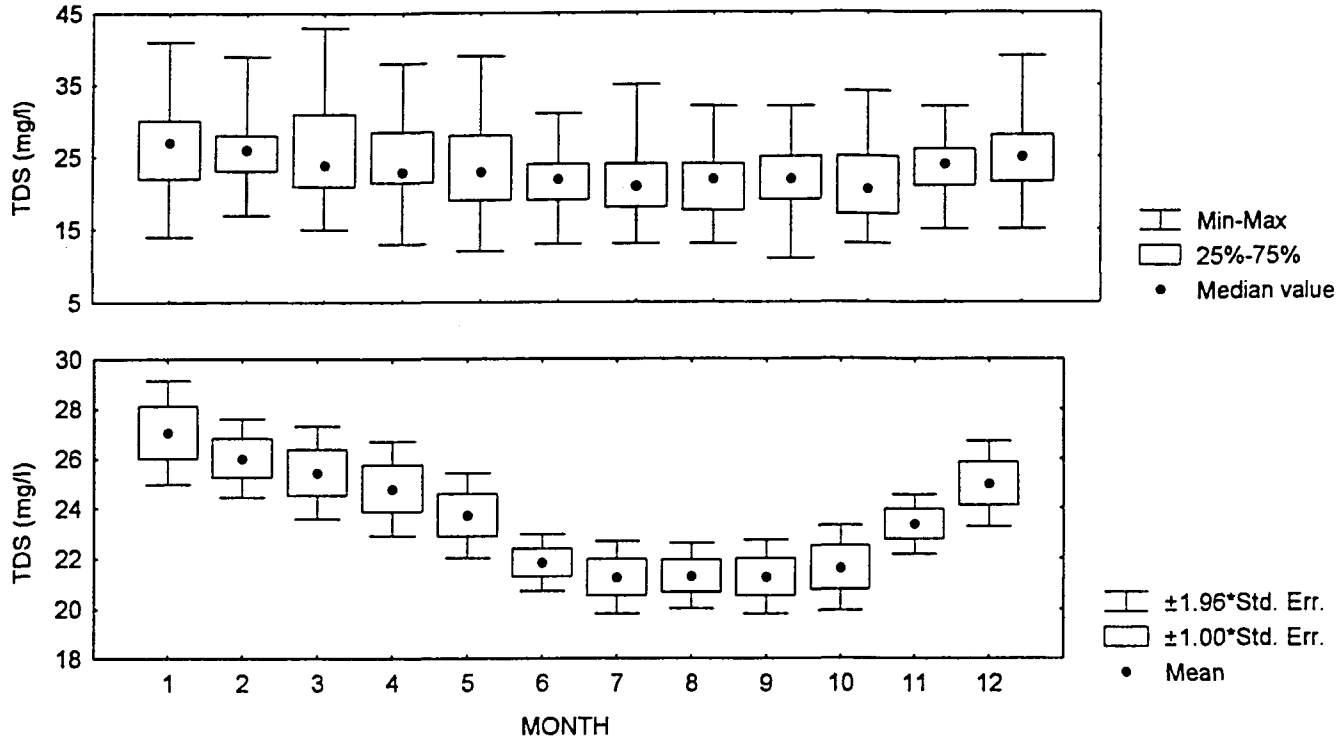


Figure 3.11. Box-and-whisker plots of monthly mean and median concentrations of TDS for a site on the Molenaars River (H1H018) representative of the foothill subregion.

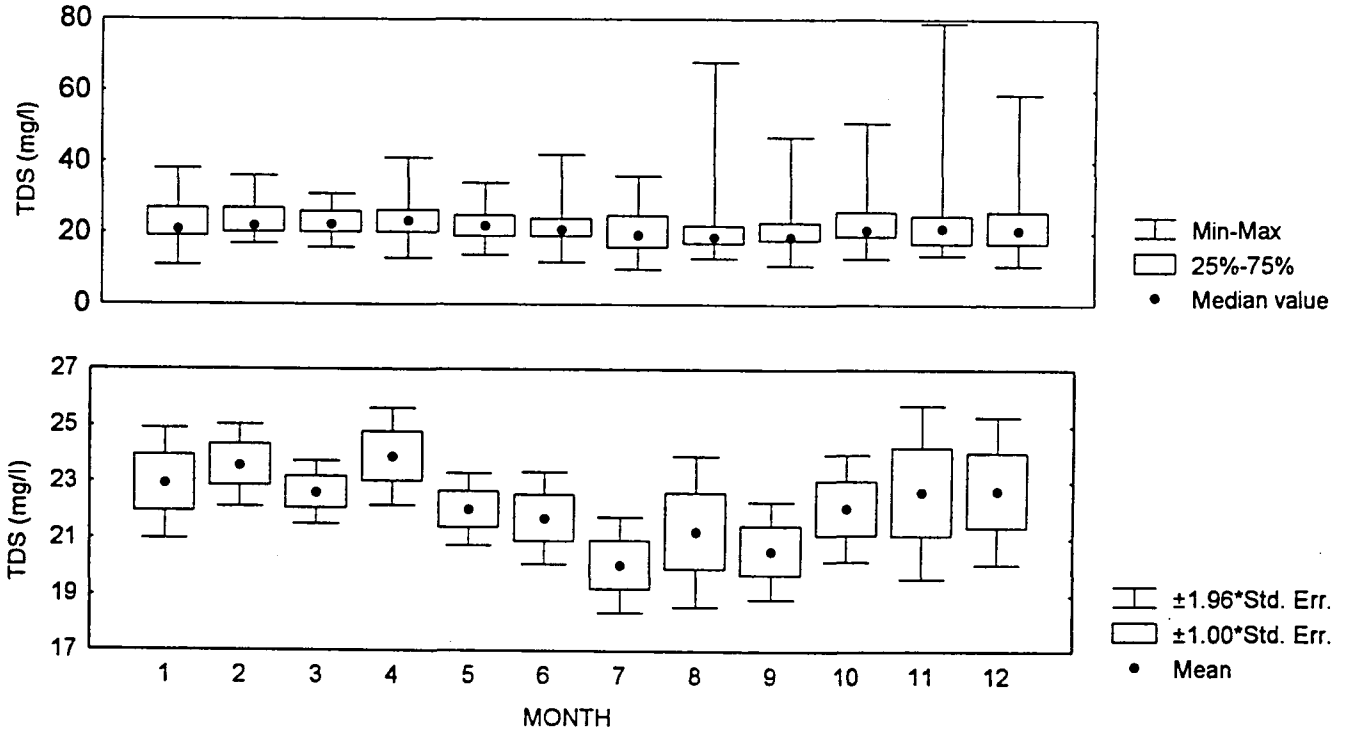


Figure 3.12. Box-and-whisker plots of monthly mean and median concentrations of TDS for a site on the Bree River (H4H017) representative of the transitional subregion.

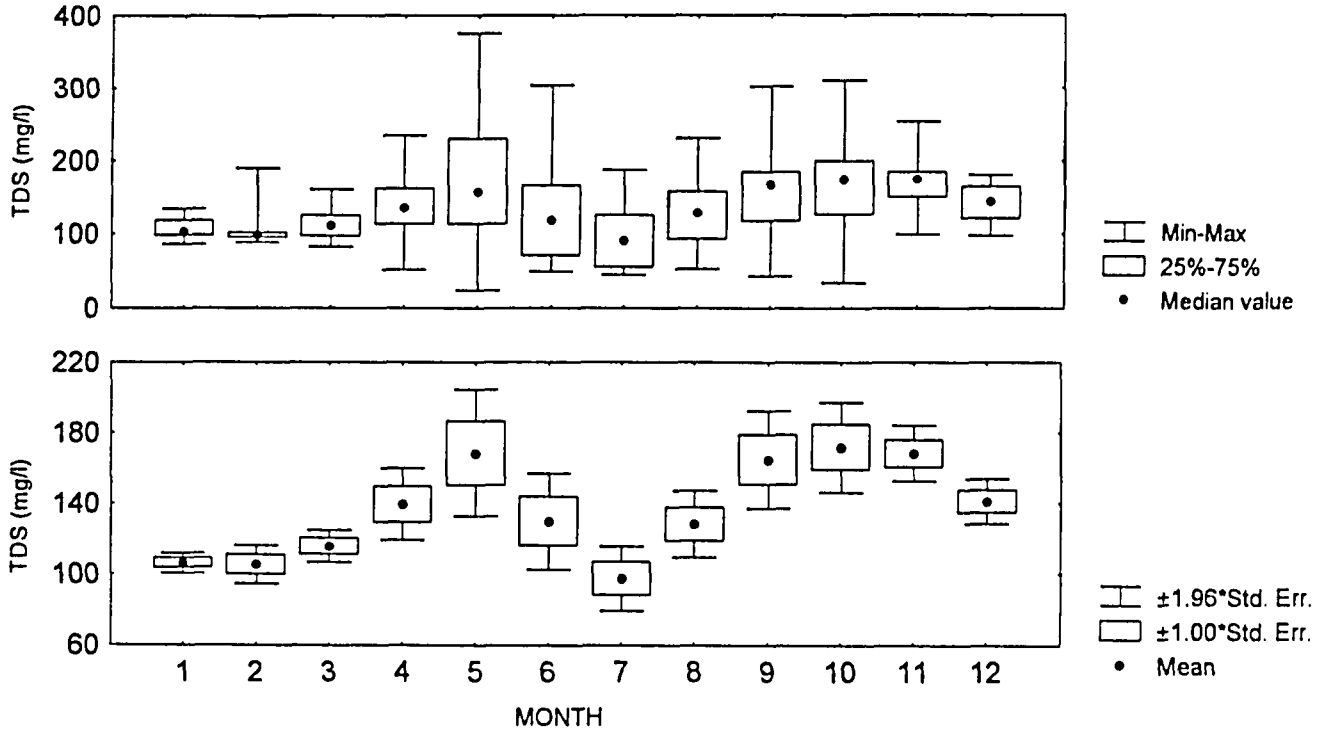
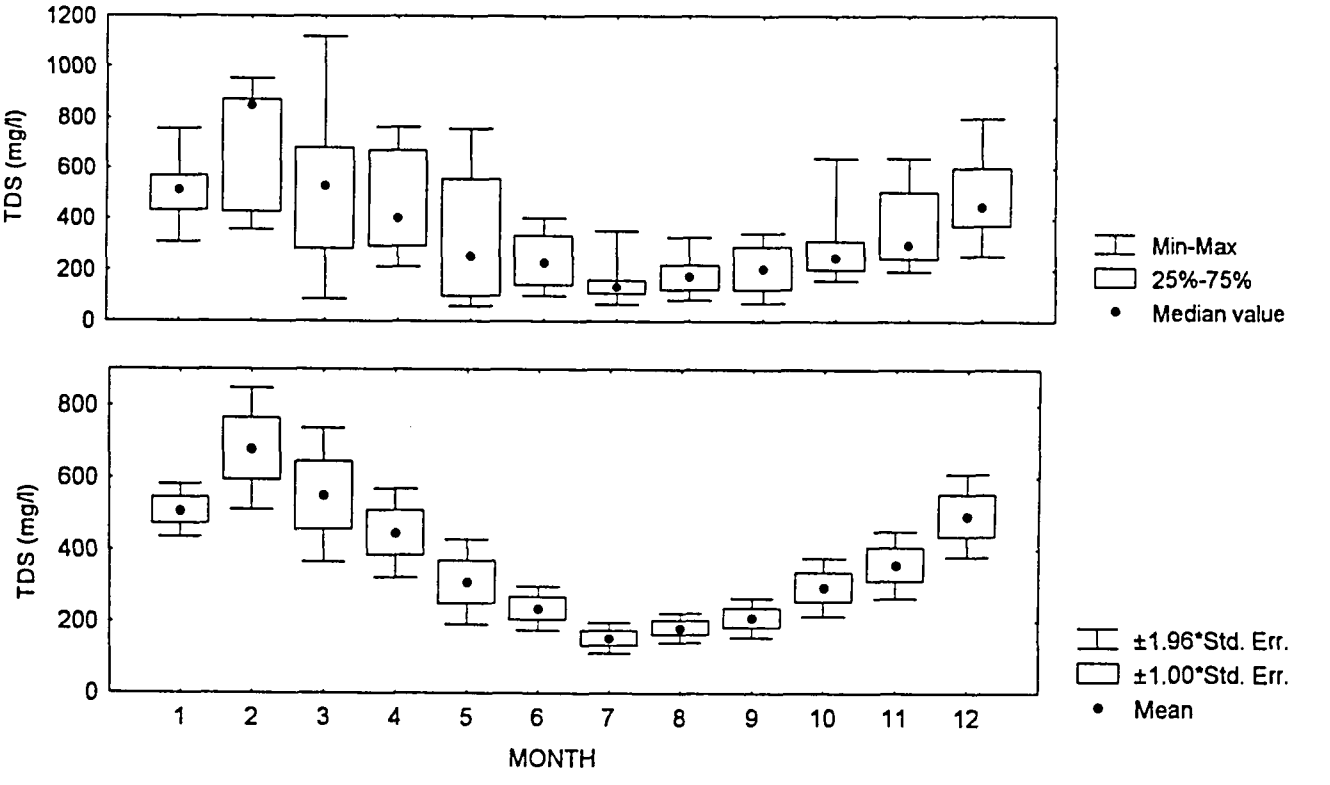


Figure 3.13. Box-and-whisker plots of monthly mean and median concentrations of TDS for a site on the Bree River (H7H006) representative of the lowland subregion.



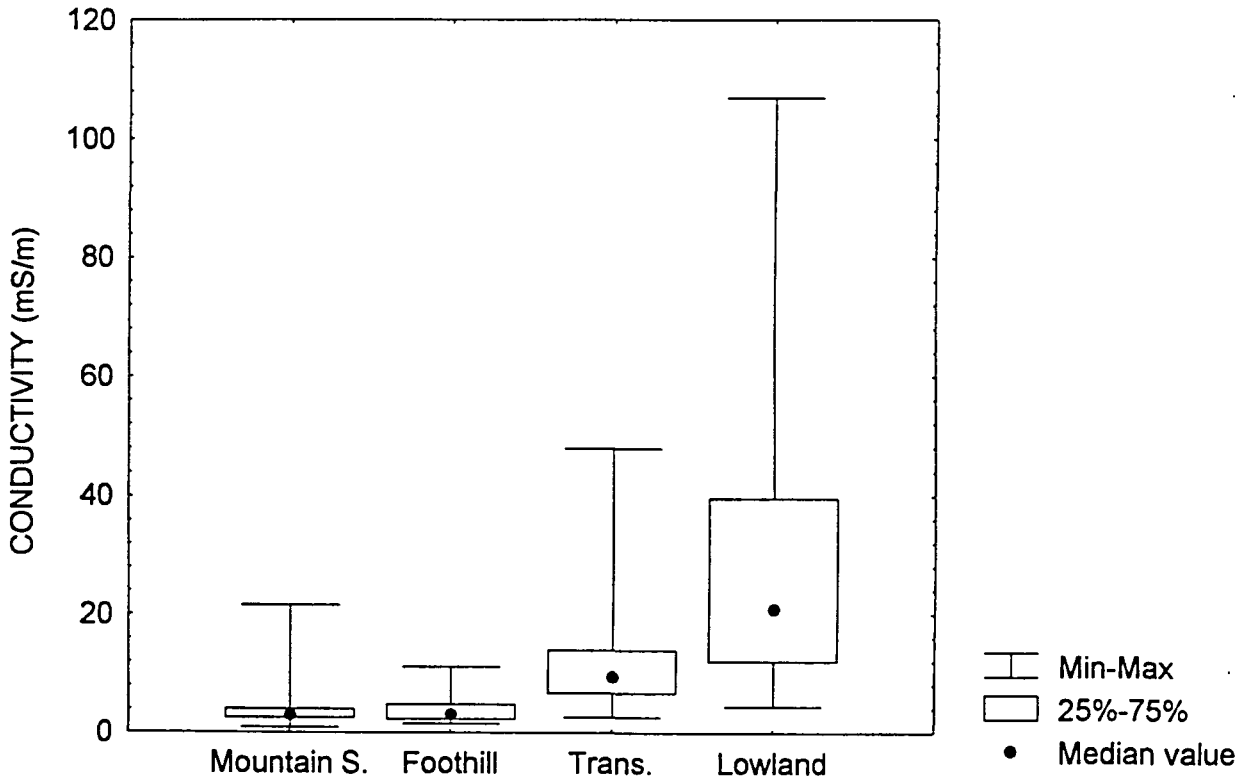
Subregional variation in conductivity

Background ranges of conductivity for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR are given in Table 3.3 and Figure 3.14. Lowland and transitional subregions were significantly different from one another and from the mountain stream and foothill subregions. Those significantly different from one another are indicated by symbols (#) in Table 3.3 ($p<0.01$; Kruskal Wallis). The number of observations i.e. sampling occasions, in addition to the number of sites (in parentheses) are also given.

Table 3.3 Median, average ± standard deviation (SD), minimum and maximum of conductivity values (mS m^{-1}) for each subregion within the southern and western coast WQMR.

Subregion	Median	Average ± SD	Minimum	Maximum	n	Sig.
Mountain Stream	3.0	3.6 ± 2.5	0.9	21.5	113 (33)	#
Foothill	3.1	3.8 ± 2.1	1.5	11.2	79 (23)	#
Transitional	9.6	10.8 ± 6.6	2.6	47.9	60 (16)	##
Lowland	21.0	39.0 ± 25.5	4.5	107	43 (10)	###

Figure 3.14. Background ranges of conductivity at least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.



Seasonal variation

Mountain Stream: Conductivity was significantly different between months for three of the four sites examined ($P<0.05$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for the site with weekly data for a ten year period (H1H007) are presented in Figure 3.15. Mean values were highest in summer and lowest in winter. Variability was highest in autumn.

Foothill: Conductivity was significantly different between months for three of the four sites examined ($P<0.01$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for the site with weekly data for a ten year period (H1H018) are presented in Figure 3.16. Values were highest in summer, decreased through autumn and were lowest in winter.

Transitional: All three sites showed seasonal trends in conductivity and monthly values were significantly different ($P<0.01$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for one of the sites (H4H017) are presented in Figure 3.17. Patterns in median and mean values varied between sites, but were generally highest in summer, autumn or spring, and lowest in winter. They were most variable in autumn or winter.

Lowland: Both sites showed seasonal trends in conductivity and monthly values were significantly different ($P<0.01$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for the site which showed significant differences (H7H006) are presented in Figure 3.18. There was a distinct seasonal trend in both median and mean values, which were highest in summer and lowest in winter.

Diel variation

Mountain Stream: Median summer baseline (i.e. under normal flow conditions) conductivity values were 3.4 mS m^{-1} for sites on the Lang and Palmiet rivers, and 2.0 mS m^{-1} for the site on the Wit river. There was no diel pattern in conductivity and values fluctuated by 0.02 mS m^{-1} under normal flow conditions. During high-flow events at two of the sites, conductivity rose to 4 mS m^{-1}, after which it decreased towards baseline conditions (Figure 3.19).

Foothill: Median summer baseline conductivity was remarkably constant with median values of 2.4, 3.0 and 3.4 mS m^{-1} at sites on the Berg, Molenaars and Du Toits rivers respectively. There was no diel pattern in conductivity and values fluctuated by a maximum of 0.02 mS m^{-1} under normal flow conditions (Figure 3.19). Conductivity did not change significantly during a high-flow event at one of the sites.

Figure 3.15. Box-and-whisker plots of monthly mean and median conductivity values for a site on the Wit River (H1H007) representative of the mountain stream subregion.

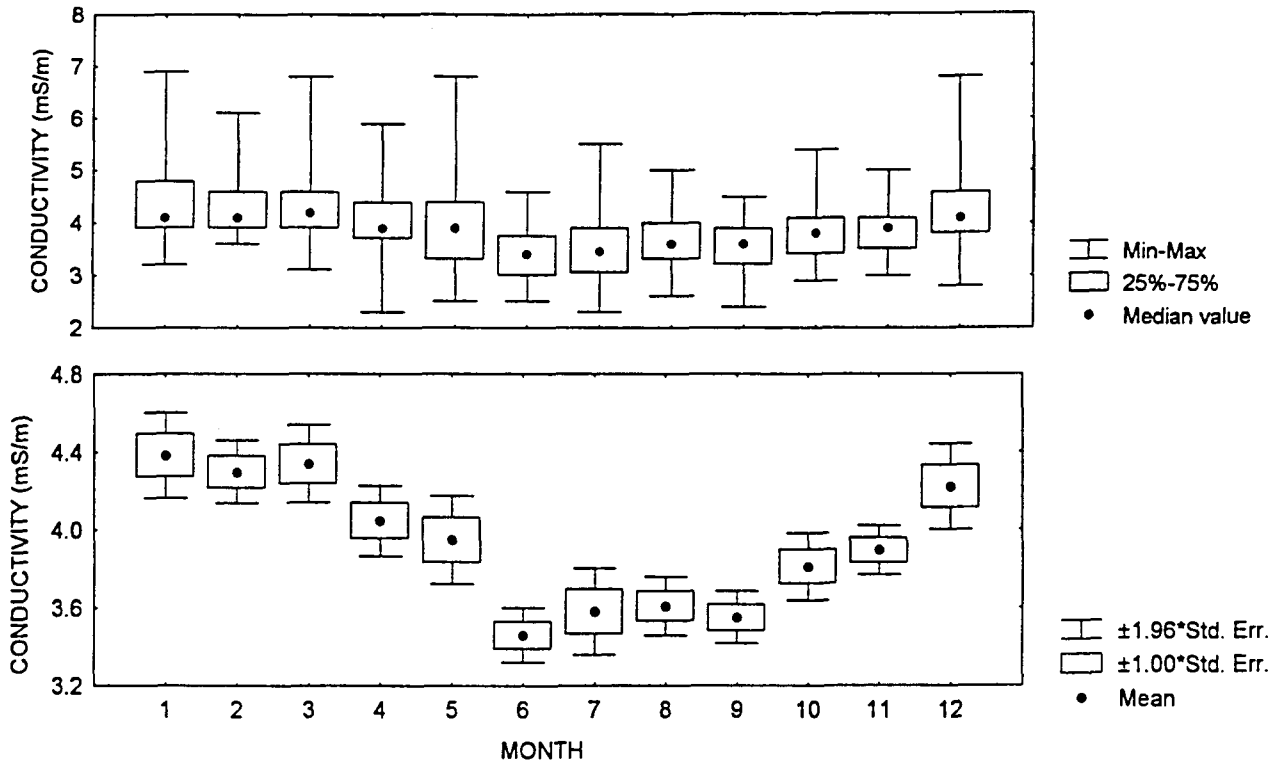


Figure 3.16. Box-and-whisker plots of monthly mean and median conductivity values for a site on the Molenaars River (H1H018) representative of the foothill subregion.

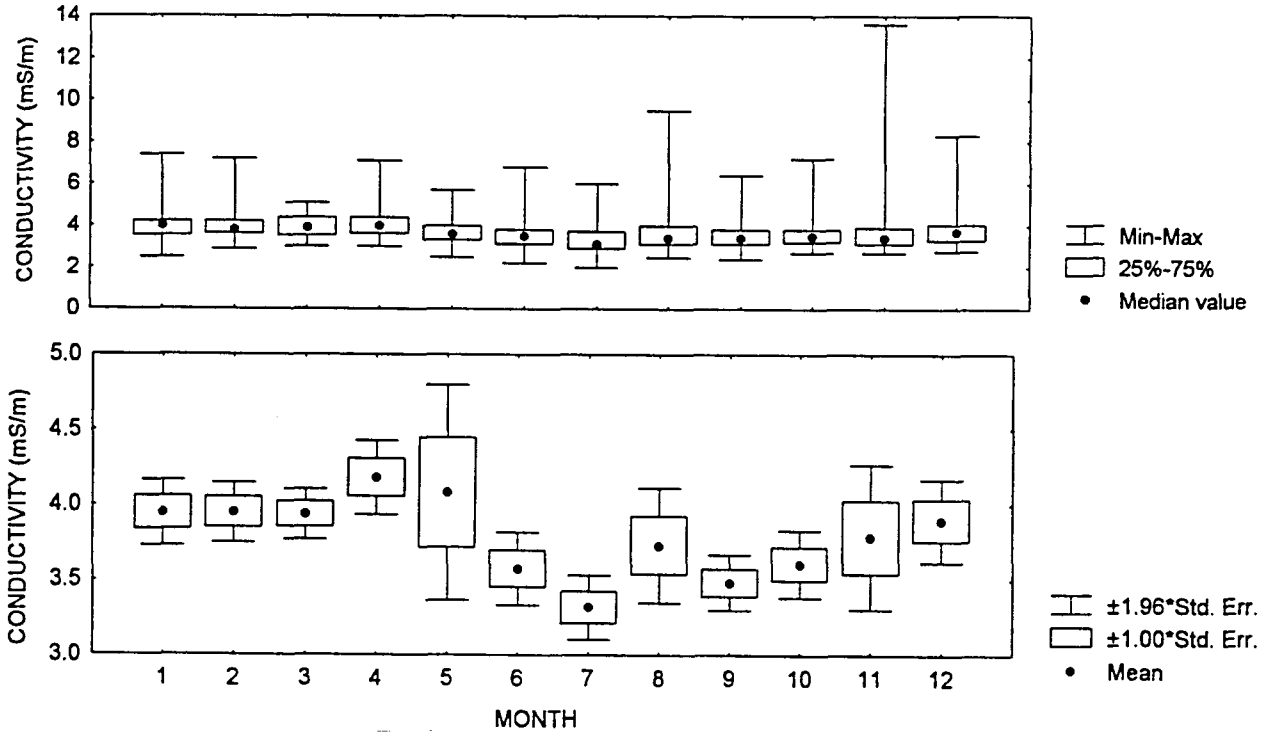


Figure 3.17. Box-and-whisker plots of monthly mean and median conductivity values for a site on the Bree River (H4H017) representative of the transitional subregion.

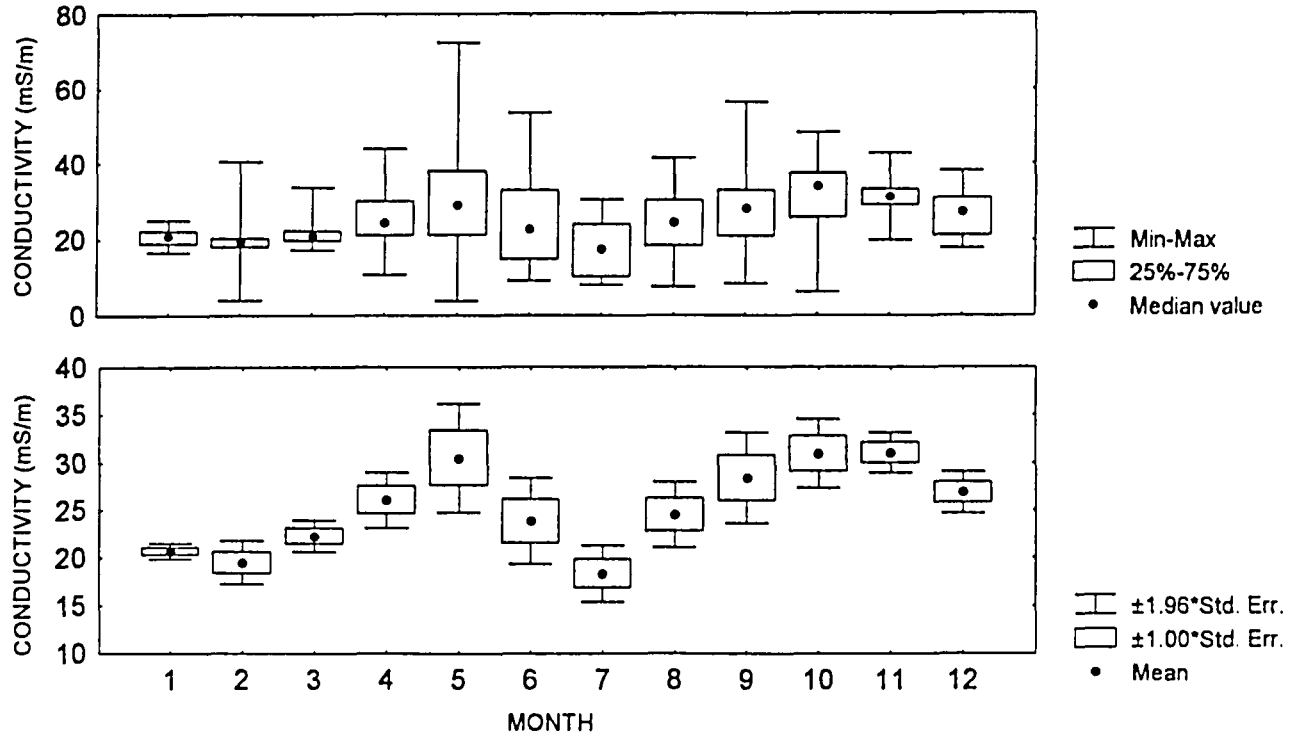


Figure 3.18. Box-and-whisker plots of monthly mean and median conductivity values for a site on the Bree River (H7H006) representative of the lowland subregion.

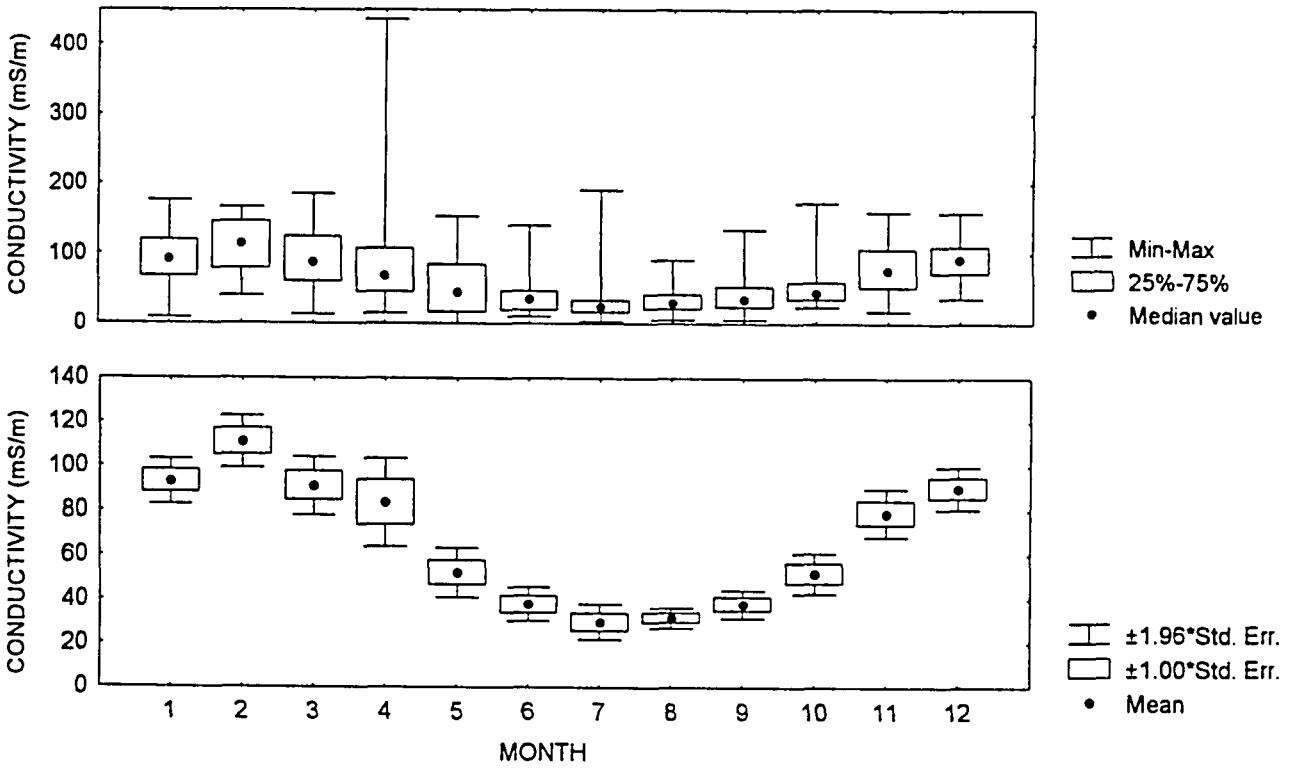
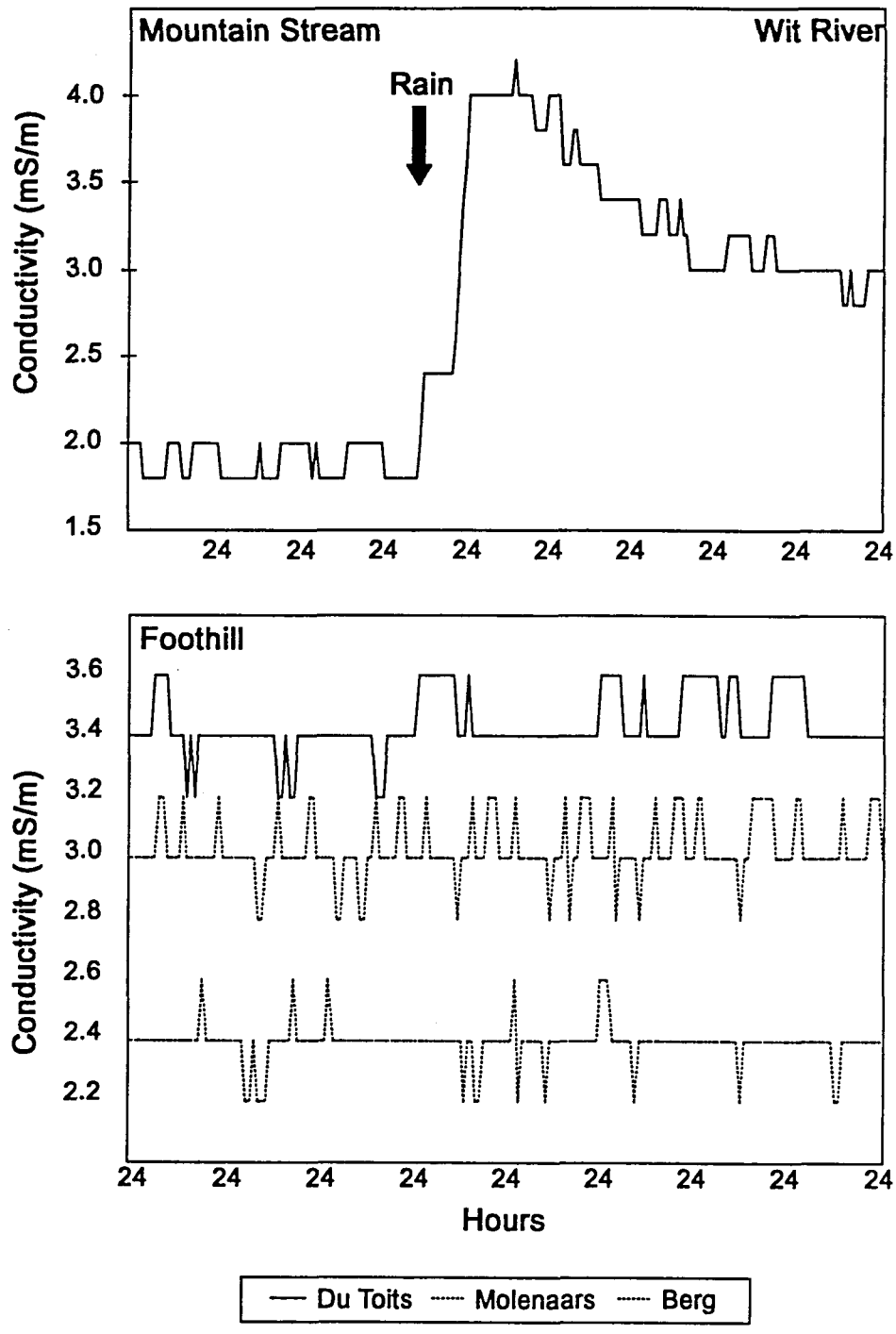


Figure 3.19. Diel variation (over a 24 hour cycle) in conductivity at one site in the mountain stream and three sites in the foothill subregion.



B. TSS and turbidity

TSS and turbidity are measured infrequently in many studies and data are therefore limited particularly for the lowland subregion. TSS is essentially a measure of the quantity (mass) of suspended material in a water body whilst, turbidity is a measure of the optical property of the water body.

Subregional variation in TSS

Background concentrations of TSS for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR are given in Table 3.4 and Figure 3.20. Lowland sites were significantly different from sites in other subregions (indicated by symbols #; $p<0.01$; Kruskal Wallis), although the number of observations is relatively small ($n=13$). The number of observations i.e. sampling occasions, in addition to the number of sites (in parenthesis) are also given. A frequency histogram of TSS concentrations for each subregion is given in Figure 3.21.

Table 3.4. Median, average ± standard deviation (SD), minimum and maximum concentrations of TSS (in mg l^{-1}) for each subregion within the southern and western coast WQMR.

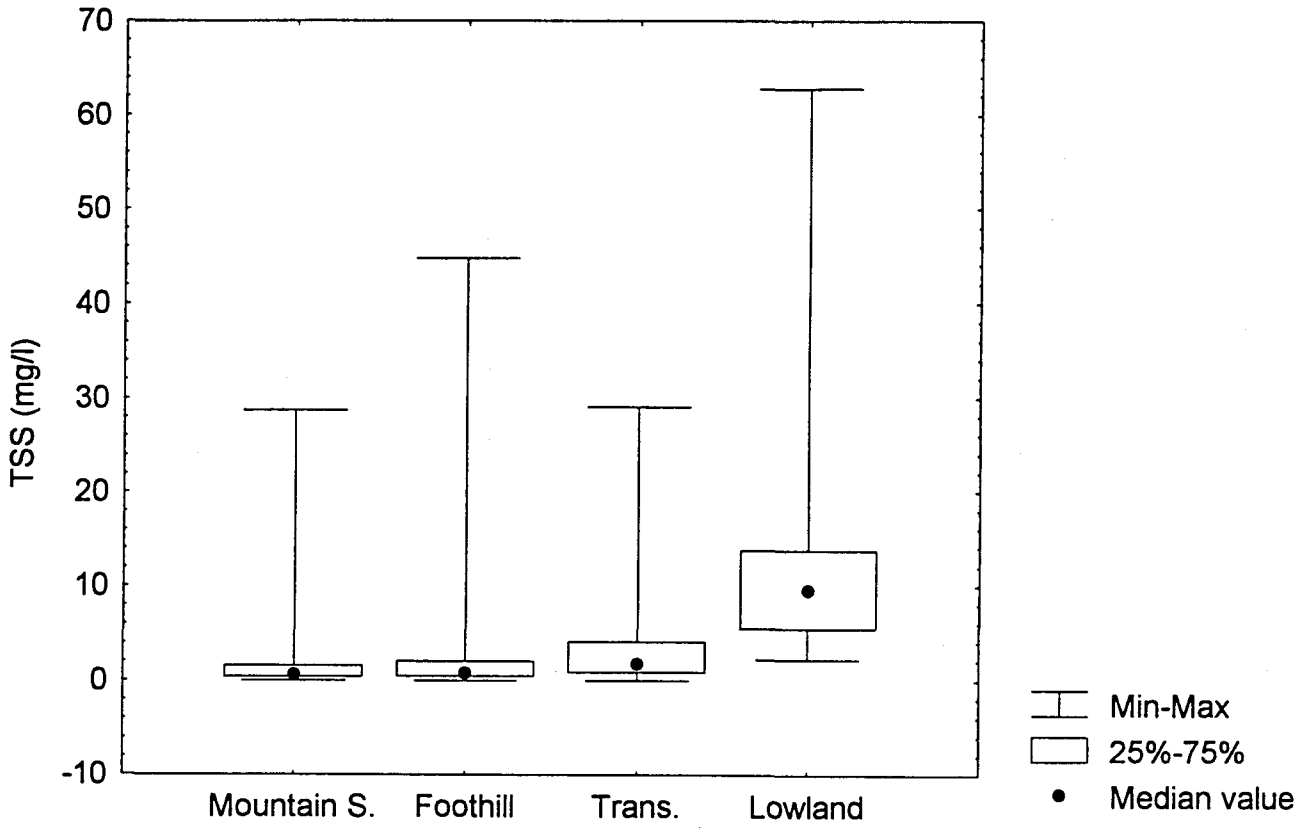
Subregion	Median	Average±SD	Minimum	Maximum	n	Sig.
Mountain Stream	0.66	1.97 ± 4.40	0.01	28.7	92 (32)	#
Foothill	0.78	2.73 ± 7.21	0.01	44.7	39 (19)	#
Transitional	1.70	3.64 ± 0.01	0.01	29.0	23 (9)	#
Lowland River	9.57	13.36 ± 15.72	2.24	62.8	13 (6)	##

Background ranges of turbidity for least-impacted sites in mountain stream, foothill and lowland subregions in the southern and western coast WQMR are given in Table 3.5. The scarcity of data precluded any analyses and results are preliminary and need to be supplemented with additional data.

Table 3.5 Median, average ± standard deviation (SD), minimum and maximum turbidity values (NTUs) for each subregion within the southern and western coast WQMR. N.D. values were below detection level.

Subregion	Median	Average ± SD	Minimum	Maximum	n
Mountain Stream	<1	0.2 ± 0.4	N.D.	1	15
Foothill	1	0.8 ± 0.8	N.D.	2	5
Lowland	3	3.3 ± 1.5	2	5	3

Figure 3.20. Background concentrations of TSS for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.



Seasonal variation

Neither TSS or turbidity is routinely monitored by DWAF and data were therefore not available to examine seasonal variation in either variables.

Diel variation

Mountain Stream: Median summer baseline turbidity was generally ≤ 1 NTU and no diel pattern was evident. During high-flow events at one of the sites (Wit River), turbidity increased to 4 NTUs after which it decreased towards baseline conditions (Figure 3.22).

Foothill: Median summer baseline turbidity was 2 NTU and no diel pattern was evident. At one of the sites (Molenaars river) significant peaks of up to 80 NTU were noted at regular intervals (Figure 3.22). It is suspected that this is in response to operational flushing from an upstream fishfarm (G. Ractliffe, Freshwater Research Unit, University of Cape Town, pers. comm.). Turbidity at the site on the Du Toits river peaked to 22 NTU in response to a high-flow event. It decreased to baseline conditions within less than 24 hours and increased gradually again to 13 NTU following constant low-intensity rain (Figure 3.22).

Figure 3.21. Frequency histogram of background concentrations of TSS for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.

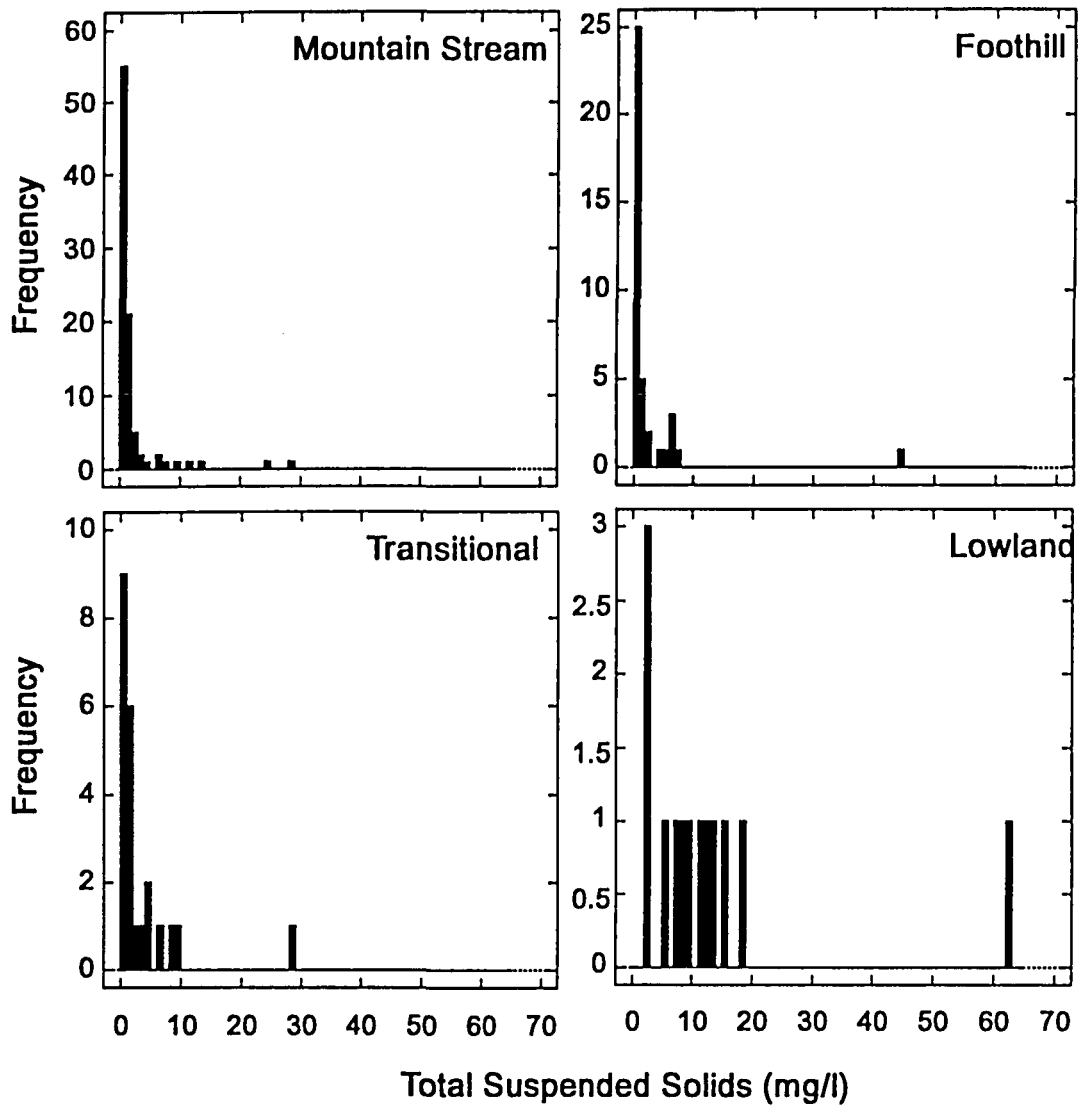
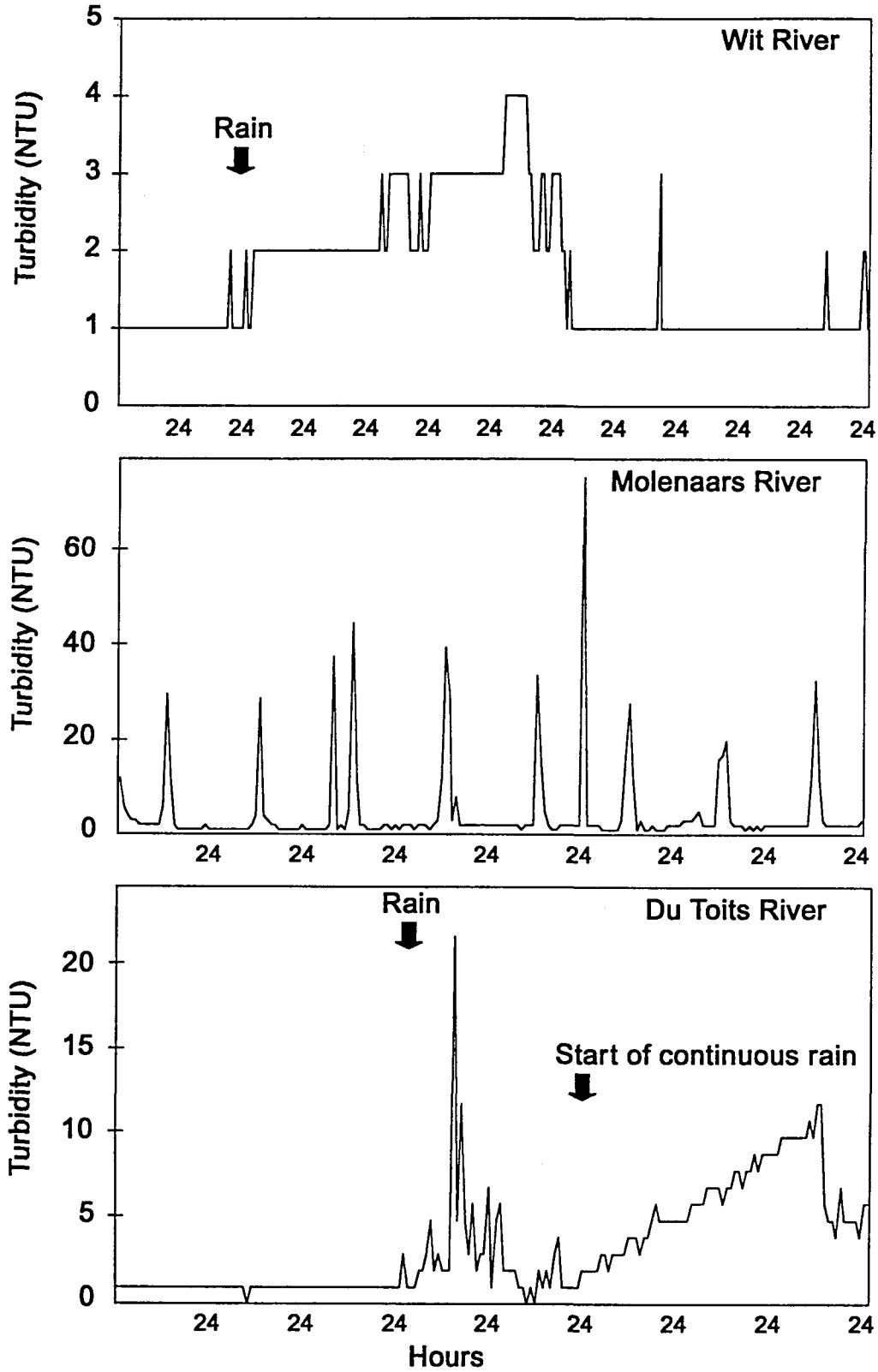


Figure 3.22. Diel variation (over a 24 hour cycle) in turbidity at one site in the mountain stream and two sites in the foothill subregion.



C. pH

Subregional variation

Background ranges of pH for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR are given in Table 3.6 and Figure 3.23. All subregions were significantly different from one another as indicated by symbols (#) ($p<0.01$; Kruskal Wallis). The number of observations i.e. sampling occasions, in addition to the number of sites (in parenthesis) are also given. A frequency histogram of pH values for each subregion is given in Figure 3.24.

Table 3.6 Median, average ± standard deviation (SD), minimum and maximum values of pH for each subregion within the southern and western coast WQMR.

Subregion	Median	Average±SD	Minimum	Maximum	n	Sig.
Mountain Stream	5.5	5.5 ± 0.9	3.6	7.9	127 (37)	#
Foothill	6.0	5.8 ± 0.8	4.0	7.2	83 (25)	##
Transitional	6.5	6.5 ± 0.8	4.3	8.9	64 (19)	###
Lowland River	7.3	7.3 ± 0.4	6.5	8.5	44 (11)	####

Seasonal variation in pH

pH is notoriously difficult to measure accurately and is dependent on the time of day, discharge, and method of measurement. DWAF routinely measures pH of water samples once they are returned to the laboratory, introducing yet another potential discrepancy in the resultant value. There was inconsistency in DWAF data for many of the sites examined, apparently related to a change in pH meters in 1989. The resultant values displayed a bimodal distribution. Analysis of data was therefore restricted to one or the other period, depending on other measurements of pH at the respective sites.

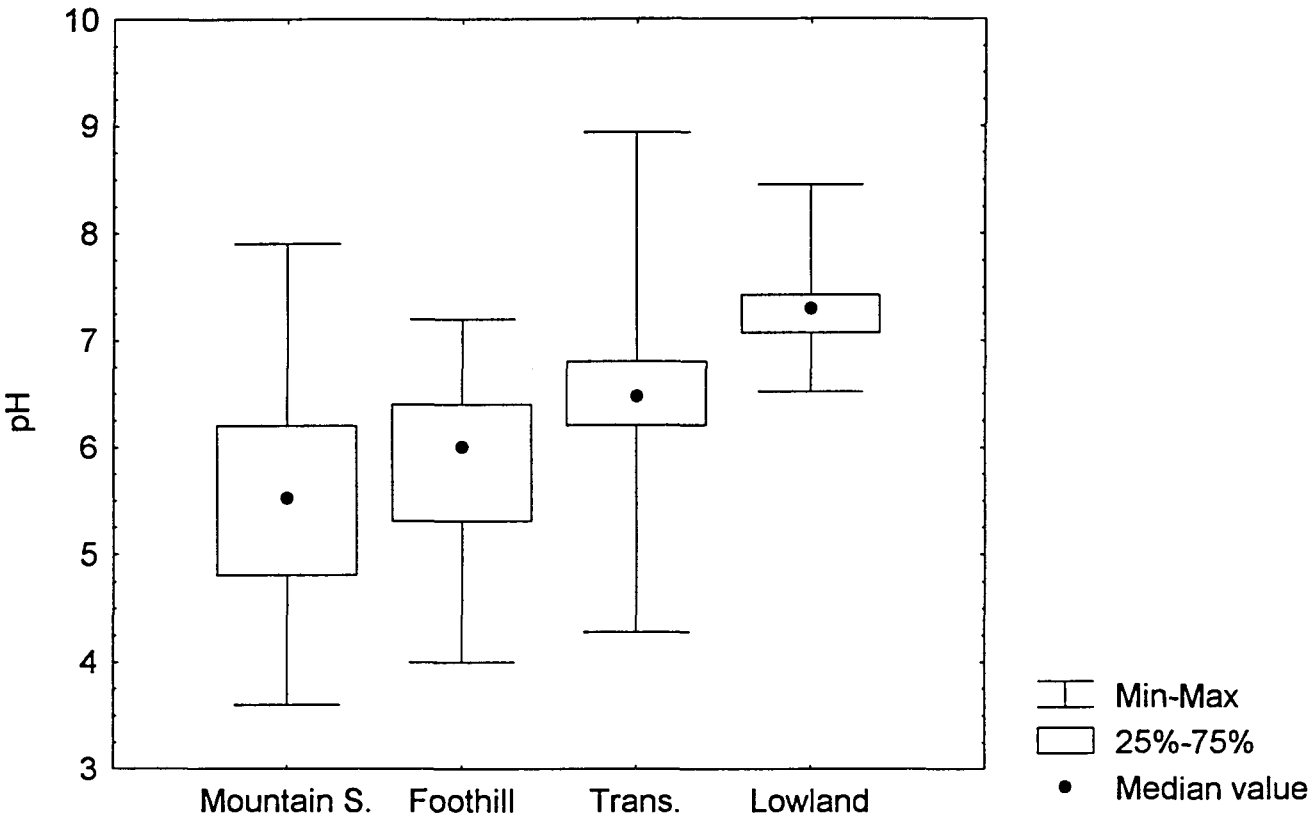
Mountain Stream: Monthly pH values were not significantly different between months. Box-and-whisker plots of monthly median and mean values for the site with weekly data for 1985 to 1989 (H1H007) are presented in Figure 3.25. Median values were between 5 and 6 although minimum and maximum values extended beyond these values.

Foothill: Monthly pH values were significantly different between months at two of the four sites ($p<0.05$; Kruskal Wallis). Box-and-whisker plots of monthly median and mean values for the site with weekly data for 1990 to 1995 (H1H018) are presented in Figure 3.26. Mean values exhibited a significant seasonal pattern with higher pH values in summer and lower ones in winter.

Transitional: Monthly pH values were significantly different between months at all sites. Box-and-whisker plots of monthly median and mean values for one of the sites (H4H017) are presented in Figure 3.27. Generally values were highest in summer, most variable in autumn and lowest in winter.

Lowland: Monthly pH values were significantly different between months at one of the two sites. Box-and-whisker plots of monthly median and mean values for 1990-1995 (H7H006) are presented in Figure 3.28. Generally mean values were higher in summer and lower in winter.

Figure 3.23 Background ranges of pH at least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.



Diel variation

Sites representative of both mountain streams and foothills exhibited distinct diel patterns in pH (Figure 3.29) with highest pHs occurring around midday during sunlit hours.

Mountain Stream: Median summer baseline pH values were 6.62, 4.85 and 4.91 in Lang, Palmiet and Wit rivers respectively. Lang River exhibited the least diel variation and had a range of 0.78 (min=6.08; max=6.86). The Palmiet River had a range of 0.93 (min=4.20; max=5.13) and Wit River a range of 1.04 (min=4.36; max=5.40). During a high-flow event on the Wit River pH dropped to around 4.65 and the diel pattern was less distinct (Figure 3.29).

Foothill: Median summer baseline pH values were 5.46, 6.46 and 5.24 for sites on the Berg, Molenaars and Du Toits rivers respectively. All exhibited strong diel differences in pH and the Berg had a range of 1.63 (min=4.38; max=6.01). The Molenaars River had a range of 1.63 (min=5.77; max=7.40) and Du Toits River a range of 0.78 (min=4.68; max=5.46). A high-flow event on the Du Toits River reduced the diel variation by a small degree (Figure 3.29).

Figure 3.24. Frequency histogram of background ranges in pH for least-impacted sites in mountain stream, foothill, transitional and lowland subregions in the southern and western coast WQMR.

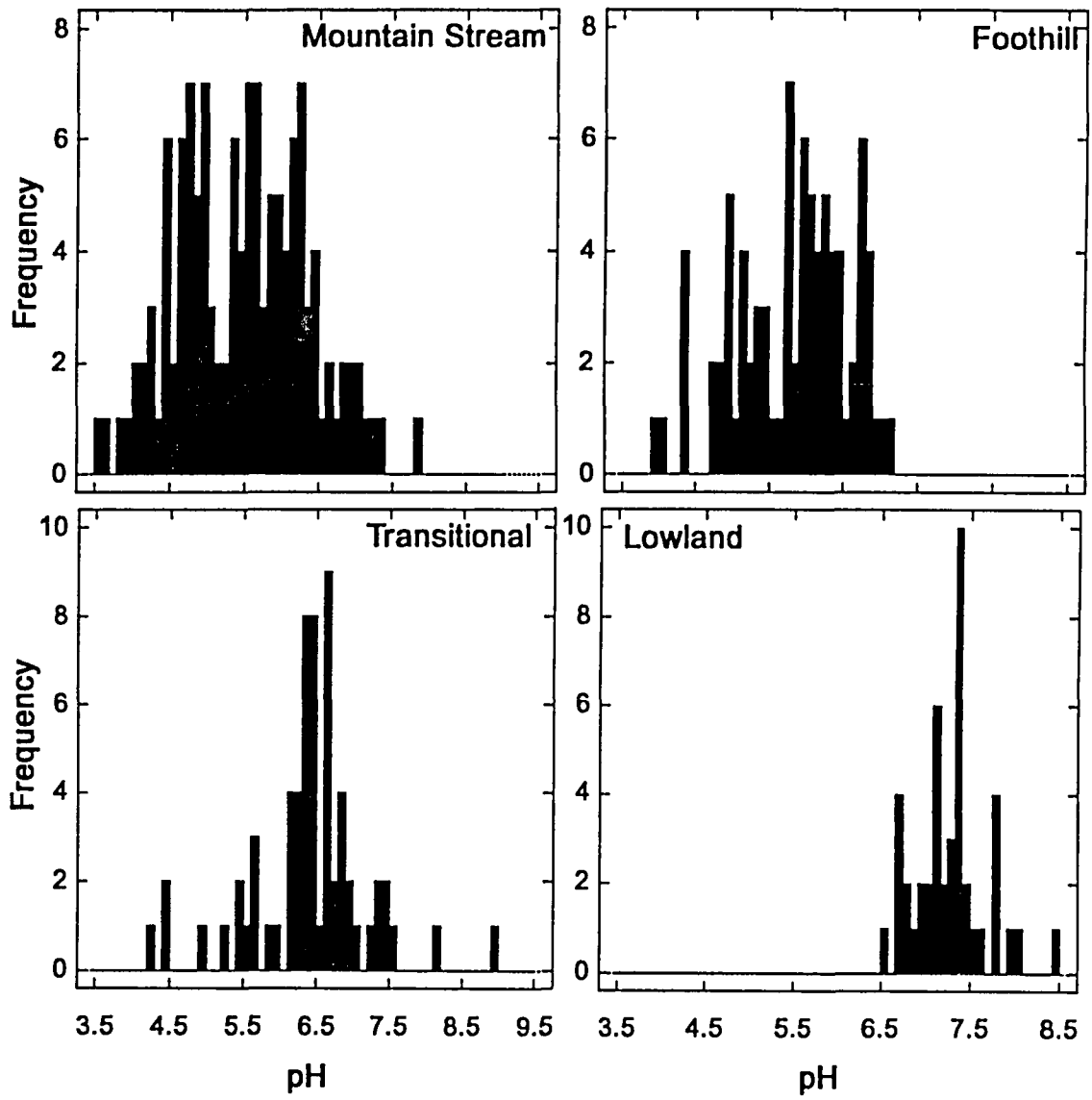


Figure 3.25. Box-and-whisker plots of monthly mean and median pH values for a site on the Wit River (H1H007) representative of the mountain stream subregion.

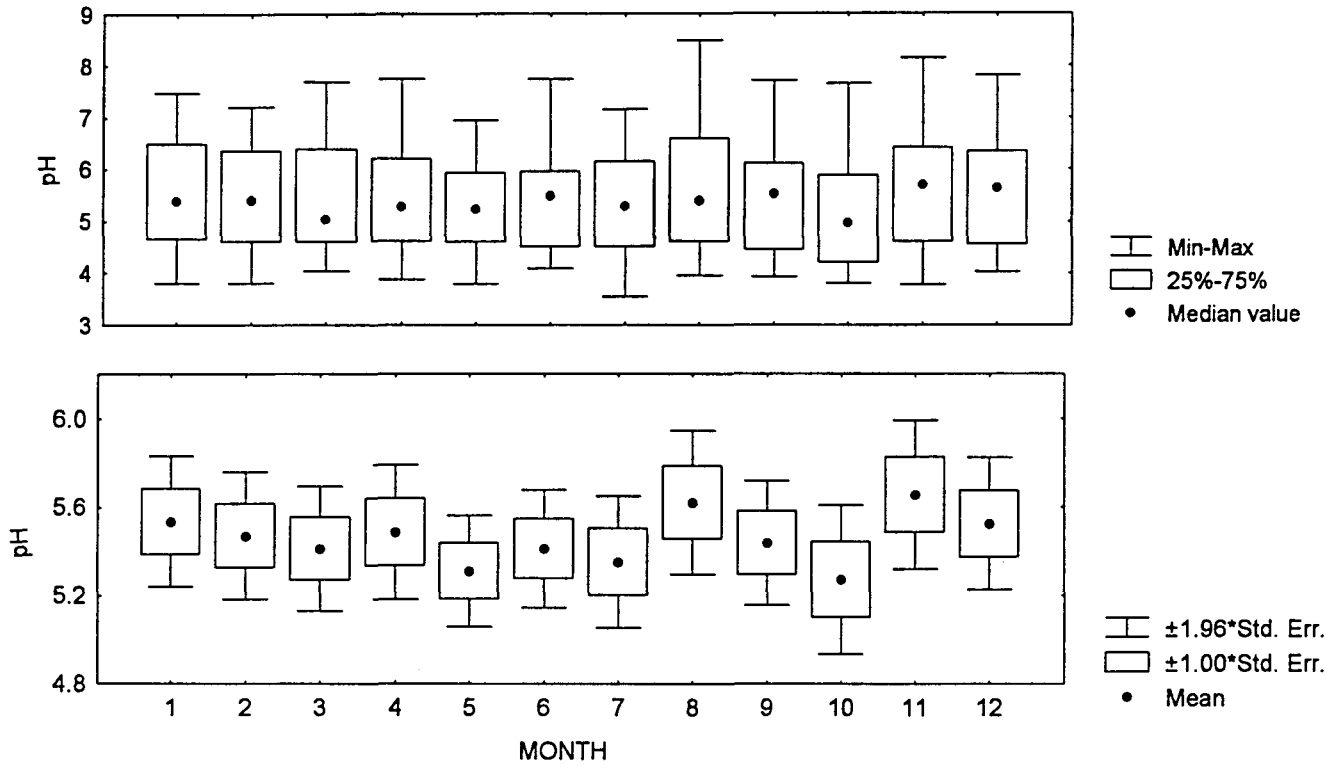


Figure 3.26. Box-and-whisker plots of monthly mean and median pH values for a site on the Molenaars River (H1H018) representative of the foothill subregion.

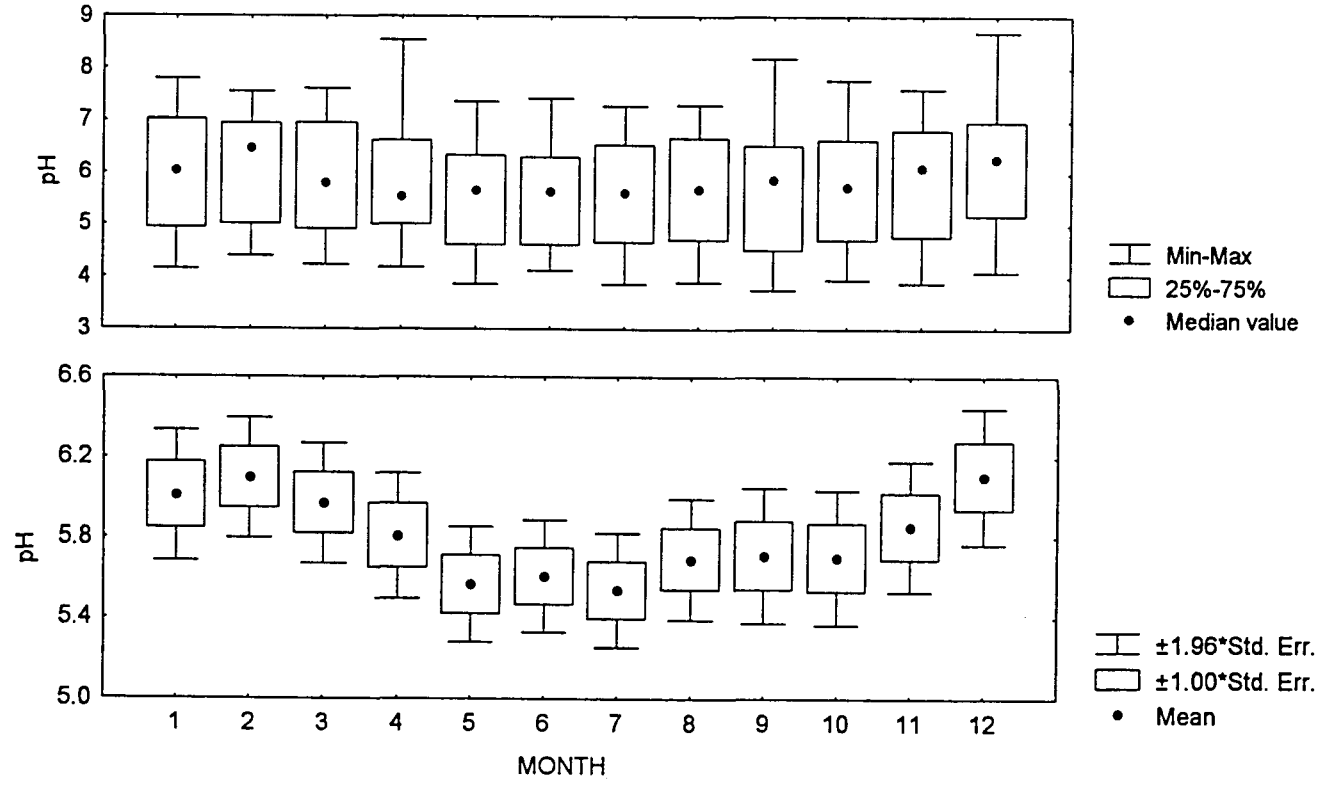


Figure 3.27. Box-and-whisker plots of monthly mean and median pH values for a site on the Bree River (H4H017) representative of the transitional subregion.

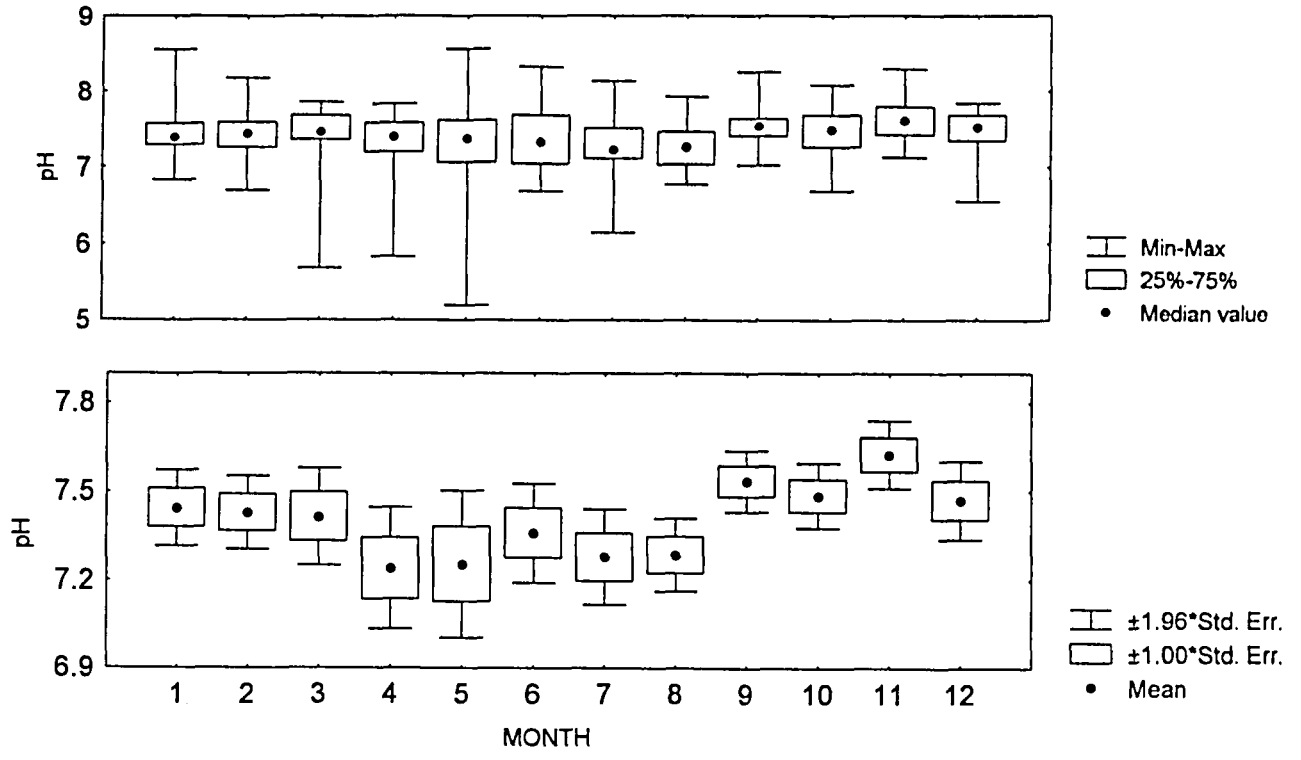


Figure 3.28. Box-and-whisker plots of monthly mean and median pH values for a site on the Bree River (H7H006) representative of the lowland subregion.

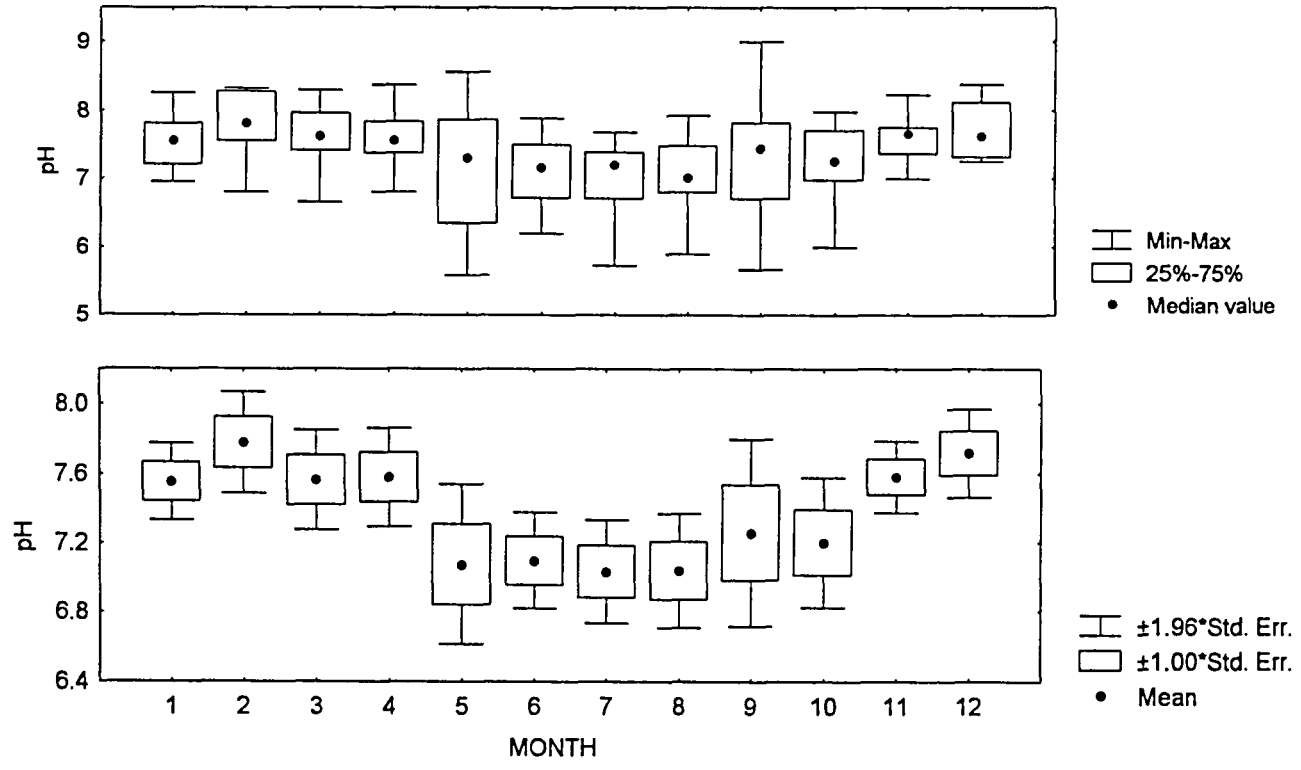
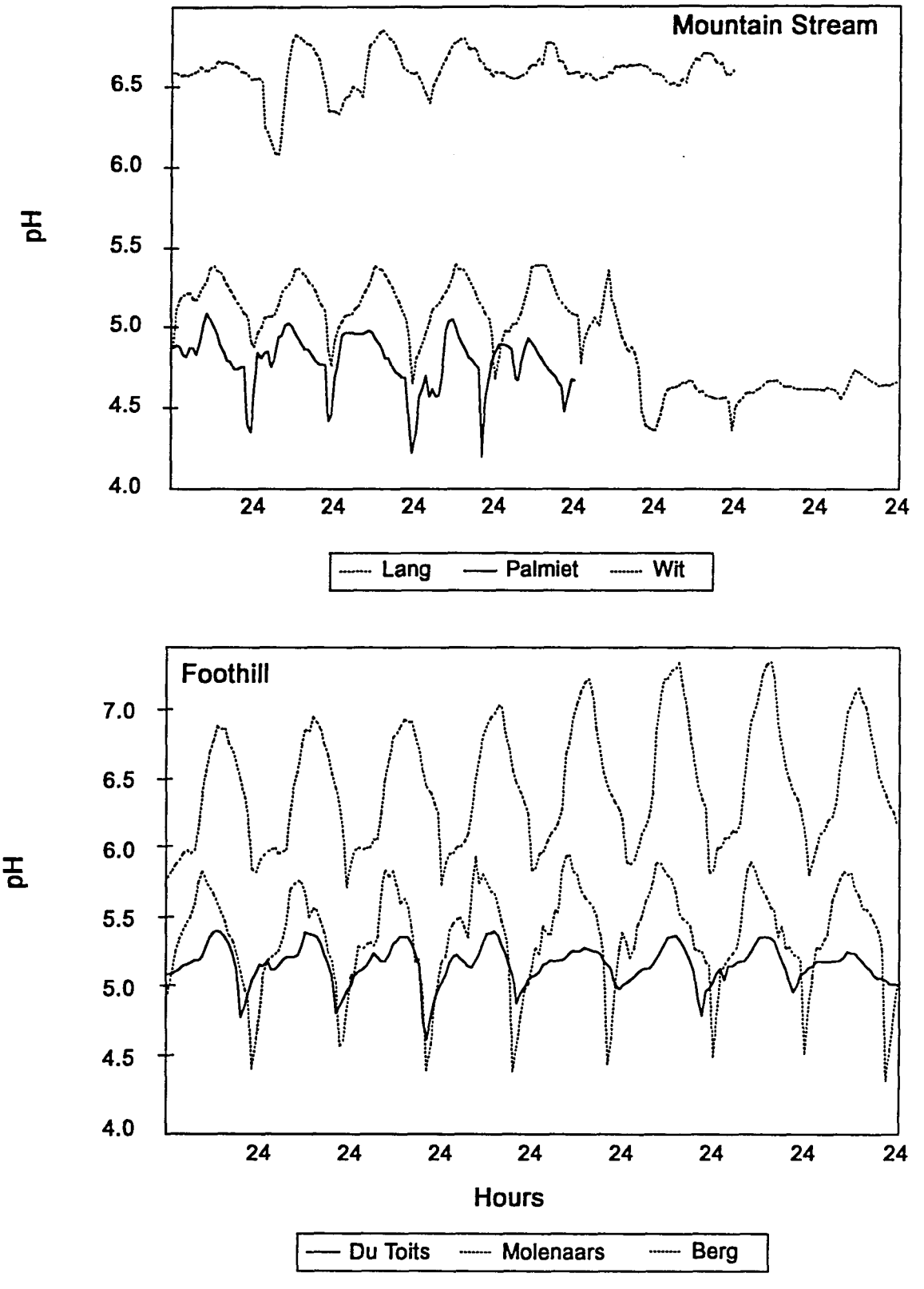


Figure 3.29. Diel variation (over a 24 hour cycle) in pH at three sites in the mountain stream and three sites in the foothill subregion.



3.3.3 Summarised information on background concentrations or ranges, seasonal and diel variation for selected water quality variables in the southern and western coast Water Quality Management Region

TDS and conductivity

There were subregional differences in TDS concentrations and conductivity, and mountain streams and foothills were significantly different from transitional and from lowland sites.

- *Mountain Stream*: Median TDS concentration and conductivity were 26.3 mg l^{-1} and 3.0 mS m^{-1} respectively. Seasonal variation was significant for conductivity, which was generally highest in summer, lowest in winter and most variable in autumn. There was no diel pattern in conductivity, although conductivity rose from 2.0 to 4.0 mS m^{-1} during a high-flow event.
- *Foothill*: Median TDS concentration and conductivity were 32.0 mg l^{-1} and 3.1 mS m^{-1} respectively. Seasonal variation in TDS concentration and conductivity was significant for two and all of the four sites respectively. Both were highest in summer and lowest in winter. There was no diel pattern in conductivity.
- *Transitional*: Median TDS concentration and conductivity were 83.6 mg l^{-1} and 9.6 mS m^{-1} respectively. Seasonal variation in TDS concentration and conductivity was significant at all three sites. Generally both were highest in summer and lowest in winter. They were most variable in autumn or winter. Diel variation was not assessed.
- *Lowland*: Median TDS concentration and conductivity were 183.0 mg l^{-1} and 21.0 mS m^{-1} respectively. Seasonal variation in TDS concentration and conductivity was significant and concentrations and values were highest in summer, lowest in winter and most variable in autumn. Diel variation was not assessed.

TSS and turbidity

There were subregional differences in TSS concentrations, and sites in mountain stream, foothill and transitional subregions were significantly different from lowland sites. Verification of these results is necessary because of the relative paucity of data, which also prevented the examination of seasonal variation for either TSS or turbidity.

- *Mountain Stream*: Median TSS concentration and turbidity were 0.66 mg l^{-1} and <1 NTU respectively. There was no diel pattern in turbidity, although turbidity rose from $\leq$ 1 NTU to 4 NTU during a high-flow event.
- *Foothill*: Median TSS concentration and turbidity were 0.78 mg l^{-1} and 1 NTU respectively. There was no diel pattern in turbidity, although turbidity rose from approximately 1 NTU to 22 NTU during a high-flow event.
- *Transitional*: Median TSS concentration was 1.70 mg l^{-1}. Diel variation was not assessed.
- *Lowland*: Median TSS concentration and turbidity were 9.57 mg l^{-1} and 3 NTU respectively. Diel variation was not assessed.

pH

There were subregional differences in pH and all subregions were significantly different from one another.

- *Mountain Stream*: Median pH was 5.5, and there was no seasonal variation. There was a distinct diel pattern in pH values, with highest values occurring during daylight hours. Diel variation was in the order of 1 pH unit. pH decreased and was less variable following a high-flow event.
- *Foothill*: Median pH was 6.0, and there was minimal seasonal variation in values. When present, pH values were higher in summer and lower in winter. There was a distinct diel pattern in pH values, with highest values occurring during daylight hours. Diel variation was in the order of 1.3 pH unit. pH was less variable following a high-flow event.
- *Transitional*: Median pH was 6.5 and pH varied seasonally. pH values were generally highest in summer, most variable in autumn and lowest in winter. Diel variation was not assessed.
- *Lowland* Median pH was 7.3, and pH values tended to be higher in summer and lower in winter. Diel variation was not assessed.

3.3.4. Background concentrations and ranges for selected water quality variables in other Water Quality Management Regions.

Background concentrations (TDS and TSS) and ranges (conductivity and pH) were established for "least-impacted" sites in each subregion within each WQMRs using data extracted from the Biological and Chemical Database. Such "least-impacted" sites may be considered representative of "reference sites" with respect to water chemistry. In certain regions data were insufficient to enable any useful information to be extracted and in others, subregions were combined. The SASS4 Score (SASS4 > 100) and ASPT (ASPT > 6.0) proposed for the interpretation of SASS results in non-acidic region in South Africa (Chutter 1995a) were used to differentiate between least-impacted and other sites. Comparisons were made between results from the inclusion of sampling occasions within quadrats 1, 2 and 3 and with that of quadrat 1 only. There was very little difference in median values although average, minimum and maximum values varied. Similarly, exclusion of the top and bottom 5% of the values (i.e. exclusion of outliers) did not affect the median value. Median, minimum, maximum and the number of observations (n) are given in Table 3.7.

Table 3.7 Median, minimum and maximum concentrations for TDS for each subregion (M = Mountain Stream, F = Foothill, T = Transitional, L = Lowland) within each WQMR. TDS = total dissolved solids in mg l^{-1}; COND = conductivity in mS m^{-1} and TSS = total suspended solids in mg l^{-1}. The number of observations refer to number of sampling occasions.

WQMR	Subregion	Variable	Median	Minimum	Maximum	n
East Coast	M+F	TDS	58.0	39.0	126.0	26
East Coast	L	TDS	175.0	61.0	118.0	26
Upper Orange/Vaal	M	TDS	59.0	53.0	83.0	3
Upper Orange/Vaal	T	TDS	160.0	95.0	263.0	12
North-east	L	TDS	139.0	85.0	628.0	17
East Coast	M+F	COND	7.0	3.6	16.0	31
East Coast	L	COND	28.3	6.2	115.0	28
Upper Orange/Vaal	T	COND	19.6	15.0	38.5	7
North-east	T	COND	46.3	32.0	57.2	26
North-east	L	COND	29.3	13.0	67.0	34
Karoo	M+F	COND	5.2	2.1	32.2	27
Karoo	M+F	TSS	5.65	1.0	16.7	22
East Coast	M+F	pH	7.46	7.20	8.00	31
East Coast	L	pH	7.69	7.10	8.12	28
Upper Orange/Vaal	M	pH	8.30	8.30	8.40	3
Upper Orange/Vaal	T	pH	8.03	7.20	8.60	12
North-east	L	pH	7.70	7.20	8.00	31
Karoo	M+F	pH	6.80	5.10	8.00	31

3.3.5. Comparison of observed concentrations or values with national water quality criteria

National water quality guidelines for non-toxic inorganic constituents for aquatic ecosystems are stated in terms of percentage change from established background or intrinsic concentrations or values. All include a stipulation that changes in concentration or values resulting from natural seasonal or diel effects be taken into consideration. It is necessary to ascertain for "least-impacted" or reference sites the percentage of observed data which is within the Target Water Quality Range (TWQR) proposed by the national water quality guidelines for each constituent. The method that we propose here is relatively simple and aims at providing an indication of the percentage of observed data which occur within pre-defined ranges related to the TWQR.

The method is demonstrated for reference sites within each subregion within the southern and western coast WQMR. Essentially the method involves:

1. Selection of time period for data analysis (ensuring that no instrument discrepancies, such as a change in pH meter, are incorporated). This may be the most recent available data if an assessment of the current condition is required.
2. Allocation of season to all weekly or monthly data (spring =September, October and November; summer =December, January and February; autumn =March, April and May; and winter =June, July and August). Appropriate groups of months may vary between water quality management regions because of differences in climate and seasonal extremes.
3. Calculation of median concentrations or values for each season
4. Formulation of "Test Ranges" for constituents of interest, e.g.

   TDS: TWQR states that the concentration should not vary by >15% of that of an unimpacted site at any time of year (DWAF 1996a). Therefore, the percentage observed data within the following "Test Ranges" may be ascertained:

   - < (-30%) of median value
   - Between (- 30%) and (-15%) of median value
   - Between (- 15%) and (+15%) of the median value, i.e. proposed national water quality guidelines
   - Between (+15%) and (+30%) of median value
   - > (+30%) of median value

   Similarly, background pH values, for a specific site and time of day, may not vary by > 0.5 of a pH unit, or by > 5% (DWAF 1996a). Therefore, the percentage observed data within the following "Test Ranges" may be ascertained:

   - < (-1.0 unit) of median value
   - Between (-1.0 unit) and (- 0.5 unit) of median value
   - Between (- 0.5 unit) and (+0.5 unit) of the median value, i.e. proposed national water quality guidelines
   - Between (+0.5 unit) and (+1.0 unit) of median value

- > (+1.0 unit) of median value

5. The percentage of observed data within each "Test Range" is then calculated using a programme such as Statistica.
6. It is also advisable to plot the observed data together with the "Test Ranges" so that the extent to which observed data exceeds the TWQR can be ascertained. This would enable the duration of the peaks and troughs to be established.

The percentage of observed data which fall within and outside the TWQR can then be assessed and, depending on the site in question, modifications made to the TWQR. Instances where modifications may be necessary include naturally saline systems in the case of TDS, sites where locally important or endemic species may be very sensitive to changes in TDS, TSS or pH; where aquatic organisms are stressed by diseases, parasites, predators, other contaminants, contaminated or insufficient food, and fluctuating or extreme conditions of flow or water quality; and where natural background concentrations or values have a range of variation which is greater than that specified by the TWQR.

The percentage observed data within each "Test Range" established for TDS, conductivity and pH were ascertained for various "least-impacted" or reference sites within each subregion in the southern and western coast WQMR (Tables 3.8 to 3.10). There were insufficient data to provide adequate analyses for TSS or turbidity. Observed data for conductivity and pH for selected sites representative of each subregion were also plotted as a function of time (Figures 3.30 to 3.37). The intensity and frequency of data collection varied between sites and between seasons. This graphical presentation enables the pattern of the data distribution to be compared to the various "Test Ranges" established for each site and season calculated as specified above.

Table 3.8. Percentage observed data within each "Test Range" established for Total Dissolved Solids on a seasonal basis. The TWQR proposed by the interim national water quality guidelines are shaded and the median concentration (mg l^{-1}) is given as X. Abbreviations: M = Mountain Stream, F = Foothill, T = Transitional, L = Lowland; SP = spring, SU = summer, AU = autumn, WI = winter.

Subregion	Site	Season	Median	n	% <(-30%) of X	% Between (-30 and -15%) of X	% Between (- 15%) and (+15%) of X	% Between (+30 and +15%) of X	% >(+30%) of X
M	H1H007	SP	22.0	67	5	15	**49**	21	10
		SU	22.0	53	4	19	**49**	9	19
		AU	23.0	78	1	14	**63**	19	3
		WI	20.0	70	3	10	**56**	16	15
	H2H005	SP	18.0	28	11	21	**43**	11	14
		SU	22.0	25	16	20	**40**	12	12
		AU	20.0	27	0	11	**63**	0	26
		WI	20.0	29	10	21	**45**	7	17
	H6H005	SP	37.0	31	0	16	**81**	3	0
		SU	43.0	28	0	18	**75**	7	0
		AU	38.0	34	0	12	**68**	3	17
		WI	37	36	0	19	**67**	11	3
F	H1H018	SP	24.0	63	8	13	**52**	19	8
		SU	27.5	54	4	17	**63**	4	12
		AU	26.0	63	3	35	**30**	18	14
		WI	23.0	71	8	18	**58**	10	6
	H2H004	SP	24.0	33	6	6	**58**	12	18
		SU	24.5	30	7	3	**54**	13	23
		AU	23.5	36	3	28	**36**	5	28
		WI	23.0	40	13	7	**53**	12	15
	H8H002	SP	55.0	44	14	14	**43**	2	27
		SU	53.5	46	7	9	**50**	19	15
		AU	56.0	49	6	25	**39**	18	12
		WI	61.0	50	6	12	**50**	18	14

Subregion	Site	Season	Median	n	% <(-30%) of X	% Between (-30 and -15%) of X	% Between (- 15%) and (+15%) of X	% Between (+30 and +15%) of X	% >(+30%) of X
T	H4H017	SP	170	65	22	8	**49**	6	15
		SU	105	56	0	4	**64**	13	19
		AU	128	67	13	15	**39**	10	23
		WI	111	20	27	9	**25**	9	30
	H1H015	SP	61.0	118	12	20	**38**	13	17
		SU	88.0	79	18	15	**34**	10	23
		AU	49.0	80	33	21	**10**	7	29
		WI	51.0	123	12	17	**33**	11	27
L	H7H006	SP	253	33	15	15	**30**	15	25
		SU	508	31	13	23	**29**	6	29
		AU	384	14	33	11	**14**	3	39
		WI	170	36	25	11	**31**	6	27
	H6H009	SP	126	34	20	21	**18**	12	29
		SU	125	32	6	28	**38**	19	9
		AU	102	34	12	18	**41**	3	26
		WI	101	38	26	8	**29**	3	34

Table 3.9. Percentage observed data within each "Test Range" established for conductivity on a seasonal basis. No TWQR was proposed by the interim national water quality guidelines and the same percentage as for TDS has been used. The TWQR range is shaded and the median conductivity value (mS m^{-1}) is given as X. Abbreviations: M = Mountain Stream, F = Foothill, T = Transitional, L = Lowland; SP = spring, SU = summer, AU = autumn, WI = winter.

Subregion	Site	Season	Median	n	% <(-30%) of X	% Between (-30 and -15%) of X	% Between (- 15%) and (+15%) of X	% Between (+30 and +15%) of X	% >(+30%) of X
M	H1H007	SP	3.4	74	0	18	**72**	1	9
		SU	3.8	72	0	4	**83**	7	6
		AU	3.8	78	1	7	**77**	9	6
		WI	3.3	76	1	9	**65**	9	16
	H2H005	SP	3.0	32	13	6	**59**	9	13
		SU	3.5	30	4	23	**60**	3	10
		AU	3.0	33	6	9	**61**	12	12
		WI	3.2	32	9	13	**56**	13	9
	H6H005	SP	7.0	33	0	6	**70**	24	0
		SU	8.2	32	3	6	**72**	19	0
		AU	7.7	36	6	19	**61**	8	6
		WI	7.0	38	0	13	**74**	11	2
F	H1H018	SP	3.8	72	0	11	**79**	7	3
		SU	4.2	73	0	5	**75**	14	4
		AU	4.0	76	0	13	**72**	8	7
		WI	3.6	77	1	17	**62**	16	4
	H2H004	SP	3.1	61	13	13	**35**	3	36
		SU	3.7	53	11	17	**36**	11	25
		AU	3.5	58	14	14	**36**	5	31
		WI	3.2	55	15	20	**27**	9	29
	H8H002	SP	11.1	76	11	14	**44**	5	26
		SU	10.9	68	4	21	**44**	18	13
		AU	9.8	90	2	10	**62**	11	15
		WI	11.1	91	5	15	**40**	20	20

Subregion	Site	Season	Median	n	% <(-30%) of X	% Between (-30 and -15%) of X	% Between (- 15%) and (+15%) of X	% Between (+30 and +15%) of X	% >(+30%) of X
T	H4H017	SP	30.5	77	21	8	**47**	13	11
		SU	20.8	73	1	7	**69**	4	19
		AU	23.9	80	9	16	**41**	10	24
		WI	21.5	75	27	12	**24**	7	30
	H1H015	SP	12.0	125	10	18	**44**	14	14
		SU	16.5	89	19	12	**32**	11	26
		AU	9.5	88	14	25	**25**	10	26
		WI	10.3	128	18	16	**27**	9	30
L	H7H006	SP	47.0	36	27	15	**19**	10	29
		SU	96.7	31	22	9	**34**	11	24
		AU	67.0	51	32	10	**16**	6	36
		WI	28.4	42	30	11	**21**	8	30
	H6H009	SP	26.1	122	29	14	**20**	10	27
		SU	23.0	127	16	15	**35**	12	22
		AU	19.0	137	12	20	**39**	7	22
		WI	20.5	132	29	14	**14**	5	38

Table 3.10. Percentage observed data within each "Test Range" established for pH presented on a seasonal basis. The TWQR proposed by the interim national water quality guidelines is shaded and the median pH value is given as X. Abbreviations: M = Mountain Stream, F = Foothill, T = Transitional, L = Lowland; SP = spring, SU = summer, AU = autumn, WI = winter.

Subregion	Site	Season	Median	n	<(-1.0 unit) of X	Between (-1.0 and -0.5 unit) of X	% Between (- 0.5) and (+0.5 unit) of X	% Between (+0.5 and +1.0 unit) of X	% >(+1.0 unit) of X
M	H1H007	SP	6.11	74	9	14	**46**	9	22
		SU	6.33	72	15	14	**53**	13	5
		AU	6.00	78	12	14	**47**	17	10
		WI	5.98	76	6	23	**38**	20	13
	H2H005	SP	6.26	17	0	29	**53**	12	6
		SU	6.53	17	18	6	**53**	23	0
		AU	6.13	20	5	15	**65**	15	0
		WI	6.39	19	11	26	**37**	16	10
	H6H005	SP	6.29	18	11	11	**50**	17	11
		SU	6.60	17	12	6	**59**	12	11
		AU	6.41	19	21	16	**42**	21	0
		WI	5.66	20	0	25	**50**	5	20
F	H1H018	SP	6.59	72	7	15	**57**	11	10
		SU	6.91	73	5	10	**70**	14	1
		AU	6.64	76	13	16	**50**	18	3
		WI	6.35	77	6	16	**60**	17	1
	H2H004	SP	5.50	33	9	21	**43**	15	12
		SU	5.73	34	3	15	**59**	17	6
		AU	5.47	36	0	25	**55**	17	3
		WI	5.47	40	2	15	**58**	15	10
	H8H002	SP	4.85	44	2	9	**59**	9	21
		SU	5.20	55	7	20	**49**	17	7
		AU	4.97	57	2	5	**68**	21	4
		WI	5.00	50	2	18	**58**	18	4

Subregion	Site	Season	Median	n	<(-1.0 unit) of X	Between (-1.0 and -0.5 unit) of X	% Between (- 0.5) and (+0.5 unit) of X	% Between (+0.5 and +1.0 unit) of X	% >(+1.0 unit) of X
T	H4H017	SP	7.54	77	0	3	**92**	5	0
		SU	7.44	73	0	6	**90**	3	1
		AU	7.26	80	10	1	**76**	12	1
		WI	7.26	75	2	4	**81**	12	1
	H1H015	SP	7.19	73	1	7	**85**	7	0
		SU	7.36	56	3	4	**86**	4	3
		AU	7.21	52	8	11	**81**	0	0
		WI	7.01	76	4	12	**76**	8	0
L	H7H006	SP	7.49	33	12	9	**73**	3	3
		SU	7.64	34	0	6	**76**	18	0
		AU	7.51	37	11	16	**59**	11	3
		WI	7.10	36	5	11	**67**	17	0
	H6H009	SP	7.26	18	0	0	**94**	6	0
		SU	7.45	19	5	5	**84**	6	0
		AU	7.16	18	0	6	**84**	5	5
		WI	7.07	20	10	0	**80**	10	0

Figure 3.30. Observed data for conductivity recorded at DWAF Site H1H007 in the mountain stream subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 15%) and (+15%) of the median value and dotted lines represent the median value ± 30%.

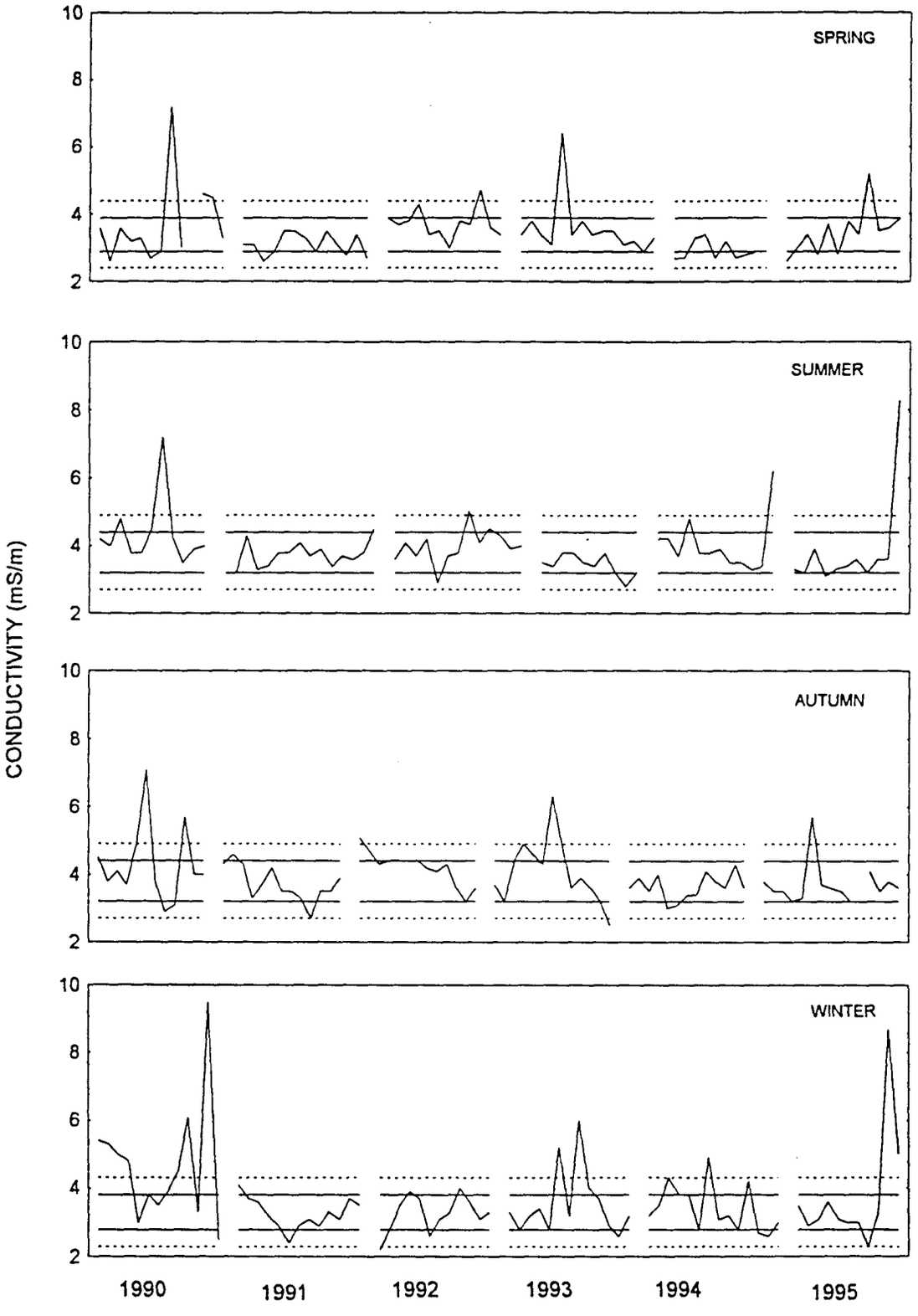


Figure 3.31. Observed data for pH recorded at DWAF Site H1H007 in the mountain stream subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 0.5 unit) and (+0.5 unit) of the median value and dotted lines represent the median value ± 1.0 unit.

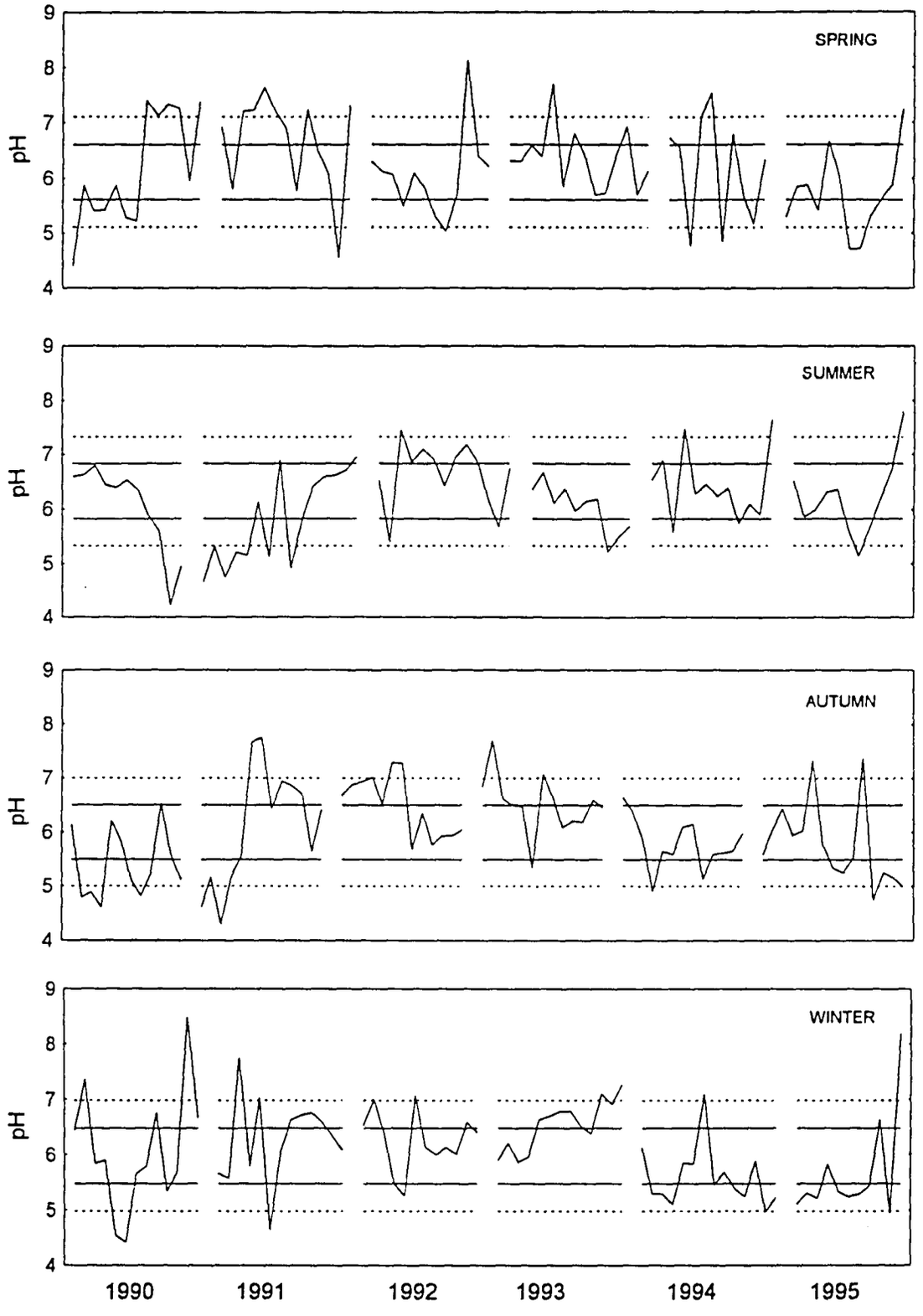


Figure 3.32. Observed data for conductivity recorded at DWAF Site H1H018 in the foothill subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 15%) and (+15%) of the median value and dotted lines represent the median value ± 30%.

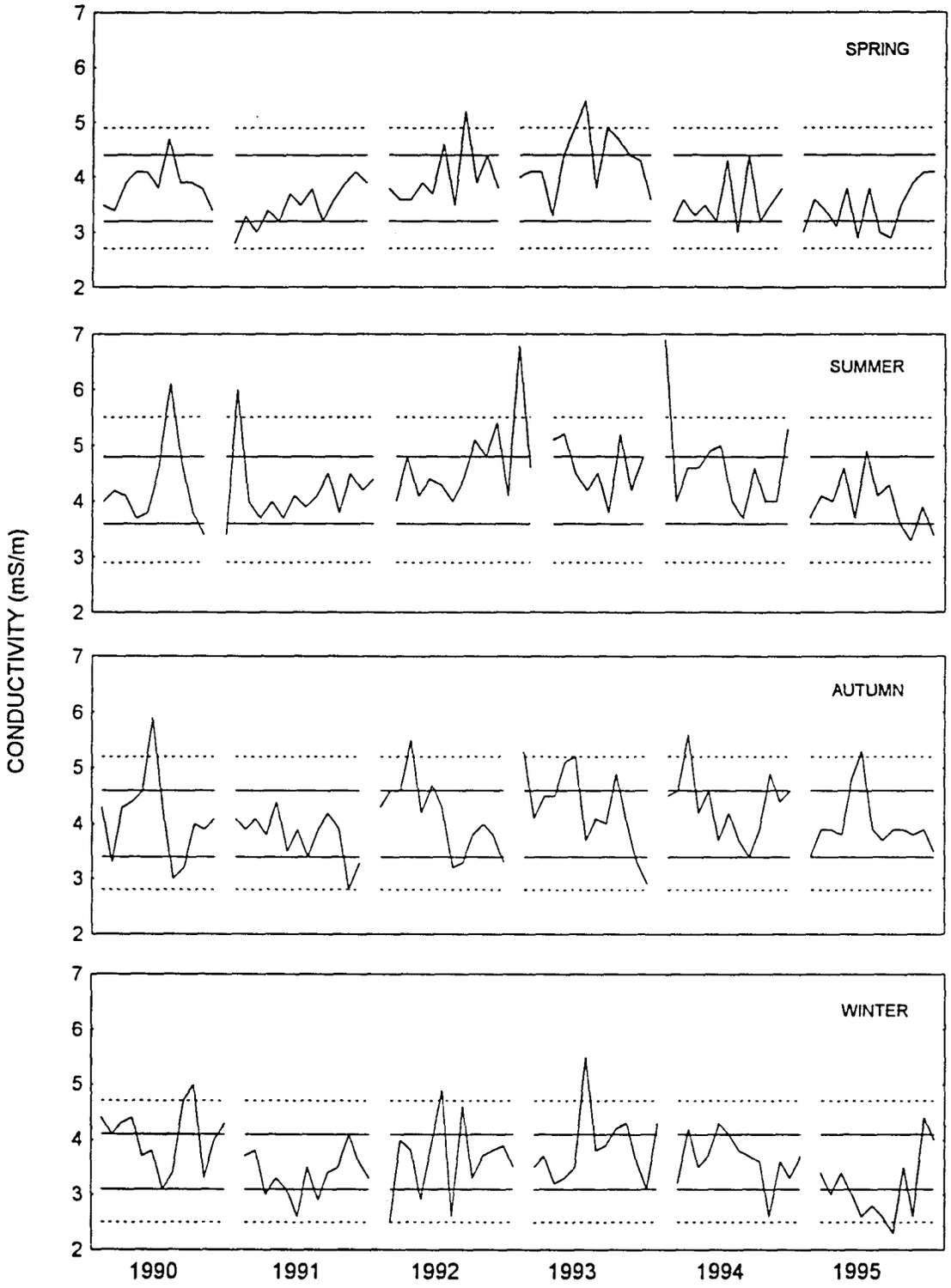


Figure 3.33. Observed data for pH recorded at DWAF Site H1H018 in the foothill subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 0.5 unit) and (+0.5 unit) of the median value and dotted lines represent the median value ± 1.0 unit.

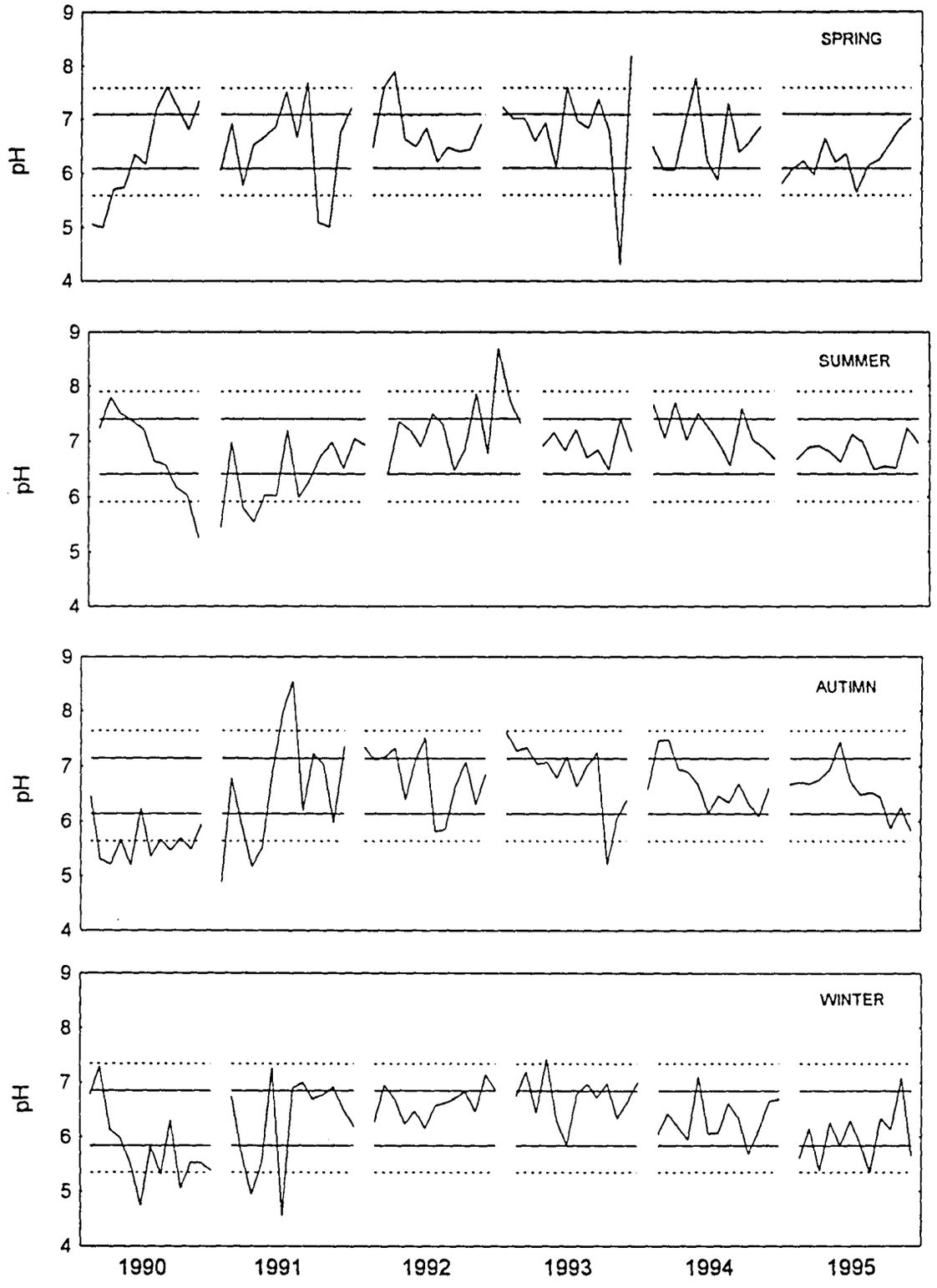


Figure 3.34. Observed data for conductivity recorded at DWAF Site H4H017 in the transitional subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 15%) and (+15%) of the median value and dotted lines represent the median value ± 30%.

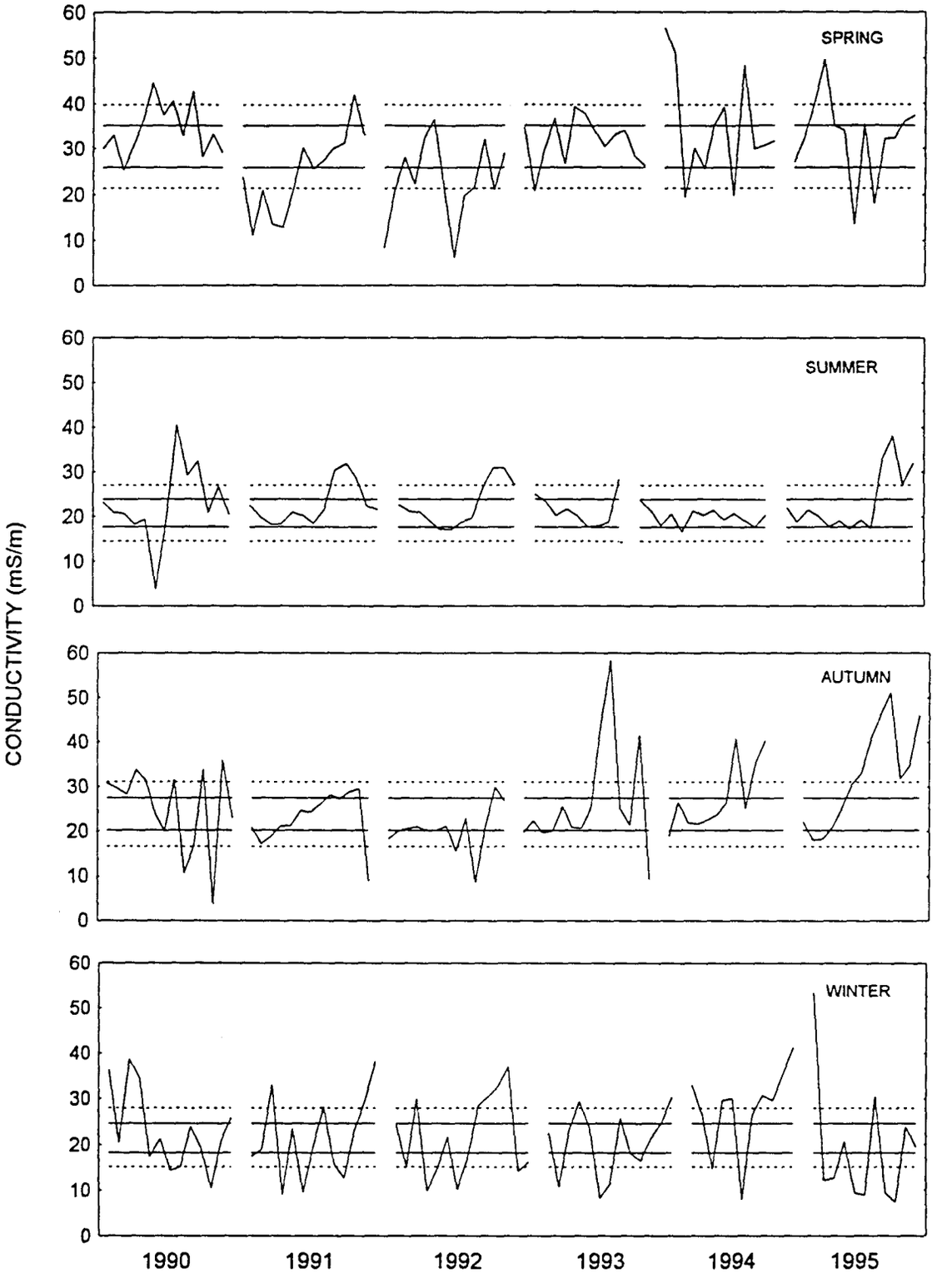


Figure 3.35. Observed data for pH recorded at DWAF Site H4H017 in the transitional subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 0.5 unit) and (+0.5 unit) of the median value and dotted lines represent the median value ± 1.0 unit.

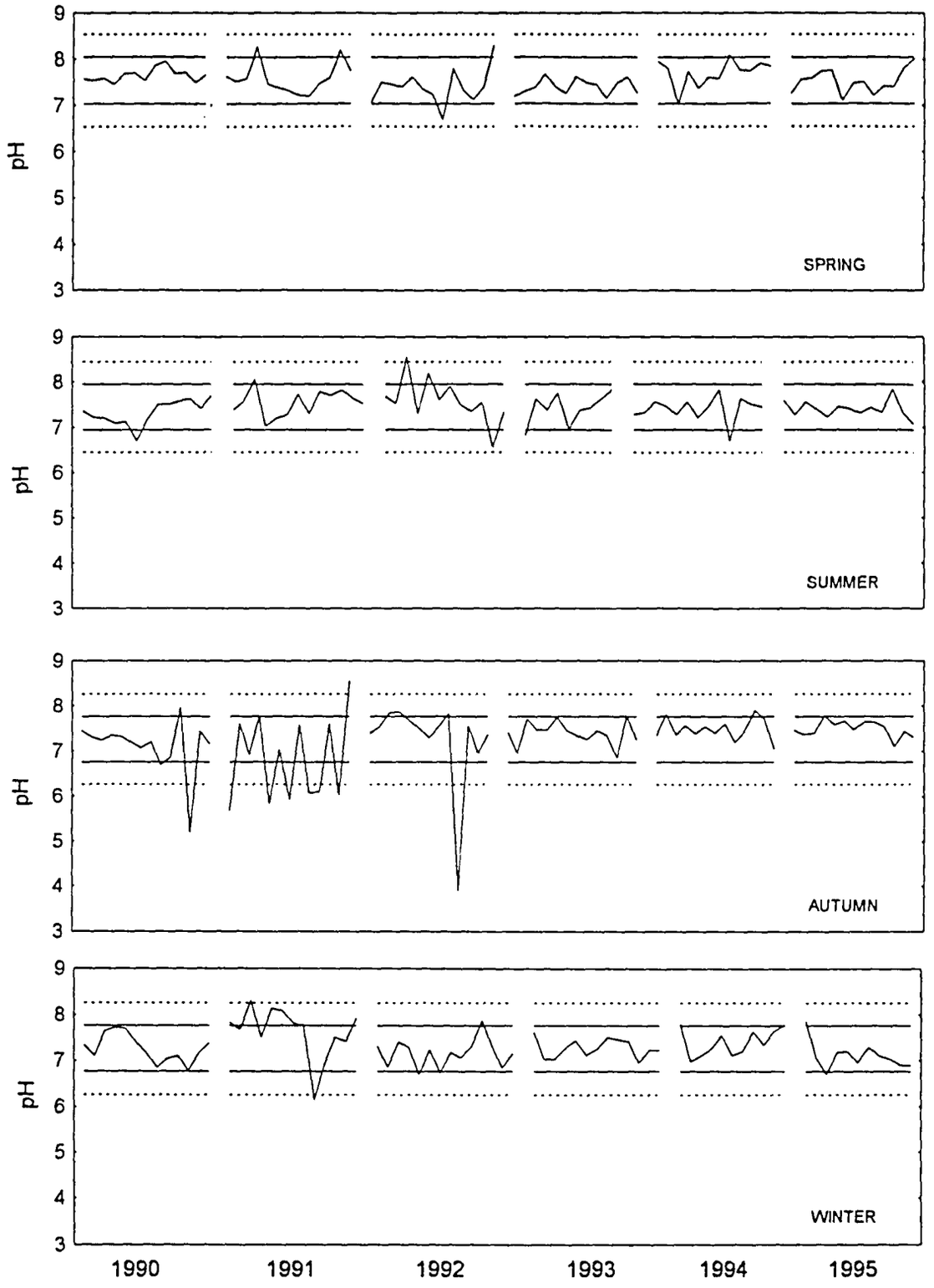


Figure 3.36. Observed data for conductivity recorded at DWAF Site H7H006 in the lowland subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 15%) and (+15%) of the median value and dotted lines represent the median value ± 30%.

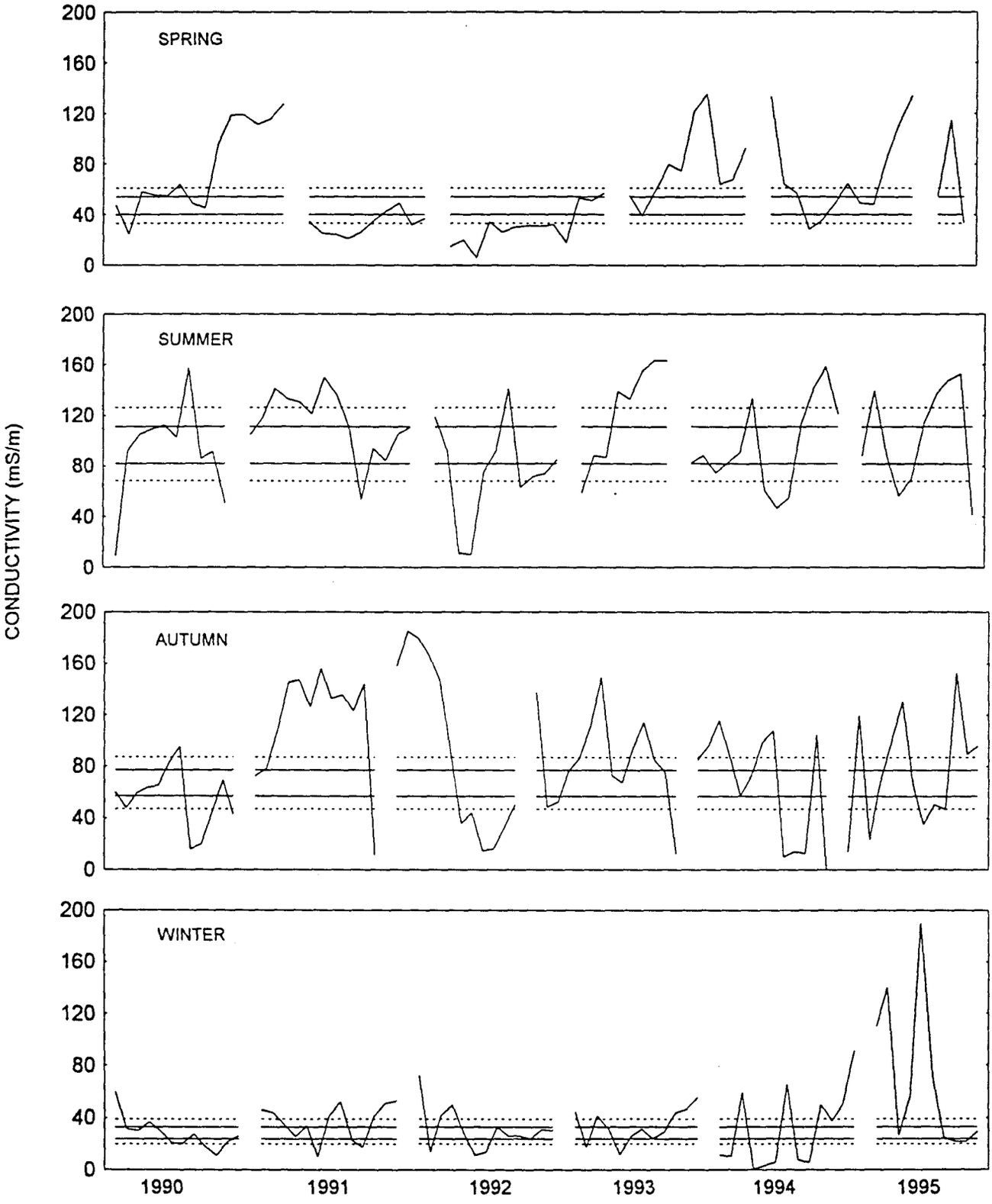
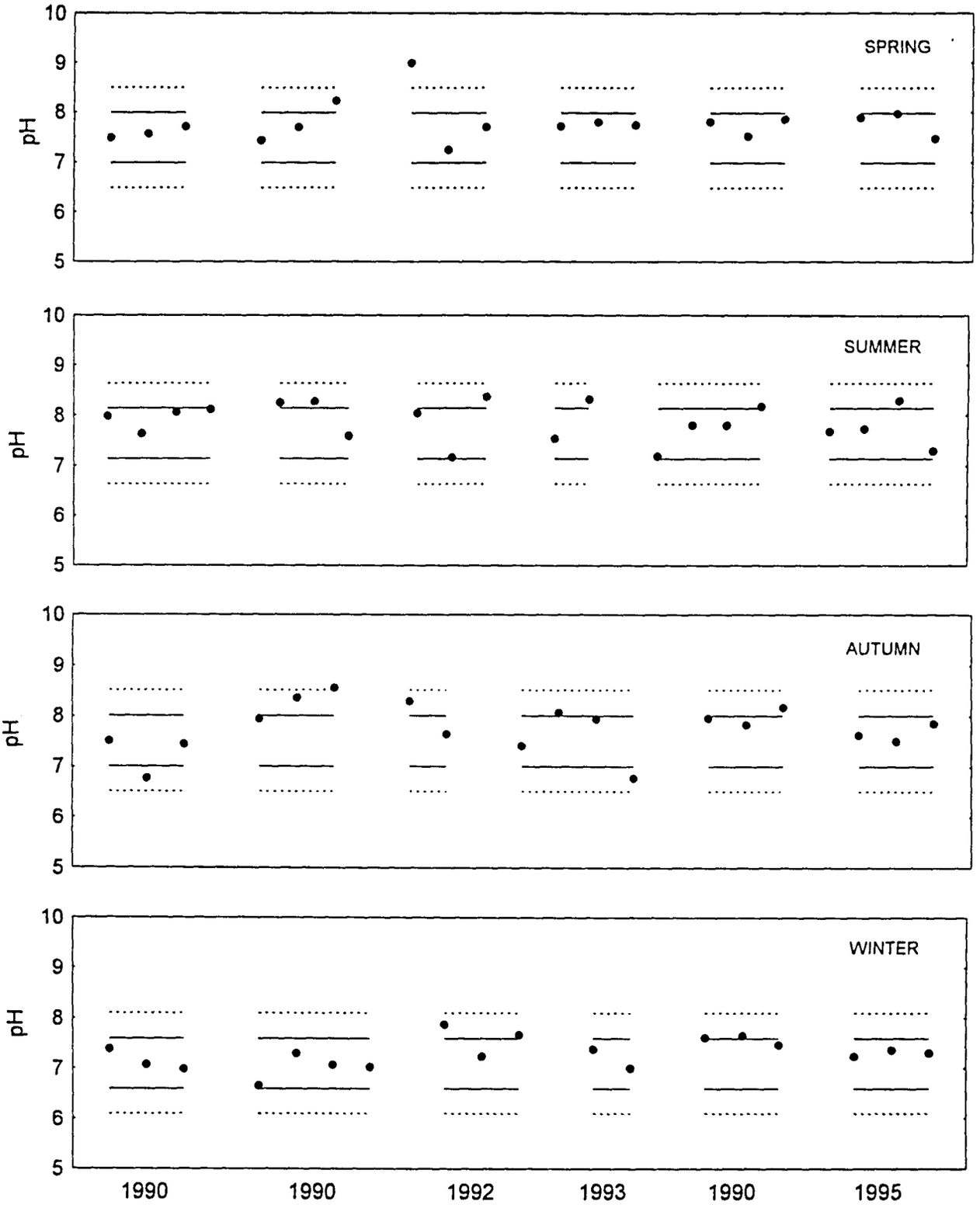


Figure 3.37. Observed data for pH recorded at DWAF Site H7H006 in the lowland subregion, plotted for each season for the years 1990 to 1995. The solid lines represent the proposed national water quality guidelines, i.e. between (- 0.5 unit) and (+0.5 unit) of the median value and dotted lines represent the median value ± 1.0 unit. Observed data are plotted as discrete points because of the scarcity of data for this site.



A. Total Dissolved Solids and conductivity

The national water quality guidelines recommend that the TDS concentration not change by >15% from that of the water body under unimpacted conditions at any time of the year and that the amplitude and frequency of natural cycles be maintained. For both TDS and conductivity, it is the higher concentrations or values which are of concern in the aquatic ecosystem. The percentage observed data within the established "Test Ranges" were calculated for ten sites (Tables 3.8 and 3.9), three each in the mountain stream and foothill subregions and two each in the transitional and lowland subregions.

- *Mountain Stream* : between 69% and 85% of the TDS concentrations and between 75% and 90% of the conductivity values were either within or below the TWQR. Examination of the plot of observed data over time (H1H007), suggest that short duration peaks in conductivity occurred periodically throughout the year (Figure 3.30).
- *Foothill* : between 72% and 85% of the TDS concentrations and between 60% and 90% of conductivity values were either within or below the TWQR. The observed conductivity plotted for Site H1H018 show that most of the values exceeding the TWQR are short duration peaks (Figure 3.32).
- *Transitional*: between 61% and 79% of the TDS concentrations and between 61% and 77% of conductivity values were either within or below the TWQR. Observed data exhibited considerable fluctuation (Figure 3.34; Site H4H017), particularly in winter, when 30% of the observed data exceeded the "Test Range" (median + 30%).
- *Lowland* : between 58% and 72% of the TDS concentrations and between 57% and 71% of conductivity values were either within or below the TWQR (Tables 3.8 and 3.9). Observed data exhibited considerable fluctuation (Figure 3.36; Site H7H006), particularly in summer and autumn, when 29 to 39% of the observed data exceeded the "Test Range" (median + 30%).

There was no distinct seasonal pattern in the percentage observed data within each "Test Range" for any of the subregions, although seasonal medians were generally higher in summer. In comparison to mountain stream and foothill subregions, sites in transitional and lowland subregions exhibited a greater fluctuation in both TDS concentration and conductivity, with more of the observed data exceeding the TWQR. This may indicate that at such sites the TWQR would need to be modified.

B. pH

The national water quality guidelines recommend that pH values should not be allowed to vary from the background pH values for a specific site and time of day, by > 0.5 of a pH unit, or by > 5%, and should be assessed by whichever estimate is more conservative. The percentage observed data within the established "Test Ranges" were calculated for ten sites (Tables 3.10), three each in the mountain stream and foothill subregions and two each in the transitional and lowland subregions.

- *Mountain Stream* : between 37% and 65% of the pH values were within the TWQR. A relatively large percentage of observed data had pH values between 0.5 and 1.0 of a pH unit above or below the TWQR (Table 3.10 and Figure 3.31 for H1H007).
- *Foothill :* between 43% and 70% of the pH values were within the TWQR. Again a relatively large

percentage of observed data had pH values between 0.5 and 1.0 of a pH unit above or below the TWQR (Table 3.10 and Figure 3.33 for H1H018).

- *Transitional :* between 76% and 92% of the pH values were within the TWQR (Table 3.10 and Figure 3.35 for H4H017). In 1990 and 1991 there were periodic decreases in pH possible in response to rainfall events although this would need to be verified.
- *Lowland :* between 59% and 94% of the pH values were within the TWQR (Table 3.10 and Figure 3.37 for Site H7H006).

There was no distinct seasonal pattern in the percentage observed data within each "Test Range" for any of the subregions, although seasonal medians were generally lower in autumn or winter. Upper catchments in the western and southern coast region are often poorly buffered and therefore exhibit considerable fluctuation in pH. Sites lower in the catchment are more buffered and pH is relatively more stable. On this basis, the TWQR may need to be modified for mountain stream and foothill subregions which exhibit considerable fluctuation in pH, both with respect to the percentage observed data exceeding the TWQR and diel variation in pH values (Figure 3.29).

3.3.6. Proposed protocol for the establishment of regional water quality guidelines for non-toxic inorganic constituents.

The following key is the proposed procedure for establishing site-specific Target Water Quality Ranges for non-toxic inorganic constituents. In some instances these TWQR will need to be established on a site-specific basis, whilst in others, regional TWQRs may suffice. Once a site has been identified, various steps need to be taken so that the national water quality guidelines for the particular variables can be translated into site- or region-specific ones. Various aspects related to the location of the site need to be taken into account, and the current condition of the site as reflected by the biotic community needs to be established. The general method involves systematically following steps A through D, after which the appropriate key option or process is followed.

Key for establishing site- or region-specific water quality guidelines for non-toxic inorganic constituents

Initial questions to be asked:

A. What Water Quality Management Region is Site X in?

B. What subregion is Site X in?

C. Have background concentrations and/or values been established for "least-impacted" or reference sites within this subregion?

D. What is the SASS4 Score and ASPT at Site X?

In relation to A to D above,

1 On the basis of SASS Scores, is Site X classed as a "least-impacted" site within the respective subregion and WQMR? 2

\- On the basis of SASS Scores, is Site X is classed as "impacted" site within the respective subregion and WQMR? 4

2. Water chemistry data are available for Site X? 3

\- Water chemistry data are not available for Site X? ..... PROCESS 1

Calculate the following for Site X:

- *Median concentrations and/or values for Site X*
- *Seasonal variation in median concentrations or values*
- *Diel variation in median concentrations or values*
- *The percentage of the observed data for each season which falls within the proposed Target Water Quality Range (TQWR)*

3. The TWQR is accurately reflecting the observed data ..... PROCESS 2

\- The TWQR is not accurately reflecting the observed data ..... PROCESS 3

4. Water chemistry data are available for Site X? ..... PROCESS 4

- Water chemistry data are not available for Site X?..... PROCESS 1

PROCESS 1:

- Ascertain median concentrations and/or values for reference site(s) in the same WQMR and subregion
- Does this median concentration or value vary seasonally?
- Does this median concentration or value vary diurnally?
- Set TWQR reflective of observed data by stipulating a percentage variation from seasonal median concentrations or values of the reference site within the same WQMR and subregion.
- Initiate a monitoring programme which incorporates both a chemical and biological component such as SASS. Recalculate % observed data within TWQR and evaluate site condition on the basis of SASS4 Scores.

PROCESS 2:

- Set TWQR reflective of observed data by stipulating a percentage variation from seasonal median concentrations or values, and translate percentages into values.

PROCESS 3:

- Modify TWQR such that they incorporate 80% of the observed data, again as a percentage variation from seasonal median concentrations or values. Please note that this percentage is a hypothetical one and is merely suggested in order to illustrate the proposed protocol.

PROCESS 4:

Calculate the following for Site X:

- *Median concentrations and/or values for Site X*
- *Seasonal variation in median concentrations or values*
- *Diel variation in median concentrations or values*
- *The percentage of the observed data for each season which falls within the proposed Target Water Quality Range (TWQR) for a reference site within the same WQMR and subregion*
- *If < 80% of the observed data fall within the TWQR, appropriate steps need to be taken to ensure that this is rectified,*

Initiate a monitoring programme which incorporates both a chemical and biological component such as SASS. Recalculate % observed data within TWQR and evaluate site condition on the basis of SASS4 Scores.

Appendix 3.1. Sampling methodology for the assessment of benthic macroinvertebrates and for the measurement and analysis of physical attributes and chemical constituents of the waterbodies

A. Benthic macroinvertebrates

Benthic macroinvertebrates were sampled using two methods, namely qualitative rapid bioassessment using SASS4 (South African Scoring System; Chapters 4, 5 and 7) and quantitative box-sampling (Chapter 7).

SASS4 sampling

For SASS4 sampling a kick net (300x300 mm frame, 950 μm-mesh) was held immediately downstream of the area to be sampled. All available biotopes, namely stones-in-current, stones-out-of-current, marginal vegetation, aquatic vegetation, gravel, sand and mud, were sampled. Stones were kicked for approximately two minutes if all were loose and for five minutes if some were immovable. Loose substratum was agitated and dislodged organisms were collected in the net. Vegetation was swept for approximately 2 metres, and other biotopes disturbed and swept with the net. The contents of the net were tipped into a large sorting tray, debris was removed and organisms were identified to Family level and recorded. The tray was searched for approximately 20 minutes or until five minutes had passed since an additional family had been found.

SASS was developed for use in riverine ecosystems (Chutter 1994) and is based on the Biological Monitoring Working Party (BMWP) method of the United Kingdom. Each macroinvertebrate taxon, mostly at Family level, is given a score based on its sensitivity/tolerance to water quality impairment. The current version, SASS4 (Chutter 1995), has three additional features, including, a sliding scale of scoring for two of the families, Baetidae (Ephemeroptera) and Hydropsychidae (Trichoptera), which have both tolerant and sensitive species within them. The second development was the grouping together and scoring of cased-caddisfly larvae (Trichoptera) based on the number of types of cases. Whilst it is possible to separate this group into their respective families given the correct level of taxonomic expertise and microscopic identification, SASS, which is designed to be a field-based, technician-driven monitoring system, does not permit such resolution. The third feature takes into account regional differences in intrinsic pH of river water, whereby the family Leptophlebiidae are allocated two scores; 13 for pH < 6.5 and 6 for pH > 6.5. Once a site has been sampled and each taxon recorded, the scores are summed to give a SASS4 Score, the number of taxa is counted, and an Average Score per Taxon (ASPT) value is calculated by dividing SASS4 Score by the number of taxa.

Box-sampling

For quantitative sampling, each sample was taken at random within the riffle biotope at each site using a box-sampler (area = 0.1 m^2, 250 μm-mesh). Fauna within the 0.1 m^2 area were displaced from the stones by systematically brushing and removing each stone from the sampling quadrat. Approximately 100 mm of substratum was vertically disturbed and all organisms were collected in a jar at the closed end of the box-net. Each sample was immediately fixed in 7% formalin and transferred to 70% alcohol in the laboratory.

B. Physical attributes and chemical constituents

A variety of physical attributes and chemical constituents of the water were measured at each site. *In situ* measurements were made of temperature using a mercury thermometer (accurate to ± 0.5 °C), conductivity using a Crison CDTM-523 conductivity meter (accurate to 0.01 mS cm^{-1} and with a built-in temperature compensation of 25 °C) and pH using a Crison pH/mv meter 506 (accurate to 0.01 pH unit). For *in situ* measurements of sites in the Breede River catchment (Chapter 4), temperature (accurate to ± 0.4 °C), conductivity (accurate to 3% between 0 and 2 000 mS m^{-1} and 4% between 2 000 and 10 000 mS m^{-1} and with a built-in temperature compensation of 25 °C) , pH (accuracy to ± 0. 2 pH unit), turbidity (accurate to ± 6% + 2NTU), dissolved oxygen (accuracy ± 2% of reading or ± mg l^{-1}, whichever is greater) were measured using a Grant YSI Water Quality Data logger 3800.

Water samples for chemical analyses were collected from rapidly flowing areas, filtered on site (Whatman 45 µm GF/F filter papers) and frozen within 24 hours. All filtered water, except that for analysis of ammonium, was bottled in polythene vials that had been pre-cleaned in 5% Extran^{R} solution (phosphate-free), and rinsed in deionised and then double-distilled water. Samples for analysis of ammonium were stored in glass vials which had been pre-washed in HCl.

- The concentration of total dissolved solids (TDS, mg l^{-1}) was determined by evaporating 800 ml of filtered water from pre-weighed pyrex glass beakers at 60°C. Weighing was done on a Sartorius precision laboratory balance accurate to 1 mg.
- The concentration of total suspended solids (TSS, mg l^{-1}) was calculated by filtering a measured volume of water through pre-weighed, precombusted Whatman GF/F filter papers, dried at 60°C for 48 hours and re-weighed. The organic fraction was calculated by difference after combustion at 450°C for 4.5 hours. Weighing was done on a Mettler AE 100 laboratory balance (readability and reproducibility of 0.1 mg).
- The concentrations of the anions sulphate and chloride were measured by means of ion exchange chromatography using an HPIC-AS4A anion exchange separator column, with a carbonate/ bicarbonate buffer eluent. Results were expressed in mg l^{-1}, accuracy ± 0.005 mg l^{-1}. The concentrations of the cations potassium, sodium, calcium and magnesium were measured by means of ion exchange chromatography using an HPIC-AS4A cation exchange separator column, with an appropriate eluent. Results were expressed in mg l^{-1}, accuracy ± 0.005 mg l^{-1}.
- Total alkalinity was measured by titrating the sample with 0.005M HCl (methyl orange indicator) according to the method prescribed by Golterman *et al.* (1978). Standardisation was against NaOH, titrated with 0.005M oxalic acid (phenolphthalein indicator). Results were obtained as mg l^{-1} $CaCO_3$, and expressed as meq l^{-1}. Accuracy is estimated at 2-10%.
- The concentration of the nutrients: ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^-- N), nitrite nitrogen (NO_2^-- N) and soluble reactive phosphorus (SRP; PO_4^{3-}- P) were determined using a Technikon Auto Analyser (AA11), unless otherwise specified. The principles of the method are outlined in Mostert (1983). Results are expressed in mg l^{-1} of the nutrient atom. For nitrite and nitrate, the detection limit is 1 µg l^{-1}.

Appendix 3.2. Details of DWAF sites, data used and statistical results for analysis of seasonal variation in TDS, conductivity and pH. Subregion: M = mountain stream, F = foothill and L = lowland subregion. Data used: W = weekly, M = monthly, MX = mixed weekly and monthly sampling.

SUBREGION	RIVER	DWAF SITE	DATA USED	VARIABLE	SIG.	KRUSKAL-WALLIS H	N
M	Wit @ Drosterskloof	H1H007	W, 1985-1995	Cond	P<0.01	73.6	464
			MX, 1985-1995	TDS	P<0.01	28.6	426
			W, 1990-1995	pH	N.S.		255
M	Rooi-elskloof @ Roode Els Berg	H2H005	M, 1985-1995	Cond	N.S.		107
			M, 1985-1995	TDS	N.S.		92
			M, 1990-1995	pH	N.S.		63
M	Baviaans @ Genadendal Mission Station	H6H005	M, 1985-1995	Cond	P<0.01	21.9	118
			M, 1985-1995	TDS	N.S.		109
			M, 1990-1995	pH	N.S.		65
M	Riviersonderend @ Nuweberg Forest Reserve	H6H008	M, 1985-1992	Cond	P<0.01	32.4	84
			M, 1985-1992	TDS	N.S.		75
			M, 1990-1992	pH	N.S.		31
F	Molenaars @ Hawequas Forest Reserve	H1H018	W, 1985-1995	Cond	P<0.01	114.7	463
			MX, 1985-1995	TDS	P<0.01	53.1	424
			W, 1990-1995	pH	P<0.01	30.3	252
F	Sanddrifskloof @ Zanddrifts Kloof	H2H004	W, 1980-1992	Cond	P<0.05	19.1	190
			M, 1990-1992	TDS	P<0.05	19.3	119
			M, 199-1992	pH	N.S.		28
F	Holsloot @ Daschbosch Rivier	H1H012	W, 1981-1986	Cond	P<0.01	37.0	175
			MX, 1981-1986	TDS	N.S.		81
			MX, 1981-1986	pH	P<0.01	23.7	90
F	Duiwenshoek @ Broken Hill	H8H002	MX, 1980-1984	Cond	P<0.05	19.7	140
			MX, 1980-1984	TDS	N.S.		71
			MX, 1980-1984	pH	N.S.		72

SUBREGION	RIVER	DWAF SITE	DATA USED	VARIABLE	SIG.	KRUSKAL-WALLIS H	N
T	Bree @ Secunda	H5H004	W, 1990-1995	Cond	P<0.01	166.5	261
			W, 1990-1995	TDS	P<0.01	138.9	222
			W, 1990-1995	pH	P<0.01	127.5	261
T	Bree @ La Chasseur	H4H017	W, 1990-1995	Cond	P<0.01	50.9	257
			W, 1990-1995	TDS	P<0.01	45.8	217
			W, 1990-1995	pH	P<0.01	17.3	257
T	Bree @ Die Nekkies	H1H015	W, 1990-1995	Cond	P<0.01	49.9	223
			W, 1990-1995	TDS	P<0.01	36.5	199
			W, 1990-1995	pH	P<0.01	34.4	223
L	Bree @ Swellendam	H7H006	W, 1985-1995	Cond	P<0.01	192.2	455
			M, 1985-1995	TDS	P<0.01	54.8	115
			M, 1990-1995	pH	P<0.05	20.4	63
L	Riviersonderend @ Reenen	H6H009	W, 1985-1995	Cond	P<0.01		441
			M, 1985-1995	TDS	N.S.		117
			M, 1990-1995	pH	N.S.		64

CHAPTER 4. BREEDE RIVER CATCHMENT ASSESSMENT

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4.1 INTRODUCTION

The previous chapter provided information on the establishment of regional water quality guidelines for non-toxic inorganic constituents. Background concentrations and values were calculated for each subregion within the southern and western Coast TWQR, and variations resulting from differences between subregion, season and diel changes explored. A protocol for establishing regional water quality guidelines for these constituents was proposed. A protocol for monitoring the effectiveness of the guidelines was also included in the original terms of reference for the current project. During the last two years, however, attention nationally has been focused on the establishment of a national biomonitoring programme for riverine ecosystems (Brown *et al.* 1996, Uys *et al.* 1996). One of the components of the proposed biomonitoring programme is SASS4 which is likely to become an integral facet of the programme. On this basis, and given its proven ability to detect changes or impairment in water quality (Chutter 1995, Dallas 1995),we propose that this method be adopted for monitoring the effectiveness of the guidelines.

Of primary importance in monitoring the effectiveness of the guidelines is the need to have a reference condition against which SASS4 Scores can be compared. The method by which this reference condition shall be calculated is not yet established, but it is clear that a selection of reference sites is needed to facilitate the process. Reference sites have been defined as relatively unimpacted sites that can be used to define the best physical habitat, water quality and biological parameters for a particular kind of river (Eekhout *et al.* 1996). Such reference sites need to be in the same bioregion, subregion (e.g. foothill or lowland river) and river type (e.g. ephemeral or perennial) as a site under investigation. SASS scores at monitoring sites, which are defined by Eekhout *et al.* (1996) as sites selected to assess condition of available physical habitat, water quality and biological parameters for a river, relative to the expected unimpacted condition (i.e. that of the reference site) can then be ascertained. The difference between "expected scores" at reference sites and "observed scores" at monitoring sites can be used to assess the impairment of water quality.

This chapter outlines an assessment undertaken of the Breede River catchment (DWAF drainage region H) aimed at establishing the current condition of the catchment with respect to the biota, as reflected by SASS4, and water quality. The intention is to provide a "state of the catchment" type of assessment from which additional clarity on SASS4 Scores and water quality characteristics can be gleaned. On the basis of this assessment and other SASS4 assessments within the southern and western coast TWQR, a preliminary reference condition for SASS will be established for each subregion (Chapter 5).

4.2 METHODOLOGY

Forty-eight sites were sampled within the Breede River catchment and two in a smaller adjacent catchment, namely the Duiwenshoek, in November 1995 (Figure 4.1, Appendix 4.1). Hereafter they are grouped together and referred to as the "Breede River catchment sites". Of these fifty sites, 38 were at DWAF gauging weirs for which chemical data are (or were) available. An additional 12 sites were selected to increase the coverage of sites. Twenty-four sites were in Mountain Streams, 15 in Foothills, six in the Transitional subregion, and five in Lowland rivers. The primary aim of the study was to

undertake biological assessments of each site, simultaneously with measurements of water quality parameters. A wide range of supplementary information was also recorded at each site. The methods used and type of information recorded at each site are listed below.

4.2.1 Biological and biotope assessments

SASS4 Assessments

Each site was scored using the rapid bioassessment method SASS4 (Chutter 1995; Appendix 4.1) and the presence of each SASS taxon recorded.

HABS1 (Habitat Quality Evaluation)

The diversity of available SASS biotopes (such as stones-in-current, stones-out-of-current, marginal vegetation, aquatic vegetation, gravel, sand and mud); and the specific biotope (i.e. riffle, run, pool, backwater etc.), may influence SASS Scores. HABS1 scores (Appendix 4.1), based on the number of SASS biotopes, were therefore calculated for each site (Chutter 1994) and the biotopes sampled were noted (Appendix 4.1). Values can vary between 0 and 100.

Habitat Assessment Matrix (HAM)

Physical degradation of habitat such as erosion, bank modification or removal of indigenous riparian vegetation, may indirectly affect SASS scores. The system adapted by Roux (1993) from that of Plafkin et al. (1989) has been used to assess this (Appendix 4.1). This scoring system relates to the physical habitat of the site and includes information on bottom substrate/available cover, embeddedness, biotope diversity categories, velocity/depth categories, area of bottom affected by scouring and deposition, pool/riffle and run/bend ratios, bank erosion potential, bank vegetation stability and streamside cover (dominant vegetation). Values can vary between 0 and 135.

4.2.2 Physical attributes and chemical parameters

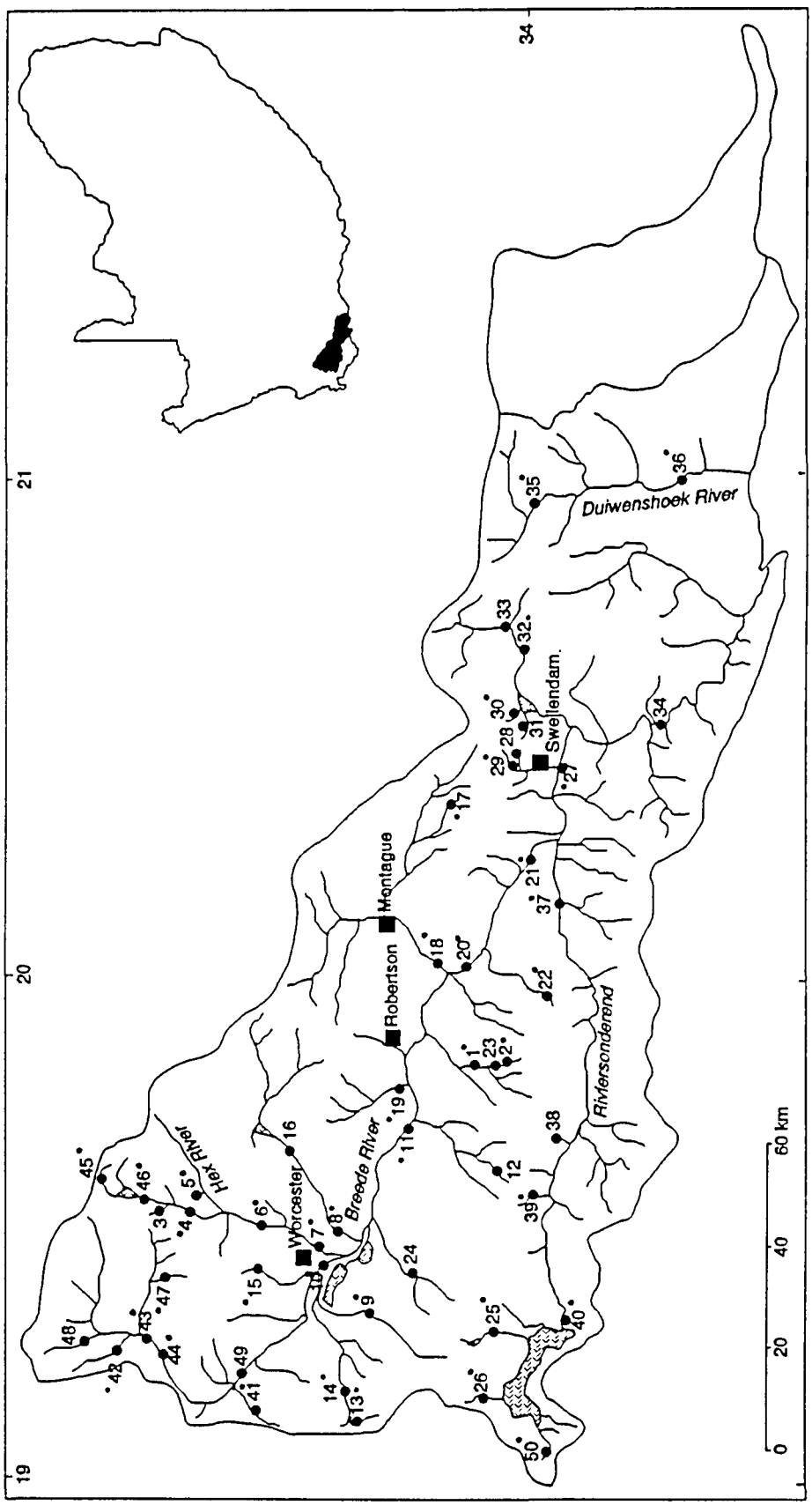
In situ measurements of conductivity, pH, temperature, dissolved oxygen and turbidity were taken; and water samples were collected for subsequent analysis of total dissolved solids (TDS), total suspended solids (TSS), total alkalinity (TAL), anions (sulphate and chloride), cations (sodium, magnesium, potassium and calcium), nutrients (nitrate-N, nitrite-N, soluble reactive phosphorus-SRP and silica) and certain metals (cadmium, zinc, chromium, copper, aluminium, iron, mercury and manganese) were measured (Appendix 4.2). Details of the analytical techniques and instruments used are given in Appendix 3.1 of Chapter 3. In addition to these analyses, Department of Water Affairs and Forestry (DWAF) chemical data were examined for 38 of the sites and median, minimum and maximum concentrations and values calculated (Appendix 4.3) for each site.

4.2.3 Physical characterisation of sites

Channel information

The type of channel (i.e. single, braided, meandering) was noted and the width of the water,

Figure 4.1. The Breede River catchment in the southern and western TWQR showing sites sampled in late October and November 1995. The sites near DWAF water quality monitoring station are indicated by asterisks.



maximum water depth, riffle depth, bank width and bank height were measured. The potential for bank erosion was estimated.

Substratum characteristics

An estimate was made of the percentage of each substratum-type including bedrock, boulder, cobble, gravel, sand and silt/mud; the percentage detritus present; and degree of embeddedness of the boulders, cobble etc.

Riparian vegetation

The percentage total cover of the riparian vegetation and width of the riparian belt were estimated, and the percentage of indigenous versus exotic vegetation approximated.

Aquatic vegetation

The presence and percentage cover of nuisance macrophytes and algae in the wetted channel were estimated.

4.2.4 Existing land use, physical modifications, water quality impacts and ecological status

Land use

Land use upstream of the site, within the first five metres adjacent to the river and beyond five metres from the river were recorded.

Physical modifications

Modifications to the bank and/or channel such as bulldozing, canalisation, in-filling, etc., were noted.

Water quality

All potential point sources (such as sewage treatment works, fish farm effluents and impoundments such as dams) and non-point sources (such as agricultural runoff, afforestation and road construction) sources of pollution were noted.

Ecological importance and status

Recent work by Eekhout & Brown (1996) aimed at developing a classification of the ecological importance of riverine systems in the Western Cape province. They defined ecological importance as a measure of the ecological (natural) values of a river. It refers specifically to the biotic and abiotic characteristics of the river under consideration (e.g. the presence of rare and endangered species, habitat diversity). Ecological status is a measure of the extent to which the river has been detrimentally affected by anthropogenic activities. Eekhout & Brown (1996) modified the assessment procedure of Kleynhans (1996) and developed a method by which the ecological status of sites could be established (Table 4.1). This work is, however, of a preliminary nature and still needs to verified more broadly. The ecological status of each site is given in Appendix 4.1.

Table 4.1. Ecological Status Classes (from Eekhout & Brown 1996)

STATUS CLASS	DESCRIPTION
1	100% of potential value; unmodified, natural
2	80-99% of potential value; largely natural with a few modifications. In this class a small change in natural habitats and biota may have taken place, but the assumption is that ecosystem functioning is essentially unchanged
3	60-79% of potential values and moderately modified and a loss or change in habitat and biota has occurred, but basic functioning appears predominantly unchanged
4	40-59% of potential values and largely modified and a loss of habitat and biota and a reduction in basic ecosystem functioning is assumed to have occurred
5	20-39% of potential value, seriously modified and at which the loss of natural habitat, biota and ecosystem functioning is extensive
6	0-19% of potential value, modifications have reached a critical level and there has been an almost complete loss of natural habitat and biota. In the worst cases, the basic ecosystem functioning has been destroyed

4.2.5 Geographic and map-based information

Information on the latitude, longitude, altitude, distance (in km) from source and stream order were derived from maps. The predominant geological type, based on the geological survey maps, and vegetation type, based on Acocks (1953) veld types, were recorded.

4.2.6 Data analysis

Biological data

Multivariate procedures were selected for analyses of macroinvertebrate community-based data gathered in this study. In contrast to univariate analyses (e.g. ANOVA, regression), multivariate procedures consider each species/family to be a variable and the presence/absence or abundance of each species/family to be an attribute of a site or time (Norris & Georges 1993). SASS taxonomic data were transformed using the presence/absence transformation (PRIMER VER.4) and the Bray-Curtis coefficient was used on these transformed data. Comparison of each sample with every other sample using this measure of similarity/dissimilarity leads to a triangular matrix, which can then be used in cluster and ordination analyses. Hierarchical agglomerative clustering, using group-average linking, was used on the data matrix. Ordination of samples by multi-dimensional scaling (MDS) was undertaken, and stress values used to assess the reliability of the MDS ordination. The distinguishing taxa responsible for the groupings were established using SIMPER (PRIMER V.4.). SASS4 Scores, ASPTs, Number of Taxa, HAM and HABS1 scores were overlaid on the biological MDS ordination, such that the magnitude of each is displayed (CONPLOT, PRIMER V.4.).

Physical variables and chemical constituents

Water chemistry data, excluding pH, and the cation and anion ratios, were $\log_{10}(x)$ transformed and the

normalised Euclidean distance measure was used on the data. Hierarchical agglomerative clustering, using a group-average linking, was used on the dissimilarity matrix (PRIMER VER.4). The chemical constituents measured in the current study and used in subsequent analyses included pH, conductivity (mS m^{-1}), dissolved oxygen (mg l^{-1}), TSS (mg l^{-1}), ($NO_2^-+NO_3^-$)-N (mg l^{-1}), Soluble Reactive Phosphorus (SRP; mg l^{-1}) and SiO_2 (mg l^{-1}). Cation $[Na^+]+[K^+]$ / $[Na^+]+[K^+]+[Ca^{2+}]+[Mg^{2+}]$, where [ ] means "concentration of", and anion $[Cl^-]$/ $[Cl^-]+[HCO_3^-]$ ratios were calculated and included in the analyses. For DWAF data, conductivity, pH, ($NO_2^-+NO_3^-$)-N, Soluble Reactive Phosphorus (SRP), NH_4, SiO_2, cation ratio and anion ratio were used in the analysis. Principal components analysis (PCA; STATISTICA Version 5) was used to display on a two- or three-dimensional graph which of these chemical constituents best explained the variation between sites. PCA analysis was also conducted on log(x) transformed metal concentrations measured at 49 of the 50 sites in the Breede River catchment.

Linking biological and chemical data

Two techniques were used to investigate the relationship between the biological communities and the physical attributes and chemical constituents of the sites. Data were analysed using BIOENV (PRIMER V.4.) which attempts to establish which physical or chemical constituents best relate to the biological data in a multi-dimensional manner. The chemical constituents used in this analysis were the same as those used for cluster analysis. Each physical attribute and chemical constituent was also overlaid on the biological MDS ordination, such that the magnitude of each variable is displayed (CONPLOT, PRIMER V.4.).

4.3 RESULTS

Categorisation of sites into water quality groups was based on the method described in Chapter 3 whereby a minimum SASS4 Score and ASPT are used to differentiate sites into "least impacted" (or "reference") sites and impacted sites. Hereafter "least impacted" sites are referred to as reference sites. On this basis, of the

- 24 sites in Mountain Streams, 15 were considered reference sites, and nine impacted;
- 15 sites in Foothills, five were considered reference sites, and ten impacted;
- six sites in the Transitional subregion, three were reference sites and three impacted; and
- five sites in Lowland rivers, three were considered reference sites, and two impacted.

4.3.1 Biological and biotope assessments

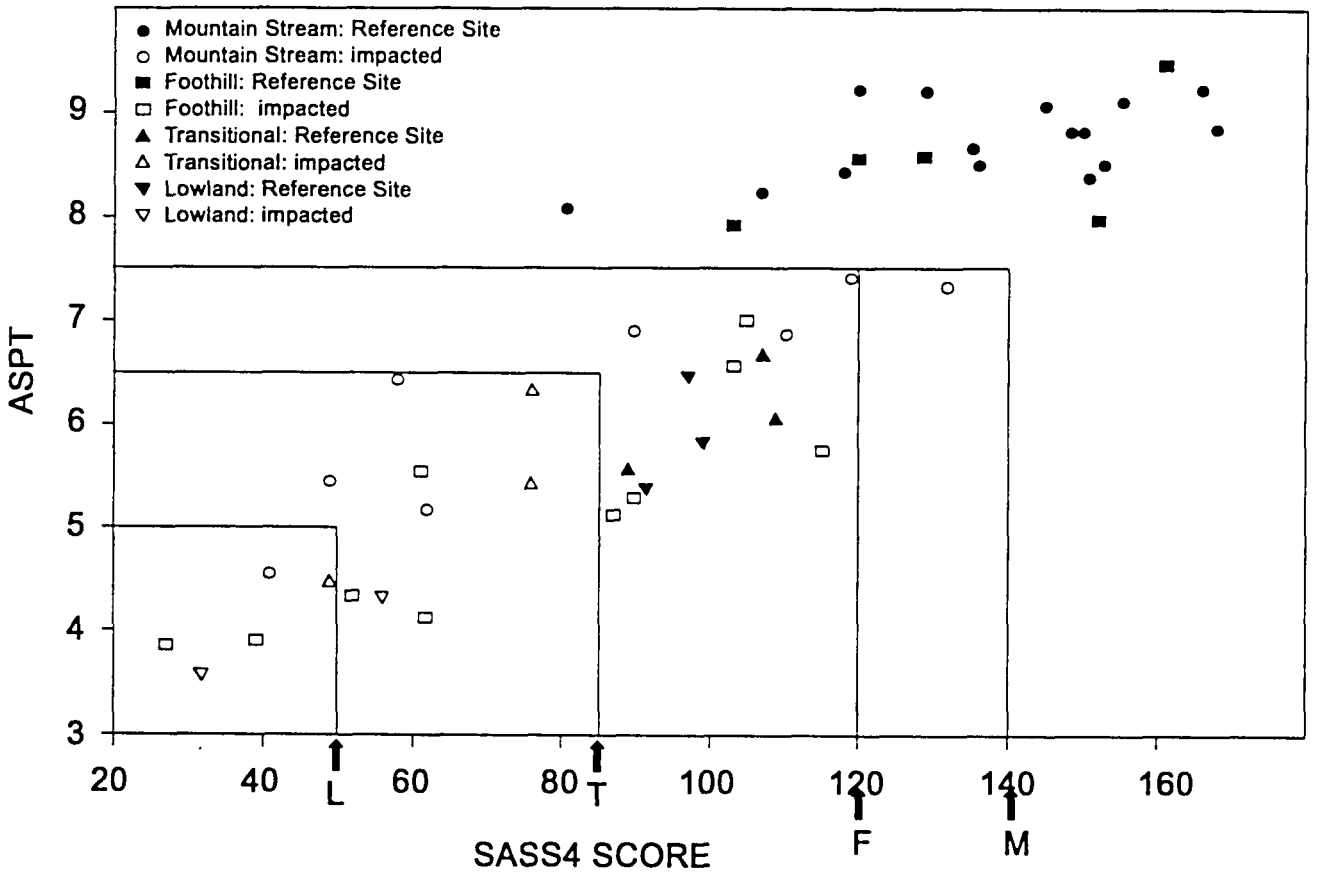
A. SASS Scores and macroinvertebrate communities

The median SASS4 Scores, ASPTs, Number of Taxa, HAM scores and HABS1 scores for reference sites are given in Table 4.2. Of the reference sites in the mountain stream and foothill subregions, all had SASS4 Scores > 140 or ASPTs > 7.5, suggesting that the differentiation between these two subregions is not necessary. Similarly, reference sites in transitional and lowland subregions all had SASS4 Scores > 85 or ASPTs > 6.5. SASS4 Scores and ASPTs for each site are plotted in Figure 4.2. The minimum SASS4 Scores and ASPT values used to differentiate reference sites from impacted ones for each subregion are indicated on the graph.

Table 4.2. Median SASS4 Scores, ASPTs, Number of Taxa, HAM scores and HASB1 scores for reference sites in different subregions within the Breede River catchment. Transitional and lowland sites are considered together.

	Mountain Stream	Foothill	Transitional + lowland
SASS4 Score	145	129	98
ASPT	8.82	8.57	5.94
Number of Taxa	16	15	17
HAM	119	119	85
HABS1	85	85	88
n	15	5	6

Figure 4.2. ASPT values plotted as a function of SASS4 Scores for fifty sites in the Breede River catchment. Solid symbols denote reference sites and open symbols impacted ones. The minimum SASS4 Score and ASPT used to differentiate sites into these two types are displayed for each subregion (M = Mountain Stream, F = Foothill, T = Transitional and L = Lowland).



The frequency with which each SASS invertebrate group or taxon occurred was calculated for sites on the basis of division into reference versus impacted sites for each subregion (Table 4.3). Transitional and lowland subregions were combined. Leptophlebiidae, which have different scores depending on the pH of water, and Baetidae, Hydropsychidae and cased-caddis, which have a sliding scale of scoring based on the number of types in the sample, are divided into more than one group in the SASS4 scoring system.

Table 4.3. The frequency of occurrence (as a percentage) of each SASS4 taxon in reference (R) and impacted (I) sites representative of mountain stream (M), foothill (F) and transitional + lowland river (T + L) sites. The number of sites (n) within each group is given. Those percentages > 50 are given in bold.

		M		F		T + L	
		R	I	R	I	R	I
	n	15	9	5	10	6	5
GROUP	TAXON						
ANNELIDA	OLIGOCHAETA	27	**56**	0	**100**	**50**	**100**
ARACHNIDA	HYDRACHNELLAE	13	**56**	20	17	0	0
COLEOPTERA	DYTISCIDAE	20	**67**	20	33	17	40
COLEOPTERA	ELMIDAE/DRYOPIDAE	**93**	33	**100**	33	**50**	40
COLEOPTERA	GYRINIDAE	40	**67**	**60**	**100**	**67**	20
COLEOPTERA	HELODIDAE LARVAE	**60**	11	**80**	0	0	0
COLEOPTERA	HYDRAENIDAE	**53**	**56**	40	0	0	0
COLEOPTERA	HYDROPHILIDAE LARVAE	0	22	0	17	0	0
COLEOPTERA	LIMNICHIDAE	40	0	0	17	33	0
CRUSTACEA	AMPHIPODA	27	0	20	0	0	0
CRUSTACEA	BRACHYURA (CRABS)	13	22	40	**67**	**50**	40
CRUSTACEA	NATANTIA (SHRIMPS)	0	0	0	0	**67**	20
DIPTERA	ATHERICIDAE	40	22	0	0	0	0
DIPTERA	BLEPHARICERIDAE	13	0	20	0	0	0
DIPTERA	CERATOPOGONIDAE	0	22	0	17	17	20
DIPTERA	CHIRONOMIDAE	**87**	**100**	**100**	**100**	**100**	**100**
DIPTERA	CULICIDAE	0	11	0	0	0	0
DIPTERA	EMPIDIDAE	7	11	0	**50**	0	20
DIPTERA	MUSCIDAE	7	11	0	0	0	0
DIPTERA	SIMULIIDAE	**100**	**100**	**100**	**100**	**83**	**100**
DIPTERA	SYRPHIDAE	0	0	0	0	0	0
DIPTERA	TABANIDAE	7	0	0	33	0	0
DIPTERA	TIPULIDAE	27	33	40	0	0	0
EPHEMEROPTERA	BAETIDAE 1 TYPE	27	22	0	0	0	**60**
EPHEMEROPTERA	BAETIDAE 2 TYPES	33	44	40	33	0	0
EPHEMEROPTERA	BAETIDAE 3 TYPES	40	33	60	**67**	**100**	40
EPHEMEROPTERA	CAENIDAE	20	33	20	**50**	**83**	**60**
EPHEMEROPTERA	EPHEMERELLIDAE	**100**	33	60	17	17	0
EPHEMEROPTERA	HEPTAGENIIDAE	13	0	60	17	33	0
EPHEMEROPTERA	LEPTOPHLEBIIDAE (pH<6.5)	**93**	22	80	0	0	0
EPHEMEROPTERA	LEPTOPHLEBIIDAE (pH>6.6)	0	33	20	**50**	**100**	20
EPHEMEROPTERA	TRICORYTHIDAE	0	0	0	33	67	0
GASTROPODA	ANCYLIDAE	0	11	0	33	**50**	**100**
GASTROPODA	LYMNAEIDAE	0	0	0	33	**50**	20
GASTROPODA	PHYSIDAE	0	0	0	17	17	0
GASTROPODA	PLANORBIDAE	7	0	0	0	0	0
HEMIPTERA	BELASTOMATIDAE	13	11	0	**50**	0	0
HEMIPTERA	CORIXIDAE	0	0	0	17	**50**	**60**
HEMIPTERA	GERRIDAE	7	11	0	17	17	0
HEMIPTERA	NAUCORIDAE	0	22	20	17	33	20
HEMIPTERA	NOTONECTIDAE	0	11	0	0	17	0
HEMIPTERA	PLEIDAE	0	0	0	17	33	40
HEMIPTERA	VELIIDAE	13	22	20	**50**	17	20
LEPIDOPTERA	PYRAUSTIDAE	0	11	0	33	0	0
MEGALOPTERA	CORYDALIDAE	**53**	22	**100**	0	0	0
ODONATA	AESHNIDAE	13	22	60	0	17	0
ODONATA	CHLOROLESTIDAE	13	22	0	17	0	0

		M		F		T + L	
		R	I	R	I	R	I
ODONATA	COENAGRIONIDAE	40	22	0	33	33	60
ODONATA	CORDULIIDAE	7	0	0	17	17	0
ODONATA	GOMPHIDAE	20	22	20	33	17	20
ODONATA	LIBELLULIDAE	7	22	20	17	33	20
ODONATA	PLATYCNEMIDIDAE	13	0	0	0	17	0
ODONATA	ZYGOPTERA JUVENILES	20	0	0	0	17	20
PELECYPODA	CORBICULIDAE	0	0	0	0	67	20
PLATYHELMINTHES	PLANARIIDAE	7	11	0	0	17	40
PLECOPTERA	NOTONEMOURIDAE	53	0	40	17	17	0
TRICHOPTERA	ECNOMIDAE	40	33	20	17	17	0
TRICHOPTERA	HYDROPSYCHIDAE 1 TYPE	47	11	60	33	33	0
TRICHOPTERA	HYDROPSYCHIDAE 2 TYPES	20	11	40	50	50	20
TRICHOPTERA	HYDROPSYCHIDAE 3 TYPES	0	0	0	0	0	20
TRICHOPTERA	HYDROPTILIDAE	0	11	0	0	50	0
TRICHOPTERA	PHILOPOTAMIDAE	53	0	80	0	0	0
TRICHOPTERA	CASE CADDIS 1 TYPE	0	22	20	33	17	20
TRICHOPTERA	CASE CADDIS 2 TYPES	20	22	20	0	17	0
TRICHOPTERA	CASE CADDIS 3 TYPES	80	11	60	17	0	0

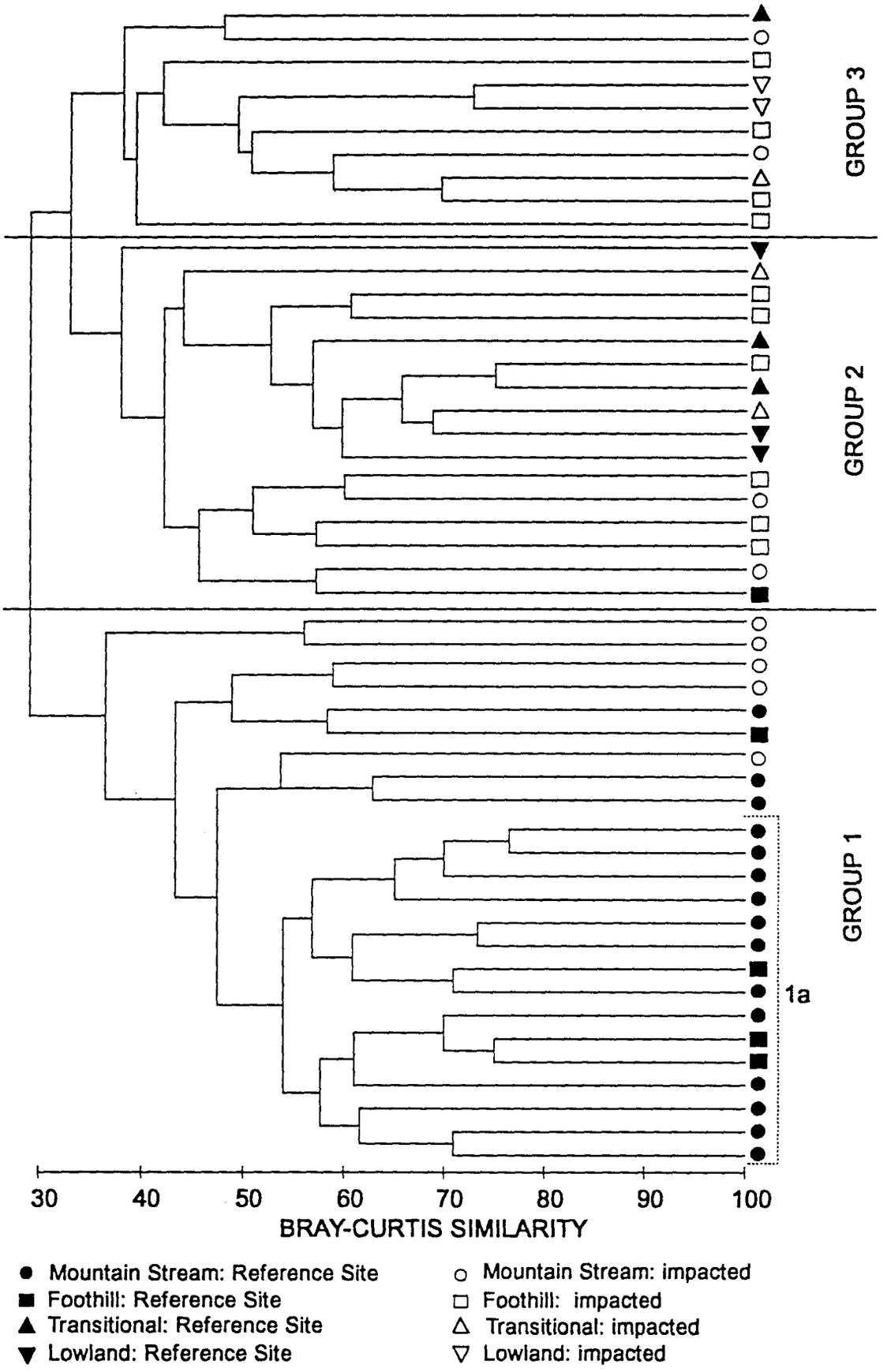
Those taxa recorded at >50% of the reference sites but <50% at the impacted sites, included the following:

- *Mountain Stream*: elmid, dryopid and helodid beetles, ephemerellid and leptophlebid (pH<6.5) mayflies, corydalid alderflies, notonemourid stoneflies, and philopotamid and cased caddisflies.
- *Foothill* : elmid, dryopid and helodid beetles, ephemerellid, heptageniid and leptophlebid (pH<6.5) mayflies, corydalid alderflies, notonemourid stoneflies, and philopotamid and cased caddisflies.
- *Transitional and lowland* : elmid, dryopid and gyrinid beetles, crabs and shrimps, three types of baetid mayflies, leptoplebid (pH>6.6) mayflies, lymnaeid snails, corbiculid bivalves, and hydropsychid and hydroptilid caddisflies.

Cluster analysis and multi-dimensional scaling (MDS)

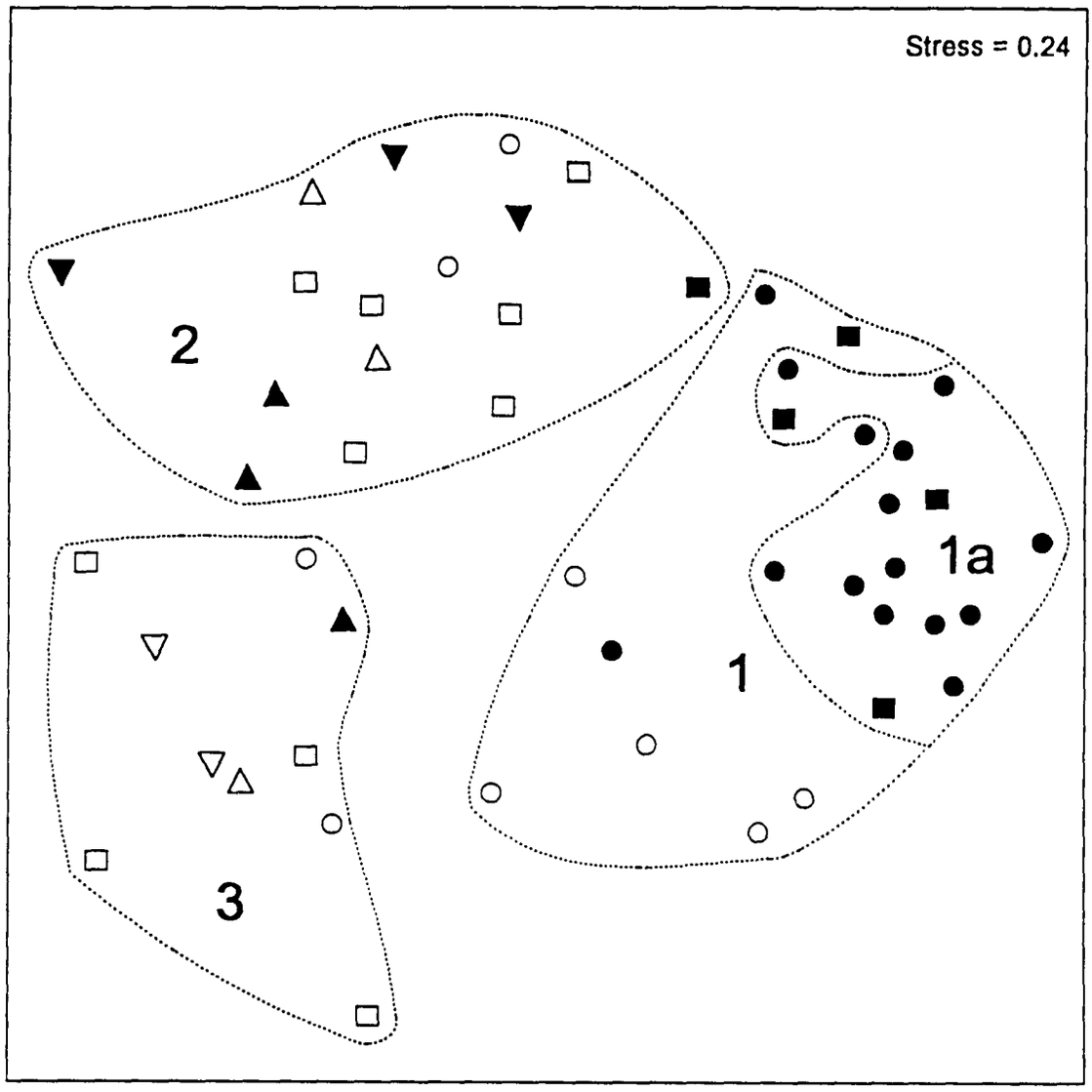
Three groups were apparent at the 35% similarity level (Figures 4.3 and 4.4). All reference sites for the mountain stream subregion and four of the five foothill reference sites grouped together (Group 1, Figures 4.3 and 4.4). Five mountain stream sites classed as impacted on the basis of SASS Scores also formed part of Group 1, although two of these sites, 15/HART and 42/KOEK, split from Group 1 at the 39% similarity level. The remaining three, 45/VALSGAT, 47/VALS and 48/CAS, had SASS4 Scores between 110 and 132 and ASPTs between 6.88 and 7.44. The formation of an intermediate category for the interpretation of SASS Scores would include these sites. This aspect is explored further in Chapter 5. A sub-group (1a) consisting of all the mountain stream sites and three foothill sites grouped together at the 63% level. Group 2 consisted of the transitional reference sites and two of the three lowland reference sites. Impacted sites within the mountain stream and foothill subregions were dispersed between groups 2 and 3. One foothill reference site, 36/HEID, occurred in Group 2, suggesting that although SASS Scores classed it as a reference site, community analysis grouped it as impacted. In the MDS ordination it was however spatially close to Group 1 (Figure 4.4). Two transitional sites, 21/DREW and 35/DUIW,

Figure 4.3 Dendrogram showing the classification of SASS4 samples collected at fifty sites in the Breede River catchment.



classed as impacted sites were also included in Group 2. These sites had SASS4 Scores and ASPTs of 80 and 76, and 5.33 and 6.33 respectively. They may again provide information of SASS scores for intermediate categories of scores for interpretation of SASS scores (Chapter 5). Group 3 consisted mostly of severely impacted sites across all subregions and had SASS4 Scores between 27 and 76 and ASPTs between 3.56 and 5.44. One transitional reference site, 10/NEK, was also in with Group 3.

Figure 4.4. Ordination of SASS4 samples collected at fifty sites in the Breede River catchment. The groups have been outlined manually on the basis of the results of the cluster analysis.



Identification of distinguishing taxa

The taxa principally responsible for differences in community structure between Groups 1, 2 and 3, as measured by the Bray-Curtis similarity measure, are in Table 4.4.

- Groups 1 and 2 (average dissimilarity = 68.6%) differed in the abundance of 15 taxa, of which Ephemerellidae, Leptophlebiidae (at pH <6.5), Corydalidae and cased-caddis Trichoptera were more numerous within sites in Group 1, and Leptophlebiidae (at pH>6.6), crabs, Oligochaeta and Gyrinidae were more numerous within sites in Group 2.
- Groups 1 and 3 (average dissimilarity = 75.3%) differed in the abundance of 16 taxa, of which Elmidae/Dryopidae, Ephemerellidae, Leptophlebiidae (at pH <6.5), cased-caddis Trichoptera and Corydalidae were more numerous within sites in Group 1, and Corixidae, Caenidae, Oligochaeta and Dytiscidae were more numerous within sites in Group 3.
- Groups 2 and 3 (average dissimilarity = 66.9%) differed in the abundance of 16 taxa, of which crabs, Leptophlebiidae (at pH>6.6), Baetidae 3 types, Gyrinidae and Elmidae/Dryopidae were more numerous within sites in Group 2, and Corixidae, Dytiscidae, Caenidae, Baetidae 1 types and Ancylidae were more numerous within sites in Group 3.

B. Relationship between macroinvertebrate community analysis and SASS, HAM and HABS1 Scores

The relationship between the MDS ordination of macroinvertebrate communities and various scores such as SASS4 Score, ASPT, HAM and HABS1 was examined for the fifty sites sampled within the Breede River catchment (Figure 4.5) by conducting CONPLOTS of the scores overlaid on the MDS ordination as shown in Figure 4.4. In these plots the size of the circle relates to the score such that the larger the circle the higher the score. For SASS4 Score (Figure 4.5A) and ASPT (Figure 4.5B), sites in Group 1 of the ordination generally had considerably higher scores than those in Groups 2 and 3. The Number of Taxa (Figure 4.5C) recorded at each site did not show the same pattern suggesting that higher scoring taxa were more frequently recorded at sites within Group 1. HAM scores were higher at sites in Group 1 and generally lowest at sites within Group 3 (Figure 4.5D). Many of the sites within Group 1 were higher in the catchment and had not been physically degraded by anthropogenic activities. HABS1 (Figure 4.5E) showed little difference between groups with the exception of one very low scoring site within Group 3 and intermediate and high scores were present in all groups. HABS1 relates directly to the diversity of SASS biotopes sampled when conducting SASS assessments and hence to biotopes available for habitation by the macroinvertebrate communities. The absence of a distinct pattern suggests that biotope availability may not affect community structure as reflected by MDS ordination.

4.3.2 Physical attributes and chemical constituents

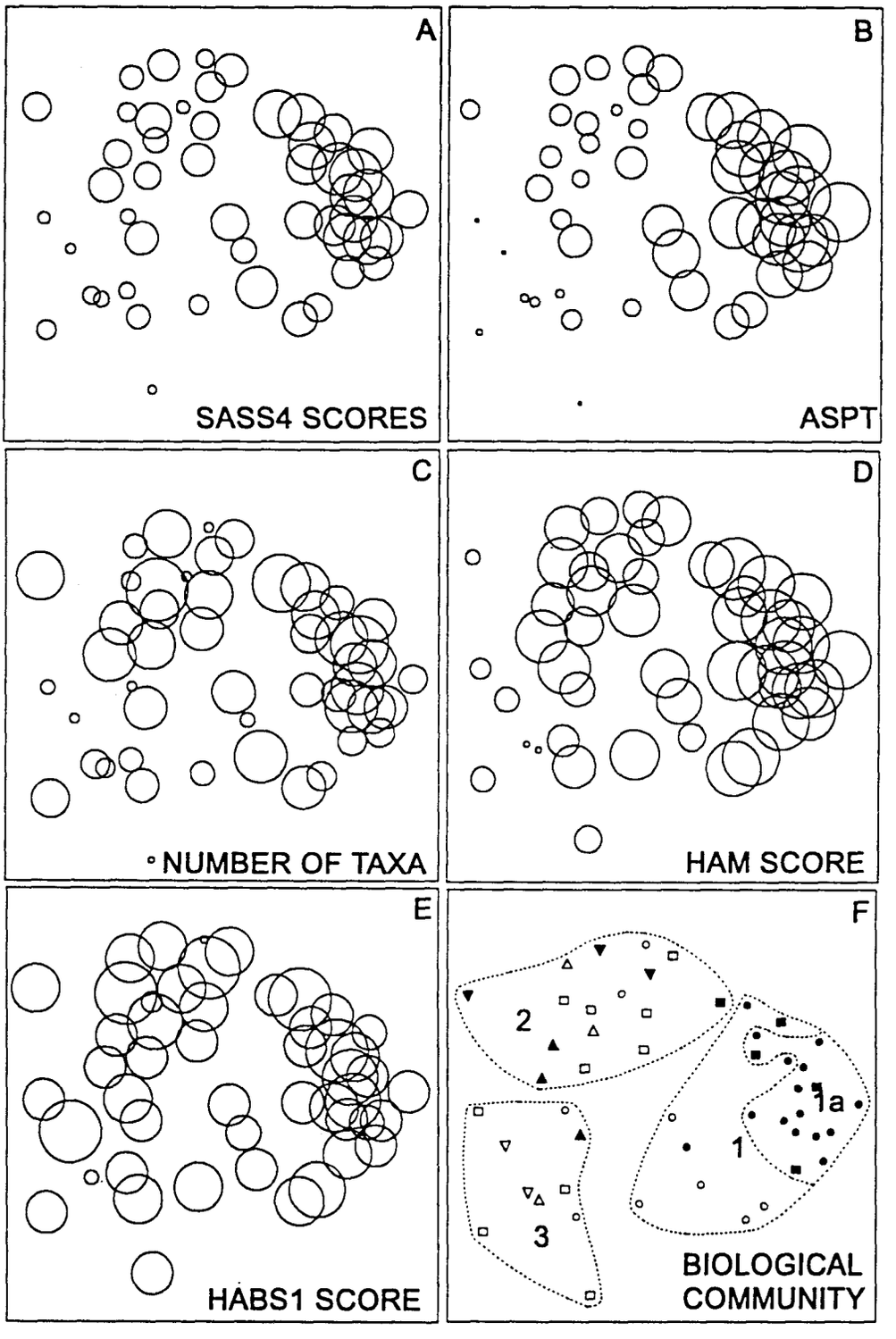
"Spot" data

Cluster analysis of chemical constituents for the fifty sites sampled in the current study revealed a separation into four groups at the normalised Euclidean distance of approximately 4.0 (Figure 4.6). Group 1 consisted of 12 of the 15 mountain stream reference sites and four of the five foothill reference sites. Six impacted mountain stream sites were also included in Group 1. A subgroup (1a) of Group 1 occurred at a Euclidean distance of 3.5. Group 2 consisted of a mix of impacted mountain stream, foothill and transitional sites, as well as the transitional and lowland reference sites. Group 3,

Table 4.4. SIMPER comparison for presence/absence transformed taxa between groups 1, 2 and 3. δi is the contribution of the *i*th taxon to the average Bray-Curtis dissimilarity, δ , between two groups, which is expressed as cumulative percentage ($\Sigma \delta i$ %). Taxa are listed in decreasing order of importance in contribution to δ. The taxon with the greater abundance is indicated with an asterisk.

AVERAGE DISSIMILARITY BETWEEN GROUP 1 AND 2 = 68.6				
	GREATER ABUNDANCE			
TAXON	GROUP 1	GROUP 2	δi	$\Sigma \delta i$ %
EPHEMERELLIDAE	X		4.4	4.4
LEPTHOPHLEBIIDAE (PH<6.5)	X		4.2	8.5
LEPTHOPHLEBIIDAE (PH>6.6)		X	3.4	11.9
BRACHYURA (CRABS)		X	3.3	15.2
CORYDALIDAE	X		3.1	18.3
CASED CADDIS 3 TYPES	X		3.1	21.3
OLIGOCHAETE		X	3.0	24.4
GYRINIDAE		X	2.7	27.1
BAETIDAE 3 TYPES		X	2.7	29.8
HELODIDAE	X		2.6	32.4
PHILOPOTAMIDAE	X		2.4	34.8
HYDRAENIDAE	X		2.4	37.1
HYDROPSYCHIDAE 2 TYPES		X	2.4	39.5
HYDROPSYCHIDAE 1 TYPE	X		2.3	41.9
ELMIDAE/DRYOPIDAE	X		2.3	44.1
VELLIDAE		X	2.2	46.4
NOTONEMOURIDAE	X		2.2	48.6
AVERAGE DISSIMILARITY BETWEEN GROUP 1 AND 3 = 75.3				
TAXON	GROUP 1	GROUP 3	δi	$\Sigma \delta i$ %
ELMIDAE/DRYOPIDAE	X		4.8	4.8
EPHEMERELLIDAE	X		4.4	9.2
LEPTHOPHLEBIIDAE (PH<6.5)	X		4.3	13.5
CORIXIDAE		X	3.4	16.9
CASED CADDIS 3 TYPES	X		3.4	20.2
CORYDALIDAE	X		3.3	23.5
CAENIDAE		X	3.2	26.7
OLIGOCHAETE		X	3.0	30.0
HELODIDAE	X		2.7	32.4
DYTISCIDAE		X	2.7	35.1
BAETIDAE 1 TYPE		X	2.5	37.6
PHILOPOTAMIDAE	X		2.5	40.1
LYMNAEIDAE		X	2.4	42.5
ANCYLIDAE		X	2.4	44.9
CERATOPOGONIDAE		X	2.4	47.3
HYDRAENIDAE	X		2.4	49.8
AVERAGE DISSIMILARITY BETWEEN GROUP 2 AND 3 = 66.9				
TAXON	GROUP 2	GROUP 3	δi	$\Sigma \delta i$ %
BRACHYURA (CRABS)	X		7.0	4.0
LEPTHOPHLEBIIDAE (PH>6.6)	X		3.9	7.9
CORIXIDAE		X	3.7	11.6
BAETIDAE 3 TYPES	X		3.6	15.2
DYTISCIDAE		X	3.4	18.6
GYRINIDAE	X		3.3	21.8
CAENIDAE		X	3.2	25.0
ELMIDAE/DRYOPIDAE	X		3.1	28.1
BAETIDAE 1 TYPE		X	3.0	31.0
ANCYLIDAE		X	2.9	33.9
LYMNAEIDAE		X	2.8	36.7
CERATOPOGONIDAE		X	2.8	39.5
HYDROPSYCHIDAE 2 TYPES	X		2.8	42.3
VELLIDAE	X		2.6	44.9
COENAGRIONIDAE	X		2.4	47.3
OLIGOCHAETE	X		2.4	49.6

Figure 4.5. CONPLOTS (PRIMER V.4.) of A) SASS4 Score, B) ASPT, C) Number of Taxa, D) HAM and E) HABS1 scores overlaid on the MDS ordination of macroinvertebrate communities (F) at fifty sites in the Breede River catchment. Minimum and maximum values for each parameter are as follows: SASS4 Score: 27 and 168; ASPT: 3.56 and 9.47; Number of Taxa: 7 and 20; HAM Score: 22 and 128; and HABS1 Score: 55 and 100.



which separated at a Euclidean distance of approximately 5.0, comprised two impacted foothill sites, one impacted transitional site and two impacted lowland sites. A fourth group consisted of two mountain stream reference sites and one foothill reference site.

Principal components analysis on the same chemical constituents used in the cluster analysis, suggests that much of the variation corresponds to a combination of conductivity, pH, TSS, $(NO_2^- + NO_3^-)$-N and the anion ratio. The aim of PCA analysis is to reduce the data set to a small number of dimensions or components that between them are able to explain a large proportion of the variance. In this context, the purpose of running PCA on the chemical constituents was to determine the significant variables for distinguishing sites from each other. Two eigenvalues or dimensions were retained. The cumulative percentage variance explained by the first two components is 56%. Component 1 explains 35.8% of the variance and corresponds to an increasing gradient in conductivity, pH, TSS and $(NO_2^- + NO_3^-)$-N (eigenvalue of 3.22; Figure 4.7). Component 2 explains 20.2% of the variance and corresponds to an increasing gradient in the anion ratio (i.e. higher proportion of Cl^- ions) (eigenvalue of 1.81). The positions of the sites were plotted on two-dimensional graphs with the axis of the graphs representing the two components. There is a distinct separation of mountain stream and foothill reference sites from impacted ones and from sites in the transitional and lowland subregions. The sites within each of the groups differentiated in cluster analysis are indicated in Figure 4.7. Sites in Groups 1 and 4 were at the lower end of the conductivity, pH, TSS and $(NO_2^- + NO_3^-)$-N gradient and if one excludes the sub-group 1a, chloride concentrations were higher than bicarbonate ones. This is typical of mountain streams in the south-western Cape which have mostly very "pure" water, dominated by $[Cl^-]$ and $[Na^+]$, and are often on Table Mountain Sandstone and therefore poorly buffered, and very little bicarbonate in the water. Sites in sub-group 1a have a higher proportion of bicarbonate and may therefore be on shales. Sites in Group 2 occurred towards the upper end of both gradients, whilst sites in Group 3 were at the higher end of the conductivity, pH, TSS and $(NO_2^- + NO_3^-)$-N gradient. In general as mountain stream and foothill sites became impacted they moved in the direction of the transitional and lowland sites with respect to chemical characteristics.

"Long term" DWAF data

The same analyses were conducted on the DWAF chemical data although the variables used were slightly different (see section on methodology). Median values of each chemical constituent were calculated for 38 of the 50 sites in the Breede River catchment (Appendix4.3) and subjected to cluster analysis. The distinction into groups was less clear than in the previous analysis and the type of site, i.e. reference or impacted site, and subregion were fairly randomly dispersed between groups (Figure 4.8). At a Euclidean distance of 4.0, all reference sites and some impacted mountain streams, foothill and transitional sites clustered together.

Principal components analysis on the same chemical constituents suggests that much of the variation corresponds to a combination of conductivity, pH, $(NO_2^- + NO_3^-)$-N, the cation ratio and NH_4-N. Three eigenvalues or dimensions were retained. The cumulative percentage variance explained by the first three components is 75%. Component 1 explains 43.4% of the variance and corresponds to an increasing gradient in conductivity, pH and $(NO_2^- + NO_3^-)$-N (eigenvalue of 3.48; Figure 4.9).

Figure 4.6. Dendrogram for the hierarchical clustering of fifty sites in the Breede River catchment on the basis of nine chemical constituents. Solid symbols indicate reference sites and open symbols impacted ones.

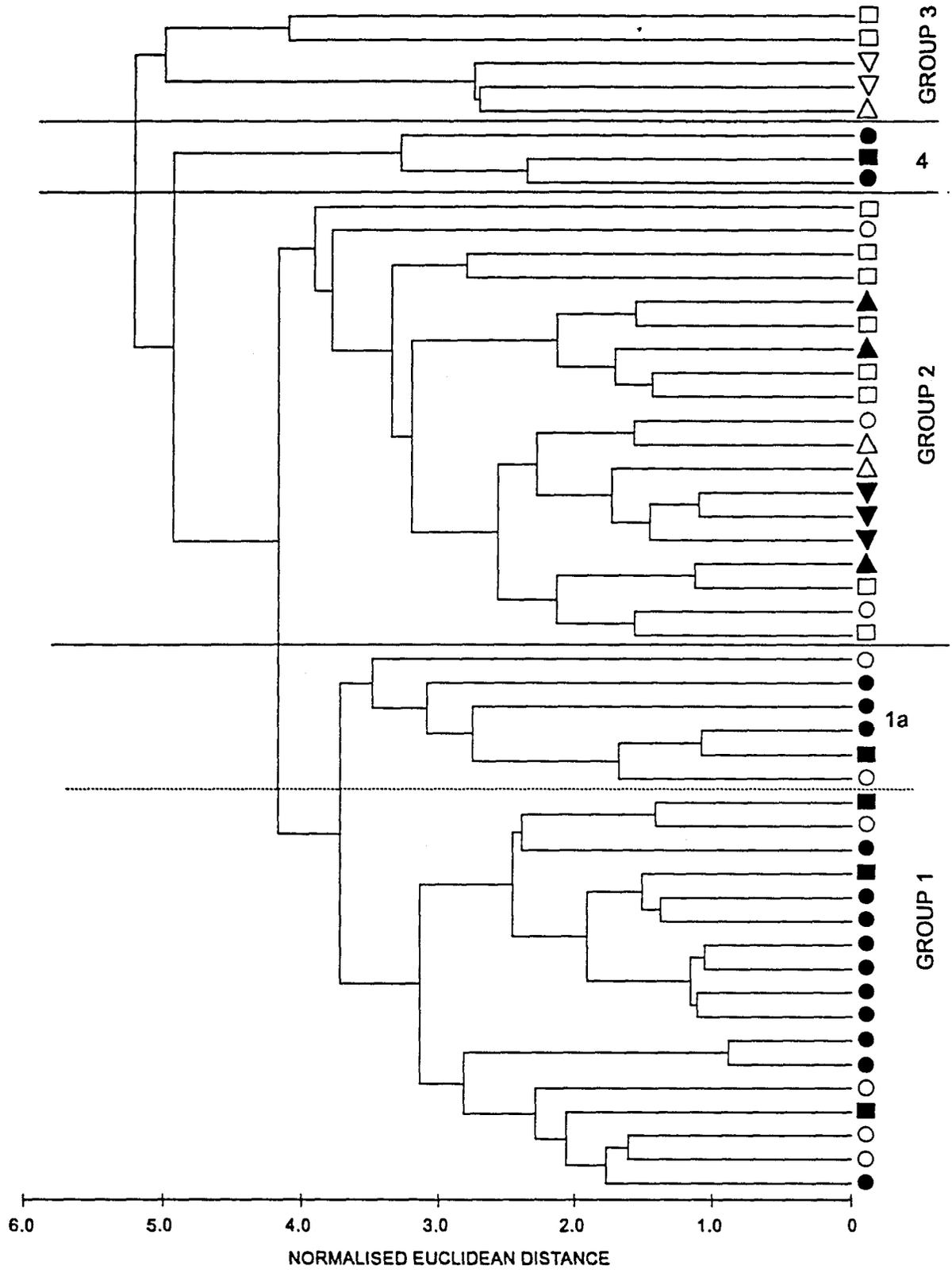


Figure 4.7. Positions of the sites in relation to components 1 and 2 of the PCA run on chemical constituent data for fifty sites in the Breede River catchment. Solid symbols indicate reference sites and open symbols impacted ones. The groups have been outlined manually on the basis of the results of the cluster analysis.

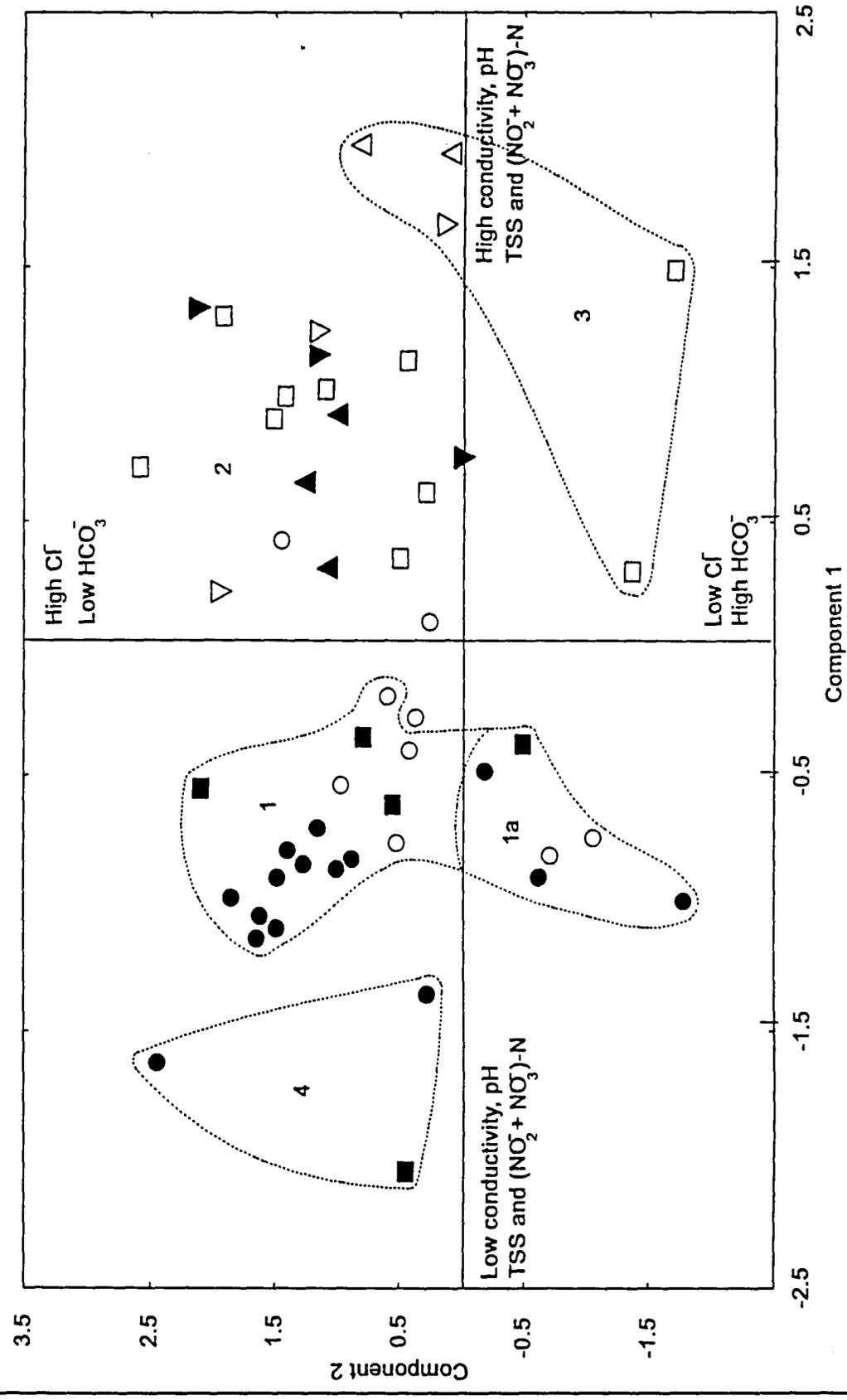


Figure 4.8. Dendrogram for the hierarchical clustering of 38 sites in the Breede River catchment on the basis of eight chemical constituents taken from DWAF data. Solid symbols indicate reference sites and open symbols impacted ones.

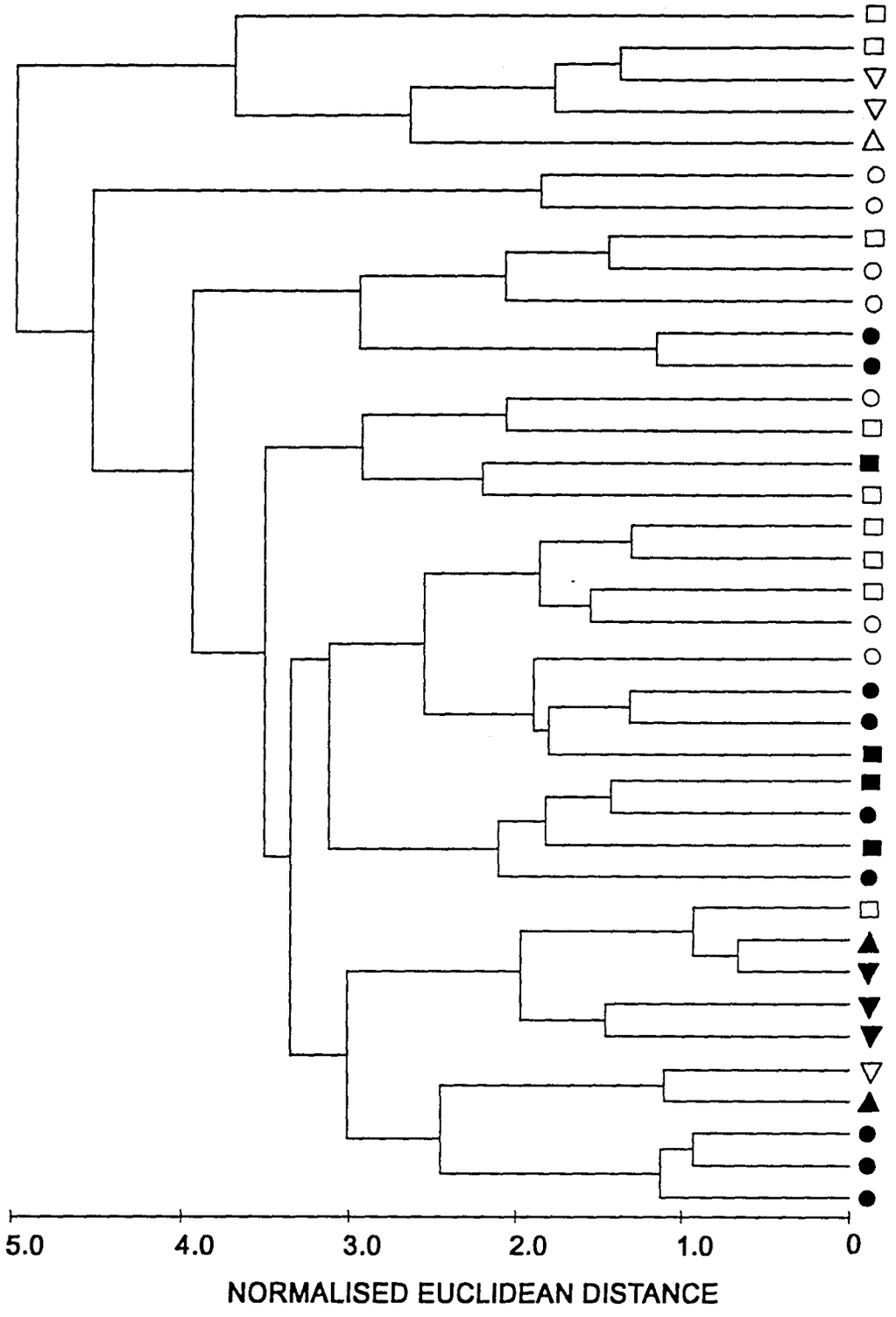
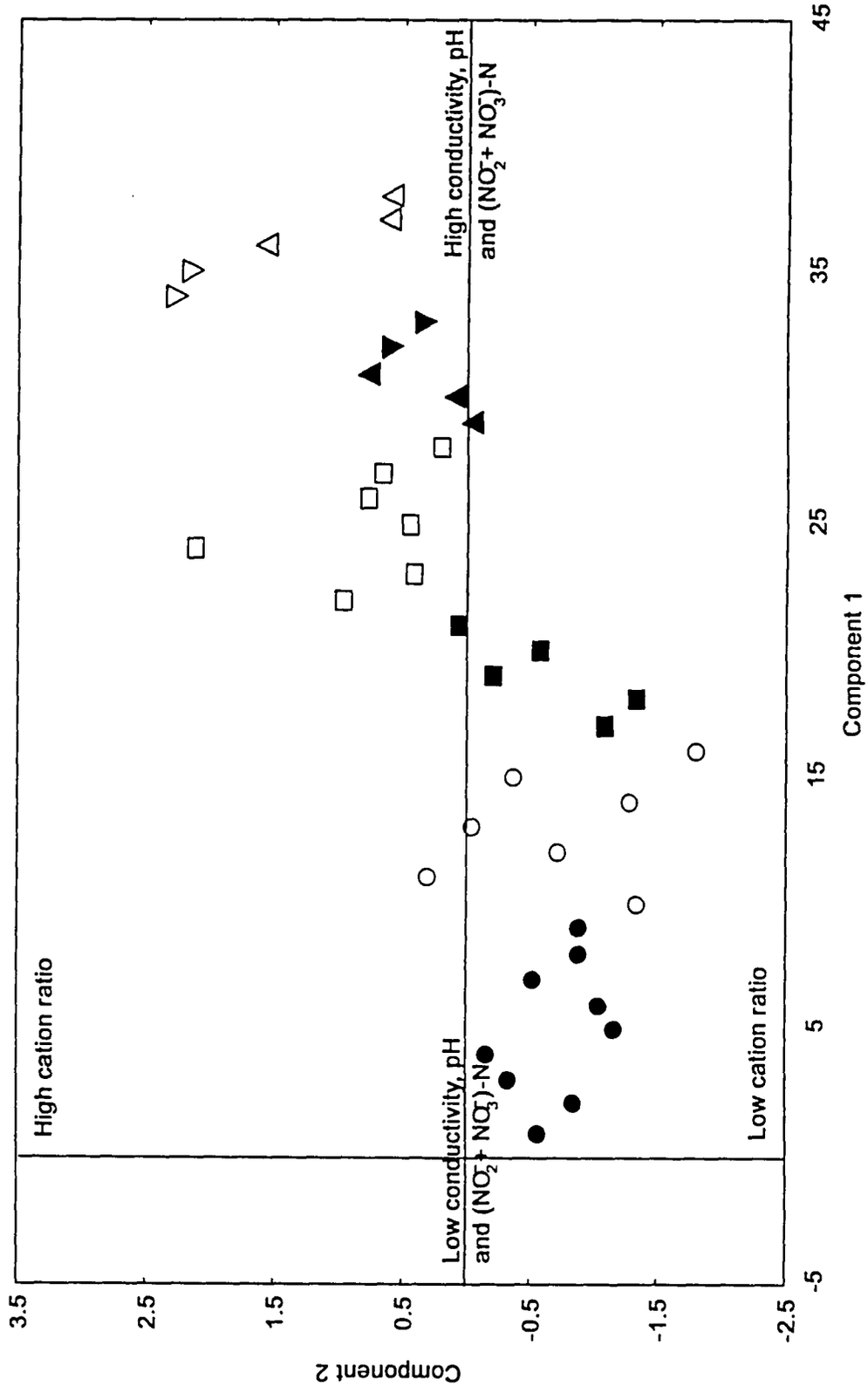


Figure 4.9. Positions of the sites in relation to components 1 and 2 of the PCA run on DWAF chemical constituent data for 38 sites. Solid symbols indicate reference sites and open symbols impacted ones.



Component 2 explains 18.9% of the variance and corresponds to an increasing gradient in the cation ratio (eigenvalue of 1.51). Component 3 explains 12.6% of the variance and corresponds to NH_4-N (eigenvalue of 1.01). The positions of the sites were plotted on two-dimensional graphs with the axis of the graphs representing the first two components. There is a distinct trend of sites with mountain stream reference sites at the lowest end of the conductivity, pH and $(NO_2^- + NO_3^-)$-N gradient, followed by impacted mountain stream sites, foothill reference sites, impacted foothill sites, transitional and lowland reference sites, and impacted transitional and lowland sites. A similar trend is apparent with foothill, transitional and lowland sites, with the respective impacted sites having a higher cation ratio than reference ones.

Examination of actual values for four variables, namely conductivity, pH, $(NO_2^- + NO_3^-)$-N and TSS, including both "spot" values and long term DWAF chemistry data (median values), enabled the calculation of ranges for reference sites. They were divided into two groups such that Mountain Stream and Foothills were combined and Transitional and Lowland subregions were combined (Table 4.5).

Table 4.5. Observed ranges for selected chemical constituents at reference sites in the Breede River catchment. Subregions have been combined such that Mountain Streams (M) and Foothills (F) are combined and Transitional (T) and Lowland (L) subregions are combined.

Chemical Constituent	Units	M + F	T + L
Conductivity	mS m^{-1}	1.2 to 12.2	11.6 to 87.3
pH		4.11 to 6.80	6.95 to 8.00
$(NO_2^- + NO_3^-)$-N	mg l^{-1}	0.008 to 0.08	0.064 to 0.520
TSS	mg l^{-1}	0.01 to 1.25	2.24 to 6.33

The ranges for conductivity, pH and TSS are within the ranges calculated for the respective subregions in the southern and western coast TWQR in Chapter 3. Ranges were not calculated for $(NO_2^- + NO_3^-)$-N in Chapter 3, but the range of concentrations calculated here shows a distinct difference between subregional groups.

Principal components analysis on the metal concentrations measured at 49 of the 50 sites in the Breede River catchment suggests that much of the variation corresponds to a combination of aluminium, copper, mercury, zinc, cadmium and manganese concentrations (Figure 4.10). Three eigenvalues or dimensions were retained. The cumulative percentage variance explained by the first three components is 71%. Component 1 explains 37.8% of the variance and corresponds to an increasing gradient in Al, Cu, Hg and Zn (eigenvalue of 3.02; Figure 4.10). Component 2 explains 17.3% of the variance and corresponds to an increasing gradient in Cd concentration (eigenvalue of 1.39). Component 3 explains 15.5% of the variance and corresponds to Mn (eigenvalue of 1.24). The positions of the sites were plotted on two-dimensional graphs with the axis of the graphs representing the first two components. There was no distinct trend between type of site, i.e. reference or impacted, or subregion. Most of the sites were at the lower end of the Al, Cu, Hg and Zn gradient, and in the middle of the Cd gradient. This analysis is based on single measurements of metal concentrations. In order to assess if the gradients noted are of importance, additional measurements would need to be undertaken.

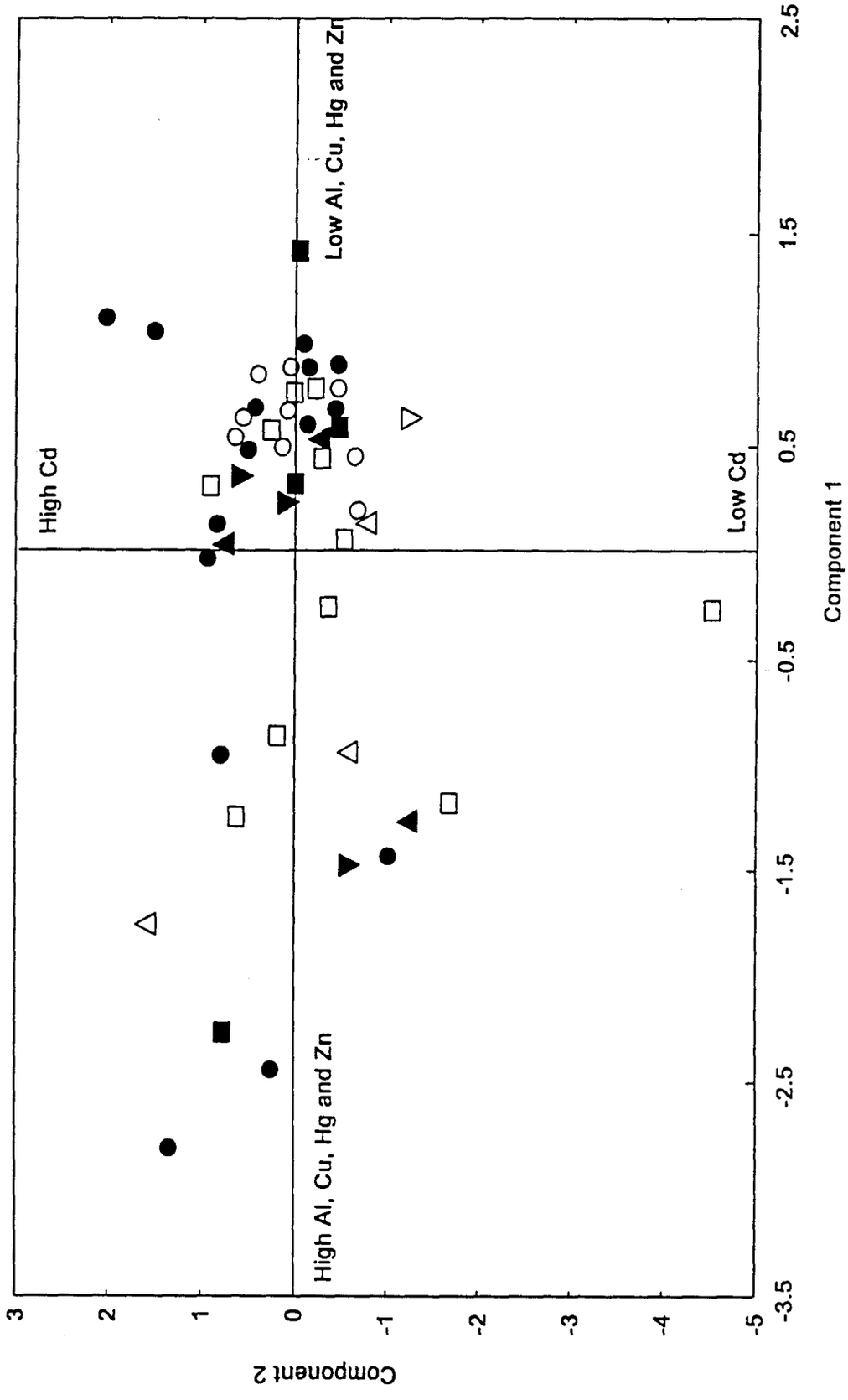
The median, minimum and maximum values from reference sites were compared with the Target Water Quality Ranges (TWQR), Chronic Effect Values (CEV) and Acute Effect Values (AEV) for eight metals taken from the interim water quality guidelines for aquatic ecosystems (Table 4.6). The TWQR is used to specify, for a particular constituent, the desired or "ideal" concentration range that would ensure protection of aquatic ecosystems. The TWQR is set equal to the No Effect Range. The CEV is defined as that concentration of a constituent at which there is expected to be a significant risk of measurable chronic effects to the aquatic population. It is used, in certain cases when the TWQR is exceeded, to set water quality requirements for each constituent of concern. The setting of water quality requirements or objectives at the CEV range protects aquatic ecosystems from acute toxicity effects. AEV is defined as that concentration of a constituent above which there is expected to be a significant risk of measurable acute effects to the aquatic community. It is used to identify those cases requiring urgent management attention because the aquatic environment is threatened. The AEV should not be used for setting water quality requirements for aquatic ecosystems.

Table 4.6. Target Water Quality Range (TWQR), Chronic Effect Value (CEV) and Acute Effect Value (AEV) for eight metals taken from the interim water quality guidelines for aquatic ecosystems compared with median, minimum and maximum values for reference sites in upper catchments (mountain stream = M and foothill = F subregions) and lower catchments (transitional = T and lowland = L subregions) in the Breede River catchment of the southern and western Coast TWQR. All concentrations are in $\mu g\ l^{-1}$. For M + F, n = 20 and T + L, n = 6.

Constituent	TWQR	CEV	AEV	Subregion	Median	Min	Max
Aluminium	0.5	1	10	M+F	231	146	598
				T+L	207	150	495
Cadmium	0.07	0.3	1.8	M+F	58	56	61
				T+L	57	55	59
Chromium (VI)	7	14	200	M+F	6	1	42
				T+L	6	1	9
Copper	0.2	0.53	1.6	M+F	6	1	26
				T+L	8	6	20
Manganese	180	370	1300	M+F	53	47	120
				T+L	55	51	98
Mercury	0.04	0.08	1.7	M+F	236	49	715
				T+L	361	164	681
Zinc	2	3.6	36	M+F	49	38	209
				T+L	48	41	66

The concentrations measured at reference sites in the Breede River catchment greatly exceeded the TWQR, CEV and AEV for five of the eight variables, namely aluminium, cadmium, copper, mercury and zinc. These sites were all selected because of the relatively high SASS Scores indicative of a healthy aquatic community. As mentioned previously, these results are based on single measurements of each metal and additional measurements would be needed to find out normal ranges for these metals at these

Figure 4.10. Positions of the sites in relation to components 1 and 2 of the PCA run on metal concentrations for 49 of the 50 Breede River catchment sites. Solid symbols indicate reference sites and open symbols impacted ones.



sites. Sublethal effects such as reduced growth or fecundity may be occurring but this would not be observed using a method such as SASS. Synergistic effects, such as those detailed in Chapter 7 of this report, may also have an effect. On the basis of SASS assessments, however, the current TWQRs for all of these metals would ensure the presence of a relatively diverse and abundant invertebrate community.

4.3.3 Relationship between biological and chemical data

The variables that correlated most highly with the macroinvertebrate community structure as reflected in the MDS ordination were conductivity and pH (Spearman rank correlation, $r=0.582$, $n=50$). The relationship between the MDS ordination of macroinvertebrate communities and the physical attributes and chemical constituents was also examined by conducting CONPLOTS of each variable overlaid on the MDS ordination (Figures 4.11 to 4.15). In these plots the sizes of the circles relate to the value or concentration such that the larger the circle the higher the value or concentration. These are not comparable between graphs and minimum and maximum values or concentrations are therefore given in the legends for figures 4.11 to 4.15. These plots provide a visual method for examination of physical or chemical variables in relation to biological ones, but are not necessarily causative. Because all measurements were single or spot ones, physical variables such as temperature, which are highly dependent on the time of measurement, only provide a rough comparison between sites.

- Temperature and pH were lower at sites within the biological Group1 (see Figure 4.4), which consisted mostly of mountain stream and foothill sites (Figure 4.11). Conductivity, TDS, TSS and turbidity were mostly lowest at sites within Group 1 and marginally higher at other sites. Between one and five sites in Group 3 had conductivity, TDS, TSS and turbidity values or concentrations considerably higher than the other sites. Dissolved oxygen was marginally higher at sites in Group 1, although four sites in Group 3 had very high concentrations. It is likely that these were the result of algal growth at these sites.
- Cation concentrations were highest at sites within Group 3 (Figure 4.12).
- Anion concentrations were highest at sites in Groups 2 and 3 and total alkalinity was highest at sites in Group 3 (Figure 4.13).
- Nitrate concentrations were highest at sites in Groups 2 and 3, nitrite concentrations were generally very low with the exception of two sites in Group 3, SRP concentrations were highest at sites in Group 3 and silica concentrations varied across groups (Figure 4.14).
- Aluminium, copper, cadmium and manganese concentrations were variable across groups, with high values of most present at sites within all groups. A single site, in Group 2, had a high chromium concentration. Mercury concentrations were marginally higher at some site in Group 3. Conversely, iron concentrations were generally lowest at sites in Group 3. Synergistic and antagonistic interactions may account for some of these observations. For example, at high pH values, iron and manganese adsorb onto organic particles and become unavailable (see Chapter 7).

Figure 4.11. Conplots of temperature, pH, conductivity, TDS, TSS, turbidity and dissolved oxygen overlaid on the MDS ordination of macroinvertebrate communities. The largest circles represent the highest value or concentration for each variable. Minimum and maximum values or concentrations for each variable are as follows: Temperature: 13.5 and 27.8 °C, pH: 4.1 and 8.7, conductivity: 1.2 and 345.0 mS m^{-1}, TDS: 6.4 and 3138.8 mg l^{-1}, TSS: 0.01 and 22.6 mg l^{-1}, turbidity: 0 and 20 NTU, dissolved oxygen: 5.7 and 10.4 mg l^{-1}.

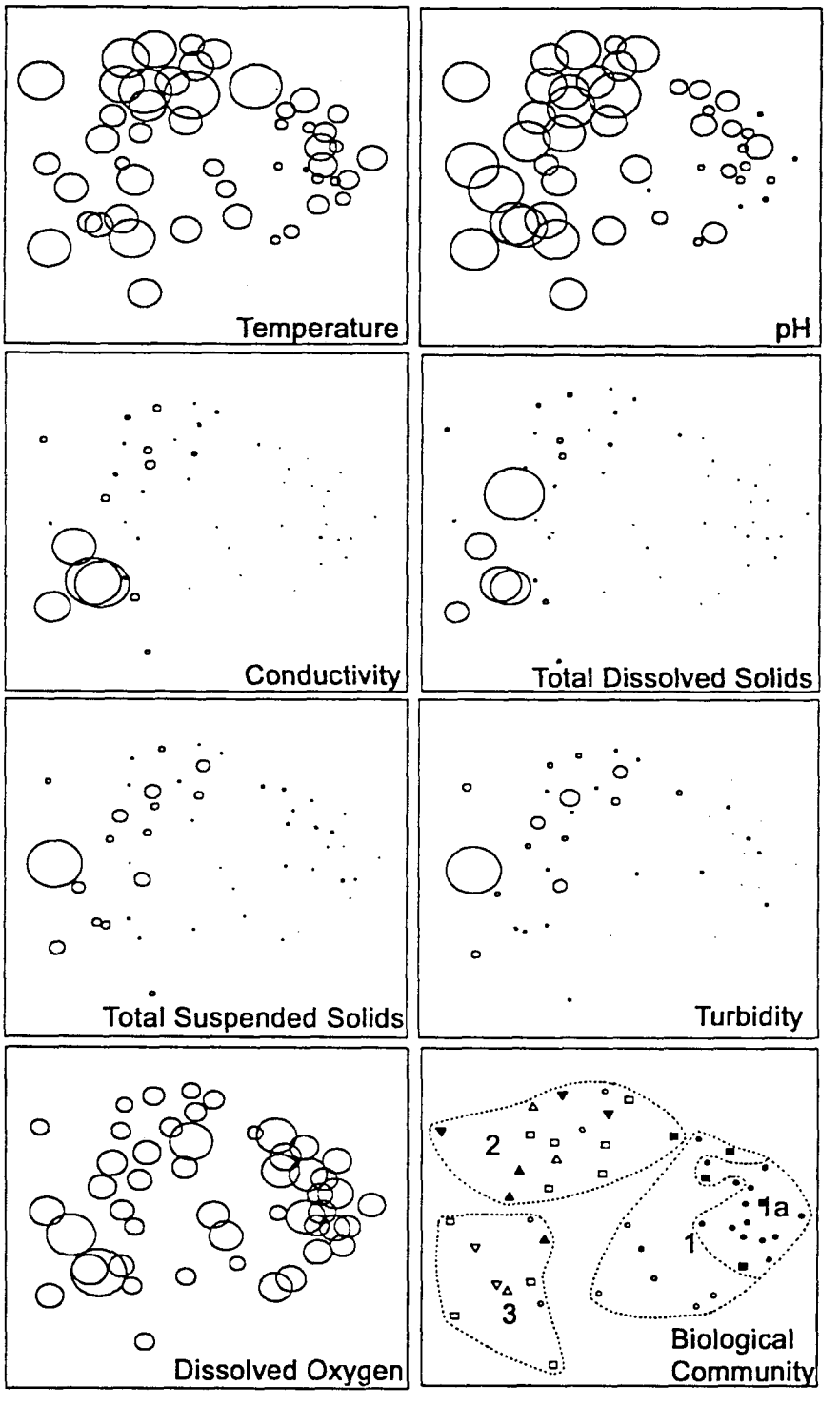


Figure 4.12. Conplots of the cations: sodium, calcium, magnesium and potassium overlaid on the MDS ordination of macroinvertebrate communities. The largest circles represent the highest value or concentration for each variable. Minimum and maximum concentrations for each variable are: sodium: 1.8 and 478.5 mg l^{-1}, calcium: 0.2 and 94.0 mg l^{-1}, magnesium: 0.01 and 109.0 mg l^{-1}, potassium: 0.01 and 11.9 mg l^{-1}.

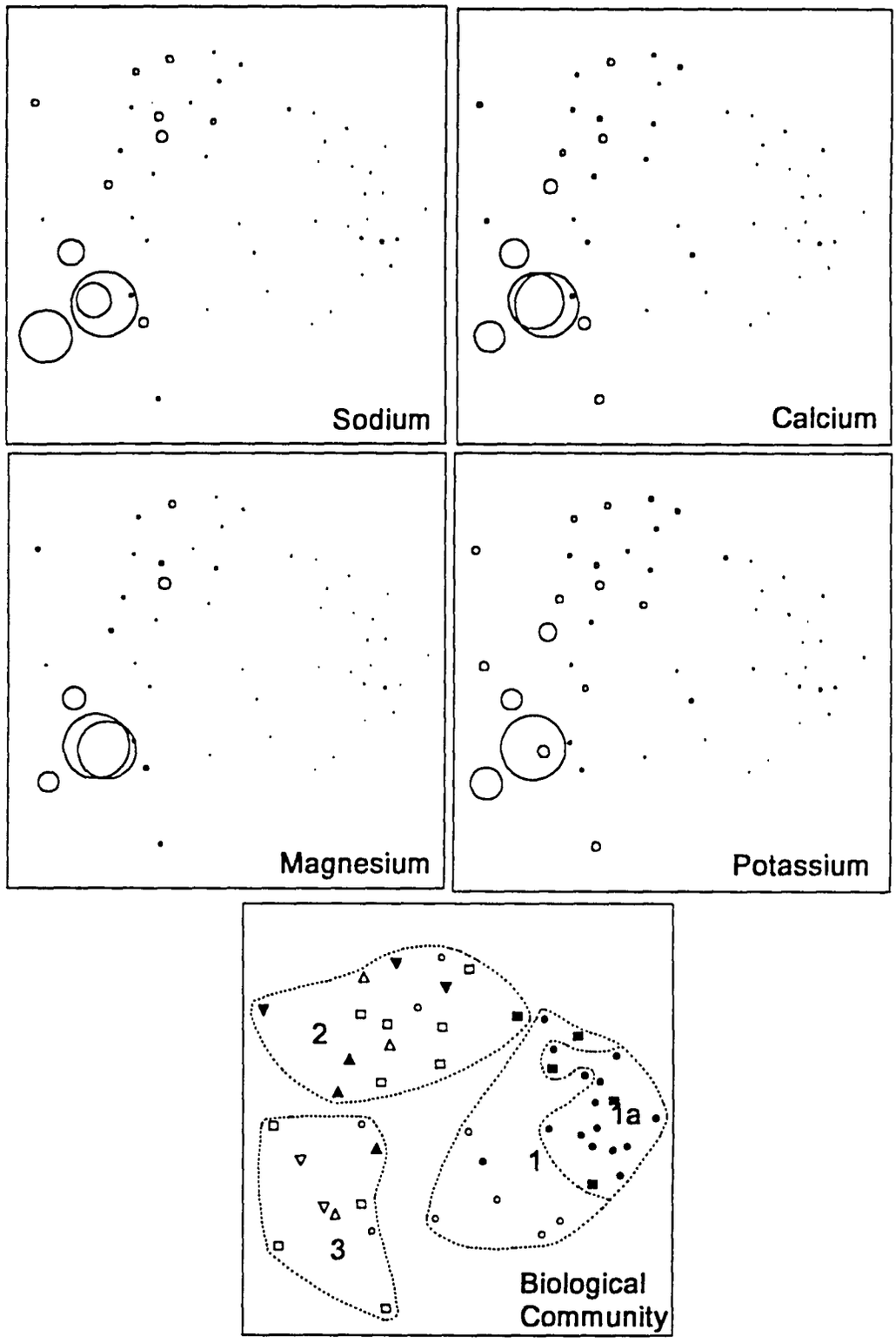


Figure 4.13. Conplots of the anions, sulphate, chloride and Total Alkalinity overlaid on the MDS ordination of macroinvertebrate communities. The largest circles represent the highest concentration for each variable. Minimum and maximum values or concentrations for each variable are as follows: sulphate: 0.4 and 94.8 mg l^{-1}, chloride: 1.8 and 426.4 mg l^{-1}, Total Alkalinity: 0.01 and 7.6 meq l^{-1}.

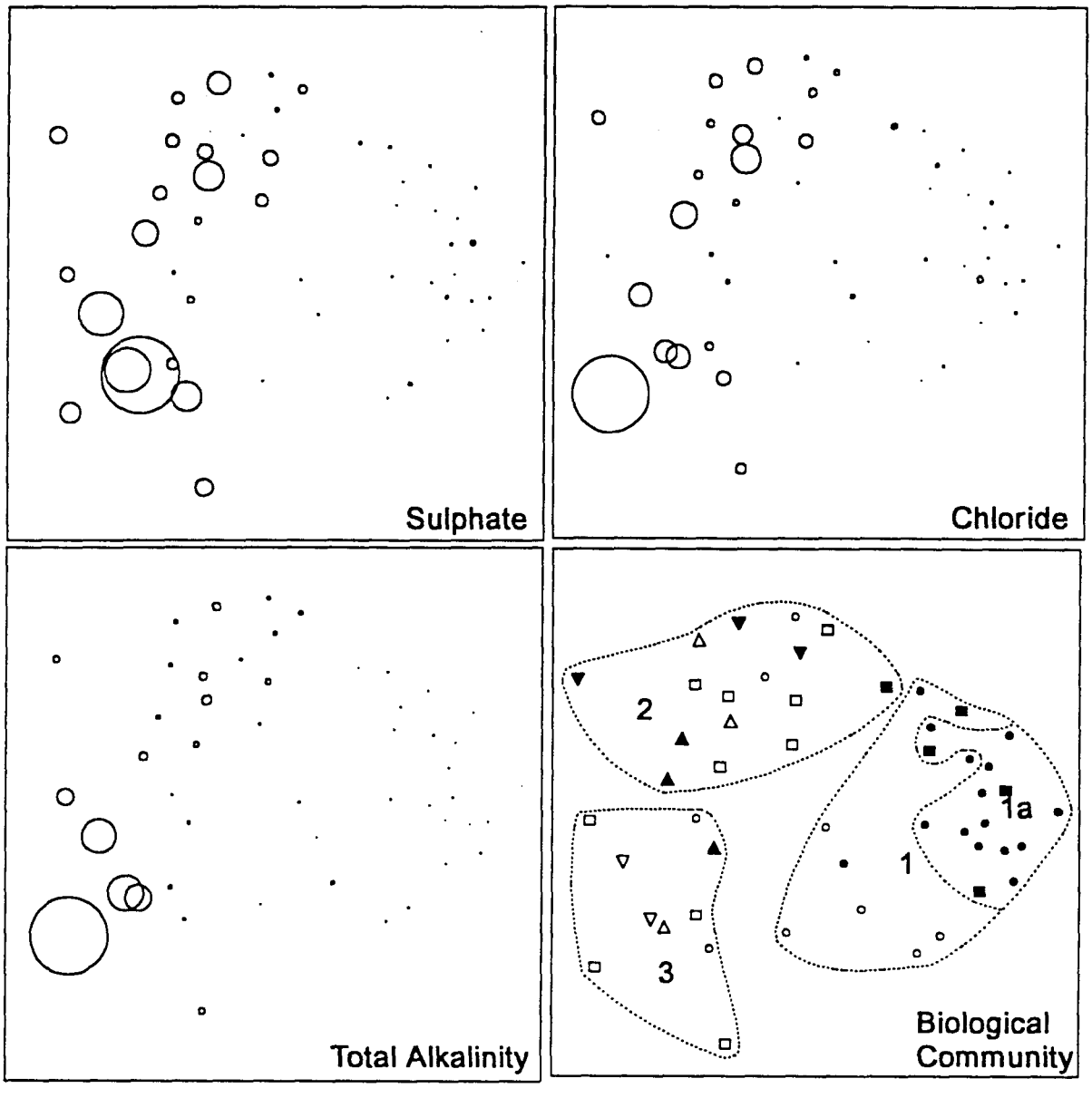


Figure 4.14. Conplots of nutrient concentrations: nitrate-N, nitrite-N, soluble reactive phosphorus-SRP and silica overlaid on the MDS ordination of macroinvertebrate communities. The largest circles represent the highest concentration for each variable. Minimum and maximum values or concentrations for each variable are as follows: nitrate-N: 0.001 and 0.044 mg l^{-1}, nitrite-N: 0.0005 and 0.5252 mg l^{-1}, SRP: 0.01 and 0.060 mg l^{-1}, silica: 0.016 and 4.900 mg l^{-1}.

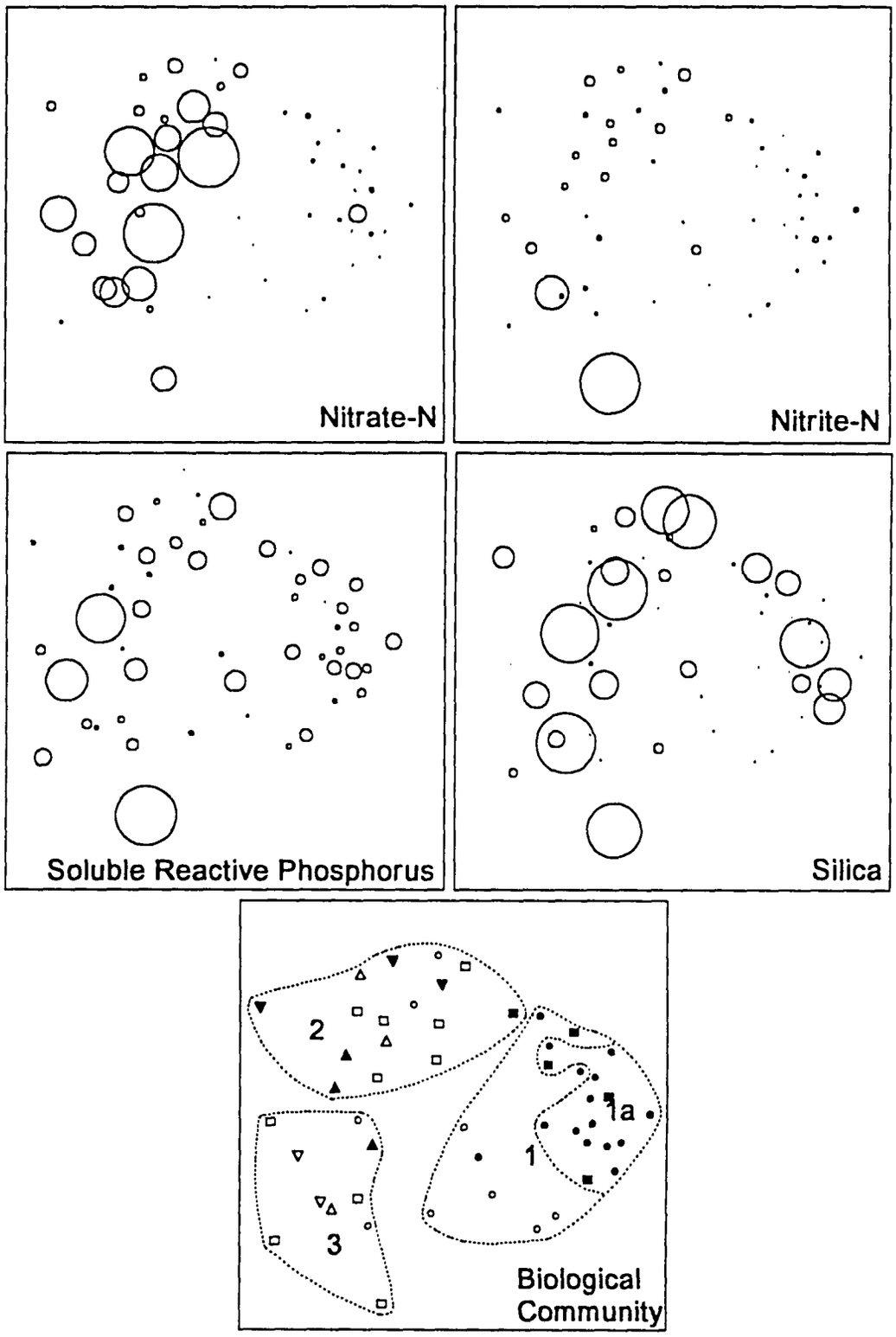
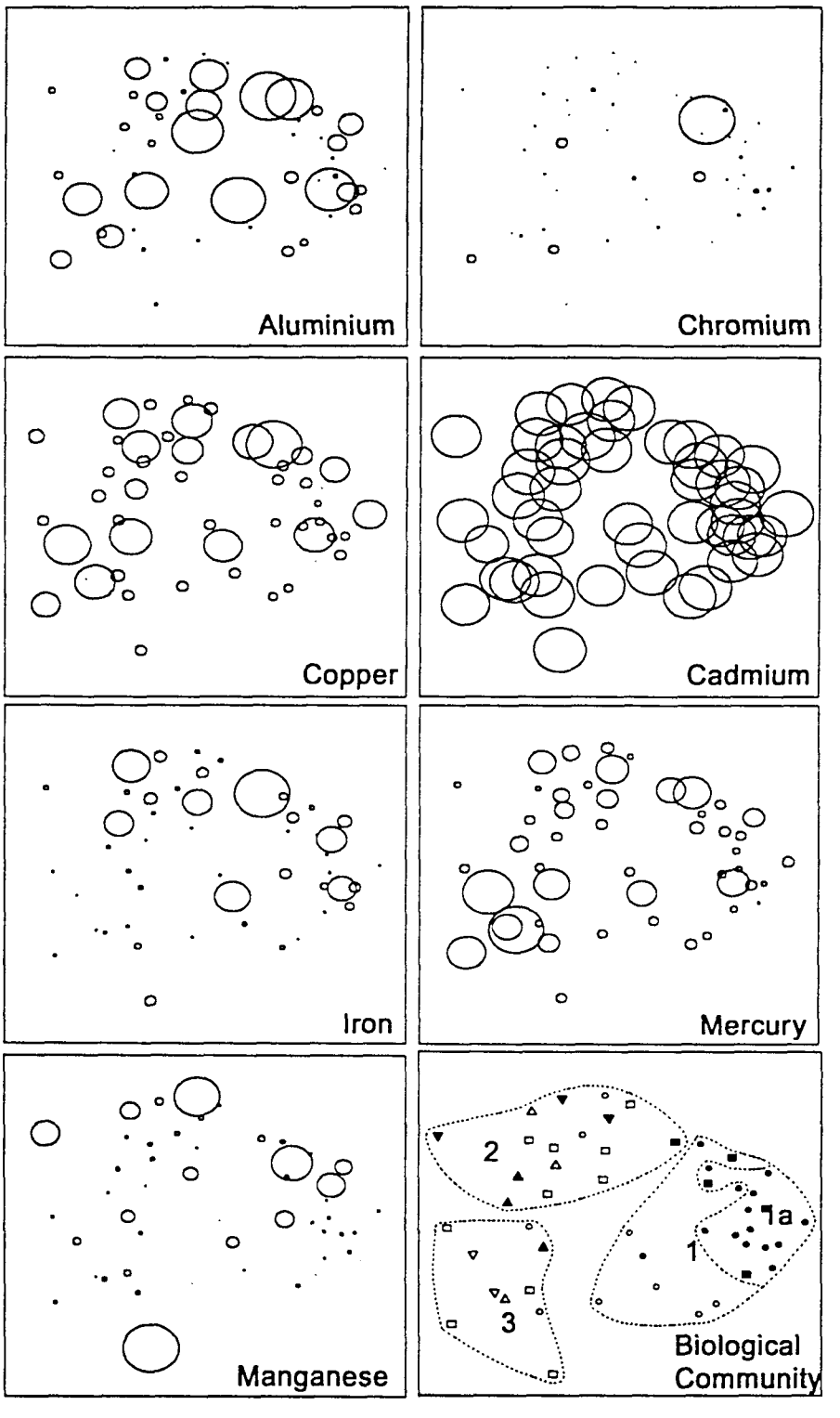


Figure 4.15. Conplots of metal concentrations: aluminium, chromium, copper, cadmium, iron, mercury and manganese overlaid on the MDS ordination of macroinvertebrate communities. The largest circles represent the highest concentration for each variable. Minimum and maximum values or concentrations for each variable are as follows: aluminium: 0.146 and 0.598 mg l^{-1}, chromium: 0.001 and 0.420 mg l^{-1}, copper: 0.001 and 0.026 mg l^{-1}, cadmium: 0.024 and 0.061 mg l^{-1}, iron: 0.116 and 0.429 mg l^{-1}, mercury: 0.049 and 1.030 mg l^{-1}, manganese: 0.047 and 0.146 mg l^{-1}.



4.3.4 Physical characteristics of the sites

This section is largely descriptive and attempts to characterise sites within each subregion on the basis of information about the channel, substratum characteristics, and riparian and aquatic vegetation. Sites are arranged in the order of subregion and type such that mountain stream reference, mountain stream impacted, foothill reference, foothill impacted etc. are grouped together (Tables 4.7 to 4.9).

Channel information

- All mountain streams were a single channel; one ran through a steep gorge and dropped sharply into a dam (Table 4.7). Average ± standard deviation of the stream water width, maximum water depth and riffle depth were 5.9 ± 4.3, 0.6 ± 0.5 and 0.15 ± 0.11 m respectively. Stream water width was between 8 and 86% of bank width. Average bank height was 1.4 ± 1.5 m and erosion potential ranged from 0 to 50%.
- Foothill sites were single or braided channels with one described as meandering and sandy. Average stream water width, maximum water depth and riffle were 21.8 ± 22.6, 0.6 ± 0.4 and 0.21 ± 0.14 m respectively. Stream water width was between 17 and 89% of bank width. Average bank height was 1.4 ± 1.5 m and erosion potential ranged from 0 to 70%.
- Transitional sites were single or meandering. Average stream water width, maximum water depth and riffle depth were 31.5 ± 21.1, 1.4 ± 0.7 and 0.25 ± 0.21 m respectively, although riffles areas were not present at all sites. Stream water width was between 29 and 70% of bank width. Average bank height was 2.2 ± 0.7 m and erosion potential ranged from 0 to 80%.
- Lowland sites were also single or meandering. Average stream water width, maximum water depth and riffle depth were 42.0 ± 31.9, 1.2 ± 0.6 and 0.15 ± 0.13 m respectively, although riffles areas were not present at all sites. Stream water width was between 60 and 83% of bank width. Average bank height was 2.4 ± 1.2 m and erosion potential ranged from 0 to 20%.

Substratum characteristics

Most mountain streams had a high percentage of boulder and/or cobble, which were generally ≤30% embedded with softer material such as sand (Table 4.8). Foothill sites had a lower percentage of boulders, although most also had a relatively high proportion of cobble substratum. The percentage of sand at each sites was higher as was the degree of embeddedness. Transitional and lowland sites varied the most in the percentage cobble and sand, and the former was absent at some sites. The degree of embeddedness also varied considerably.

Riparian and aquatic vegetation

The percentage cover afforded by the riparian vegetation varied considerably, as did the width of the riparian belt (Table 4.9). Generally mountain stream and foothill sites had a higher percentage of indigenous than exotic vegetation. Nuisance macrophytes and algae, both of which are indicative of nutrient enrichment, were largely absent at reference sites in all subregions but became more common at impacted sites.

Table 4.7. Characteristics of the channel, including details of channel type, water width, maximum water depth, riffle depth, bank width and height, and erosion potential for each site in the Breede River catchment. NP means not present.

Site	Channel Type	Water Width (m)	Max Water Depth (m)	Riffle Depth (m)	Bank Width	Bank Height	Erosion Potential (%)
02/HOUT	single channel	3.8	0.25	0.18	5.3	0.6	10
03/TRIBSAND	single channel	4.2	0.53	0.11	6.2	0.7	50
05/ROOI	single channel	3.5	0.90	0.45	5.1	0.4	0
12/RIET	single channel	1.0	0.15	0.50	2.0	0.9	20
13/EPAD	single channel	10.3	0.60	0.20	19.3	0.8	10
22/BOES	single channel	2.0	0.20	0.10	5.5	0.9	10
23/MAC	single channel	3.5	0.20	0.14	9.5	0.6	10
28/MAR	single channel	3.1	0.28	0.08	7.5	0.6	5
29/HERM	single channel	7.0	0.35	0.12	17.0	0.5	10
30/KLOOF	single channel in gorge	6.0	2.00	0.10	7.0	8.0	0
31/MEUL	single channel	5.0	0.30	0.12	9.4	0.4	50
38/BOES	single channel	2.7	0.25	0.08	8.7	0.8	5
39/GEN	single channel	5.5	0.25	0.08	11.5	1.5	10
41/BAIN	single channel	12.0	0.75	0.20	37.0	0.5	10
50/RIV	single channel	10.5	0.70	0.18	15.0	1.5	10
15/HART	single channel	4.4	0.50	0.20	9.2	1.5	10
17/DWAR	single channel	5.3	0.25	0.10	10.3	1.5	30
25/ELAND	single channel	6.7	0.18	0.08	14.7	3.0	30
40/THEE	single channel	20.0	2.00	0.12	35.0	2.5	10
42/KOEK	single channel	12.5	0.90	0.12	22.5	0.7	10
45/VALSGAT	single channel	3.3	0.30	0.06	11.3	1.0	30
46/LANG	single channel	1.2	0.18	0.05	15.0	2.5	10
47/VALS	single channel	5.0	0.90	0.12	13.0	1.9	10
48/CAS	single channel	4.0	0.90	NP	11.0	0.5	1
04/SAND	single channel	6.9	0.68	0.40	8.0	1.1	0
09/HOL	braided channel	30.0	0.40	0.30	34.5	1.3	10
14/MOL	braided channel	18.0	0.90	0.25	24.4	0.5	10
26/DUT	single channel	17.0	0.32	0.14	21.0	1.8	10
36/HEID	single channel	9.5	0.55	0.20	35.5	1.8	10
01/MCG	single channel	10.0	0.57	0.20	23.5	1.5	70
06/GLEN	single channel	23.6	0.25	0.25	33.6	2.5	20
07/DRIE	braided channel	50.0	0.60	0.60	56.0	0.6	20
16/LEIP	single channel	7.7	0.20	0.18	12.7	0.6	30
24/HOEK	meandering channel	2.5	0.28	0.10	14.5	1.5	20
32/SUUR	braided channel	13.1	0.25	0.08	31.1	1.3	50
33/KRUIS	braided channel	10.0	0.35	0.15	19.5	1.6	10
43/DWARS	single channel	12.0	1.50	NP	24.0	0.9	30
44/CERES	single channel	21.0	0.60	0.20	47.0	1.5	30
49/SLANG	braided channel	95.0	1.50	0.10	120.0	2.0	20
10/NEK	meandering	30.0	1.50	0.35	55.0	1.0	70
11/CHAS	single channel	74.0	2.00	0.45	106.0	2.3	10
20/SECUND	meandering	30.0	2.00	0.55	48.0	3.0	10
19/VINK	single channel	7.2	0.62	NP	14.2	1.8	80
21/DREW	single channel	33.0	2.00	NP	113.0	2.0	10
35/DUIW	meandering	15.0	0.45	0.15	27.0	3.0	10
27/SWELL	meandering	80.0	1.50	0.30	120.0	3.5	10
34/NAP	meandering	80.0	2.00	0.18	96.0	4.0	20
37/KLIP	meandering	30.0	1.50	0.25	50.0	2.0	10
08/NUY	single channel	10.8	0.68	NP	15.8	1.8	20
18/KOG	single channel	9.0	0.45	NP	12.0	0.7	20

Table 4.8. Characteristics of the substratum, including the percentage of each type, the degree of embeddedness of the substratum.

Site	% Bedrock	% Boulder	% Cobble	% Shale	% Gravel	% Sand	% Silt/Mud	% Embeddedness
02/HOUT		5	95					5
03/TRIBSAND		20	70		10			5
05/ROOI		70	10		10	10		5
12/RIET			50			50		60
13/EPAD	5	30	55		5	5		10
22/BOES		5	95					5
23/MAC		20	80					20
28/MAR		30	70					10
29/HERM		40	60					10
30/KLOOF	95		5					0
31/MEUL		20	80					5
38/BOES		30	59		10		1	20
39/GEN	5		80		5	10		50
41/BAIN	40	20	35		5			10
50/RIV		30	64		5		1	10
15/HART	6	20	20					20
17/DWAR		10	50		20	10	10	30
25/ELAND		10	80		5	5		20
40/THEE	90	5	5					0
42/KOEK	10	30	50				10	30
45/VALSGAT			25			75		70
46/LANG			30		30	20	20	60
47/VALS	40	40	20					30
48/CAS	70	15	10			5		30
04/SAND		20	60		10	10		10
09/HOL		20	70			10		10
14/MOL		30	65			5		10
26/DUT		15	75		5	5		15
36/HEID			80		10	10		20
01/MCG	40		10			40	10	50
06/GLEN			90			10		30
07/DRIE			100					50
16/LEIP				50	20	30		70
24/HOEK				30		70		60
32/SUUR			30		10	60		60
33/KRUIS			60			30	10	60
43/DWARS	25	10	5			60		50
44/CERES		20	75		5			10
49/SLANG			80		10	10		10
10/NEK			40		10	50		50
11/CHAS				40	20	40		50
20/SECUND	5	5	60			30		10
19/VINK			20			40	40	90
21/DREW	20	20	50			10		10
35/DUIW			80		10	10		70
27/SWELL		20		15	15	50		20
34/NAP	5		5		30	60		80
37/KLIP	20	10	10		10	45	5	10
08/NUY							100	100
18/KOG			5		20	75		80

Table 4.9. An estimate of the percentage cover of riparian vegetation, width, and percentage indigenous versus exotic vegetation. An estimate of the instream percentage macrophytes and algae is also tabulated.

Site	% Cover	Width (m)	% Indigenous	% Exotic	% Nuisance Macrophytes	% Algae
02/HOUT	90	10	100	0	0	1
03/TRIBSAND	95	25	100	0	0	5
05/ROOI	100	10	100	0	0	1
12/RIET	70	20	100	0	0	0
13/EPAD	70	5	100	0	0	0
22/BOES	100	20	80	20	0	1
23/MAC	95	15	85	15	1	5
28/MAR	100	20	100	0	0	0
29/HERM	100	20	100	0	0	0
30/KLOOF	5	1	100	0	0	0
31/MEUL	100	15	100	0	0	0
38/BOES	100	10	95	5	0	0
39/GEN	100	5	5	95	0	0
41/BAIN	80	10	90	10	0	0
50/RIV	80	10	100	0	0	5
15/HART	80	10	100	0	0	15
17/DWAR	90	6	100	0	0	5
25/ELAND	80	5	50	50	0	20
40/THEE	60	10	40	60	0	5
42/KOEK	100	10	90	10	0	0
45/VALSGAT	30	3	10	90	0	50
46/LANG	100	15	100	0	0	1
47/VALS	30	15	100	0	0	20
48/CAS	100	10	100	0	0	0
04/SAND	100	10	100	0	0	0
09/HOL	30	5	20	80	0	0
14/MOL	100	10	80	20	0	0
26/DUT	100	10	100	0	0	1
36/HEID	80	5	50	50	0	0
01/MCG	60	10	10	90	0	10
06/GLEN	95	5	30	60	0	10
07/DRIE	15	5	0	100	0	0
16/LEIP	90	2	95	5	0	0
24/HOEK	80	5	50	50	0	0
32/SUUR	70	10	0	100	0	40
33/KRUIS	100	10	50	50	0	5
43/DWARS	60	10	5	95	5	5
44/CERES	70	20	15	85	0	1
49/SLANG	80	10	5	95	5	1
10/NEK	20	5	0	100	0	0
11/CHAS	100	10	50	50	0	5
20/SECUND	95	10	5	95	0	0
19/VINK	10	2	0	100	0	60
21/DREW	90	5	20	80	0	0
35/DUIW	100	10	50	50	0	30
27/SWELL	70	10	20	80	5	10
34/NAP	60	5	50	50	5	1
37/KLIP	90	15	15	85	0	5
08/NUY	80	1	0	100	50	30
18/KOG	100	3	50	50	10	10

4.3.5 Existing land use, physical modification, water quality impacts and ecological status

Activities in the catchment affect both the physical attributes and the chemical constituents of the water body and therefore also affect the biotic community. The longitudinal nature of river systems also means that effects are often cumulative as one moves down the catchment. Transitional and lowland subregions are therefore often subject to numerous effects resulting from upstream and adjacent activities. This section will attempt to characterise the major activities within each subregion of the catchment, including descriptions of broad land use, physical modifications to the channel and/or river banks and potential water quality impacts (Table 4.10).

- Mountain stream reference sites were mostly within areas termed "land use: nature conservation", i.e. land more or less natural without any obvious perturbations. Two of the sites had low intensity recreational activities such as camping or hiking. Physical modifications generally occurred only downstream of the site, with the exception of two sites which had small impoundments upstream whose discharges did not appear to be affected at this time of year. Water quality effects were considered to be negligible. Four of the sites were in Ecological Status Class 1, i.e. 100% of potential value; unmodified, natural; and eleven of the sites were in Class 2, i.e. 80-99% of potential value; largely natural with a few modifications. In this class a small change in natural habitats and biota may have taken place, but the assumption is that ecosystem functioning is essentially unchanged.

- Impacted mountain streams often had some areas, either adjacent to or upstream of the site, in which land use was classed as "nature conservation". Six had water storage facilities upstream, five had agricultural activities such as fruit orchards or vineyards upstream or adjacent to the site, and one had forestry activities adjacent to the site. Six of the nine sites had large impoundments and/or weirs upstream, but none had physical modifications to the banks. Agricultural runoff and the effects of the impoundments might potentially affect water quality. Interestingly, of those sites that grouped with the reference sites on the basis of biological community analysis, three had large impoundments approximately 5 km upstream and two had agricultural activities upstream. The land use in the immediate vicinity of the sites was classed as "nature conservation" however. Six of the sites were in Ecological Status Class 2, two in Class 3 and one in Class 4. In Class 3, 60-79% of potential values and moderately modified and a loss or change in habitat and biota has occurred, but basic functioning appears predominantly unchanged. In Class 4, 40-59% of potential values and largely modified and a loss of habitat and biota and a reduction in basic ecosystem functioning is assumed to have occurred.

- Reference sites in the foothill subregion were characterised by mixed land use including "nature conservation", agriculture or road/bridge construction upstream or adjacent to the sites. Three had large impoundments approximately 5 km upstream and/or weirs downstream. One had a weir upstream. Water quality impacts were considered to be of relatively low intensity. Four sites were in Ecological Status Class 2 and one in Class 3.

- Impacted foothill sites ranged from sites within or below high-intensity urban and/or industrial areas, to agricultural land (vineyards or fruit orchards), undeveloped open land and small "nature

conservation" areas. One site had a large impoundment upstream, four had weirs upstream and/or low-flow bridges upstream or downstream of the site. Two of the sites had bulldozed banks and one had banks stabilised with wire mesh. Water quality impacts ranged from high-intensity urban and industrial pollution, to agricultural runoff. Three sites were in Ecological Status Class 2, five in Class 3 and two in Class 4.

- Land use activities at transitional and lowland reference sites ranged from agriculture, including vineyards, fruit orchards and wheat fields, undeveloped open land and small "nature conservation" areas. Most had bridges or weirs upstream or downstream, and one had a partially reinforced bank. Water quality impacts were mostly those resulting from agricultural runoff. One site was in Ecological Status Class 2, four in Class 3 and one in Class 4.

- Impacted transitional and lowland sites were high-intensity agricultural areas, including vineyards, fruit orchards and livestock. Livestock watering was often within 5 metres of the water's edge. Weirs and/or bridges were generally present and banks were bulldozed at one of the sites and reinforced at another. Water quality impacts were mostly those resulting from urban pollution at one site and agricultural runoff at all sites. One site was in Ecological Status Class 2, one in Class 3, two in Class 4 and one in Class 5, i.e. 20-39% of potential value, seriously modified and at which the loss of natural habitat, biota and ecosystem functioning is extensive.

4.3.6 Geographic and map-based information

Geographic and map-based information such as river, altitude, latitude and longitude, together with geological and vegetation type, for each site are tabulated in Table 4.11.

Table 4.10. Land use adjacent to and upstream of the site, physical modifications to the channel and bank and potential water quality impacts within the area.

Site	Land use			Physical modifications		Water Quality Impact
	Beyond 5m	Upstream	Within 5m	In Channel Modifications	Bank Modifications	
02/HOUT	Nature Conservation	Nature Conservation	Nature Conservation	Small impoundment upstream Weir upstream	None None	None in vicinity
03/TRIBSAND	Nature Conservation	Nature Conservation	Nature Conservation	No obvious impacts	None	None in vicinity
05/ROOI	Nature Conservation	Nature Conservation	Nature Conservation	Weir downstream	None	None in vicinity
12/RIET	Nature Conservation	Nature Conservation	Nature Conservation	Canal downstream	Canalised below	None in vicinity
13/EPAD	Nature Conservation	Fishfarm on upstream tributary Nature Conservation	Nature Conservation	Weir downstream	None	None in vicinity
22/BOES	Nature Conservation	Nature Conservation	Nature Conservation	Small pool upstream	Canal adjacent to stream	None in vicinity
23/MAC	Nature Conservation	Nature Conservation	Nature Conservation	Canal downstream	None	None in vicinity
28/MAR	Nature Conservation	Nature Conservation	Nature Conservation	No obvious impacts	None	None in vicinity
29/HERM	Nature Conservation	Nature Conservation	Nature Conservation	Weir downstream	None	None in vicinity
30/KLOOF	Nature Conservation	Nature Conservation	Nature Conservation	Weir downstream	None	None in vicinity
31/MEUL	Nature Conservation	Nature Conservation	Nature Conservation	Low-flow bridge downstream	None	None in vicinity
38/BOES	Urban: low intensity Nature Conservation	Nature Conservation	None	No obvious impacts	None	None in vicinity
39/GEN	Nature Conservation	Nature Conservation	Nature Conservation	Weir downstream	Bulldozed bank: partial	None in vicinity
41/BAIN	Nature Conservation	Recreational activities	Nature Conservation	Weir downstream	None	None in vicinity
50/RIV	Nature Conservation	Nature Conservation	Nature Conservation	Weir downstream	None	None in vicinity
15/HART	Nature Conservation	Water storage Facility	Nature Conservation	Large impoundment upstream	None	None in vicinity
17/DWAR	Agriculture: vineyards Agriculture: fruit orchards	Agriculture: vineyards Agriculture: fruit orchards	None	Canal downstream	None	Agricultural runoff
25/ELAND	Natural area on one side	Agriculture: not specified Water storage Facility	Nature Conservation Road adjacent to site	Large impoundment upstream Weir upstream	None	Agricultural runoff
40/THEE	Natural area on one side Agriculture: fruit orchards	Water storage Facility Agriculture: fruit orchards	None	Weir upstream Large impoundment upstream	None	Agricultural runoff Effects of impoundment
42/KOEK	Road adjacent to site Nature Conservation	Water storage Facility Agriculture: not specified	None	Low-flow bridge downstream Large impoundment upstream	None	Effects of impoundment
45/VALSGAT	Agriculture: fruit orchards	Forestry: partial Nature Conservation	Forestry: partial	Canal downstream Weir downstream	None	Agricultural runoff
46/LANG	Nature Conservation	Water storage Facility	Nature Conservation	Large impoundment upstream	None	Effects of impoundment
				Weir downstream		
47/VALS	Nature Conservation	Nature Conservation	Nature Conservation	Large impoundment upstream	None	Effects of impoundment

Site	Land use			Physical modifications		Water Quality Impact
	Beyond 5m	Upstream Water storage Facility	Within 5m	In Channel Modifications	Bank Modifications	
48/CAS	Nature Conservation Agriculture: not specified	Nature Conservation Agriculture: not specified	Nature Conservation	No obvious impacts	None	None in vicinity
04/SAND	Nature Conservation	Nature Conservation	Nature Conservation	Large impoundment 5 km upstream Weir upstream	None	None in vicinity
09/HOL	Agriculture: vineyards	Agriculture: vineyards	None	Large impoundment 5 km upstream Low-flow bridge upstream	None	Agricultural runoff
14/MOL	Road and bridge construction Nature Conservation	Road and bridge construction	None	Weir upstream	Reinforced bank	Road/bridge construction
26/DUT	Nature Conservation	Nature Conservation	Nature Conservation	Weir downstream	None	None in vicinity
36/HEID	Agriculture: fruit orchards Agricultural: livestock	Agriculture: not specified	None	Low-flow bridge downstream Large impoundment 5 km upstream	None None	Agricultural runoff
01/MCG	Agriculture: vineyards	Urban: high intensity	None	Weir upstream	None	Agricultural runoff Urban runoff
06/GLEN	Agriculture: vineyards	Agriculture: vineyards Undeveloped open land	None	Weir upstream	Bulldozed cobble bank	Agricultural runoff
07/DRIE	Undeveloped open land	Industrial area Urban: high intensity Informal settlement	Undeveloped open land	Bridge downstream	None	Industrial runoff Urban runoff
16/LEIP	Forestry: partial	Undeveloped open land	Undeveloped open land	Large impoundment 5 km upstream	None	Forestry: felled area
24/HOEK	Undeveloped open land Nature Conservation	Nature Conservation Agriculture: not specified	Undeveloped open land Nature Conservation	Low-flow bridge downstream	None	Agricultural runoff
32/SUUR	Urban: high intensity	Urban: high intensity	None	Low-flow bridge upstream	None	Agricultural runoff Various urban points
33/KRUIS	Agriculture: fruit orchards	Agriculture: fruit orchards	None	Low-flow bridge downstream	None	Agricultural runoff Farm dwellings
43/DWARS	Recreational activities	Urban: high intensity	None	Weir upstream	None	Fertiliser runoff Various urban points
44/CERES	Small dwelling	Nature Conservation	None	Weir upstream	Stabilised left bank	None in immediate vicinity
49/SLANG	Agriculture: vineyards	Agriculture: vineyards	None	Low-flow bridge upstream	Bulldozed partial	Agricultural runoff
10/NEK	Undeveloped open land	Wetland area	Undeveloped open land	Bridge downstream	None	None in vicinity
11/CHAS	Agriculture: vineyards	Agriculture: vineyards Undeveloped open land	None	Weir upstream	None	Agricultural runoff
20/SECUND	Nature Conservation Agriculture: vineyards	Agriculture: vineyards	Undeveloped open land	Weir upstream	None	Agricultural runoff Farm dwellings
19/VINK	Agriculture: vineyards Agriculture: fruit orchards	Agriculture: vineyards Agriculture: fruit orchards	Rubble and debris	Weir upstream	Bulldozed banks	Agricultural runoff Farm dwellings

Site	Land use			Physical modifications		Water Quality Impact
	Beyond 5m	Upstream	Within 5m	In Channel Modifications	Bank Modifications	
21/DREW	Agriculture: lucern	Agriculture: vineyards Undeveloped open land	Undeveloped open land	Low-flow bridge upstream	Reinforced bank	Agricultural runoff Farm dwellings
35/DUIW	Agriculture: not specified	Agriculture: not specified	None	Low-flow bridge downstream	None	Agricultural runoff
27/SWELL	Road adjacent to site Agriculture: wheat	Agriculture: wheat	None	Weir upstream	Partially reinforced bank	Agricultural runoff
34/NAP	Agriculture: wheat	Agriculture: wheat	None	No obvious impacts	None	Agricultural runoff
						Farm dwellings
37/KLIP	Nature Conservation	Agriculture: vineyards Urban: high intensity	None	Weir upstream	None	Agricultural runoff Various urban points
08/NUY	Agricultural: livestock	Agricultural: livestock	Agricultural: livestock	Weir downstream	Canalised Concrete and cobble bank	Farm dwellings Livestock feedlot Agricultural runoff
18/KOG	Agriculture: fruit orchards	Agriculture: fruit orchards Urban: high intensity	Undeveloped open land	Bridge downstream Weir upstream	None None	Agricultural runoff Urban runoff Livestock watering area

Table 4.11. Geographic and map-based information such as river, altitude, latitude and longitude, together with geological and vegetation type, for each site.

Site	River	Altitude	Distance from source	Order	Latitude				Longitude				Geological type	Vegetation type
02/HOUT	Houtbaais	320	10.0	3	33	59	30	S	19	49	00	E	Table Mountain	Macchia (Fynbos)
03/TRIBSAND	Tributary of Sanddrifskloof	520	3.0	3	33	27	10	S	19	33	10	E	Table Mountain	Macchia (Fynbos)
05/ROOI	Rooielskloof	500	8.5	3	33	27	30	S	19	37	00	E	Table Mountain	Macchia (Fynbos)
12/RIET	Rietvleikloof	300	5.5	3	33	52	40	S	19	40	45	E		
13/EPAD	Elandspad	460	15.0	4	33	44	00	S	19	06	54	E	Table Mountain	Macchia (Fynbos)
22/BOES	Boesmans	280	9.5	3	34	02	35	S	19	57	50	E	Bokkeveld	Macchia (Fynbos)
23/MAC	Houtbaais	280	12.0	3	33	58	30	S	19	49	10	E	Table Mountain	Macchia (Fynbos)
28/MARL	Duiwelsbos	200	2.0	2	33	59	55	S	20	27	30	E		
29/HERM	Hermitage	200	8.0	2	33	59	15	S	20	25	30	E	Table Mountain	Macchia (Fynbos)
30/KLOOF	Grootkloof	100	8.5	3	34	00	05	S	20	32	58	E	Bokkeveld	Coastal Renosterveld
31/MEUL	Meulkloof	120	7.0	3	34	00	12	S	20	31	43	E		
38/BOES	Boesmanskloof	240	15.0	3	34	02	27	S	19	37	30	E		
39/GEN	Baviaans	160	11.0	3	34	01	45	S	19	33	30	E	Table Mountain	Macchia (Fynbos)
41/BAIN	Wit	280	19.0	3	33	34	00	S	19	09	00	E	Table Mountain	Macchia (Fynbos)
50/RIV	Riviersonderend	360	9.0	3	34	03	50	S	19	04	15	E	Table Mountain	Macchia (Fynbos)
15/HART	Hartbees	440	3.0	3	33	33	30	S	19	26	00	E	Table Mountain	Macchia (Fynbos)
17/DWAR	Water-Dwariega	1280	13.0	3	33	53	30	S	20	20	15	E		
25/ELAND	Elandskloof	360	11.5	4	33	57	15	S	19	16	52	E	Table Mountain	Macchia (Fynbos)
40/THEE	Riviersonderend	280	10.0	3	34	04	39	S	19	17	27	E	Bokkeveld	Macchia (Fynbos)
42/KOEK	Koekedou	660	15.5	3	33	21	32	S	19	17	54	E	Table Mountain	Macchia (Fynbos)
45/VALSGAT	Valsgat	1180	4.0	3	33	19	45	S	19	38	30	E	Table Mountain	Macchia (Fynbos)
46/LANG	Spek	900	1.0	2	33	22	00	S	19	34	50	E	Malmesbury, Kango, Gariep	Macchia (Fynbos)
47/VALS	Vals	760	5.5	2	33	26	05	S	19	24	17	E	Table Mountain	Coastal Renosterveld
48/CAS	Modder	500	13.0	3	33	18	42	S	19	17	01	E		
04/SAND	Sanddrifskloof	400	17.5	3	33	29	00	S	19	31	45	E	Table Mountain	Macchia (Fynbos)
09/HOL	Holsloot	300	24.0	3	33	45	30	S	19	19	45	E	Table Mountain	Macchia (Fynbos)
14/MOL	Molenaars	380	13.0	4	33	43	24	S	19	10	13	E	Table Mountain	Macchia (Fynbos)
26/DUT	Du Toits	380	10.0	3	33	56	30	S	19	10	15	E	Table Mountain	Macchia (Fynbos)
36/HEID	Duiwenshoek	140	17.5	5	34	01	15	S	20	56	00	E	Bokkeveld	Coastal Renosterveld
01/MCG	Keisers	200	22.5	4	33	56	00	S	19	50	15	E	Table Mountain	Macchia (Fynbos)
06/GLEN	Hex	320	36.0	5	33	34	30	S	19	30	25	E	Table Mountain	Macchia (Fynbos)
07/DRIE	Hex	220	49.0	5	33	40	30	S	19	27	50	E	Malmesbury, Kango, Gariep	Karroid Broken Veld
16/LEIP	Nuy	350	11.0	3	33	37	50	S	19	40	30	E		
24/HOEK	Hoeks	240	15.0	4	33	51	30	S	19	24	30	E	Table Mountain	Mountain Renosterbos
32/SUUR	Buffelsjag	120	42.5	5	34	00	15	S	20	39	30	E	Table Mountain	Coastal Renosterveld
33/KRUIS	Kruis	140	13.5	4	34	00	30	S	20	42	10	E		

43/DWARS	Breede	400	24.5	5	33	22	45	S	19	18	15	E	Table Mountain	Macchia (Fynbos)
44/CERES	Breede	300	31.0	5	33	25	15	S	19	16	00	E	Table Mountain	Macchia (Fynbos)
49/SLANG	Breede	240	20.5	6	33	32	28	S	19	12	25	E		
10/NEK	Breede	200	80.0	6	33	41	03	S	19	25	19	E	Table Mountain	Karroid Broken Veld
11/CHAS	Breede	180	115.0	6	34	49	00	S	19	41	30	E	Table Mountain	Karroid Broken Veld
20/SECUND	Breede	140	156.0	6	33	53	45	S	20	00	45	E	Table Mountain	Karroid Broken Veld
19/VINK	Vink	180	17.5	4	33	49	15	S	19	47	45	E	Table Mountain	Karroid Broken Veld
21/DREW	Breede	100	191.0	6	34	00	15	S	20	12	30	E	Table Mountain	Karroid Broken Veld
35/DUIW	Duiwenshoek	20	31.0	5	34	15	15	S	20	59	30	E	Bokkeveld	Coastal Renosterveld
27/SWELL	Breede	60	222.0	7	34	03	00	S	20	24	15	E	Bokkeveld	Coastal Renosterveld
34/NAP	Breede	20	274.0	7	34	14	25	S	20	30	45	E		
37/KLIP	Riviersonderend	100	95.5	5	34	04	45	S	20	08	45	E	Table Mountain	Karroid Broken Veld
08/NUY	Nuy	200	33.0	4	33	43	00	S	19	28	45	E	Malmesbury, Kango, Gariep	Karroid Broken Veld
18/KOG	Kogmanskloof	140	60.5	4	33	52	15	S	20	00	12	E	Table Mountain	Karroid Broken Veld

4.4 DISCUSSION AND SUMMARY

The results presented in this chapter describe the condition of fifty sites within a single DWAF drainage region (H) and within two catchments, the Breede and Duiwenshoek catchments. Effective management of water quality in riverine ecosystems necessitates the examination of systems rather than single sites.

On the basis of SASS Scores, 19% of the mountain stream sites, 67% of the foothill sites, 50% of the transitional sites and 60% of the lowland sites were categorised as impacted. "Least impacted" or reference sites in the mountain stream and foothill subregions had SASS4 Scores>140 or ASPTs>7.5 suggesting that differentiation between these subregions with respect to SASS4 Scores is not necessary. Similarly, transitional and lowland reference sites all had SASS4 Scores>85 and ASPTs>6.5. Cluster and ordination analysis of biological communities generally supported the SASS groupings with the exception of a few sites detailed in section 4.3.1. Conplots of SASS4 Scores and ASPTs overlaid on the MDS ordination also supported the groups. Interestingly, HABS1, developed to aid in the interpretation of SASS scores, showed little correlation with either SASS4 Score or ASPT.

Examination of the frequency of occurrence of each macroinvertebrate taxon at reference sites (Table 4.3), supported the observed similarity between mountain stream and foothill subregions. Eight of the most frequently recorded taxa were common to reference sites in both subregions, with an additional taxon, Heptageniidae, also important at foothill reference sites. Most of these taxa were highlighted as important in differentiating Group 1 (i.e. mostly mountain stream and foothill reference sites) from Groups 2 and 3 (Table 4.4). On this basis it should be possible to establish reference conditions for SASS Scores. This aspect will be examined in more detail in Chapter 5.

Principal components analysis of the physical attributes and chemical constituents measured at each site, including both data from the current study and long term DWAF data, showed that the primary gradient corresponded to conductivity, pH, $(NO_2^- + NO_3^-)$-N. TSS, which was only measured in the current study, was also included as a factor in the respective analysis. There was a distinct gradient with mountain stream and foothill reference sites at the lower end of the gradient, with transitional and lowland reference sites and impacted mountain stream and foothill sites progressively moving along the gradient towards the higher values or concentrations. A second gradient corresponded to the anion or cation ratio, with mountain stream and foothill reference sites with high anion or low cation ratios, and transitional or lowland sites and impacted mountain stream and foothill sites with low anion or high cation ratios. Of these chemical constituents, conductivity and pH were most highly correlated with the biological community data.

Examination of land use, physical modifications and water quality impacts at each site, and relating these to the physical attributes, chemical constituents and biological communities recorded at the sites, revealed the effects that the former have on the latter. Activities in the catchment clearly affect water quality which is in turn reflected in SASS Scores. Sites below urban areas and/or in high intensity agricultural areas, particularly those which had livestock watering points adjacent to the river, were identifiable on the basis of both chemical characteristics of the water, particularly conductivity, pH, $(NO_2^- + NO_3^-)$-N and TSS, and with respect to the biological community, both in terms of SASS Scores and

community composition. As a site becomes impacted with respect to water quality, it assumes the characteristics of sites lower in the catchment, such that mountain streams resemble foothills, transitional or lowland sites and foothills resemble transitional or lowland sites.

Appendix 4.1. SASS4 Scores (SASS4), ASPTs, Number of Taxa (NT), Habitat Assessment Matrix (HAM; modified from Plafkin *et al.* 1989), Habitat Score (HABS1; Chutter 1994) for 50 sites within the Breede River catchment given by subregion (M = Mountain Stream, F = Foothill, T = Transitional and L = Lowland). Type of site: R = reference site; I = impacted site. The ecological status (ES: Classes 1 to 5) and DWAF gauging weir number are also given. Biotopes sampled at each site are indicated with a P (SIC = stones-in-current, SOOC = stones-out-of-current, MV = marginal vegetation, AQV = aquatic vegetation, GR = gravel, S = sand and MS = mud/silt).

SUBREGION	TYPE	ES	SITE	DWAF SITE	SASS4	ASPT	NT	HAM	HABS1	SIC	SOOC	MV	AQV	GR	S	MS
F	I	4	01/MCG	H4H016	62	4.13	15	64	95	P	P	P	P		P	
M	R	2	02/HOUT	H4H015	118	8.43	14	123	95	P	P	P	P			
M	R	1	03/TRIBSAND		129	9.21	14	128	90	P	P	P				
F	R	2	04/SAND	H2H004	129	8.60	15	115	95	P	P	P	P			
M	R	2	05/ROOI	H2H005	166	9.22	18	124	100	P	P	P	P	P	P	
F	I	2	06/GLEN	H2H006	105	6.56	16	111	85	P	P	P			P	
F	I	3	07/DRIE	H2H010	39	3.90	10	58	85	P		P	P			
L	I	5	08/NUY	H4H020	56	4.31	13	32	65		P	P				P
F	R	3	09/HOL	H1H012	120	8.57	14	119	85	P	P	P			P	
T	R	2	10/NEK	H1H015	107	6.69	16	81	85	P	P	P				
T	R	3	11/CHAS	H4H017	89	5.56	16	95	85	P	P	P				
M	R	2	12/RIET		153	8.50	18	93	85	P	P	P			P	
M	R	2	13/EPAD	H1H017	150	8.82	17	127	100	P	P	P	P	P	P	
F	R	2	14/MOL	H1H018	161	9.47	17	119	85	P	P	P			P	
M	I	2	15/HART	H1H020	90	6.92	13	120	95	P	P	P	P			
F	I	3	16/LEIP		87	5.12	17	88	85	P		P		P	P	
M	I	2	17/DWAR	H3H009	76	5.43	14	95	90	P	P	P		P		
L	I	4	18/KOG	H3H011	32	3.56	9	64	100	P	P	P	P	P	P	
T	I	4	19/VINK	H4H019	49	4.45	11	22	55	P	P					P
T	R	3	20/SECUND	H5H004	109	6.06	18	111	85	P	P	P			P	
T	I	3	21/DREW	H5H005	80	5.33	15	107	95	P	P	P	P			
M	R	2	22/BOES	H5H003	136	8.50	16	122	85	P	P		P			
M	R	2	23/MAC		107	8.23	13	113	85	P	P		P			
F	I	2	24/HOEK	H4H013	52	4.33	12	76	85	P	P	P			P	
M	I	2	25/ELAND	H6H015	41	4.56	9	105	90	P	P	P		P	P	

SUBREGION	TYPE	ES	SITE	DWAF SITE	SASS4	ASPT	NT	HAM	HABS1	SIC	SOOC	MV	AQV	GR	S	MS
F	R	2	26/DUT	H6H007	103	7.92	13	119	90	P	P	P		P		
L	R	3	27/SWELL	H7H006	99	5.82	17	85	90	P	P	P		P	P	
M	R	1	28/MAR		155	9.12	17	118	80	P	P					
M	R	2	29/HERM	H7H005	145	9.06	16	119	80	P	P					
M	R	2	30/KLOOF	H7H007	81	8.10	10	100	80	P		P				
M	R	1	31/MEUL		120	9.23	13	122	85	P	P		P			
F	I	3	32/SUUR	H7H003	90	5.29	17	82	90	P	P	P		P	P	
F	I	3	33/KRUIS		115	5.75	20	88	70	P	P				P	
L	R	3	34/NAP		91	5.35	17	47	90	P	P	P		P	P	
T	I	2	35/DUIW	H8H001	76	6.33	12	97	90	P	P	P		P	P	
F	R	2	36/HEID	H8H002	152	8.00	19	100	85	P	P	P				
L	R	4	37/KLIP	H6H009	97	6.47	15	84	100	P	P	P		P	P	P
M	R	2	38/BOES		168	8.84	19	110	90	P	P	P		P		
M	R	2	39/GEN	H6H005	150	8.82	17	91	85	P	P	P			P	
M	I	4	40/THEE	H6H014	49	5.44	9	112	90	P	P	P				
M	R	2	41/BAIN	H1H007	151	8.39	18	120	95	P	P	P	P	P		
M	I	3	42/KOEK	H1H013	62	5.17	12	107	90	P	P	P				
F	I	3	43/DWARS	H1H003	27	3.86	7	68	85	P	P	P			P	
F	I	2	44/CERES	H1H006	105	7.00	15	106	90	P	P	P		P		
M	I	3	45/VALSGAT	H2H008	132	7.33	18	69	85	P	P	P			P	
M	I	2	46/LANG	H2H016	58	6.44	9	84	60	P	P				P	P
M	I	2	47/VALS	H1H014	110	6.88	16	116	90	P	P	P		P		
M	I	2	48/CAS		119	7.44	16	105	85	P	P	P			P	
F	I	4	49/SLANG		61	5.55	11	108	100	P	P	P	P	P	P	
M	R	2	50/RIV	H6H008	135	8.67	16	119	95	P	P	P	P	P		

Appendix 4.2. Chemical data for each site sampled in the Breede River catchment in late October/November 1995. The site, subregion, physical attributes and chemical constituents are given. All concentrations are in mg l^{-1}, except for conductivity in mS m^{-1}, pH, turbidity in NTU and total alkalinity in meq l^{-1}. TURBOBS refers to the appearance of the water (1 = light brown and clear, 2 = light brown and turbid, 3 = dark brown and clear, 4 = dark brown and turbid).

Site	Subregion	COND	TDS	PH	TEMP	DO	DOPER	TSS	TURB	TURBOBS
01/MCG	F	221.0	1259.5	8.10	24.7	8.05	101.1	6.25	3	2
02/HOUT	M	5.2	47.0	4.61	15.5	7.19	73.6	0.90	1	2
03/TRIBSAND	M	1.2	10.3	5.37	14.6	9.06	92.1	0.50	0	1
04/SAND	F	2.0	16.7	6.18	16.5	8.97	93.6	1.15	0	1
05/ROOI	M	1.4	21.0	5.68	16.6	8.94	93.4	1.00	0	1
06/GLEN	F	11.0	68.1	7.06	22.0	7.85	91.4	0.47	0	1
07/DRIE	F	15.0	95.0	8.51	20.0	8.68	97.8	22.60	20	3
08/NUY	L	345.0	2146.5	8.16	19.7	8.74	98.9	3.65	1	2
09/HOL	F	2.0	11.9	5.99	20.8	8.14	93.1	0.78	1	1
10/NEK	T	11.6	83.1	6.95	22.7	7.37	87.6	6.33	5	4
11/CHAS	T	21.4	132.7	7.23	20.0	8.21	92.2	6.00	5	4
12/RIET	M	12.2	64.4	4.76	16.3	7.81	81.4	0.00	0	1
13/EPAD	M	1.4	8.4	5.85	13.5	9.16	90.9	1.22	0	1
14/MOL	F	2.2	21.9	6.39	17.0	8.74	91.3	0.23	1	1
15/HART	M	1.8	6.4	6.09	17.5	8.26	8.26	0.11	0	1
16/LEIP	F	17.4	109.1	7.59	19.3	7.75	84.8	3.10	2	4
17/DWAR	M	53.2	272.1	7.93	25.1	7.36	90.9	0.80	0	1
18/KOG	L	270.0	1600.7	8.66	22.1	9.88	115.3	5.29	2	4
19/VINK	T	338.0	2119.5	8.05	20.7	10.4	118.5	3.45	1	4
20/SECUND	T	50.0	3138.8	8.00	21.9	8.09	93.8	2.93	2	4
21/DREW	T	61.4	339.6	8.06	22.8	8.04	95.1	3.01	1	4
22/BOES	M	6.2	43.1	4.72	19.1	7.93	87.1	0.63	0	2
23/MAC	M	5.6	46.5	4.50	17.3	7.84	83.1	0.25	1	1
24/HOEK	F	22.2	148.6	7.57	22.1	7.86	91.8	1.05	1	1
25/ELAND	M	5.6	40.4	7.26	22.2	7.61	89.1	1.10	1	1
26/DUT	F	3.2	25.9	4.33	19.0	8.13	89.4	0.00	0	1
27/SWELL	L	47.4	269.1	7.82	24.6	7.51	91.5	2.40	2	4
28/MAR	M	5.6	70.4	4.11	16.0	8.31	84.8	1.25	0	2
29/HERM	M	4.2	27.1	4.48	18.6	8.17	88.2	0.45	0	2
30/KLOOF	M	5.8	63.1	4.31	18.6	8.61	93.6	0.45	0	2
31/MEUL	M	4.4	37.9	4.45	21.0	8.05	91.7	0.25	0	2
32/SUUR	F	31.0	186.6	8.40	27.8	9.39	121.4	3.43	3	4
33/KRUIS	F	50.4	294.8	7.42	27.0	5.74	74.8	6.36	7	4
34/NAP	L	39.6	219.8	7.92	25.2	7.23	90.1	2.24	3	4
35/DUIW	T	31.6	197.4	7.17	25.5	7.11	88.5	0.96	2	4
36/HEID	F	11.2	109.4	5.50	27.0	7.01	89.4	1.25	2	2
37/KLIP	L	20.2	136.1	6.97	22.3	7.56	87.9	5.40	5	4
38/BOES	M	5.8	45.4	5.09	19.3	7.92	86.8	1.10	1	2
39/GEN	M	6.6	45.6	5.06	18.3	8.39	90.1	0.70	0	1
40/THEE	M	8.2	50.0	6.09	17.1	7.74	81.2	0.24	1	1
41/BAIN	M	2.2	14.4	4.92	20.8	8.08	91.6	0.00	0	1
42/KOEK	M	3.8	27.6	6.76	21.3	7.39	84.9	0.74	0	3
43/DWARS	F	33.0	197.3	7.12	22.0	7.38	85.6	2.20	1	4
44/CERES	F	17.0	106.6	7.60	22.4	7.52	87.9	0.70	1	1
45/VALSGAT	M	1.8	9.5	5.29	20.8	7.07	99.6	0.55	0	1
46/LANG	M	11.2	72.8	5.86	19.8	7.28	81.2	0.65	1	1
47/VALS	M	1.8	13.0	4.79	15.8	8.56	87.8	0.55	0	4
48/CAS	M	4.2	28.9	6.70	18.7	8.45	92.1	0.40	1	1
49/SLANG	F	14.2	86.1	7.50	24.8	7.33	98.3	0.73	1	1
50/RIV	M	3.2	26.0	4.88	21.5	7.89	89.9	0.30	0	1

Site	Na^+	Ca^{2+}	K^+	Mg^{2+}	SO_4^{2-}	Cl^-	TAL	$(NO_2^- + NO_3^-)$-N	SRP	SiO_2
01/MCG	382.7	44.8	5.9	33.8	25.4	426.4	7.61	0.024	0.0176	3.6788
02/HOUT	6.8	0.7	0.3	0.3	1.4	12.0	0.05	0.024	0.0156	0.0407
03/TRIBSAND	1.8	0.6	0.1	0.1	1.4	3.0	0.07	0.024	0.0064	0.0407
04/SAND	2.3	0.8	0.2	0.2	1.1	2.7	0.06	0.024	0.0074	0.1017
05/ROOI	2.6	0.5	0.3	0.2	0.8	1.8	0.10	0.024	0.0014	0.0162
06/GLEN	10.1	4.2	1.2	1.7	15.0	7.2	0.18	0.528	0.0014	0.0162
07/DRIE	12.7	6.3	1.7	2.5	17.5	10.7	1.63	0.312	0.0105	0.0162
08/NUY	252.3	81.3	11.9	109.0	55.4	125.7	3.46	0.224	0.0105	1.3592
09/HOL	6.5	2.1	0.3	1.2	2.4	5.4	0.08	0.008	0.0166	1.9818
10/NEK	11.3	4.9	1.0	2.4	8.4	20.7	0.25	0.520	0.0227	2.3359
11/CHAS	26.7	7.8	1.4	4.4	16.3	45.9	0.39	0.432	0.0054	0.0407
12/RIET	17.1	1.1	0.4	1.5	3.5	33.8	0.01	0.008	0.0146	1.4324
13/EPAD	2.8	0.6	0.2	0.3	2.5	4.6	0.07	0.040	0.0227	2.3600
14/MOL	3.4	1.0	0.3	0.5	5.7	14.8	0.01	0.040	0.0095	0.0529
15/HART	2.6	0.8	0.1	0.3	4.5	12.2	0.10	0.024	0.0135	0.0773
16/LEIP	11.7	5.6	0.7	2.4	8.1	33.3	0.55	0.328	0.0176	0.2726
17/DWAR	70.2	17.8	0.7	7.4	36.9	79.4	0.23	0.056	0.0125	0.0890
18/KOG	189.9	41.9	3.8	38.0	53.7	126.3	3.31	0.208	0.0420	2.1283
19/VINK	478.5	94.0	2.2	96.7	94.8	132.8	2.58	0.256	0.0054	4.8997
20/SECUND	56.6	19.7	3.2	6.8	30.7	145.3	0.81	0.184	0.0491	4.7650
21/DREW	82.8	11.2	1.5	19.5	36.5	165.3	0.93	0.008	0.0054	4.8997
22/BOES	11.8	1.5	0.3	0.5	1.7	11.2	0.05	0.008	0.0095	2.6899
23/MAC	7.9	1.0	0.3	0.3	1.2	9.7	0.10	0.008	0.0095	2.4946
24/HOEK	25.7	6.0	0.7	5.6	13.8	45.2	0.35	0.296	0.0074	0.0407
25/ELAND	6.9	0.2	0.5	0.7	1.4	5.9	0.18	0.280	0.0125	0.0407
26/DUT	3.8	0.9	0.1	0.1	1.0	6.6	0.07	0.008	0.0054	0.0529
27/SWELL	51.8	10.0	1.1	10.9	27.8	84.0	0.78	0.128	0.0064	1.5540
28/MAR	23.0	4.2	0.6	2.6	1.6	10.4	0.01	0.032	0.0166	0.1139
29/HERM	4.9	1.9	0.3	0.3	1.8	6.9	0.04	0.024	0.0135	0.0895
30/KLOOF	10.9	5.7	0.7	0.9	1.9	22.3	0.01	0.008	0.0217	0.1261
31/MEUL	4.1	0.5	0.3	0.4	1.4	9.1	0.01	0.024	0.0166	0.0895
32/SUUR	38.4	4.6	0.7	4.5	18.1	75.2	0.58	0.216	0.0186	0.9319
33/KRUIS	62.4	7.3	0.9	7.8	18.6	107.7	0.78	0.064	0.0166	2.2260
34/NAP	51.6	7.5	1.5	6.8	20.6	73.0	0.64	0.080	0.0054	1.7377
35/DUIW	44.6	4.4	1.0	4.7	14.4	73.5	0.37	0.064	0.0156	0.4558
36/HEID	16.6	1.6	0.6	1.7	3.0	27.4	0.02	0.024	0.0166	0.1750
37/KLIP	20.2	2.7	0.7	2.5	5.1	45.4	0.35	0.064	0.0064	0.5168
38/BOES	6.4	0.5	0.0	0.5	1.0	14.6	0.05	0.016	0.0115	0.1505
39/GEN	7.2	1.5	0.2	0.6	1.1	18.2	0.05	0.024	0.0105	0.1872
40/THEE	7.0	2.7	0.5	0.8	3.2	17.6	0.12	0.080	0.0034	0.2726
41/BAIN	3.3	0.5	0.2	0.2	0.5	5.1	0.10	0.152	0.0085	0.0895
42/KOEK	4.3	0.8	0.3	0.6	1.2	7.2	0.06	0.008	0.0054	0.7854
43/DWARS	28.5	12.4	1.6	5.9	21.4	56.9	0.63	0.256	0.0603	4.4724
44/CERES	16.7	6.3	0.9	3.2	10.5	31.4	0.36	0.128	0.0268	4.3381
45/VALSGAT	2.5	1.3	0.1	0.3	0.5	4.0	0.35	0.008	0.0034	0.0895
46/LANG	8.8	4.8	0.9	1.3	4.2	19.8	0.30	0.008	0.0034	3.8620
47/VALS	2.7	1.7	0.1	0.2	0.4	3.0	0.07	0.008	0.0064	0.0651
48/CAS	5.3	1.8	0.3	0.6	1.3	11.8	0.14	0.008	0.0054	1.3104
49/SLANG	14.3	5.2	0.7	2.8	16.1	42.1	0.33	0.088	0.0054	0.1627
50/RIV	4.2	1.2	0.2	0.5	2.5	6.7	0.06	0.008	0.0054	3.9841

Site	Cd	Zn	Cr	Cu	Al	Fe	Hg	Mn
01/MCG	0.056	0.044	0.066	0.014	0.313	0.131	0.727	0.053
02/HOUT	0.057	0.049	0.083	0.005	0.252	0.181	0.049	0.081
03/TRIBSAND	0.056	0.046	0.006	0.005	0.152	0.116	0.191	0.051
04/SAND	0.056	0.042	0.006	0.006	0.163	0.128	0.293	0.055
05/ROOI	0.060	0.046	0.004	0.006	0.155	0.117	0.246	0.047
06/GLEN	0.024	0.032	0.001	0.006	0.558	0.126	0.251	0.073
07/DRIE	0.058	0.062	0.001	0.006	0.214	0.127	0.221	0.052
08/NUY	0.058	0.037	0.001	0.001	0.220	0.126	0.576	0.049
09/HOL	0.057	0.052	0.025	0.010	0.230	0.143	0.226	0.050
10/NEK	0.055	0.051	0.001	0.020	0.495	0.144	0.681	0.053
11/CHAS	0.059	0.044	0.009	0.006	0.214	0.282	0.226	0.054
12/RIET	0.056	0.058	0.001	0.019	0.551	0.159	0.607	0.051
13/EPAD	0.061	0.183	0.001	0.026	0.533	0.162	0.715	0.055
14/MOL	-	-	-	-	-	-	-	-
15/HART	0.059	0.045	0.001	0.005	0.206	0.125	0.197	0.053
16/LEIP	0.058	0.050	0.081	0.011	0.200	0.125	0.227	0.049
17/DWAR	0.060	0.043	0.071	0.006	0.173	0.153	0.425	0.055
18/KOG	0.053	0.044	0.001	0.022	0.454	0.123	0.957	0.061
19/VINK	0.057	0.056	0.014	0.019	0.356	0.133	1.030	0.055
20/SECUND	0.059	0.041	0.006	0.007	0.150	0.137	0.368	0.051
21/DREW	0.060	0.039	0.001	0.007	0.197	0.134	0.391	0.054
22/BOES	0.057	0.052	0.022	0.005	0.232	0.180	0.149	0.051
23/MAC	0.058	0.049	0.012	0.006	0.239	0.166	0.088	0.053
24/HOEK	0.057	0.042	0.011	0.007	0.157	0.132	0.178	0.059
25/ELAND	0.061	0.042	0.025	0.006	0.176	0.140	0.191	0.056
26/DUT	0.057	0.046	0.015	0.001	0.164	0.129	0.175	0.050
27/SWELL	0.056	0.042	0.006	0.006	0.174	0.184	0.353	0.061
28/MAR	0.059	0.044	0.032	0.005	0.321	0.276	0.243	0.052
29/HERM	0.061	0.072	0.006	0.014	0.345	0.195	0.424	0.077
30/KLOOF	0.059	0.209	0.001	0.018	0.585	0.316	0.574	0.069
31/MEUL	0.060	0.039	0.014	0.016	0.146	0.123	0.257	0.051
32/SUUR	0.058	0.066	0.008	0.015	0.428	0.283	0.429	0.050
33/KRUIS	0.058	0.067	0.004	0.018	0.313	0.189	0.336	0.054
34/NAP	0.057	0.052	0.006	0.008	0.199	0.145	0.164	0.098
35/DUIW	0.058	0.109	0.006	0.017	0.347	0.328	0.530	0.082
36/HEID	0.058	0.075	0.001	0.019	0.598	0.429	0.562	0.059
37/KLIP	0.056	0.066	0.001	0.019	0.444	0.180	0.637	0.056
38/BOES	0.057	0.049	0.001	0.001	0.295	0.286	0.229	0.097
39/GEN	0.060	0.038	0.420	0.006	0.161	0.182	0.181	0.120
40/THEE	0.057	0.050	0.006	0.006	0.175	0.140	0.211	0.071
41/BAIN	0.059	0.048	0.005	0.005	0.177	0.128	0.159	0.052
42/KOEK	0.056	0.044	0.008	0.006	0.160	0.129	0.217	0.047
43/DWARS	0.059	0.042	0.002	0.006	0.169	0.178	0.229	0.146
44/CERES	0.059	0.051	0.001	0.007	0.156	0.139	0.156	0.050
45/VALSGAT	0.059	0.046	0.013	0.006	0.164	0.143	0.225	0.049
46/LANG	0.058	0.046	0.004	0.005	0.156	0.139	0.263	0.128
47/VALS	0.059	0.044	0.001	0.005	0.241	0.145	0.252	0.047
48/CAS	0.057	0.050	0.022	0.006	0.150	0.129	0.224	0.047
49/SLANG	0.058	0.043	0.009	0.005	0.209	0.145	0.147	0.052
50/RIV	0.057	0.046	0.015	0.004	0.164	0.129	0.175	0.050

Appendix 4.3. Department of Water Affairs & Forestry chemical data for 38 of the 50 sites sampled in the Breede River. For each site the corresponding DWAF site code, median, minimum and maximum values or concentrations, and the number of analyses (n) are tabulated. In all cases the most recent data available prior to 1996 were used. All concentrations are in mg l^{-1} except for conductivity in mS m^{-1}, temperature in °C and pH.

VARIABLE	SITE	DWAF	n	Median	Min	Max
Conductivity	01/MCG	H4H016	116	153.2	4.4	544.0
Conductivity	02/HOUT	H4H015	37	6.8	4.6	10.4
Conductivity	04/SAND	H2H004	31	4.8	3.2	6.2
Conductivity	05/ROOI	H2H005	38	3.2	2.0	5.6
Conductivity	06/GLEN	H2H006	149	18.4	3.5	31.9
Conductivity	07/DRIE	H2H010	146	279.0	70.3	395.0
Conductivity	08/NUY	H4H020	155	419.0	49.5	600.0
Conductivity	09/HOL	H1H012	97	3.5	2.2	8.0
Conductivity	10/NEK	H1H015	139	13.8	5.2	36.5
Conductivity	11/CHAS	H4H017	148	25.1	7.5	72.3
Conductivity	13/EPAD	H1H017	133	3.6	2.2	7.8
Conductivity	14/MOL	H1H018	150	3.9	2.3	6.9
Conductivity	15/HART	H1H020	30	2.2	1.8	12.1
Conductivity	17/DWARS	H3H009	27	44.6	12.8	72.9
Conductivity	18/KOG	H3H011	150	320.5	117.8	534.0
Conductivity	19/VINK	H4H019	151	236.0	15.9	419.0
Conductivity	20/SECUND	H5H004	156	87.3	0.2	350.0
Conductivity	21/DREW	H5H005	148	108.7	5.7	225.0
Conductivity	22/BOES	H5H003	38	11.8	6.6	15.4
Conductivity	24/HOEK	H4H013	63	30.9	9.8	154.3
Conductivity	25/ELAND	H6H015	15	9.8	5.7	12.4
Conductivity	26/DUT	H6H007	34	5.0	3.8	6.6
Conductivity	27/SWELL	H7H006	130	67.6	0.6	190.2
Conductivity	29/HERM	H7H005	34	3.7	3.1	11.9
Conductivity	30/KLOOF	H7H007	83	5.7	2.6	29.4
Conductivity	32/SUUR	H7H003	111	21.0	7.6	50.0
Conductivity	35/DUIW	H8H001	119	37.9	7.2	311.0
Conductivity	36/HEID	H8H002	80	11.7	3.2	82.1
Conductivity	37/KLIP	H6H009	115	28.4	3.6	199.7
Conductivity	39/GEN	H6H005	36	7.0	5.3	11.0
Conductivity	41/BAIN	H1H007	150	3.5	2.3	8.7
Conductivity	42/KOEK	H1H013	36	6.0	3.3	11.2
Conductivity	43/DWARS	H1H003	151	26.5	9.5	109.8
Conductivity	44/CERES	H1H006	151	13.1	3.2	37.4
Conductivity	45/VALSGAT	H2H008	70	3.9	0.3	77.8
Conductivity	46/LANG	H2H016	36	12.2	5.1	16.2
Conductivity	47/VALS	H1H014	97	2.9	1.2	45.9
Conductivity	50/RIV	H6H008	34	4.4	3.2	6.6
TDS	01/MCG	H4H016	35	1371	179	3911
TDS	02/HOUT	H4H015	37	37	27	72
TDS	04/SAND	H2H004	29	25	18	38
TDS	05/ROOI	H2H005	38	23	15	39
TDS	06/GLEN	H2H006	149	100	28	167
TDS	07/DRIE	H2H010	146	1875	483	2628
TDS	08/NUY	H4H020	155	2744	260	3941
TDS	09/HOL	H1H012	26	28	18	46
TDS	10/NEK	H1H015	139	77	26	205
TDS	11/CHAS	H4H017	148	128	45	376
TDS	13/EPAD	H1H017	87	21	14	54

TDS	14/MOL	H1H018	150	26	14	43
TDS	15/HART	H1H020	25	20	14	38
TDS	17/DWARS	H3H009	26	242	65	398
TDS	18/KOG	H3H011	150	1981	844	3519
TDS	19/VINK	H4H019	151	1456	90	2628
TDS	20/SECUND	H5H004	156	536	31	2179
TDS	21/DREW	H5H005	148	665	34	1436
TDS	22/BOES	H5H003	38	60	45	119
TDS	24/HOEK	H4H013	55	153	55	786
TDS	25/ELAND	H6H015	15	67	34	82
TDS	26/DUT	H6H007	32	24	18	37
TDS	27/SWELL	H7H006	37	359	59	872
TDS	29/HERM	H7H005	34	26	19	40
TDS	30/KLOOF	H7H007	83	34	15	156
TDS	32/SUUR	H7H003	33	109	52	324
TDS	35/DUIW	H8H001	43	192	76	546
TDS	36/HEID	H8H002	25	68	18	430
TDS	37/KLIP	H6H009	34	168	74	667
TDS	39/GEN	H6H005	36	38	28	65
TDS	41/BAIN	H1H007	150	23	14	59
TDS	42/KOEK	H1H013	36	33	22	56
TDS	43/DWARS	H1H003	151	151	56	618
TDS	44/CERES	H1H006	151	70	21	204
TDS	45/VALSGAT	H2H008	23	30	16	220
TDS	46/LANG	H2H016	36	70	46	91
TDS	47/VALS	H1H014	30	20	13	78
TDS	50/RIV	H6H008	32	23	11	34
PH	01/MCG	H4H016	35	8.25	7.44	8.95
PH	02/HOUT	H4H015	37	5.95	4.69	7.99
PH	04/SAND	H2H004	31	6.13	4.83	7.23
PH	05/ROOI	H2H005	38	6.52	5.56	8.45
PH	06/GLEN	H2H006	149	7.19	5.90	7.98
PH	07/DRIE	H2H010	146	8.26	7.67	8.76
PH	08/NUY	H4H020	155	8.21	6.97	8.73
PH	09/HOL	H1H012	26	5.44	4.33	6.20
PH	10/NEK	H1H015	139	7.25	6.21	7.93
PH	11/CHAS	H4H017	148	7.44	6.71	8.09
PH	13/EPAD	H1H017	133	6.24	4.52	8.00
PH	14/MOL	H1H018	150	6.67	4.31	8.20
PH	15/HART	H1H020	25	4.79	3.85	5.62
PH	17/DWARS	H3H009	26	7.16	6.40	7.57
PH	18/KOG	H3H011	150	8.26	7.74	9.03
PH	19/VINK	H4H019	151	8.08	7.45	8.66
PH	20/SECUND	H5H004	156	7.95	6.65	8.81
PH	21/DREW	H5H005	148	8.10	6.78	8.75
PH	22/BOES	H5H003	38	6.80	4.89	7.65
PH	24/HOEK	H4H013	55	6.77	5.30	7.70
PH	25/ELAND	H6H015	15	7.46	7.14	8.02
PH	26/DUT	H6H007	34	6.26	1.83	8.21
PH	27/SWELL	H7H006	37	7.73	6.78	8.33
PH	29/HERM	H7H005	34	4.44	3.31	7.16
PH	30/KLOOF	H7H007	83	4.04	3.00	7.16
PH	32/SUUR	H7H003	39	7.20	4.65	8.54
PH	35/DUIW	H8H001	43	7.19	5.53	8.08
PH	36/HEID	H8H002	27	5.25	3.40	6.49
PH	37/KLIP	H6H009	34	7.32	6.87	8.04

PH	39/GEN	H6H005	36	6.16	4.86	7.90
PH	41/BAIN	H1H007	150	6.03	4.73	8.19
PH	42/KOEK	H1H013	36	6.37	5.29	7.10
PH	43/DWARS	H1H003	151	7.45	6.78	8.18
PH	44/CERES	H1H006	151	7.24	5.89	8.54
PH	45/VALSGAT	H2H008	23	6.81	6.11	7.97
PH	46/LANG	H2H016	36	7.36	6.41	7.85
PH	47/VALS	H1H014	33	4.90	3.69	6.50
PH	50/RIV	H6H008	34	5.72	1.88	7.31
Temperature	01/MCG	H4H016	112	17.9	9.9	33.8
Temperature	02/HOUT	H4H015	36	17.3	10.6	28.4
Temperature	05/ROOI	H2H005	27	14.3	7.6	22.3
Temperature	06/GLEN	H2H006	96	17.4	8.7	27.9
Temperature	07/DRIE	H2H010	141	16.4	8.0	26.0
Temperature	08/NUY	H4H020	150	16.3	8.4	25.8
Temperature	10/NEK	H1H015	98	19.2	9.8	28.3
Temperature	11/CHAS	H4H017	142	19.1	9.8	27.9
Temperature	13/EPAD	H1H017	51	14.3	9.8	25.0
Temperature	14/MOL	H1H018	131	16.0	7.5	28.0
Temperature	18/KOG	H3H011	139	19.1	9.2	30.6
Temperature	19/VINK	H4H019	146	17.9	9.8	28.0
Temperature	20/SECUND	H5H004	150	19.7	10.0	30.1
Temperature	21/DREW	H5H005	145	20.5	10.8	30.0
Temperature	22/BOES	H5H003	38	18.3	11.5	26.0
Temperature	24/HOEK	H4H013	49	18.0	9.7	27.0
Temperature	25/ELAND	H6H015	11	10.8	8.7	20.5
Temperature	26/DUT	H6H007	15	13.2	10.2	25.0
Temperature	27/SWELL	H7H006	129	19.4	10.2	30.1
Temperature	29/HERM	H7H005	6	13.0	10.3	19.8
Temperature	30/KLOOF	H7H007	6	15.8	11.3	21.7
Temperature	35/DUIW	H8H001	116	18.7	9.8	27.5
Temperature	37/KLIP	H6H009	113	17.9	9.3	30.3
Temperature	39/GEN	H6H005	30	16.3	10.4	26.3
Temperature	41/BAIN	H1H007	146	17.6	8.8	28.8
Temperature	42/KOEK	H1H013	35	18.0	8.9	24.6
Temperature	43/DWARS	H1H003	144	18.5	8.8	29.1
Temperature	44/CERES	H1H006	144	16.8	8.8	28.2
Temperature	45/VALSGAT	H2H008	69	14.2	5.5	30.2
Temperature	46/LANG	H2H016	34	17.1	9.7	28.9
Temperature	47/VALS	H1H014	14	15.8	10.3	25.0
Temperature	50/RIV	H6H008	13	11.0	8.5	19.5
Sodium	01/MCG	H4H016	35	310.5	41.8	1005.0
Sodium	02/HOUT	H4H015	37	7.1	4.2	10.7
Sodium	04/SAND	H2H004	31	3.0	1.3	4.9
Sodium	05/ROOI	H2H005	38	2.9	1.1	9.6
Sodium	06/GLEN	H2H006	149	14.4	3.2	25.3
Sodium	07/DRIE	H2H010	146	395.9	97.7	580.2
Sodium	08/NUY	H4H020	155	603.7	50.9	896.1
Sodium	09/HOL	H1H012	26	4.2	2.2	8.8
Sodium	10/NEK	H1H015	139	12.5	4.5	44.1
Sodium	11/CHAS	H4H017	148	26.6	6.4	86.0
Sodium	13/EPAD	H1H017	94	2.3	0.6	4.6
Sodium	14/MOL	H1H018	150	3.9	1.7	6.6
Sodium	15/HART	H1H020	25	3.1	2.3	7.4
Sodium	17/DWARS	H3H009	26	57.8	18.0	97.1

Sodium	18/KOG	H3H011	150	479.3	138.2	891.8
Sodium	19/VINK	H4H019	151	307.8	15.4	588.6
Sodium	20/SECUND	H5H004	156	124.6	5.1	544.2
Sodium	21/DREW	H5H005	148	157.3	4.3	339.4
Sodium	22/BOES	H5H003	38	14.1	6.7	18.7
Sodium	24/HOEK	H4H013	55	34.9	11.0	185.2
Sodium	25/ELAND	H6H015	15	5.7	3.7	6.9
Sodium	26/DUT	H6H007	34	4.1	1.4	10.0
Sodium	27/SWELL	H7H006	37	88.9	13.1	214.8
Sodium	29/HERM	H7H005	34	4.2	3.0	5.2
Sodium	30/KLOOF	H7H007	83	5.8	2.8	39.0
Sodium	32/SUUR	H7H003	34	28.0	9.5	77.6
Sodium	35/DUIW	H8H001	43	47.0	13.0	148.8
Sodium	36/HEID	H8H002	25	17.7	1.1	130.3
Sodium	37/KLIP	H6H009	34	40.0	15.9	195.4
Sodium	39/GEN	H6H005	36	7.7	5.5	11.4
Sodium	41/BAIN	H1H007	150	3.2	0.9	5.3
Sodium	42/KOEK	H1H013	36	5.5	3.0	8.7
Sodium	43/DWARS	H1H003	151	26.0	8.5	129.5
Sodium	44/CERES	H1H006	151	11.2	2.7	48.0
Sodium	45/VALSGAT	H2H008	23	2.7	1.8	6.3
Sodium	46/LANG	H2H016	36	10.5	2.8	13.9
Sodium	47/VALS	H1H014	30	3.1	1.6	15.5
Sodium	50/RIV	H6H008	34	2.9	0.7	7.2
Calcium	01/MCG	H4H016	35	39.9	5.1	102.0
Calcium	02/HOUT	H4H015	37	1.3	0.5	8.9
Calcium	04/SAND	H2H004	31	1.5	0.4	2.4
Calcium	05/ROOI	H2H005	38	1.2	0.1	5.4
Calcium	06/GLEN	H2H006	149	8.5	1.1	18.8
Calcium	07/DRIE	H2H010	146	85.7	25.2	118.3
Calcium	08/NUY	H4H020	155	124.4	14.2	183.2
Calcium	09/HOL	H1H012	24	1.0	0.2	2.3
Calcium	10/NEK	H1H015	139	4.9	1.4	15.5
Calcium	11/CHAS	H4H017	148	6.6	2.3	18.0
Calcium	13/EPAD	H1H017	93	1.0	0.1	8.4
Calcium	14/MOL	H1H018	150	1.3	0.3	4.7
Calcium	15/HART	H1H020	18	0.5	0.2	1.8
Calcium	17/DWARS	H3H009	26	12.2	1.8	29.3
Calcium	18/KOG	H3H011	150	70.4	43.0	109.0
Calcium	19/VINK	H4H019	151	84.0	5.6	144.7
Calcium	20/SECUND	H5H004	156	20.6	1.7	69.7
Calcium	21/DREW	H5H005	148	24.1	2.0	48.6
Calcium	22/BOES	H5H003	38	1.7	0.8	7.9
Calcium	24/HOEK	H4H013	55	6.3	1.9	34.6
Calcium	25/ELAND	H6H015	15	9.1	1.7	11.9
Calcium	26/DUT	H6H007	33	0.9	0.2	3.1
Calcium	27/SWELL	H7H006	37	11.4	3.6	27.0
Calcium	29/HERM	H7H005	33	0.9	0.2	10.9
Calcium	30/KLOOF	H7H007	79	0.9	0.1	18.7
Calcium	32/SUUR	H7H003	34	4.1	1.7	10.7
Calcium	35/DUIW	H8H001	43	4.9	1.4	12.9
Calcium	36/HEID	H8H002	25	1.8	0.8	7.2
Calcium	37/KLIP	H6H009	34	4.3	2.4	11.3
Calcium	39/GEN	H6H005	36	1.4	0.5	8.5
Calcium	41/BAIN	H1H007	150	1.1	0.1	9.4
Calcium	42/KOEK	H1H013	36	1.8	0.8	3.0

Calcium	43/DWARS	H1H003	151	9.4	3.2	31.9
Calcium	44/CERES	H1H006	151	4.6	0.2	14.6
Calcium	45/VALSGAT	H2H008	23	2.9	0.4	26.3
Calcium	46/LANG	H2H016	36	5.7	2.1	9.1
Calcium	47/VALS	H1H014	27	0.5	0.2	6.0
Calcium	50/RIV	H6H008	33	0.9	0.2	1.8
Magnesium	01/MCG	H4H016	35	43.3	5.4	132.2
Magnesium	02/HOUT	H4H015	37	1.4	0.4	5.5
Magnesium	04/SAND	H2H004	31	1.3	0.6	2.1
Magnesium	05/ROOI	H2H005	38	0.9	0.3	2.1
Magnesium	06/GLEN	H2H006	149	4.8	1.1	8.7
Magnesium	07/DRIE	H2H010	146	90.9	23.3	133.9
Magnesium	08/NUY	H4H020	155	143.2	13.2	213.6
Magnesium	09/HOL	H1H012	26	0.7	0.3	1.9
Magnesium	10/NEK	H1H015	139	3.7	0.8	11.0
Magnesium	11/CHAS	H4H017	148	6.2	1.8	17.7
Magnesium	13/EPAD	H1H017	95	0.9	0.2	2.6
Magnesium	14/MOL	H1H018	150	0.9	0.2	2.3
Magnesium	15/HART	H1H020	25	0.4	0.1	1.3
Magnesium	17/DWARS	H3H009	26	8.4	2.1	16.0
Magnesium	18/KOG	H3H011	150	89.1	23.5	161.0
Magnesium	19/VINK	H4H019	151	70.4	3.5	129.3
Magnesium	20/SECUND	H5H004	156	23.1	1.6	99.6
Magnesium	21/DREW	H5H005	148	28.7	1.6	62.0
Magnesium	22/BOES	H5H003	38	2.4	1.3	6.4
Magnesium	24/HOEK	H4H013	55	7.5	2.2	43.9
Magnesium	25/ELAND	H6H015	15	1.6	1.1	2.0
Magnesium	26/DUT	H6H007	34	1.2	0.6	2.0
Magnesium	27/SWELL	H7H006	37	14.5	3.0	39.5
Magnesium	29/HERM	H7H005	34	0.9	0.3	1.6
Magnesium	30/KLOOF	H7H007	83	1.0	0.3	5.9
Magnesium	32/SUUR	H7H003	34	4.9	2.2	14.2
Magnesium	35/DUIW	H8H001	43	6.4	1.7	22.1
Magnesium	36/HEID	H8H002	25	2.9	0.3	13.7
Magnesium	37/KLIP	H6H009	34	6.4	2.9	23.4
Magnesium	39/GEN	H6H005	36	1.5	0.8	2.5
Magnesium	41/BAIN	H1H007	150	1.0	0.3	3.7
Magnesium	42/KOEK	H1H013	36	1.6	0.9	3.0
Magnesium	43/DWARS	H1H003	151	6.8	2.1	33.6
Magnesium	44/CERES	H1H006	151	3.3	0.6	11.3
Magnesium	45/VALSGAT	H2H008	23	1.3	0.1	15.3
Magnesium	46/LANG	H2H016	36	2.9	0.9	4.0
Magnesium	47/VALS	H1H014	29	0.4	0.1	3.5
Magnesium	50/RIV	H6H008	34	1.0	0.4	2.1
Potassium	01/MCG	H4H016	35	6.2	1.7	17.1
Potassium	02/HOUT	H4H015	24	0.4	0.0	2.9
Potassium	04/SAND	H2H004	31	0.4	0.0	0.6
Potassium	05/ROOI	H2H005	24	0.4	0.0	3.3
Potassium	06/GLEN	H2H006	149	2.9	0.9	4.7
Potassium	07/DRIE	H2H010	146	8.5	3.6	56.9
Potassium	08/NUY	H4H020	155	16.6	2.6	81.8
Potassium	09/HOL	H1H012	26	0.3	0.0	0.7
Potassium	10/NEK	H1H015	139	1.9	0.3	3.1
Potassium	11/CHAS	H4H017	148	2.0	0.7	5.2
Potassium	13/EPAD	H1H017	95	0.4	0.0	2.1

Potassium	14/MOL	H1H018	135	0.6	0.0	2.0
Potassium	15/HART	H1H020	25	0.1	0.0	0.4
Potassium	17/DWARS	H3H009	26	0.8	0.0	1.9
Potassium	18/KOG	H3H011	150	11.0	2.1	23.0
Potassium	19/VINK	H4H019	151	2.8	0.3	19.7
Potassium	20/SECUND	H5H004	156	3.7	0.8	12.9
Potassium	21/DREW	H5H005	148	4.4	0.9	10.0
Potassium	22/BOES	H5H003	32	0.5	0.0	3.1
Potassium	24/HOEK	H4H013	55	1.4	0.4	4.3
Potassium	25/ELAND	H6H015	15	2.2	0.7	3.9
Potassium	26/DUT	H6H007	34	0.4	0.0	0.9
Potassium	27/SWELL	H7H006	37	3.1	0.8	6.1
Potassium	29/HERM	H7H005	34	0.3	0.0	1.2
Potassium	30/KLOOF	H7H007	80	0.3	0.0	1.1
Potassium	32/SUUR	H7H003	34	0.6	0.2	2.2
Potassium	35/DUIW	H8H001	42	2.0	0.3	3.9
Potassium	36/HEID	H8H002	24	0.7	0.2	2.8
Potassium	37/KLIP	H6H009	34	1.8	0.7	3.6
Potassium	39/GEN	H6H005	25	0.5	0.0	1.6
Potassium	41/BAIN	H1H007	94	0.4	0.0	1.6
Potassium	42/KOEK	H1H013	36	0.7	0.1	2.4
Potassium	43/DWARS	H1H003	151	2.6	1.0	9.1
Potassium	44/CERES	H1H006	147	0.9	0.0	3.4
Potassium	45/VALSGAT	H2H008	19	0.5	0.0	1.2
Potassium	46/LANG	H2H016	35	1.9	0.8	3.0
Potassium	47/VALS	H1H014	30	0.3	0.0	2.0
Potassium	50/RIV	H6H008	34	0.3	0.0	0.7
Sulphate	01/MCG	H4H016	35	97.7	22.0	333.0
Sulphate	02/HOUT	H4H015	37	7.4	1.6	16.3
Sulphate	04/SAND	H2H004	31	3.4	1.0	12.1
Sulphate	05/ROOI	H2H005	38	4.6	0.6	14.1
Sulphate	06/GLEN	H2H006	149	24.5	3.4	45.0
Sulphate	07/DRIE	H2H010	146	388.2	92.4	583.9
Sulphate	08/NUY	H4H020	155	403.5	36.8	559.0
Sulphate	09/HOL	H1H012	26	5.6	1.8	18.1
Sulphate	10/NEK	H1H015	139	10.1	3.9	23.4
Sulphate	11/CHAS	H4H017	148	18.6	5.6	48.9
Sulphate	13/EPAD	H1H017	95	4.3	0.1	10.2
Sulphate	14/MOL	H1H018	150	4.2	0.7	16.6
Sulphate	15/HART	H1H020	25	2.9	0.6	6.3
Sulphate	17/DWARS	H3H009	26	29.8	3.7	54.8
Sulphate	18/KOG	H3H011	150	206.7	46.9	386.5
Sulphate	19/VINK	H4H019	151	166.9	12.2	307.9
Sulphate	20/SECUND	H5H004	156	60.8	4.2	243.6
Sulphate	21/DREW	H5H005	148	74.1	9.4	159.1
Sulphate	22/BOES	H5H003	38	11.3	6.2	22.8
Sulphate	24/HOEK	H4H013	55	18.8	3.4	92.6
Sulphate	25/ELAND	H6H015	15	4.0	2.6	9.9
Sulphate	26/DUT	H6H007	34	4.6	1.6	9.4
Sulphate	27/SWELL	H7H006	37	35.5	7.3	96.5
Sulphate	29/HERM	H7H005	33	7.9	0.7	13.5
Sulphate	30/KLOOF	H7H007	72	5.1	0.2	21.4
Sulphate	32/SUUR	H7H003	34	14.5	4.9	35.2
Sulphate	35/DUIW	H8H001	43	29.8	15.4	48.4
Sulphate	36/HEID	H8H002	20	8.0	3.1	24.9
Sulphate	37/KLIP	H6H009	34	18.4	3.1	55.4

Sulphate	39/GEN	H6H005	36	5.9	0.8	15.4
Sulphate	41/BAIN	H1H007	150	5.0	0.5	15.9
Sulphate	42/KOEK	H1H013	36	5.3	1.6	12.4
Sulphate	43/DWARS	H1H003	151	18.2	4.3	105.6
Sulphate	44/CERES	H1H006	151	9.9	0.1	40.2
Sulphate	45/VALSGAT	H2H008	23	5.4	1.7	10.7
Sulphate	46/LANG	H2H016	36	9.0	1.3	19.8
Sulphate	47/VALS	H1H014	28	4.8	0.4	10.7
Sulphate	50/RIV	H6H008	34	5.7	0.9	10.7
Chloride	01/MCG	H4H016	35	416.8	55.0	1303.3
Chloride	02/HOUT	H4H015	37	11.3	4.9	22.7
Chloride	04/SAND	H2H004	31	9.6	1.4	14.4
Chloride	05/ROOI	H2H005	38	4.5	2.2	9.7
Chloride	06/GLEN	H2H006	149	20.7	4.2	50.2
Chloride	07/DRIE	H2H010	146	548.0	147.4	815.0
Chloride	08/NUY	H4H020	155	1094.1	95.6	1608.9
Chloride	09/HOL	H1H012	26	7.2	3.6	12.0
Chloride	10/NEK	H1H015	139	22.0	5.1	93.3
Chloride	11/CHAS	H4H017	148	43.2	10.2	159.0
Chloride	13/EPAD	H1H017	95	6.8	2.0	16.1
Chloride	14/MOL	H1H018	150	5.6	2.6	11.3
Chloride	15/HART	H1H020	25	4.2	2.4	11.4
Chloride	17/DWARS	H3H009	26	85.5	24.3	145.4
Chloride	18/KOG	H3H011	150	798.8	179.4	1532.2
Chloride	19/VINK	H4H019	151	572.0	27.2	1101.1
Chloride	20/SECUND	H5H004	156	203.3	6.5	894.6
Chloride	21/DREW	H5H005	148	244.3	7.7	541.1
Chloride	22/BOES	H5H003	38	21.2	10.6	27.4
Chloride	24/HOEK	H4H013	55	64.2	19.2	401.7
Chloride	25/ELAND	H6H015	15	8.5	4.3	11.3
Chloride	26/DUT	H6H007	34	9.6	4.5	13.6
Chloride	27/SWELL	H7H006	37	148.9	18.1	330.2
Chloride	29/HERM	H7H005	34	6.5	2.7	10.4
Chloride	30/KLOOF	H7H007	83	10.0	2.9	64.3
Chloride	32/SUUR	H7H003	34	47.3	20.0	126.5
Chloride	35/DUIW	H8H001	43	70.7	20.9	255.7
Chloride	36/HEID	H8H002	25	31.7	7.4	195.6
Chloride	37/KLIP	H6H009	34	67.5	27.2	316.0
Chloride	39/GEN	H6H005	36	12.4	7.8	19.5
Chloride	41/BAIN	H1H007	150	5.5	1.7	14.4
Chloride	42/KOEK	H1H013	36	8.1	4.8	13.3
Chloride	43/DWARS	H1H003	151	47.1	13.6	223.4
Chloride	44/CERES	H1H006	151	19.3	4.6	80.6
Chloride	45/VALSGAT	H2H008	23	4.6	2.6	11.6
Chloride	46/LANG	H2H016	36	17.9	2.7	25.5
Chloride	47/VALS	H1H014	30	4.2	2.3	26.9
Chloride	50/RIV	H6H008	34	7.8	3.4	14.6
Total alkalinity	01/MCG	H4H016	35	292.50	38.20	866.80
Total alkalinity	02/HOUT	H4H015	37	5.30	0.10	25.80
Total alkalinity	04/SAND	H2H004	31	4.70	1.00	9.70
Total alkalinity	05/ROOI	H2H005	37	6.10	1.60	13.90
Total alkalinity	06/GLEN	H2H006	149	14.30	3.20	30.50
Total alkalinity	07/DRIE	H2H010	146	262.05	57.30	356.50
Total alkalinity	08/NUY	H4H020	155	305.80	35.50	391.80
Total alkalinity	09/HOL	H1H012	25	7.00	1.60	12.30

Total alkalinity	10/NEK	H1H015	139	14.70	1.90	39.80
Total alkalinity	11/CHAS	H4H017	148	20.35	6.80	43.40
Total alkalinity	13/EPAD	H1H017	90	3.90	0.10	21.40
Total alkalinity	14/MOL	H1H018	150	6.40	1.20	15.70
Total alkalinity	15/HART	H1H020	25	6.30	3.00	25.70
Total alkalinity	17/DWARS	H3H009	26	39.35	9.80	90.80
Total alkalinity	18/KOG	H3H011	150	267.20	140.50	399.90
Total alkalinity	19/VINK	H4H019	151	201.90	18.10	310.60
Total alkalinity	20/SECUND	H5H004	156	74.55	4.50	266.80
Total alkalinity	21/DREW	H5H005	148	101.35	5.50	225.80
Total alkalinity	22/BOES	H5H003	38	7.85	1.80	40.90
Total alkalinity	24/HOEK	H4H013	55	14.90	3.50	67.30
Total alkalinity	25/ELAND	H6H015	15	28.10	6.40	37.20
Total alkalinity	26/DUT	H6H007	31	3.00	0.10	12.70
Total alkalinity	27/SWELL	H7H006	37	47.80	9.70	140.10
Total alkalinity	29/HERM	H7H005	33	5.90	1.70	11.80
Total alkalinity	30/KLOOF	H7H007	82	6.80	0.40	32.00
Total alkalinity	32/SUUR	H7H003	34	13.45	3.80	46.80
Total alkalinity	35/DUIW	H8H001	43	22.00	7.40	69.80
Total alkalinity	36/HEID	H8H002	26	5.80	0.80	45.10
Total alkalinity	37/KLIP	H6H009	34	17.95	6.80	47.30
Total alkalinity	39/GEN	H6H005	35	6.10	0.80	21.00
Total alkalinity	41/BAIN	H1H007	148	4.75	0.20	29.20
Total alkalinity	42/KOEK	H1H013	36	5.55	1.20	13.20
Total alkalinity	43/DWARS	H1H003	151	29.10	9.30	69.40
Total alkalinity	44/CERES	H1H006	151	13.70	3.80	41.50
Total alkalinity	45/VALSGAT	H2H008	23	9.50	2.60	134.00
Total alkalinity	46/LANG	H2H016	36	17.80	10.70	26.60
Total alkalinity	47/VALS	H1H014	33	5.80	0.80	10.60
Total alkalinity	50/RIV	H6H008	31	3.10	0.10	9.00
Fluoride	01/MCG	H4H016	35	0.79	0.21	1.22
Fluoride	02/HOUT	H4H015	37	0.15	0.08	0.29
Fluoride	04/SAND	H2H004	31	0.09	0.02	0.22
Fluoride	05/ROOI	H2H005	38	0.14	0.05	0.55
Fluoride	06/GLEN	H2H006	149	0.16	0.04	0.66
Fluoride	07/DRIE	H2H010	146	0.56	0.01	0.94
Fluoride	08/NUY	H4H020	155	0.72	0.19	1.17
Fluoride	09/HOL	H1H012	18	0.03	0.01	0.11
Fluoride	10/NEK	H1H015	139	0.17	0.03	0.42
Fluoride	11/CHAS	H4H017	148	0.19	0.08	0.50
Fluoride	13/EPAD	H1H017	94	0.10	0.01	0.31
Fluoride	14/MOL	H1H018	150	0.16	0.06	0.46
Fluoride	15/HART	H1H020	13	0.09	0.01	0.25
Fluoride	17/DWARS	H3H009	26	0.13	0.01	0.30
Fluoride	18/KOG	H3H011	150	0.50	0.21	0.86
Fluoride	19/VINK	H4H019	151	0.52	0.06	0.92
Fluoride	20/SECUND	H5H004	156	0.27	0.10	0.85
Fluoride	21/DREW	H5H005	148	0.34	0.09	0.72
Fluoride	22/BOES	H5H003	38	0.16	0.08	0.39
Fluoride	24/HOEK	H4H013	52	0.10	0.01	1.15
Fluoride	25/ELAND	H6H015	15	0.14	0.05	0.21
Fluoride	26/DUT	H6H007	34	0.10	0.03	0.32
Fluoride	27/SWELL	H7H006	37	0.26	0.11	0.57
Fluoride	29/HERM	H7H005	25	0.09	0.02	0.31
Fluoride	30/KLOOF	H7H007	55	0.06	0.01	0.37
Fluoride	32/SUUR	H7H003	34	0.12	0.08	0.36

Fluoride	35/DUIW	H8H001	43	0.20	0.10	0.46
Fluoride	36/HEID	H8H002	21	0.08	0.01	0.28
Fluoride	37/KLIP	H6H009	34	0.22	0.07	0.41
Fluoride	39/GEN	H6H005	36	0.17	0.05	0.45
Fluoride	41/BAIN	H1H007	150	0.16	0.04	0.63
Fluoride	42/KOEK	H1H013	36	0.15	0.06	0.44
Fluoride	43/DWARS	H1H003	151	0.18	0.03	0.53
Fluoride	44/CERES	H1H006	151	0.17	0.06	0.84
Fluoride	45/VALSGAT	H2H008	23	0.17	0.06	0.33
Fluoride	46/LANG	H2H016	36	0.16	0.05	0.36
Fluoride	47/VALS	H1H014	20	0.07	0.01	0.30
Fluoride	50/RIV	H6H008	34	0.09	0.02	0.23
(Nitrate + Nitrite)-N	01/MCG	H4H016	35	0.040	0.005	1.061
(Nitrate + Nitrite)-N	02/HOUT	H4H015	37	0.021	0.006	0.064
(Nitrate + Nitrite)-N	04/SAND	H2H004	27	0.023	0.003	0.058
(Nitrate + Nitrite)-N	05/ROOI	H2H005	38	0.028	0.010	0.063
(Nitrate + Nitrite)-N	06/GLEN	H2H006	149	1.104	0.070	2.903
(Nitrate + Nitrite)-N	07/DRIE	H2H010	146	1.223	0.040	2.856
(Nitrate + Nitrite)-N	08/NUY	H4H020	155	0.491	0.008	1.558
(Nitrate + Nitrite)-N	09/HOL	H1H012	23	0.020	0.010	0.600
(Nitrate + Nitrite)-N	10/NEK	H1H015	139	0.380	0.008	2.990
(Nitrate + Nitrite)-N	11/CHAS	H4H017	148	0.181	0.002	1.447
(Nitrate + Nitrite)-N	13/EPAD	H1H017	87	0.077	0.014	0.366
(Nitrate + Nitrite)-N	14/MOL	H1H018	150	0.130	0.020	0.344
(Nitrate + Nitrite)-N	15/HART	H1H020	8	0.015	0.010	0.120
(Nitrate + Nitrite)-N	17/DWARS	H3H009	26	0.035	0.010	0.770
(Nitrate + Nitrite)-N	18/KOG	H3H011	150	0.636	0.006	1.836
(Nitrate + Nitrite)-N	19/VINK	H4H019	151	0.652	0.168	1.422
(Nitrate + Nitrite)-N	20/SECUND	H5H004	156	0.242	0.005	1.293
(Nitrate + Nitrite)-N	21/DREW	H5H005	147	0.143	0.001	1.249
(Nitrate + Nitrite)-N	22/BOES	H5H003	38	0.031	0.006	0.069
(Nitrate + Nitrite)-N	24/HOEK	H4H013	54	0.278	0.020	1.700
(Nitrate + Nitrite)-N	25/ELAND	H6H015	15	0.147	0.045	0.605
(Nitrate + Nitrite)-N	26/DUT	H6H007	25	0.022	0.001	0.095
(Nitrate + Nitrite)-N	27/SWELL	H7H006	37	0.207	0.007	0.929
(Nitrate + Nitrite)-N	29/HERM	H7H005	30	0.053	0.002	0.219
(Nitrate + Nitrite)-N	30/KLOOF	H7H007	58	0.030	0.010	0.240
(Nitrate + Nitrite)-N	32/SUUR	H7H003	33	0.154	0.024	0.358
(Nitrate + Nitrite)-N	35/DUIW	H8H001	43	0.137	0.008	0.434
(Nitrate + Nitrite)-N	36/HEID	H8H002	22	0.035	0.010	0.360
(Nitrate + Nitrite)-N	37/KLIP	H6H009	34	0.153	0.037	0.778
(Nitrate + Nitrite)-N	39/GEN	H6H005	36	0.030	0.010	0.086
(Nitrate + Nitrite)-N	41/BAIN	H1H007	150	0.029	0.002	0.165
(Nitrate + Nitrite)-N	42/KOEK	H1H013	36	0.650	0.097	1.404
(Nitrate + Nitrite)-N	43/DWARS	H1H003	151	0.320	0.005	2.069
(Nitrate + Nitrite)-N	44/CERES	H1H006	151	0.144	0.006	1.197
(Nitrate + Nitrite)-N	45/VALSGAT	H2H008	23	0.048	0.001	0.932
(Nitrate + Nitrite)-N	46/LANG	H2H016	36	0.068	0.014	0.159
(Nitrate + Nitrite)-N	47/VALS	H1H014	30	0.020	0.010	0.590
(Nitrate + Nitrite)-N	50/RIV	H6H008	27	0.020	0.002	0.049
Ammonium-N	01/MCG	H4H016	35	0.028	0.001	0.151
Ammonium-N	02/HOUT	H4H015	33	0.018	0.001	0.086
Ammonium-N	04/SAND	H2H004	29	0.033	0.010	0.083
Ammonium-N	05/ROOI	H2H005	38	0.026	0.008	0.074
Ammonium-N	06/GLEN	H2H006	149	0.032	0.001	0.321

Ammonium-N	07/DRIE	H2H010	146	0.057	0.010	0.358
Ammonium-N	08/NUY	H4H020	155	0.075	0.011	0.592
Ammonium-N	09/HOL	H1H012	23	0.030	0.010	0.100
Ammonium-N	10/NEK	H1H015	137	0.028	0.002	0.659
Ammonium-N	11/CHAS	H4H017	145	0.027	0.001	0.114
Ammonium-N	13/EPAD	H1H017	88	0.063	0.008	0.375
Ammonium-N	14/MOL	H1H018	150	0.028	0.004	0.158
Ammonium-N	15/HART	H1H020	24	0.035	0.010	0.090
Ammonium-N	17/DWARS	H3H009	25	0.070	0.010	0.200
Ammonium-N	18/KOG	H3H011	150	0.059	0.008	1.223
Ammonium-N	19/VINK	H4H019	151	0.043	0.002	0.216
Ammonium-N	20/SECUND	H5H004	153	0.034	0.002	2.180
Ammonium-N	21/DREW	H5H005	144	0.039	0.002	0.126
Ammonium-N	22/BOES	H5H003	33	0.019	0.001	0.187
Ammonium-N	24/HOEK	H4H013	55	0.060	0.010	0.110
Ammonium-N	25/ELAND	H6H015	15	0.027	0.015	0.051
Ammonium-N	26/DUT	H6H007	32	0.053	0.005	0.110
Ammonium-N	27/SWELL	H7H006	35	0.030	0.002	0.223
Ammonium-N	29/HERM	H7H005	30	0.030	0.002	0.150
Ammonium-N	30/KLOOF	H7H007	80	0.040	0.006	0.180
Ammonium-N	32/SUUR	H7H003	33	0.059	0.017	0.100
Ammonium-N	35/DUIW	H8H001	37	0.017	0.001	0.166
Ammonium-N	36/HEID	H8H002	25	0.060	0.010	0.150
Ammonium-N	37/KLIP	H6H009	31	0.013	0.002	0.069
Ammonium-N	39/GEN	H6H005	32	0.024	0.002	0.224
Ammonium-N	41/BAIN	H1H007	149	0.024	0.002	0.098
Ammonium-N	42/KOEK	H1H013	36	0.030	0.012	0.083
Ammonium-N	43/DWARS	H1H003	148	0.046	0.002	1.157
Ammonium-N	44/CERES	H1H006	146	0.031	0.004	0.249
Ammonium-N	45/VALSGAT	H2H008	23	0.023	0.006	0.106
Ammonium-N	46/LANG	H2H016	36	0.029	0.011	0.088
Ammonium-N	47/VALS	H1H014	30	0.030	0.010	0.130
Ammonium-N	50/RIV	H6H008	32	0.048	0.010	0.081
Total nitrogen	01/MCG	H4H016	34	0.082	0.023	1.154
Total nitrogen	02/HOUT	H4H015	37	0.039	0.011	0.104
Total nitrogen	04/SAND	H2H004	29	0.057	0.020	0.109
Total nitrogen	05/ROOI	H2H005	38	0.055	0.020	0.136
Total nitrogen	09/HOL	H1H012	25	0.040	0.010	0.610
Total nitrogen	13/EPAD	H1H017	88	0.153	0.042	0.667
Total nitrogen	15/HART	H1H020	24	0.045	0.010	0.140
Total nitrogen	17/DWARS	H3H009	26	0.105	0.010	0.830
Total nitrogen	22/BOES	H5H003	38	0.048	0.017	0.225
Total nitrogen	24/HOEK	H4H013	55	0.310	0.060	1.790
Total nitrogen	25/ELAND	H6H015	15	0.184	0.060	0.641
Total nitrogen	26/DUT	H6H007	32	0.065	0.020	0.171
Total nitrogen	27/SWELL	H7H006	37	0.238	0.019	0.950
Total nitrogen	32/SUUR	H7H003	32	0.225	0.067	0.408
Total nitrogen	35/DUIW	H8H001	43	0.155	0.017	0.442
Total nitrogen	36/HEID	H8H002	26	0.100	0.010	0.400
Total nitrogen	37/KLIP	H6H009	34	0.175	0.042	0.795
Total nitrogen	42/KOEK	H1H013	36	0.677	0.147	1.424
Total nitrogen	45/VALSGAT	H2H008	22	0.082	0.020	0.974
Total nitrogen	46/LANG	H2H016	36	0.110	0.031	0.234
Total nitrogen	47/VALS	H1H014	33	0.050	0.010	0.610
Total nitrogen	50/RIV	H6H008	32	0.066	0.021	0.130

Phosphate-P	01/MCG	H4H016	35	0.023	0.011	0.102
Phosphate-P	02/HOUT	H4H015	37	0.024	0.004	0.090
Phosphate-P	04/SAND	H2H004	30	0.010	0.001	0.031
Phosphate-P	05/ROOI	H2H005	38	0.021	0.002	0.074
Phosphate-P	06/GLEN	H2H006	149	0.019	0.001	0.178
Phosphate-P	07/DRIE	H2H010	146	0.040	0.007	0.139
Phosphate-P	08/NUY	H4H020	155	0.052	0.003	0.805
Phosphate-P	09/HOL	H1H012	24	0.010	0.002	0.030
Phosphate-P	10/NEK	H1H015	139	0.017	0.002	0.119
Phosphate-P	11/CHAS	H4H017	147	0.022	0.001	0.152
Phosphate-P	13/EPAD	H1H017	93	0.018	0.001	0.464
Phosphate-P	14/MOL	H1H018	150	0.026	0.001	0.163
Phosphate-P	15/HART	H1H020	25	0.016	0.009	0.025
Phosphate-P	17/DWARS	H3H009	24	0.011	0.004	0.014
Phosphate-P	18/KOG	H3H011	150	0.068	0.006	0.583
Phosphate-P	19/VINK	H4H019	151	0.019	0.003	0.079
Phosphate-P	20/SECUND	H5H004	155	0.022	0.004	0.434
Phosphate-P	21/DREW	H5H005	148	0.020	0.003	0.104
Phosphate-P	22/BOES	H5H003	38	0.020	0.007	0.081
Phosphate-P	24/HOEK	H4H013	50	0.011	0.001	0.077
Phosphate-P	25/ELAND	H6H015	15	0.015	0.002	0.037
Phosphate-P	26/DUT	H6H007	34	0.012	0.002	0.063
Phosphate-P	27/SWELL	H7H006	37	0.021	0.010	0.061
Phosphate-P	29/HERM	H7H005	34	0.025	0.002	0.067
Phosphate-P	30/KLOOF	H7H007	83	0.025	0.002	0.151
Phosphate-P	32/SUUR	H7H003	34	0.031	0.014	0.075
Phosphate-P	35/DUIW	H8H001	43	0.036	0.011	0.224
Phosphate-P	36/HEID	H8H002	25	0.028	0.007	0.108
Phosphate-P	37/KLIP	H6H009	34	0.027	0.009	0.120
Phosphate-P	39/GEN	H6H005	36	0.019	0.002	0.064
Phosphate-P	41/BAIN	H1H007	149	0.024	0.002	0.166
Phosphate-P	42/KOEK	H1H013	36	0.015	0.002	0.032
Phosphate-P	43/DWARS	H1H003	151	0.024	0.004	0.408
Phosphate-P	44/CERES	H1H006	151	0.024	0.006	0.106
Phosphate-P	45/VALSGAT	H2H008	23	0.016	0.006	0.063
Phosphate-P	46/LANG	H2H016	35	0.016	0.004	0.075
Phosphate-P	47/VALS	H1H014	28	0.008	0.002	0.042
Phosphate-P	50/RIV	H6H008	34	0.016	0.005	0.036
Silica	01/MCG	H4H016	35	5.430	1.400	15.700
Silica	02/HOUT	H4H015	37	2.230	1.000	3.210
Silica	04/SAND	H2H004	31	1.540	0.840	2.400
Silica	05/ROOI	H2H005	38	2.540	0.460	3.450
Silica	06/GLEN	H2H006	149	2.420	1.090	3.500
Silica	07/DRIE	H2H010	146	5.400	2.170	8.080
Silica	08/NUY	H4H020	155	4.620	1.270	8.310
Silica	09/HOL	H1H012	26	1.930	0.580	7.000
Silica	10/NEK	H1H015	139	1.460	0.110	3.590
Silica	11/CHAS	H4H017	148	1.085	0.230	2.530
Silica	13/EPAD	H1H017	95	2.260	0.360	4.410
Silica	14/MOL	H1H018	150	3.185	0.080	5.550
Silica	15/HART	H1H020	25	2.510	0.900	3.360
Silica	17/DWARS	H3H009	26	3.330	2.170	5.340
Silica	18/KOG	H3H011	150	2.940	1.210	6.440
Silica	19/VINK	H4H019	151	4.980	1.590	8.860
Silica	20/SECUND	H5H004	156	1.495	0.410	4.830
Silica	21/DREW	H5H005	148	1.145	0.180	5.580

Silica	22/BOES	H5H003	38	2.480	1.150	3.790
Silica	24/HOEK	H4H013	55	2.370	0.710	4.230
Silica	25/ELAND	H6H015	15	2.310	1.000	3.380
Silica	26/DUT	H6H007	34	1.980	0.550	3.480
Silica	27/SWELL	H7H006	37	1.310	0.220	3.250
Silica	29/HERM	H7H005	34	1.090	0.500	6.830
Silica	30/KLOOF	H7H007	82	1.125	0.380	7.090
Silica	32/SUUR	H7H003	34	2.150	1.250	2.680
Silica	35/DUIW	H8H001	43	2.140	0.420	2.770
Silica	36/HEID	H8H002	25	2.220	0.510	3.260
Silica	37/KLIP	H6H009	34	1.765	0.810	2.570
Silica	39/GEN	H6H005	36	2.230	0.760	3.570
Silica	41/BAIN	H1H007	150	1.780	0.430	3.400
Silica	42/KOEK	H1H013	36	3.055	0.460	3.920
Silica	43/DWARS	H1H003	151	2.870	1.150	4.860
Silica	44/CERES	H1H006	151	2.920	0.770	3.790
Silica	45/VALSGAT	H2H008	23	1.440	0.930	7.710
Silica	46/LANG	H2H016	36	2.035	1.380	3.110
Silica	47/VALS	H1H014	30	1.295	0.490	7.840
Silica	50/RIV	H6H008	34	1.295	0.130	3.210

CHAPTER 5. MONITORING THE EFFECTIVENESS OF THE WATER QUALITY GUIDELINES: SASS SCORES FOR REFERENCE SITES

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5.1 INTRODUCTION

This chapter provides a preliminary exploration of the establishment of SASS Scores for sites which can be used as reference sites and against which scores from monitoring sites can be compared. The likely adoption of SASS for monitoring the effectiveness of the water quality guidelines, and its inclusion as one of the primary tools in National Biomonitoring Programme for Riverine Ecosystems (NBP) (Uys *et al.* 1996), indicate the importance of establishing reference scores. The NBP will be established within a spatial framework incorporating bioregions, subregions and river types (Eekhout *et al.* 1996). Reference sites, defined as relatively unimpacted sites that can be used to define the best physical habitat, water quality and biological parameters for a particular kind of river (Eekhout *et al.* 1996), will be established within this framework at the level of river types. Monitoring sites, defined as sites selected to assess condition of available physical habitat, water quality and biological parameters for a river, relative to the expected unimpacted condition (Eekhout *et al.* 1996) i.e. that of the reference site, will also be established.

The Target Water Quality Ranges (TWQR) developed by DWAF (1995) aim to ensure that water quality variables are maintained within the "no effect" range, i.e. such that the aquatic ecosystems is not detrimentally affected by the addition of effluents. Regional and subregional differences explored in previous chapters (see Chapter 3 and 4) necessitate that reference SASS Score be established within regions (e.g. WQMRs or Bioregions) and within subregions. Similarities between SASS Scores for various reference sites identified in Chapter 4 suggest that, for the southern and western Coast WQMR, certain subregions can be combined. It seems that mountain stream and foothill subregions may be grouped together, while transitional and lowland subregions may also be grouped together.

On this basis, using sites identified as "least-impacted" or reference sites within the southern and western Coast WQMR, reference scores have been calculated. Various techniques for calculating these scores have been explored, including using median values from reference sites, maximum (i.e. "best attainable") scores, and calculating scores based on the most frequently occurring taxa within reference sites. It seems that using "best attainable" score, for both SASS4 Scores and ASPTs, provides an optimal solution. This technique will enable monitoring sites identified within a particular subregion, to be sampled using SASS4, and compared to the reference scores within the same subregion.

5.2 METHODOLOGY AND RESULTS

5.2.1 SASS4 Scores and ASPTs

Between 1993 and 1996 numerous sites have been assessed using SASS4 in the southern and western Coast WQMR, or rather in the Fynbos bioregion (Eekhout *et al.* 1996). Some of these sites have been assessed on more than one occasion. The number of SASS4 assessments therefore includes 175 within the mountain stream and foothill subregions and 87 in the transitional and lowland subregions. For each subregional group, the maximum SASS4 Score and maximum ASPT were ascertained. These then formed the "best attainable" scores against which scores from all other assessments were compared.

Each site score (SASS4 Score and ASPT) was divided by the appropriate "best attainable" score and expressed as a percentage. These were then plotted as percentage "best attainable" ASPT against percentage "best attainable" SASS4 Score (Figures 5.1 and 5.2) for each subregional group. The "best attainable" scores for each subregional group are as follows:

- mountain stream and foothill subregions: SASS4 Score = 239; ASPT = 10.42
- transitional or lowland subregions: SASS4 Score = 182; ASPT = 9.6

Using minimum SASS4 Scores and ASPTs as modified in Chapter 4 (i.e. SASS4 Score > 140 and ASPT > 7.5 in mountain stream and foothill subregions; and SASS4 Score > 85 and ASPT > 6.5 in transitional and lowland subregions) each site in Figures 5.1 and 5.2 has been coded using symbols.

Mountain streams and foothills

Sites above this minimum limit (referred to as reference sites in Chapters 3 and 4) generally have ASPTs >70% of the "best attainable " score **OR** SASS4 Scores >60% of the "best attainable " score (Figure 5.1). There was a large amount of variation in % SASS4 Score, ranging from 25 to 100%. % ASPT was less variable and ranged from 60 to 100%. It should be possible to establish percentage bands which can assist in the interpretation of water quality at monitoring sites. For example, monitoring sites with both scores > 75% may fall within the least-impacted or unimpaired band, sites with scores between 60 and 75% may be moderately impaired and sites between 50 and 60% considerably impaired and sites <50% severely impaired (indicated in Figure 5.1). Similar terminology (i.e. unimpacted, moderately, considerably and severely) to that used by Thirion *et al.* (1995) has been used to describe these percentage bands. The method proposed by Thirion *et al.* (1995) incorporates SASS4 Scores and a Habitat Quality Index (HQI, adapted from Plafkin *et al.*, 1989, by P. McMillan, CSIR). Using these parameters, four categories of biological integrity have been proposed. However, the ASPT value is not incorporated. The method proposed in the current study utilises both SASS4 Score and ASPT in a manner that habitat, or rather biotope, variability is accounted for. The utility and authenticity of the proposed method still needs to be tested on a broader scale however.

Transitional and lowland subregions

Sites above the minimum limit for these subregions generally had ASPTs >70% of the "best attainable " score **OR** SASS4 Scores >50% of the "best attainable " score (Figure 5.2). The percentage of SASS4 Scores is comparatively low and may be attributed to the wide variation in SASS4 Scores recorded at sites in these subregions. There was a large amount of variation in % SASS4 Score, ranging from 30 to 100%. % ASPT was marginally less variable and ranged from 45 to 100%. Deciding on a lower limit with respect to SASS4 Score and ASPT for sites within these subregions is extremely difficult given that all sites are moderately to severely impacted. Calculating percentages of "best attainable" scores should provide a means of checking the differentiation into reference and impacted sites. Incorporating percentage bands will also provide additional differentiation into categories of impairment. Again some verification is needed.

Figure 5.1. Percentage "best attainable" ASPT plotted against percentage "best attainable" SASS4 Score for the mountain stream and foothill subregional group. Open circles represent reference sites and closed ones impacted sites.

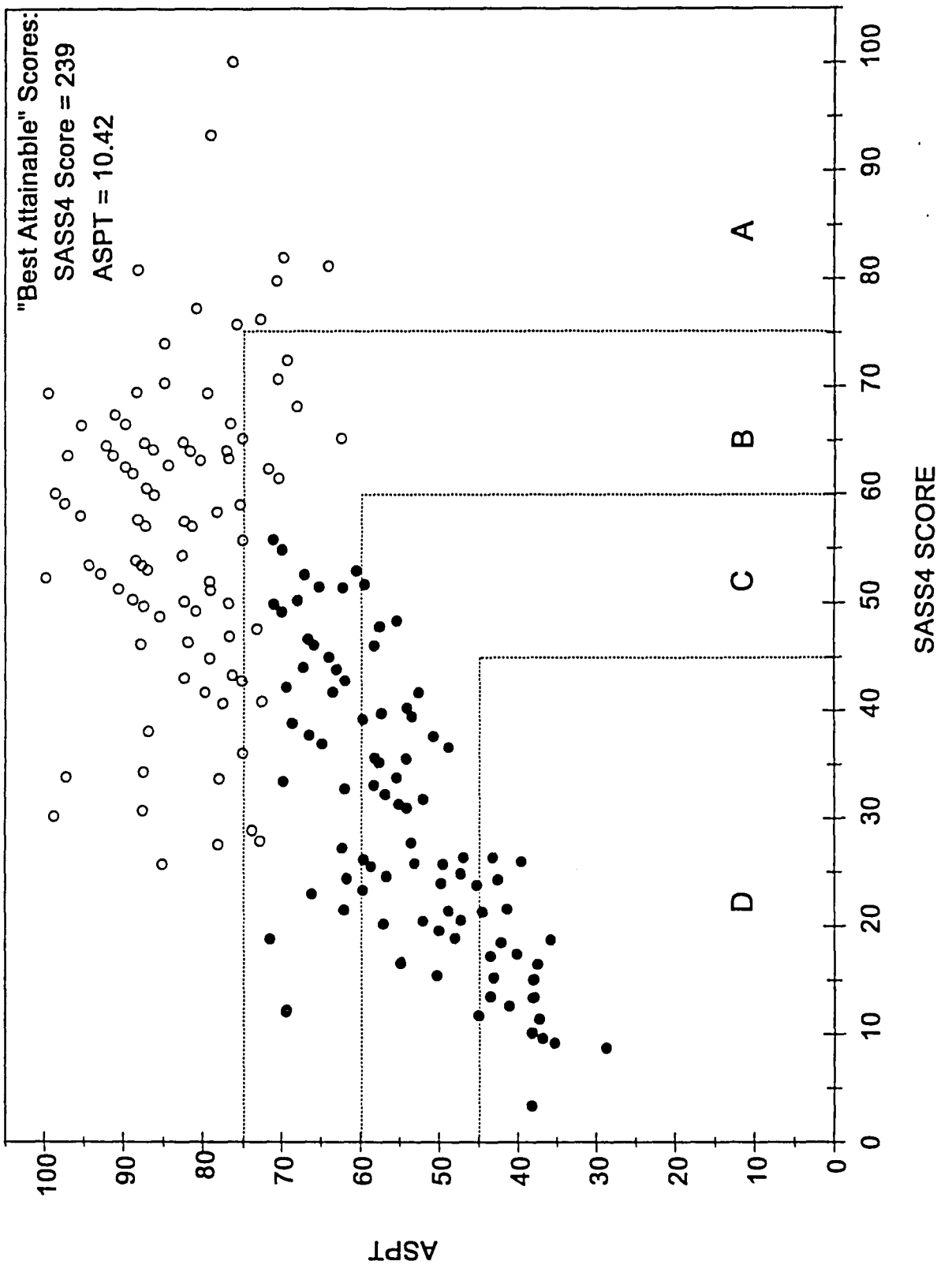
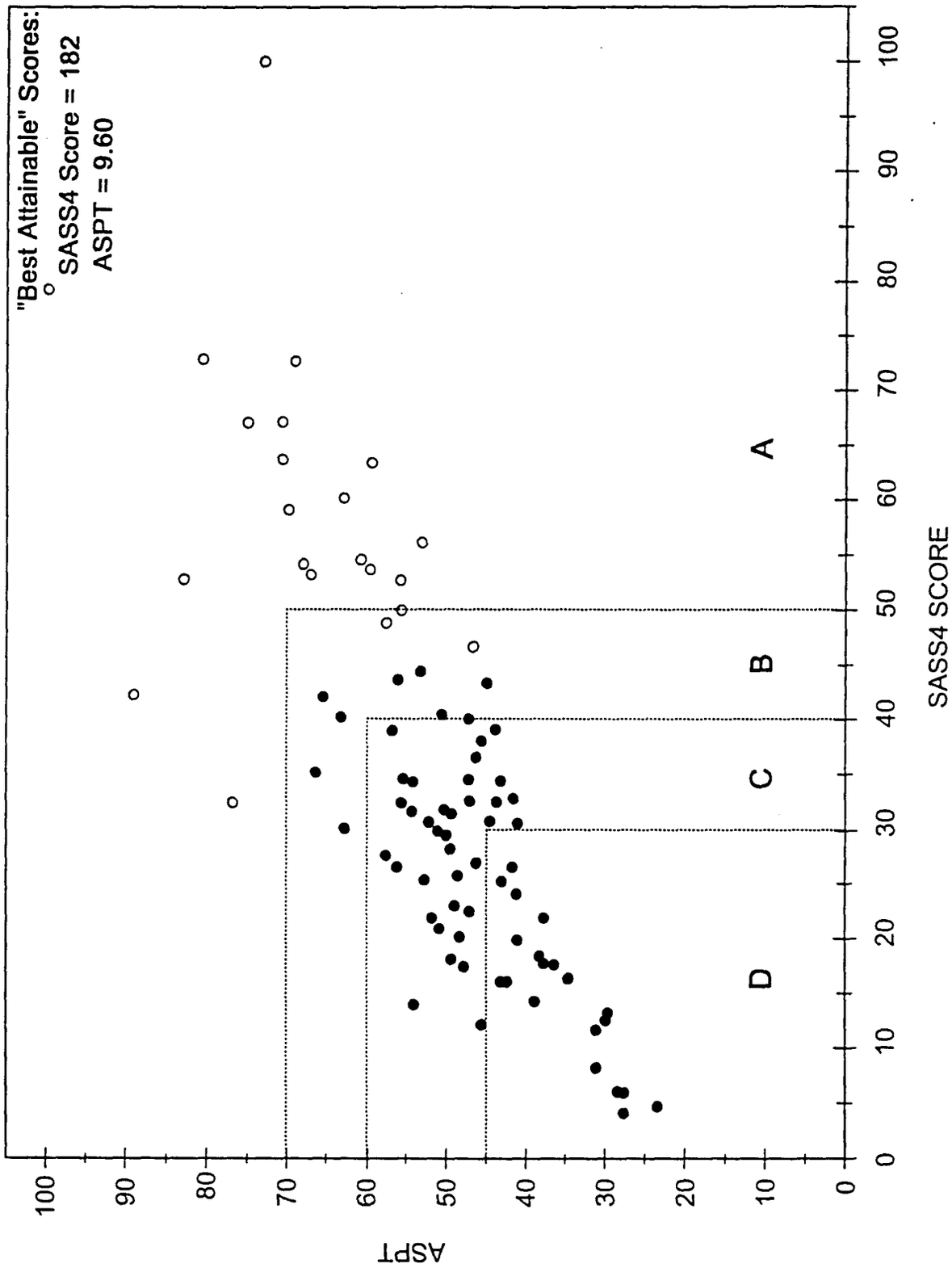


Figure 5.2. Percentage "best attainable" ASPT plotted against percentage "best attainable" SASS4 Score for the transitional and lowland subregional group. Open circles represent reference sites and closed ones impacted sites.



5.2.2 Frequency of occurrence of taxa

Using the same technique as employed in Chapter 4, the frequency of occurrence of each SASS taxon at reference sites versus impacted sites was calculated for each subregional group (Table 5.1, Figures 5.3 and 5.4).

Mountain streams and foothills

The following taxa were common at mountain stream and foothill reference sites and less common at impacted ones:

- mayflies: Leptophlebiidae (pH < 6.5) and Ephemerellidae,
- stoneflies: Notonemouridae,
- megalopterans: Corydalidae,
- coleopterans (beetles): Elmidae/Dryopidae, Hydraenidae and Helodidae,
- trichopterans: cased caddis (3 types) and Philopotamidae, and
- dipteran (fly) larvae: Athericidae.

All of these taxa were present at ≥40% of the reference sites. Three additional taxa, namely Amphipoda, Blephariceridae and Ecnomidae, whilst not as common at reference sites, were extremely rare at impacted ones.

Transitional and lowland subregions

The following taxa were common at transitional and lowland reference sites and less common at impacted ones:

- mayflies: Baetidae (3 types), Caenidae, Heptageniidae and Tricorythidae,
- dragon- and damselflies: Aeschnidae and Libellulidae,
- coleopterans (beetles): Elmidae/Dryopidae and Gyrinidae, and
- trichopterans: cased caddis (all types).

All of these taxa were present at ≥40% of the reference sites (Table 5.1 and Figure 5.4).

5.3 PRELIMINARY CONCLUSIONS AND FUTURE DIRECTION

As mentioned previously, results presented in this chapter are preliminary. They do however provide a platform from which additional work can be conducted so that results may be verified. Preliminary "Best attainable" scores for subregional groups in the southern and western Coast WQMR or Fynbos bioregion have been established. These scores will enable new sites which are assessed using the SASS method to be categorised on the basis of differences between "observed" scores at these sites and "expected" scores (i.e. "best attainable") from reference sites. Common taxa associated with reference sites have also been ascertained.

A complementary approach towards establishing reference scores for SASS taxa and hence establishing typical or "expected" groups of taxa for subregions, would be to examine the water quality ranges at which each SASS taxon has been recorded. It might be expected that taxa occurring frequently at reference sites would have narrower ranges in particular water quality variables, whilst those frequently

Table 5.1. Percentage occurrence of each SASS taxon at reference (R) and impacted (I) sites in the mountain stream (M) and foothill (F), and transitional (T) and lowland (L) subregions in the southern and western water Coast WQMR. n represents the number of SASS assessments within each.

		M+F			T+L	
		R	I		R	I
	n	93	96		21	68
GROUP	TAXON					
ANNELIDA	OLIGOCHAETA	34	72		57	67
ANNELIDA	HIRUDINEA	0	0		5	13
ARACHNIDA	HYDRACHNELLAE	10	25		10	16
COLEOPTERA	DYTISCIDAE	23	19		24	36
COLEOPTERA	ELMIDAE/DRYOPIDAE	71	33		57	9
COLEOPTERA	GYRINIDAE	34	47		67	33
COLEOPTERA	HELODIDAE LARVAE	59	3		5	0
COLEOPTERA	HYDRAENIDAE	45	17		14	7
COLEOPTERA	HYDROPHILIDAE	4	6		0	6
COLEOPTERA	LIMNICHIDAE	25	13		10	0
CRUSTACEA	AMPHIPODA	19	0		5	0
CRUSTACEA	BRACHYURA (CRABS)	18	27		19	38
CRUSTACEA	NATANTIA (SHRIMPS)	0	0		19	1
DIPTERA	ATHERICIDAE	51	19		14	0
DIPTERA	BLEPHARICERIDAE	27	1		0	0
DIPTERA	CERATOPOGONIDAE	3	9		10	13
DIPTERA	CHIRONOMIDAE	88	98		90	99
DIPTERA	CULICIDAE	4	5		0	13
DIPTERA	DIXIDAE	6	2		0	0
DIPTERA	EMPIDIDAE	1	16		10	1
DIPTERA	EPHYDRIDAE	0	1		0	1
DIPTERA	MUSCIDAE	4	18		0	1
DIPTERA	SIMULIIDAE	97	86		86	59
DIPTERA	SYRPHIDAE	0	1		0	0
DIPTERA	TABANIDAE	1	3		0	10
DIPTERA	TIPULIDAE	33	17		5	3
EPHEMEROPTERA	BAETIDAE 1 TYPE	23	31		19	45
EPHEMEROPTERA	BAETIDAE 2 TYPES	27	40		19	16
EPHEMEROPTERA	BAETIDAE 3 TYPES	48	27		62	29
EPHEMEROPTERA	CAENIDAE	25	35		81	43
EPHEMEROPTERA	EPHEMERELLIDAE	83	14		29	0
EPHEMEROPTERA	HEPTAGENIIDAE	40	21		48	6
EPHEMEROPTERA	LEPTOPHLEBIIDAE (pH<6.5)	94	18		10	1
EPHEMEROPTERA	LEPTOPHLEBIIDAE (pH>6.6)	2	12		33	3
EPHEMEROPTERA	TRICORYTHIDAE	0	2		48	7
GASTROPODA	ANCYLIDAE	0	23		33	43
GASTROPODA	LYMNAEIDAE	0	13		19	6
GASTROPODA	PHYSIDAE	0	8		19	14
GASTROPODA	PLANORBIDAE	1	0		0	0
HEMIPTERA	BELASTOMATIDAE	5	5		5	0
HEMIPTERA	CORIXIDAE	16	36		43	80
HEMIPTERA	GERRIDAE	12	7		14	22
HEMIPTERA	NAUCORIDAE	10	3		48	10
HEMIPTERA	NEPIDAE	0	2		0	3
HEMIPTERA	NOTONECTIDAE	11	2		19	19
HEMIPTERA	PLEIDAE	1	3		14	29
HEMIPTERA	VELIIDAE	24	26		48	43

		M+F		T+L	
		R	I	R	I
	n	93	96	21	68
LEPIDOPTERA	PYRAUSTIDAE	8	5	14	1
MEGALOPTERA	CORYDALIDAE	74	29	19	0
ODONATA	AESHNIDAE	33	29	57	19
ODONATA	CHLOROCYPHIDAE	0	0	14	3
ODONATA	CHLOROLESTIDAE	12	6	5	3
ODONATA	COENAGRIONIDAE	24	23	57	62
ODONATA	CORDULIIDAE	4	6	10	3
ODONATA	GOMPHIDAE	16	37	48	38
ODONATA	LIBELLULIDAE	18	35	67	14
ODONATA	PLATYCNEMIDIDAE	3	0	5	0
ODONATA	ZYGOPTERA JUVENILES	3	1	5	1
PELECYPODA	CORBICULIDAE	0	0	19	1
PLATYHELMINTHES	PLANARIIDAE	14	31	24	9
PLECOPTERA	NOTONEMOURIDAE	70	12	10	0
TRICHOPTERA	ECNOMIDAE	27	8	10	1
TRICHOPTERA	HYDROPSYCHIDAE 1 TYPE	38	40	33	17
TRICHOPTERA	HYDROPSYCHIDAE 2 TYPES	31	13	29	13
TRICHOPTERA	HYDROPSYCHIDAE 3 TYPES	2	0	19	7
TRICHOPTERA	HYDROPTILIDAE	4	4	19	3
TRICHOPTERA	PHILOPOTAMIDAE	45	9	5	0
TRICHOPTERA	CASE CADDIS 1 TYPE	26	27	29	7
TRICHOPTERA	CASE CADDIS 2 TYPES	24	12	19	0
TRICHOPTERA	CASE CADDIS 3 TYPES	41	7	24	0

occurring at impacted sites would have broader ranges.

Although testing to see if these recorded ranges are close to actual limits would require laboratory experimentation, the recorded ranges should provide a relative scale by which SASS taxa can be ranked with respect to their sensitivity to or tolerance of the impairment of water quality. Ultimately it should be feasible, to have not only reference SASS scores for each subregion or subregional group, but also a list of "expected" taxa which could be checked, and used to categorise monitoring sites with respect to water quality and possibly to general ecological integrity. This would ultimately provide a robust means of monitoring the effectiveness of the water quality guidelines developed to ensure the protection of aquatic ecosystems.

Figure 5.3. Bar diagram showing the relative frequencies of occurrence of each SASS taxon at reference and impacted sites within the mountain stream and foothill subregional group.

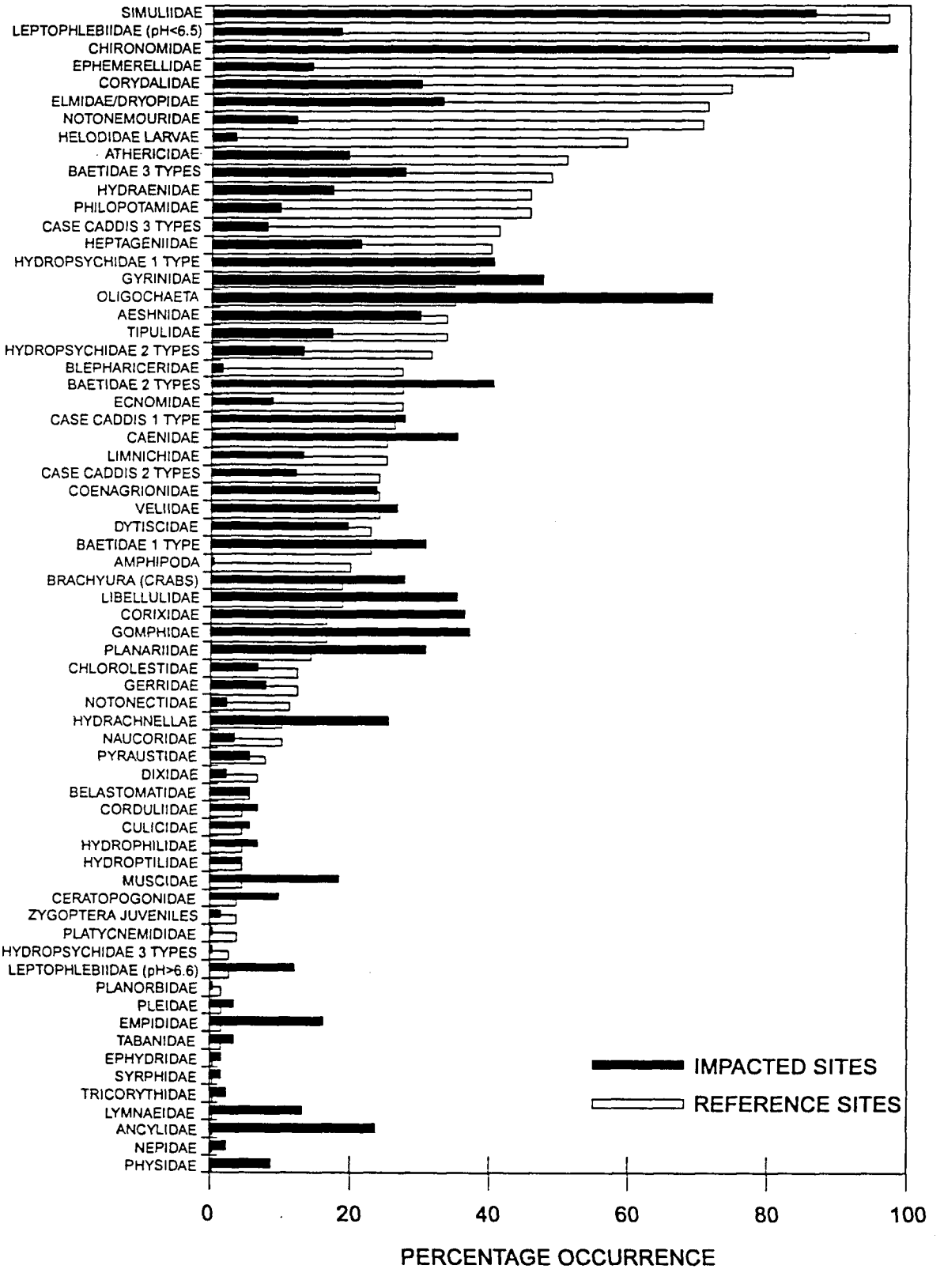
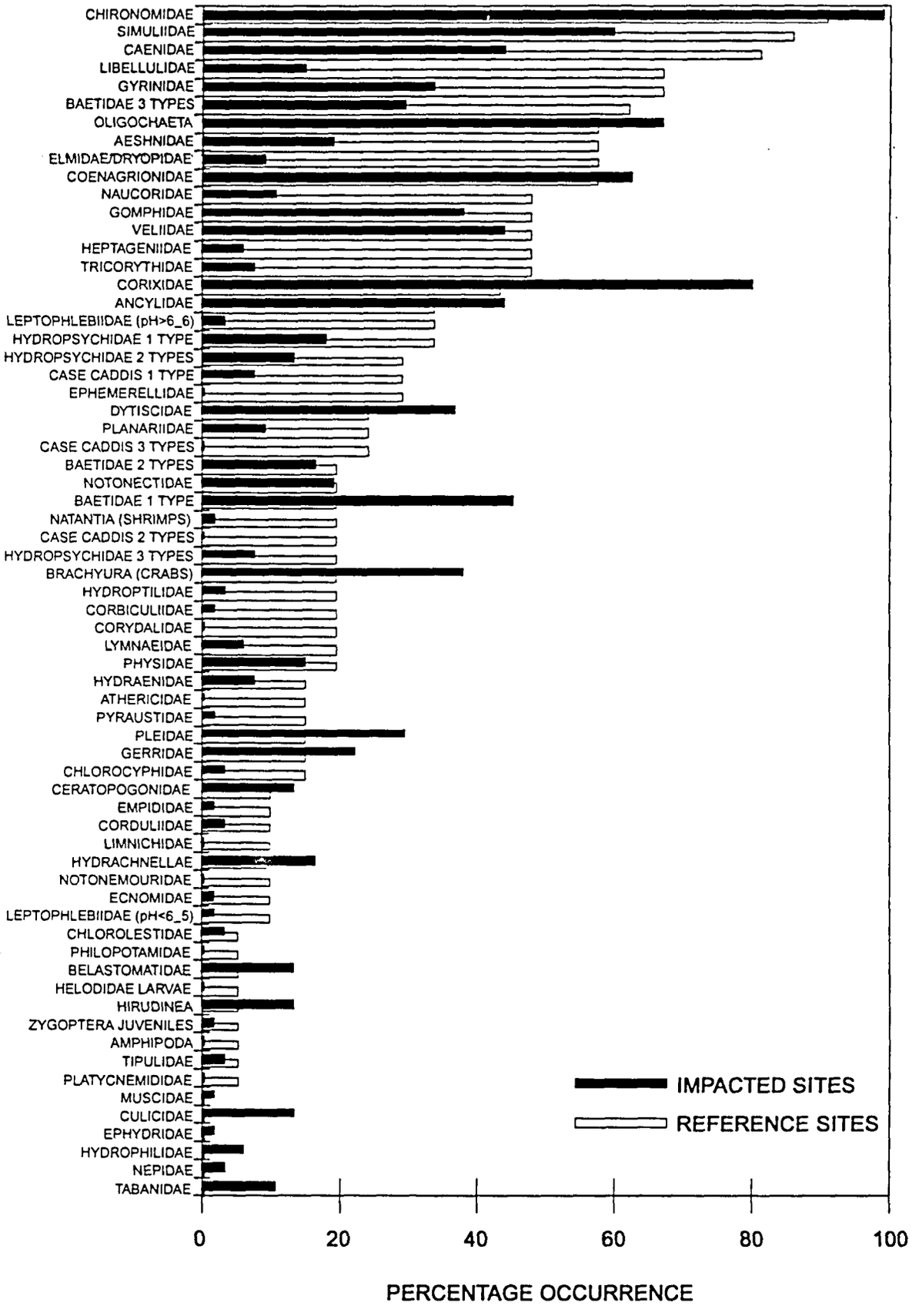


Figure 5.4. Bar diagram showing the relative frequencies of occurrence of each SASS taxon at reference and impacted sites within the transitional and lowland subregional group.



CHAPTER 6. TOXICOLOGICAL STUDIES OF THE COMBINED EFFECTS OF ALUMINIUM, COPPER AND MANGANESE ON AN ENDEMIC FRESHWATER AMPHIPOD *Paramelita nigroculus* IN ACIDIC WATERS

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6.1 INTRODUCTION

This chapter is a summary of sections of a doctoral thesis of D. Musibono (Musibono 1997) which is available from the University of Cape Town library and is presently being prepared for publication as a number of papers.

6.1.1 Heavy metals in the aquatic environment

Water quality is a major concern for aquatic resource managers and for the conservation of biodiversity. Indeed, as municipalities, industries, agricultural activities, , etc discharge wastes, receiving water bodies become more and more polluted. Aquatic and human life are threatened through toxins such as heavy metals accumulating in the food-chains, which may be a real threat. Organs adversely affected by heavy metals include the central nervous system (CNS), the peripherical nervous system, the kidneys, the liver, the blood cells, oral and nasal mucosas, the respiratory tract, the skeletal system, the cardiovascular system and the reproductive system. Teratogenesis and chromosomal aberrations may also result from contamination with heavy metals. The organs affected depend on the metal species and on the age and sex of people exposed. Indeed, children are more at risk from damage to the CNS by methyl-Hg and Pb, and older women are more sensitive to the effects of cadmium (Cd) on bones. It is not rare to hear about poisoning of communities after continuous consumption of fish from polluted waters. Examples of mercury poisoning include human communities from Minamata Bay (1953-60s), Iraq (1956, 1960, 1971-72), Guatemala (1963-65), Niigata (1965), Ghana (1967), Pakistan (1969) and Canada (1970s) (Walker 1975, Baloh *et al.* 1979, Butler 1979, Clarkson *et al.* 1984, Bruaux & Svartengren 1985, Patterson & Passino 1989).

Pollution may be defined as the introduction by humans, directly or indirectly, of substances or energy into aquatic environments that result in such deleterious effects as harm to living resources, hazards to human health, hindrance to aquatic activities e.g. fishing, impairment of quality for use of the water body (Reish & Oshida 1986, Schuiling *et al.* 1994). Pollution may become the key cause of degradation in water quality, and therefore, the main constraint to biodiversity. The effects of pollutants on aquatic ecosystems have allowed the World Health Organisation (WHO) and many governments (e.g. Dutch, South African, United States) to define standard values or criteria for the protection of aquatic life (Table 6.1) (Lamb 1985, WHO 1987, Musibono 1992, Hespanol & Prost 1994, DWAF 1995).

Synergistic and antagonistic effects

Unfortunately, all these criteria are based on the individual effects of single elements in the natural environment despite the fact that all elements in water exist in mixtures and may interact synergistically or antagonistically. Synergism is the result of toxins having a greater effect in combination than either would have alone. Antagonism is the opposite effect, where two or more toxins are less toxic in combination than alone. Synergistic interactions may have adverse effects on aquatic organisms and may result in long-term toxicity (e.g. Eaton 1973, Muska & Weber 1977, Anderson *et al.* 1979, Broderius & Smith 1979, Kiokemeister 1979, Hermens *et al.* 1984, Hutchinson & Sprague 1986).

Table 6.1. Acute Effect Values for eight metals in freshwater environments. Sources: WHO (WHO 1987, 1990, Musibono 1992, Hespanol & Prost 1994; Dutch =Enserink *et al.* 1991, Musibono 1992; South African = DWAF 1995; U.S. = Lamb 1985, Spehar & Fiandt 1986.

Metal species (μg l^{-1})	WHO criteria	Dutch criteria	South African criteria	U.S. criteria
Aluminium (Al)	200	200	10	100
Cadmium (Cd)	12	2.5	1.8	12
Chromium (Cr VI)	50	50	200	50
Copper (Cu)	1000	50	1.6	100
Mercury (Hg)	0.5	0.5	1.7	0.5
Manganese (Mn)	100	50	1300	50
Lead (Pb)	50	50	4	5
Zinc (Zn)	500	200	36	300

Although many studies on aquatic toxicology report on the effects of individual toxins, few works deal with synergistic effects of pollutants on ecosystems (e.g. Hermens *et al.* 1984, Biesinger *et al.* 1986, Enserink *et al.* 1991, Roux *et al.* 1993). One of the few examples is reported by Enserink *et al.* (1991), who tested complex mixtures of eight metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) on *Daphnia magna* at Dutch criterion levels. They showed that the criteria for these elements were inadequate for protecting aquatic life when the elements were present in combination. As, Cd, Cr, Cu, Hg, Pb, Ni and Zn were tested singly and in equitoxic mixtures based on the LC_{50} (individual *Daphnia magna*) or EC_{50} (populations) of the individual metals. The expected toxicities of these mixtures were expressed as toxic units based on concentration addition. The LC_{50} and EC_{50} values indicated an additive chronic toxicity of the metals with respect to individual survival as well as to population growth in *Daphnia magna*. Combined at the maximum levels of the present Dutch water quality criteria, these metals were severely toxic to *D. magna* and caused 50% mortality in developing rainbow trout (*Salmo gairdneri*). Even a reduction of these concentrations by a factor of five produced a 10% decrease of the yield of *D. magna* populations. Similar results have been reported by Van Leeuwen *et al.* (1987), who tested binary mixtures of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn at Dutch criterion levels on *D. magna*. They also reported the combined effects to be additive and to have affected reproduction. Indeed, while concentrations of 50 μg l^{-1} for Ni, As, Cu, Cr, and Pb, 200 μg l^{-1} for Zn, 2.5 μg l^{-1} for Cd and 0.5 μg l^{-1} for Hg showed no adverse effects, in combination, concentrations of 31 μg l^{-1} for Ni, As, Cu, Cr and Pb; 124 μg l^{-1} for Zn, 1.55 μg l^{-1} for Cd and 0.31 μg l^{-1} for Hg provoked 50% sterility in *Daphnia magna*. Biesinger *et al.* (1986) tested binary mixtures Cd, Cu and Cr in chronic toxicity experiments and concluded that concentrations of metals which caused no significant effects on the reproduction of *Daphnia magna* , if present singly, exerted a toxic action in mixtures.

Spehar and Fiandt (1986) showed that metal mixtures (i.e. As, Cd, Cr, Cu, Hg and Pb) based on the United States water quality criteria induced chronic effects in two fish (Rainbow trout *Salmo gairdneri* and Fathead minnows *Pimephales promelas*) and one invertebrate (*Ceriodaphnia dubia*). As, Cd, Cr, Cu, Hg and Pb combined at criterion maxima caused almost 100% mortality in rainbow trout and *C. Dubia* during acute exposures. Chronic tests showed that the joint action was less than additive for Fathead minnows but nearly strictly additive for daphnids, indicating that long-term metal interactions may be

different in fish than in lower invertebrates. Adverse effects were observed at mixture concentrations of one-half to one-third the maximum allowable toxicant concentration for fathead minnows and daphnids, respectively, suggesting that components of mixtures at or below no effect concentrations may contribute significantly to the chronic toxicity of a mixture. Musibono (1994) reported mixtures of Cd, Co, Cr, Cu, Pb and Zn to be toxic to the Nile lettuce, *Pistia stratiotes* , at WHO criteria levels, in both acute (96h exposure) and chronic (21d exposure) toxicity tests. All these results point out the need for additional studies to determine the type and degree of interaction of toxicants because single-chemical water quality criteria may not sufficiently protect some species when other toxicants are also present.

The combined effects of metals are not always negative. They may also reduce toxicity in same cases. Thus As (III) for example, is very toxic when present alone. In combination with manganese (II) it is not toxic though because As (III) is oxidised into the non-toxic As (V)(Driehaus *et al.* 1995). Pb (toxic) competes with iron (an essential metal) in the intestine, inhibiting the incorporation of iron (Fe) into protoporphyrin IX; Pb increases the deficiency of calcium on one hand, and on the other hand, calcium can alleviate Pb toxicity (this may explain why lead workers are asked to drink milk); Pb interferes with Zn enzymes and added Zn can alleviate the effects of Pb; Pb increases Cu deficiency (Clarkson *et al.* 1984, Patterson & Passino 1989). In short, mixtures of heavy metals in water or in organisms may increase or reduce the toxicity. This document reports on a series of experiments on the effects of three common metals in local freshwater environments: aluminium (Al), Copper (Cu) and manganese (Mn).

Aluminium

Aluminium (Al) is the third most abundant element in the earth's crust. It participates in biogeochemical reactions and is a strongly hydrolysing metal under highly acidic (pH<6) or alkaline (pH>8) conditions. Many Al salts are used for coagulation and flocculation in the process of producing drinking water. This metal is toxic at low pH (pH<6), a feature common in south-western Cape streams. A recent study by Tian (1996) reports the endemic freshwater amphipod *Paramelita nigroculus* to be tolerant to high concentrations of Al in acidic conditions.

Copper

Copper (Cu) is one of the most widely used metals in the world. It occur sin aquatic environment as a result of weathering processes or from the dissolution of Cu minerals. This essential element is toxic to aquatic organisms even at very low concentrations (e.g. Monteiro *et al.* 1995).

Manganese

Manganese (Mn), another essential element, is the second most abundant metal in nature. Its toxicity has been reported by Nussey *et al.* (1995a, b) for fish in the Olifants River. Mn also plays an important role in aquatic toxicology by increasing or reducing the toxicity of other metals when in mixtures. For example Mn reduces the toxicity of As (III) by oxidising this element into As (V), which is a non-toxic form. The oxidation of non-toxic Cr (III) form into the toxic Cr (VI) shows how Mn can increase the toxicity of this metal when present in mixtures (Driehaus *et al.* 1995).

This study aimed to establish the effects of mixtures of these metals (i.e. Al, Cu and Mn) using the South African intermediate guidelines for each individual metal.

6.1.2 Test organisms used in aquatic toxicological studies

Aquatic toxicology: Definition and types of bioassays

The study of pollutants in ecosystems, or ecotoxicology, is of world-wide interest. To understand what happens in aquatic environments with respect to heavy metal pollution, laboratory studies are performed using selected toxicants and test organisms. The duration, experimental scheme and parameters examined may vary. Different toxicity tests (=bioassays) are run in the short-term to ascertain acute toxicity and for longer periods to ascertain chronic toxicity. The lengths of time commonly used are 96 hours for acute toxicity tests and 21 days for chronic toxicity tests. Test organisms are exposed to a number of concentrations of a toxicant in order to follow some effect in the organism. Death is generally used as a criterion of a change in 96 hour tests. The concentration which causes 50% mortality is defined as the lethal concentration or LC_{50}. One or more controls are employed in which organisms are exposed to similar conditions but without the toxicant to provide a measure of experimental acceptability. These experiments are conducted under controlled laboratory conditions. The data generated can be used to evaluate the effect of a toxicant that might be discharged into the aquatic environment and thus assists in the development and application of water quality criteria for protection of the aquatic environment.

Test organisms used in aquatic toxicological studies

Various taxa, including algae, diatoms, bacteria, invertebrates and fish are used as test organisms in aquatic toxicology. Of these, fish are the most commonly used, particularly salmonids such as *Salmo solar*, *S. trutta*, *S. gairdneri*, *Onchorhynchus mykiss* and *Salvelinus fontinalis* (e.g. Spehar & Fiandt 1986, USEPA 1991, Buckler *et al.*1995). In South Africa, tilapia and catfish species have been used in aquatic toxicological studies (Van Vuren *et al.* 1994, Nussey *et al.* 1995a, b). The use of invertebrates is widespread and organisms such as the waterflea *Daphnia magna*, the amphipod *Gammarus pulex*, the isopod *Asellus aquaticus*, and chironomids are commonly used as bioindicators of water quality (Phillips & Segar 1986, WHO 1987, Gabric *et al.* 1990, Elendt & Bias 1990, Muzinger 1990).

In South Africa, endemic organisms are increasingly being used in aquatic toxicological tests. Fish, snails, mayflies, amphipods, bacteria, protozoans, isopods and worms have or are being used (Slabbert & Grabow 1986, Slabbert 1988, Roux *et al.* 1993, Van Vuren *et al.* 1994, , Wepener *et al.* 1992, Reinecke *et al.* 1996a, 1996b). In the south-western Cape, the endemic freshwater amphipod *P. nigroculus* (Barnard) has been examined as a potential test organism for biomonitoring of Western Cape acidic waters. *P. nigroculus* is abundant in the black waters of the south-western Cape region (pH<6 and dissolved organic carbon 75-135mg C l^{-1}), is robust and survives well under laboratory conditions (Tian 1996). It is easy to feed and has no aerial phase. *P. nigroculus* also lives in "unpolluted" stream water (i.e. Skeleton Gorge in the Kirstenbosch Botanical Garden/Table mountain in the Cape Peninsula). Its life cycle of a year and its robustness make *P. nigroculus* an ideal test organism for use in chronic toxicity tests. As well as these advantages, *P. nigroculus* also has some disadvantages. It is very tolerant towards low pH, high dissolved humic materials, varying Al concentrations and salinity changes, which might make *P. nigroculus* unsuitable as a test organism for acute toxicity tests (96h exposure). More information and data on this amphipod are still needed regarding its reproductive biology, physiology and ethology.

The South African Department of Water Affairs and Forestry (DWAF) is in the process of defining guidelines for water quality for sustaining aquatic life. Three types of value or criterion are defined for each constituent: the Target Water Quality Range (TWQR) at which no toxic effect is perceived; the Chronic Effect Values (CEV) which should not have effects even after long-term exposure and the Acute Effect Values (AEV) which should not have an effect if short-term exposure occurs. Each of these is set for single constituents and does not take into account the potential synergistic or antagonistic reactions between constituents in real effluents.

6.1.3 Chemical speciation in freshwater environments

Natural aquatic environments consist of four main components: water as a solution of various elements; organisms; suspended materials and sediments. The availability of a given element depends on the interactions between these four components, whilst bioavailability (the form in which the metal is biologically active) essentially relates to the dissolved form by Förstner (1985). In sediments, heavy metals accumulate according to the following major mechanisms leading to five categories of metals as reported by Förstner (1985), Pardo *et al.* (1990):

- adsorptive and exchangeable;
- bound to carbonates phases;
- bound to reducible phases (i.e. Fe and Mn oxides),
- bound to organic matter and sulphides, and finally
- detrital or lattice metals.

Under changing environmental conditions, these five categories of metals behave differently with respect to remobilization. The more mobile and dangerous fractions are those that are adsorptive/exchangeable, bound to carbonates and bound to reducible phases (Förstner 1985, Pardo *et al.* 1990). In natural waters, free metal ions and colloids of diameter size<0.45 μm are the most toxic because they are biologically available.

Alkalinity and pH play an important role in heavy metal toxicity. Low pH values usually allow the dissolution of metals and therefore increase the toxicity, while high pH allows binding and therefore reduces the bioavailability (and toxicity) of metal ions (Shuttleworth & Unz 1991). Let us use the example of Al behaviour in aquatic environments to illustrate the above facts. Al behaviour in aquatic environments is strongly pH-dependent. Although Al is the most abundant metallic element in the earth's crust, it is generally highly insoluble and therefore unable to participate in biogeochemical transformations. Under highly acidic (pH<6) or alkaline (pH>8) conditions, or in the presence of complexing ligands, however, elevated concentrations may be mobilised to the aquatic environment (Dallas & Day 1993, Driscoll & Schecher 1993, Brady & Griffiths 1995). In acid-sensitive watersheds with limited release of basic cations (calcium, magnesium, potassium and sodium) and/or retention of strong acid anions (sulphates, nitrates, chlorides), Al is mobilised within the soil, causing elevated concentrations in soil solutions and surface waters. So, as a result of solubility constraints, concentrations of aqueous Al increase exponentially with decreases in pH below 6.0. Monomeric Al occurs as a series of complexes in the aqueous environment including aquo, OH^-, F^-, SO_4^{2-}, HCO_3 and organic species. Of these, aquo, OH^-, F^- and organic complexes are the most significant in natural waters.

Elevated concentrations of Al are ecologically significant because (Dallas & Day 1995):

- Al is an important buffer in acidic waters, regulating the lower limit of pH values following acidification by strong acids;
- through adsorption and coagulation reactions, Al may alter the cycling and availability of important elements like phosphorus, organic carbon and certain trace elements;
- Al may serve as a coagulant facilitating the removal of light-attenuating materials, thereby increasing the clarity and decreasing the thermal stability of lakes; finally,
- Al is potentially toxic to aquatic organisms.

The toxicity of Al varies with the life history stage of fish. At pH 4.2 to 4.8, the presence of Al improves egg survival, while reducing survival and growth of white sucker (*Catostomus commersoni*) and brook trout sac-fry and fry (Baker & Schofield 1982). The extent of toxicity is dependent on concentration and the speciation of aqueous Al. Driscoll *et al.* (1980) reported that toxicity to fry was greatly reduced when Al was complexed with organic solutes. Henriksen *et al.* (1984) reported that episodic changes in pH and inorganic monomeric Al during high-flow, snowmelt conditions were responsible for fish kill of Atlantic salmo (*Salmo solar*) in Norway. Brady and Griffiths (1995), studying the effects of pH and Al on the growth and feeding behaviour of smooth and palmate newt larvae, reported that the distribution of smooth and palmate news (*Triturus vulgaris* and *T. helveticus*) may be related to water quality. Indeed comparing the larval growth and feeding behaviour of both species under sublethal levels of Al and low pH, the growth of both species was inhibited to a similar degree under acidic conditions with Al toxicity dependent upon both low pH and development stage. The two species were differentially affected by low pH in terms of feeding behaviour. *T. vulgaris* larvae took significantly longer to snap at food under low pH than the apparently acid-tolerant *T. helveticus*. Acute toxicity of Al was reported from acidic solutions that are oversaturated with respect to $Al(OH)_3$ solubility. Calcium may reduce the toxicity of Al (Brown 1983) as may the presence of some organic molecules which reduce Al availability by complexation (Cathalifaud *et al.* 1997).

6.1.4 Aims of this study

This study aims to ascertain the combined effects of Al, Cu and Mn in chronic exposures at low pH ($pH<5.0$), asking a number of questions. Previous studies by Tian (1996) showed *P. nigroculus* to be tolerant to Al alone at $pH<5.5$. Cu, an essential element, is reported to be toxic to aquatic life (e.g Nussey *et al.* 1995a, b, Taylor *et al.* 1995). What happens when *P. nigroculus* is exposed to Cu in mixtures with Al? Mn, another essential element, reduces or increases the toxicity of some metals in aquatic environments. What are its effects on both Cu and Al? Finally, synergistic or the antagonistic reactions may occur in the mixtures of these three metals. It has been reported that Al (III) reduces the toxicity of Cd to plants, Mn increases the toxicity of Cr (III) into Cr (VI) which is very toxic. Mn also reduces the toxicity of As (III) into the harmless As (V) (e.g. Shuttleworth & Unz 1991, Driehaus *et al.* 1995). Will Mn reduce or increase the toxicity of Al and Cu? Will the mixtures of Al and Cu increase or reduce the tolerance of Al by *P. nigroculus*? In South African industrial and mining areas (e.g. the Olifants River in Mpumalanga) high concentrations of these metals (Table 6.2.) are reported by Van Vuren et al. (1997).

Table 6.2. Al, Cu and Mn concentrations in water and sediment in the Olifants River (from Van Vuren *et al.* 1997)

Metal	Al	Cu	Mn
In water (μg l^{-1})	80 - 43680	1 - 60	14 - 35040
In sediment (μg kg^{-1})	8839 - 263898	7- 215	31 - 13410

This study on the combined effects of three heavy metals common in freshwater environments provides preliminary responses to the following questions:

1. Are South African intermediate criteria adequate for aquatic life in the south-western Cape region?
2. What kind of interactions occur between the three metals (Al, Cu and Mn) tested?
3. Is the endemic freshwater amphipod, *P. nigroculus*, a good bioindicator of pollution by heavy metals (bioaccumulator or regulator)?

The test organism used is the amphipod *P. nigroculus* Barnard (Paramelitae, Crangonyctoidea: Amphipoda) from the Skeleton Gorge stream (33°58'S, 18°25'E) on the Cape Peninsula, South Africa.

6.2 MATERIALS AND METHODS

6.2.1 Chemicals and preparation of test solutions

Al(III) in the form of $Al_2(SO_4)_3.18H_2O$ (Merck extra pure), Cu(II) in the form of $CuSO_4.5H_2O$ (Analar 99.5%) and Mn(II) in the form of $MnSO_4.4H_2O$ (BDH 97%) were used in test solutions. Pure sodium chloride (NaCl, Univar 99.5%, 85mg l^{-1}), hydrated calcium chloride ($CaCl_2.2H_2O$, Merck 99.5%,10mg l^{-1}) and hydrated magnesium sulphate ($MgSO_4$, Merck 70%, 5mg/L) were dissolved in distilled water to prepare '"artificial"' water with a total dissolved solids (TDS) concentration of 100mg l^{-1} (e.g. USEPA 1991, Tian 1995). Stream water from Skeleton Gorge on Table Mountain in the south-western part of the Western Cape in South Africa was used to acclimatite amphipods to the laboratory prior to their exposure to pollutants and also to make some test solutions. Containers were cleaned in a phosphate-free surfactant solution (Contrad, Merck) before they were used in the experiments. Concentrated nitric acid was used to adjust the pH 4.5 - 5.8 and also to preserve samples when chemical analyses could not be performed on the same day.

6.2.2 Experimental methodology

Two sets of sixty-three white plastic containers of the same depth and volume (500 ml) were washed in Contrad and rinsed with distilled water prior to their use as test chambers. Each then received 200 ml of test solutions. Each treatment consisted of three replicates and each experiment was run five times. Tests were run using Al+Cu, and Al+Cu+Mn, at South African criterion levels (DWAF 1995), at 50% above criterion levels, and at 50% below criteria levels. Additional test concentrations labelled AEV2a and AEV2b corresponded to the highest values of the new interim AEV criteria (DWAF 1995). The Target Water Quality Range (TWQR), Chronic Effect Value (CEV) and Acute Effect Value (AEV) were

tested for each set of experiments. Because natural stream water contains a variable amount of dissolved organic matter, which compounds the modelling of chemical speciation, two experiments were run. One set of 63 containers, corresponding to 21 treatments, used "artificial" water as the medium of dilution and another set of 63 containers, corresponding to 21 treatments, used natural stream water from the natural habitat of *Paramelita*. Stock solutions were filtered through 0.45 mm GF/C Whatman filter paper using a plastic funnel. Total hardness (TH) was determined using a Hach model 16900-01 digital titrator and a 0.800M EDTA cartridge 14364-01. A Crison pH.mV-meter model 506 was used to measure pH. Conductivity and temperature were measured using a Hach model 44600 Conductivity/TDS meter. The concentrations of the test solutions are indicated in Table 6.3.

Table 6.3. Concentrations of test solutions in mg l^{-1}. TWQR = target water quality range; CEV = chronic effect value; AEV = acute effect value.

	Al	Cu	Mn
A1a1 (TWQR)	0.062	0.001	
A1a2 (TWQR)	0.062	0.001	1.217
A1b1 (CEV)	0.185	0.004	
A1b2 (CEV)	0.185	0.004	2.434
A1c1 (AEV)	0.926	0.008	
A1c2 (AEV)	0.926	0.008	9.328
B2a1 (TWQR + 50%)	0.0925	0.0025	
B2a2 (TWQR + 50%)	0.0925	0.0025	1.825
B2b1 (CEV + 50%)	0.2775	0.005	
B2b2 (CEV + 50%)	0.2775	0.005	3.65
B2c1 (AEV + 50%)	1.388	0.0175	
B2c2 (AEV + 50%)	1.388	0.0175	13.993
C3a1 (TWQR - 50%)	0.030	0.0025	
C3a2 (TWQR - 50%)	0.030	0.0025	0.6075
C3b1 (CEV - 50%)	0.0925	0.0175	
C3b2 (CEV - 50%)	0.0925	0.0175	1.218
C3c1 (AEV - 50%)	0.4325	0.004	
C3c2 (AEV - 50%)	0.4325	0.004	4.665
AEV2a (new AEV)	0.1225	0.005	
AEV2b (new AEV)	0.1225	0.005	5.273
Control	0	0	0

6.2.3 Amphipod collection and treatments

Test animals were specimens of the amphipod *P. nigroculus* , which is endemic to mountain streams in the south-west of the Western Cape province of South Africa (Stewart 1991). In the laboratory, amphipods were acclimated for at least a week in water from Skeleton Gorge, a small tributary of the

Liesbeek River, which drains the eastern flank of Table Mountain. The temperature was kept constant at 14±1°C and water was replaced every day. The animals, which are shredders, were fed only on conditioned leaves of a riparian tree, *Rapanea melanophloeos*. Light intensity was at laboratory levels (10-20 $mE.m^{-2}$ s^{-1}) and the photoperiod was set at 12h dark:12h light. The water was not aerated (Stewart 1991).

Adult animals (body length >4mm: Tian 1996) of either sex were selected using a 125-950 mm-mesh sieve, a magnifying glass and graph paper (Stewart 1991, Winger *et al.* 1993, Tian 1996). Mature breeding females were excluded because of their sensitivity to pollution and because of environmental ethics. Individuals <4 mm were considered to be juveniles; moulting individuals were identified by colour and transparency (Stewart 1991; Tian 1996). Each container of 500 ml capacity received 200 ml of test solution and 10 individuals of either mature amphipods, moulting individuals or juveniles as test animals. All organisms were randomly selected by numbering each container consecutively and selecting test organisms for a particular concentration and replicate by following the 'random numbers from the hat' method Clarke (1980) and Zar (1996). This is why, in the tables of results, treatments are randomly distributed.

During the first 96h of exposure, amphipods were not fed. From the fifth day 0.5 g (dry weight) of leaves of *Rapanea melanophloeos*, previously soaked in distilled water for 24 hours, were introduced into each container. Test solutions and food were renewed twice a week. Dead amphipods were removed from test containers every day. Each experiment lasted 21 days. During the experiments, containers were not washed. After 21 days, amphipods were removed from the test solutions and kept for 30 hours in clean "artificial" water to allow depuration. No food was given during this period. Animals were then washed in distilled water and dried at 75°C to constant mass. The dry weight was recorded. Finally, the dried amphipods were ignited at 650°C in a muffle furnace for 10 hours. The ash obtained was weighed, then 0.5 g of each ash sample digested in 5 ml of concentrated nitric acid for at least 8 hours and filtered into a 50 ml Erlenmeyer flask. The volume was made up with distilled water and analysed by Inductively-Coupled Plasma spectrometry.

At the end of each experiment, test solutions were filtered through 0.45 mm Whatman filter paper. Concentrated acid (1ml per container) was used to preserve samples, which were stored at 4°C prior to analysis. Stream water, "artificial" water, *Rapanea melanophleos* leaves and control amphipods were also chemically analysed for Al, Cu and Mn. Acute toxicity was expressed as 96h LC_{50} and chronic toxicity as LT_{50}. Survival after 24 h, 96 h, 8 d and 21 d was noted. Growth was assessed as changes in body weight (dry weight) after 21d exposures to different treatments. The size and number of the organisms prevented measurement of other parameters such as length. Twenty juvenile amphipods were dried and weighted at the start of each experiment to act as a reference weight. Average dry body weight per amphipod of test organisms after the experiment could then be compared with the reference value. There were three replicates per treatment and each experiment was run five times.

The endpoints for the experiments were as follows:

- significant mortality as LC_{50} and LT_{50};
- growth as significant changes in body weight after 21d exposures to test solutions;

- Growth as change in numbers of individuals as a result of reproduction after 45d exposures.

Data analysis

Analysis of variance (ANOVA) and Newman-Keuls test of comparison were applied where F values were significant. Mann-Whitney U-test was performed on the reproduction data. Survival times and regression analyses was performed using Genstat/Statistica packages and Cox's proportional hazard equation (Collett 1994).

6.3 RESULTS

All results are summarised in the following abstract. Details are reported in the doctoral thesis.

6.3.1 Baseline conditions and concentrations of Al, Cu and Mn

The chemical composition of natural water (NW) and "artificial" water (AW), including pH, total hardness (TH) and conductivity, in addition to the concentrations of Al, Cu and Mn were ascertained (Table 6.4). The concentration of each metal in *R. melanophloeos* leaves and amphipods was also ascertained (Table 6.4). The presence of Al, Cu and Mn in stream water (NW) from which amphipods were collected may play an important role in the pre-adaptation of *P. nigroculus* to the toxicity of these metal species. Indeed, the pre-exposure in chronic toxicity may develop hormesis (acclimation) in the organism as reported by Roesijadi and Fellingham (1987), Munzinger (1990), Forbes and Forbes (1994) and Roux *et al.* (1993). The sensitivity to pollutants will therefore be reduced.

Table 6.4. Dissolved metal concentrations of Al, Cu and Mn ± S.D. in μg l^{-1} in dilution waters, NW=natural stream water, AW="artificial" water. *R. melanophloeos* leaves (RML) and control amphipods *P. nigroculus* prior to experiments. Standard deviations are given in parentheses when appropriate (n=5). N.A.= not analysed

Parameter	NW	AW	RML	*P. nigroculus*
Al	221 ±15	0	0	157
Cu	9 ± 6	0	<1	14 ± 7
Mn	323 ± 34	0	<1	52 ± 23
% Organics	1.1 ± 0.5	0	N.A.	N.A.
pH range	4.5 - 5.5	4.5 - 5.8	N.A.	N.A.
TH (mg l^{-1})	30 ± 6	30 ± 4	N.A.	N.A.
Conductivity range (μS cm^{-1})	120 - 350	120 - 350	N.A.	N.A.

6.3.2 Survival and mortality of *P. nigroculus* in different test solutions

Survival and mortality of *P. nigroculus* after 24h, 96h, 8d and 21d of exposure to test solutions are reported in Tables 6.5 and 6.6 for mature individuals and Tables 6.7 and 6.8 for juvenile individuals.

Survival of mature individuals in natural stream water was as follows: after 24h, 38 individuals (16.6% of the total) had died; after 96h, 24 individuals (10.5%) had died; after 8d 120 individuals (52.4%) had died and after 21d 47 individuals (20.5%) had died. Mortality of mature individuals in "artificial" water was as follows: mortality after 24h (15.7%) was higher than after 96h (10.7%); and mortality after 8d (51.7%) was higher than after 21d (21.9%).

Mortality of juveniles in stream water after 24h was higher (29.2%) than after 96h (13.4%); and mortality after 8d was higher (36.5%) than after 21d (21.8%). Mortality of juveniles in "artificial" water after 24h was higher (32.1%) than after 96h (16.0%) and mortality after 8d was higher (34.7%) than after 21d (17.2%).

The average survival of moulting amphipods after 24h, 96h, 8d and 21d exposures to Al, Cu and Mn mixtures in stream water (and in "artificial" water) solutions (n=3) was very low. Mortality:

- after 24h exposure = 227 (274) individuals = 38% (44%)
- after 96h exposure =154 (181) individuals = 25% (29%)
- after 8d exposure = 170 (140) individuals = 28% (23%)
- after 21d exposure = 54 (26) individuals = 9% (4%)

However, mortality in the stream water control after 21d exposure was 22/30 individuals (73.3%) and in the in "artificial" water control was 27/30 individuals (90%). Because of these high mortalities in the control, the results are not useful and this category of amphipods as test organisms was rejected.

Suitable data on mortality were available after 24h and 8d for acute and chronic tests respectively. This observation may be useful in the routine monitoring of the water quality. Using *Daphnia magna* in chronic toxicity tests, Santojanni *et al.* (1995) suggested that both acute and chronic tests should be shortened to 24h and 8d exposures instead of the 96h and 21d actually used. Shortening of test time may be useful for the evaluation of chronic effects of pollutants in environmental control. The 24h mortality of mature amphipods is lower than the 24h mortality of juveniles (namely 16.6%<29.2% in natural water solutions, and 15.7%<32.1% in "artificial" water solutions); while the 8d mortality of mature amphipods was higher than the 8d mortality of juveniles in both dilution waters (namely 52.5%>35.6% in natural water solutions, and 51.7%>34.7% in "artificial" water solutions. This may be due to pre-exposure in the natural environment. Mature amphipods from Skeleton Gorge stream live in metal mixtures in natural conditions and they may have developed an adaptive response. As the concentration increases in the body, however, their resistance becomes reduced and death may result. For juveniles, mortality is high after 24h exposure because they have not yet developed a protective response.

6.3.3 Growth of *P. nigroculus* after 21d exposures

Average growth rates of juvenile amphipods after 21d exposures to Al, Cu and Mn mixtures in natural and "artificial" water is given in Table 6.9. Growth occurred in all treatments compared to the reference value.

Table 6.5. Number of adults surviving and dying (parentheses) after exposure to mixtures of Al+Cu, or Al+Cu+Mn in natural stream water.

	Al	Cu	Mn	24h	96h	8d	21d
A1a1	0.062	0.001		26 (4)	24 (2)	18 (6)	16 (2)
A1a2	0.062	0.001	1.217	28 (2)	28 (0)	23 (5)	20 (3)
A1b1	0.185	0.004		27 (3)	26 (1)	18 (8)	15 (3)
A1b2	0.185	0.004	2.434	29 (1)	28 (1)	23 (5)	20 (3)
A1c1	0.926	0.008		28 (2)	26 (1)	15 (11)	13 (2)
A1c2	0.926	0.008	9.328	29 (1)	28 (1)	22 (6)	19 (3)
B2a1	0.092	0.002		25 (5)	23 (2)	18 (5)	16 (2)
B2a2	0.092	0.002	1.825	28 (2)	27 (1)	21 (6)	19 (2)
B2b1	0.277	0.005		27 (3)	26 (1)	18 (8)	15 (3)
B2b2	0.277	0.005	3.65	29 (1)	27 (2)	23 (4)	20 (3)
B2c1	1.388	0.017		27 (3)	25 (2)	14 (11)	12 (2)
B2c2	1.388	0.017	13.99	29 (1)	28 (1)	22 (6)	18 (4)
C3a1	0.030	0.002		29 (1)	29 (0)	25 (4)	25 (0)
C3a2	0.030	0.002	0.607	29 (1)	28 (1)	26 (2)	25 (1)
C3b1	0.092	0.017		29 (1)	27 (2)	19 (8)	16 (3)
C3b2	0.092	0.017	1.218	29 (1)	28 (1)	25 (3)	24 (1)
C3c1	0.432	0.004		28 (2)	27 (1)	20 (7)	16 (4)
C3c2	0.432	0.004	4.665	29 (1)	28 (1)	25 (3)	24 (1)
AEV2a	0.122	0.005		29 (1)	27 (2)	21 (6)	17 (4)
AEV2b	0.122	0.005	5.273	29 (1)	28 (1)	25 (3)	24 (1)
Control	0	0	0	29 (1)	29 (0)	26 (3)	26 (0)

Table 6.6. Number of adults surviving and dying (parentheses) after exposure to mixtures of Al+Cu or Al+Cu+Mn in 'artificial' water.

	Al	Cu	Mn	24h	96h	8d	21d
A1a1	0.062	0.001		26 (3)	25 (1)	17 (8)	15 (2)
A1a2	0.062	0.001	1.217	29 (1)	27 (2)	22 (5)	20 (2)
A1b1	0.185	0.004		28 (2)	26 (2)	17 (9)	15 (2)
A1b2	0.185	0.004	2.434	29 (1)	28 (1)	23 (5)	19 (4)
A1c1	0.926	0.008		29 (1)	28 (1)	14 (14)	13 (1)
A1c2	0.926	0.008	9.328	29 (1)	28 (1)	21 (7)	19 (2)
B2a1	0.092	0.002		25 (5)	20 (5)	16 (4)	14 (2)
B2a2	0.092	0.002	1.825	28 (2)	27 (1)	21 (6)	18 (3)
B2b1	0.277	0.005		25 (5)	24 (1)	18 (6)	14 (4)
B2b2	0.277	0.005	3.65	29 (1)	26 (3)	19 (7)	17 (2)
B2c1	1.388	0.017		26 (4)	25 (1)	14 (11)	11 (2)
B2c2	1.388	0.017	13.99	28 (2)	28 (0)	22 (6)	19 (3)
C3a1	0.030	0.002		29 (1)	28 (1)	26 (2)	24 (2)
C3a2	0.030	0.002	0.607	29 (1)	28 (1)	26 (2)	24 (2)
C3b1	0.092	0.017		30 (0)	29 (1)	21 (8)	16 (5)
C3b2	0.092	0.017	1.218	29 (1)	27 (2)	26 (1)	25 (1)
C3c1	0.432	0.004		28 (2)	28 (0)	20 (8)	14 (6)
C3c2	0.432	0.004	4.665	29 (1)	29 (0)	26 (3)	25 (1)
AEV2a	0.122	0.005		28 (2)	27 (1)	21 (6)	16 (5)
AEV2b	0.122	0.005	5.273	29 (1)	28 (1)	24 (4)	23 (1)
Control	0	0	0	29 (1)	29 (0)	26 (3)	25 (1)

Table 6.7. Number of juveniles surviving and dying (parentheses) after exposure to mixtures of Al+Cu, or Al+Cu+Mn in natural stream water.

	Al	Cu	Mn	24h	96h	8d	21d
A1a1	0.062	0.001		27 (3)	23 (4)	17 (6)	13 (4)
A1a2	0.062	0.001	1.217	27 (3)	27 (0)	21 (6)	18 (3)
A1b1	0.185	0.004		25 (5)	24 (1)	16 (8)	12 (4)
A1b2	0.185	0.004	2.434	28 (2)	26 (2)	20 (6)	14 (6)
A1c1	0.926	0.008		23 (7)	20 (3)	15 (5)	11 (4)
A1c2	0.926	0.008	9.328	23 (7)	20 (3)	15 (5)	11 (4)
B2a1	0.092	0.002		20 (10)	19 (1)	17 (2)	13 (4)
B2a2	0.092	0.002	1.825	24 (6)	21 (3)	18 (3)	17 (1)
B2b1	0.277	0.005		22 (8)	19 (3)	14 (5)	10 (4)
B2b2	0.277	0.005	3.65	25 (5)	24 (1)	19 (5)	17 (2)
B2c1	1.388	0.017		23 (7)	19 (4)	14 (5)	10 (4)
B2c2	1.388	0.017	13.99	25 (5)	23 (2)	20 (3)	17 (3)
C3a1	0.030	0.002		28 (2)	27 (1)	24 (3)	21 (2)
C3a2	0.030	0.002	0.607	29 (1)	28 (1)	24 (4)	22 (2)
C3b1	0.092	0.017		28 (2)	27 (1)	23 (4)	22 (1)
C3b2	0.092	0.017	1.218	29 (1)	28 (1)	25 (3)	23 (2)
C3c1	0.432	0.004		27 (3)	26 (1)	15 (11)	14 (1)
C3c2	0.432	0.004	4.665	29 (1)	27 (2)	21 (6)	20 (1)
AEV2a	0.122	0.005		28 (2)	27 (1)	23 (4)	20 (3)
AEV2b	0.122	0.005	5.273	28 (2)	26 (2)	23 (3)	21 (2)
Control	0	0	0	29 (1)	28 (1)	24 (4)	23 (1)

Table 6.8. Number of juveniles surviving and dying (parentheses) after exposure to mixtures of Al+Cu, or Al+Cu+Mn in 'artificial' water.

	Al	Cu	Mn	24h	96h	8d	21d
A1a1	0.062	0.001		21 (9)	20 (1)	16 (4)	14 (2)
A1a2	0.062	0.001	1.217	24 (6)	24 (0)	20 (4)	16 (4)
A1b1	0.185	0.004		24 (6)	22 (2)	16 (6)	14 (2)
A1b2	0.185	0.004	2.434	26 (4)	25 (1)	19 (6)	18 (1)
A1c1	0.926	0.008		25 (5)	21 (4)	14 (7)	12 (2)
A1c2	0.926	0.008	9.328	27 (3)	26 (1)	19 (7)	17 (2)
B2a1	0.092	0.002		21 (9)	20 (1)	16 (4)	14 (2)
B2a2	0.092	0.002	1.825	24 (6)	24 (0)	20 (4)	18 (2)
B2b1	0.277	0.005		23 (7)	19 (4)	16 (3)	14 (2)
B2b2	0.277	0.005	3.65	26 (4)	23 (3)	20 (3)	17 (3)
B2c1	1.388	0.017		22 (8)	20 (2)	12 (8)	9 (3)
B2c2	1.388	0.017	13.99	25 (5)	20 (5)	19 (1)	16 (3)
C3a1	0.030	0.002		27 (3)	27 (0)	24 (3)	22 (2)
C3a2	0.030	0.002	0.607	28 (2)	27 (1)	24 (3)	23 (1)
C3b1	0.092	0.017		27 (3)	26 (1)	22 (4)	18 (4)
C3b2	0.092	0.017	1.218	29 (1)	26 (3)	24 (2)	22 (2)
C3c1	0.432	0.004		29 (1)	24 (5)	14 (10)	12 (2)
C3c2	0.432	0.004	4.665	29 (1)	25 (4)	21 (4)	19 (2)
AEV2a	0.122	0.005		27 (3)	25 (2)	21 (4)	17 (4)
AEV2b	0.122	0.005	5.273	29 (1)	26 (3)	21 (5)	20 (1)
Control	0	0	0	29 (1)	28 (1)	25 (3)	24 (1)

Table 6.9. Average (±standard deviation) growth (in mg per amphipod) as changes in dry body weight of juvenile amphipods after 21d exposures to Al, Cu and Mn mixtures in stream water (NW) and "artificial" water (AW) solutions (n=5). The reference value was 1.3 mg per amphipod (dry weight).

Solution		Concentration in µg l^{-1}	Average (SD)	
			NW	AW
1	D0	0.00	3.90 (0.00)	2.61 (0.01)
2	C3a1	2.65	3.83 (0.09)	2.50 (0.01)
3	A1a1	5.30	3.25 (0.06)	1.90 (0.01)
4	B2a1	7.95	2.80 (0.21)	1.83 (0.01)
5	C3b1	8.00	3.49 (0.20)	1.84 (0.01)
6	AEV2a	11.60	3.43 (0.09)	1.85 (0.01)
7	A1b1	16.00	2.81 (0.14)	1.79 (0.01)
8	B2b1	24.00	2.47 (0.13)	1.74 (0.02)
9	C3c1	36.50	2.06 (0.02)	1.79 (0.01)
10	A1c1	78.00	2.18 (0.17)	1.72 (0.01)
11	B2c1	117.00	1.83 (0.08)	1.69 (0.02)
12	C3a2	152.65	4.07 (0.06)	2.90 (0.01)
13	A1a2	305.30	3.64 (0.03)	2.46 (0.01)
14	C3b2	308.00	3.72 (0.09)	2.05 (0.01)
15	B2a2	457.95	3.16 (0.04)	2.06 (0.00)
16	A1b2	616.00	3.40 (0.15)	2.03 (0.02)
17	B2b2	924.00	3.78 (0.09)	2.05 (0.01)
18	C3c2	1186.50	3.68 (0.09)	2.04 (0.01)
19	AEV2b	1311.60	2.92 (0.06)	1.93 (0.00)
20	A1c2	2378.00	3.32 (0.14)	1.91 (0.00)
21	B2c2	3567.00	2.75 (0.06)	1.90 (0.01)

6.4 DISCUSSION AND SUMMARY

6.4.1 Mortality/survival

- Average mortality of mature amphipods in stream water solutions after 24h, 96h, 8d and 21d exposures were 16.6%, 10.5%, 52.4% and 20.5% respectively. Mortality after 1d > 4d and 8d > 21d.
- Average mortality of mature amphipods in "artificial" water solutions after 24h, 96h, 8d and 21d exposures were 15.7%, 10.7%, 51.7% and 21.9% respectively. Mortality after 1d>4d, and 8d > 21d.
- Average mortality of juveniles in stream water solutions after 24h, 96h, 8d and 21d exposures were 29.2%, 13.4%, 35.65% and 21.8% respectively. Mortality after 1d > 4d, and 8d > 21d.
- Average mortality of juveniles in "artificial" water solutions after 24h, 96h, 8d and 21d exposures were 32.1%, 16.0%, 34.7% and 17.2% respectively. Mortality after 1d > 4d, and 8d > 21d.

- Average mortality of juvenile amphipods in "artificial" water after 24h, 96h, 8d and 21d exposures were 32.1%, 16.0%, 34.7% and 17.2% respectively. Mortality after 1d > 4d; and 8d > 21d.
- Average mortality of moulting individuals in stream water solutions after 24h, 96h, 8d and 21d exposures were 38%, 25%, 28% and 9% respectively. Mortality of moults after 1d > 4d, and 8d > 21d; and finally,
- Average mortality of moulting individuals in "artificial" water solutions after 24h, 96h, 8d and 21d exposures were 44%, 29%, 23% and 4% respectively. Mortality after 1d > 4d, and 8d >21d.

Statistical analyses on survival using ANOVA and the Newman-Keuls tests of significance, showed significant difference ($p<0.05$) in the survival within some concentrations and the control due to effects of the metals. The mixtures of Al+Cu were more toxic than Al+Cu+Mn mixtures, which may be explained by chemical speciation. Indeed, the study of interactions between the three metals, chemical speciation and toxicity modelling using MINTEQA2 and PRODEFA2, showed that Mn increases the precipitation of Al and that solid hydroxides of Al adsorb Cu ions. This reduces the bioavailability of metal ions and therefore toxicity.

Taking survival of juveniles in natural water solutions as the baseline, the risk analysis using Cox regression equation gave the following results for the effects of concentrations:

- when concentration increases by 1 $\mu g\ l^{-1}$, the risk increases by 1.000086;
- the addition of Al and Cu mixtures increases the risk of death 2.64 times;
- the addition of Al, Cu and Mn increases the risk of death 1.45 times. So the presence of Mn reduces the risk of death;
- compared to a juvenile, the risk of death for an adult is only 0.77 or 77%;
- compared to a juvenile, the risk to a moulting amphipod is 5.33 times greater giving an overall increase in risk in the presence of these metals (Al, Cu) of 9.8 times. When Al and Cu are present the risk to a moulting individual increases a further 1.84%;
- compared to natural water, the risk is 90% in "artificial" water (probably due to the presence of other pollutants, but also the increase of Al, Cu and Mn concentrations since these elements were present in the stream water: 221 $\mu g\ l^{-1}$ Al; 9 $\mu g\ l^{-1}$ Cu; and 323 $\mu g\ l^{-1}$ Mn).

6.4.2 Growth as changes in body weight after 21d exposure and reproduction after 45days

Growth in stream and "artificial" water solutions of Al+Cu+Mn mixtures

Using the reference weight (dry weight) of one juvenile amphipod before the experiments (i.e.1.30 mg), growth occurred in all test solutions. However, significant differences were reported within some concentrations and the control as confirmed by ANOVA and Newman-Keuls tests. For example, growth of juveniles in stream and "artificial" water solutions of Al+Cu+Mn mixtures gave F values of 76.17 and 1759.63 respectively at $p<0.05$. The Newman-Keuls test of comparison showed differences within concentrations and treatments. Growth in stream and water mixtures of Al+Cu fitted the null hypothesis: differences observed were not due to the effects of the metals.

Amphipods in stream water solutions grew bigger than in "artificial" water solutions. This may be explained by the presence of nutrients in stream water allowing conditioning of the food . Compared to Al+Cu, amphipods grew bigger in Al+Cu+Mn mixtures in either stream or "artificial" water solutions. This means that the combination of Al+Cu was more toxic than that of Al+Cu+Mn.

Reproduction after 45d exposure

Reproduction in stream water solutions of Al, Cu and Mn, using mature amphipods only, was reported from all treatments including the control. However, the differences were noted within concentrations and control, but also within Al+Cu and Al+Cu+Mn mixtures as confirmed by Mann-Whitney U-tests of significance. Compared to Al+Cu mixtures, reproduction in Al+Cu+Mn mixtures in either stream or "artificial" waters, was higher than in Al+Cu mixtures; this means that the Al+Cu combination is more toxic than that of Al+Cu+Mn. Reproduction in "artificial" water occurred in all treatments after 45d exposures. However, some differences were reported (using the comparison-paired tests) between the controls and some treatments. The reproductive rate was not significantly different in the two dilution waters (i.e. average growth rate 0.041 per day in natural water and 0.040 in "artificial" water).

6.4.3 Interactions between Al, Cu and Mn

The interactions between Al, Cu and Mn and toxicity modelling were performed using Gaddum diagrams (Ward & Parrish 1983) and the MINTEQA2/PRODEFA2 package for modelling chemical equilibrium. The results showed the following mixtures from the most to the least toxic: Cu+Mn > Al+Cu > Al+Mn > Al+Cu+Mn, with supra-additive (Cu+Mn), additive (Al+Cu) and antagonistic (Al+Mn and Al+Cu+Mn) effects respectively. Al adsorbs other ions and reduces the bioavailability of metal species. The precipitation of Al is higher when Mn is present. The median survival times (LT_{50}) in different mixtures are 73, 107, 139 and 147 for Cu+Mn, Al+Cu, Al+Mn and Al+Cu+Mn respectively.

6.5 CONCLUSION

Are South-African criteria adequate for protecting the biotas of freshwater environments?

Yes, on the basis of toxicity to the test organism, *Paramelita nigroculus,* South African criteria are adequate for protecting aquatic life, since LC_{50} values were not reached after 21d exposures. 62% of adults survived in "artificial" water at the highest values. 61.5 % of juveniles survived at the same concentration in "artificial" water. Due to high mortality in controls (>93.3%) for moults and the pre-adaptation of adults (hormesis), juveniles are the best test organisms to use. More information is required on the reproductive biology and the ethology of *P. nigroculus* .

Does Mn (II) reduce or increase the toxicity of Al+Cu?

Mn (II) reduces the toxicity of Al+Cu mixtures and the mixtures Al+Cu+Mn are less toxic compared to Al+Cu mixtures at low pH values (pH < 5.8).

Is P. nigroculus an accumulator or regulator for these elements?

P. nigroculus is an accumulator of Al and a weak accumulator-regulator of Cu and Mn.

The high mortality at 24h and 8d exposures in acute and chronic toxicity respectively may allow us to shorten the exposures times during the water quality and environmental control tests: 24h instead of 96h and 8d instead of 21d respectively. Under natural conditions of acidic mountain streams in the south-western Cape (pH<6.0, total hardness <40 mg l^{-1}) stream water which supported an abundant and diverse aquatic fauna, had elevated levels of Al and Cu (Chapter 4). Median values for aluminium were 0.207 mg $l^{-1}$and for Cu 0.008 mg l^{-1} .

CHAPTER 7: PRE-CONSTRUCTION MONITORING OF THE UPPER BERG RIVER

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7.1 BACKGROUND

Construction of the Skuifraam Dam, in the upper reaches of the Berg River, has been scheduled to begin before the year 2002, and it is envisaged that the new dam will form an important component of the supplementary water supplies required to supply the burgeoning population of Cape Town. Proposals for the construction of Skuifraam led to extensive deliberation and assessments by both engineers and ecologists, which culminated in the Berg River Instream Flow Requirements (IFR) Workshop, held in 1996 (DWAF 1996b). Prior to this, two series of workshops took place between 1992 and 1993, dealing with the IFRs of the Berg River estuary, and of the upper Berg, respectively, as a follow-on from reports commissioned by the Western Cape Systems Analysis. When this work was first proposed in 1993, the construction of the dam seemed inevitable. However, the final decision is scheduled to be made this year. If construction of the dam goes ahead, it is of critical ecological importance that efforts be made to mitigate against its likely effect on the already impacted Berg River.

It is in the light of the proposed construction of Skuifraam Dam that this section of the report was commissioned. A problem frequently encountered by riverine environmental monitoring teams is the lack of adequate data pertaining to conditions prior to the particular impact being monitored. Under such circumstances, monitoring, and thus management, of post-impact conditions may be reduced to best-guessing, based on evaluations of conditions in other but similar systems. In the case of the Skuifraam Dam, however, an unusual opportunity existed in the fact that sufficient time remained prior to the onslaught of actual construction, to allow for an assessment of pre-impoundment conditions on the upper Berg River. Such an assessment is potentially of great value, primarily because it indicates actual conditions existing in the river prior to the anticipated impact. In the light of this information, the impacts of the impoundment itself should be more easily distinguishable, and their mitigation thus more feasible. Moreover, if pre-impact data show that existing impacts might be mitigated by the application of additional measures during or after construction, then some benefits might even be derived from the proposed construction.

It was a recognition of these facts, as well as of the rare opportunity presented by the Berg River for monitoring of pre-impoundment conditions at selected sites up- and downstream of the proposed Skuifraam site, that led to the initiation of the monitoring programme presented in this section of the report. The programme aimed at providing a "state-of-the-river" assessment, in terms of both the physical attributes and chemical constituents of the water, as well as the aquatic macroinvertebrate communities, to inform future monitoring programmes of conditions pertaining to these sites prior to construction.

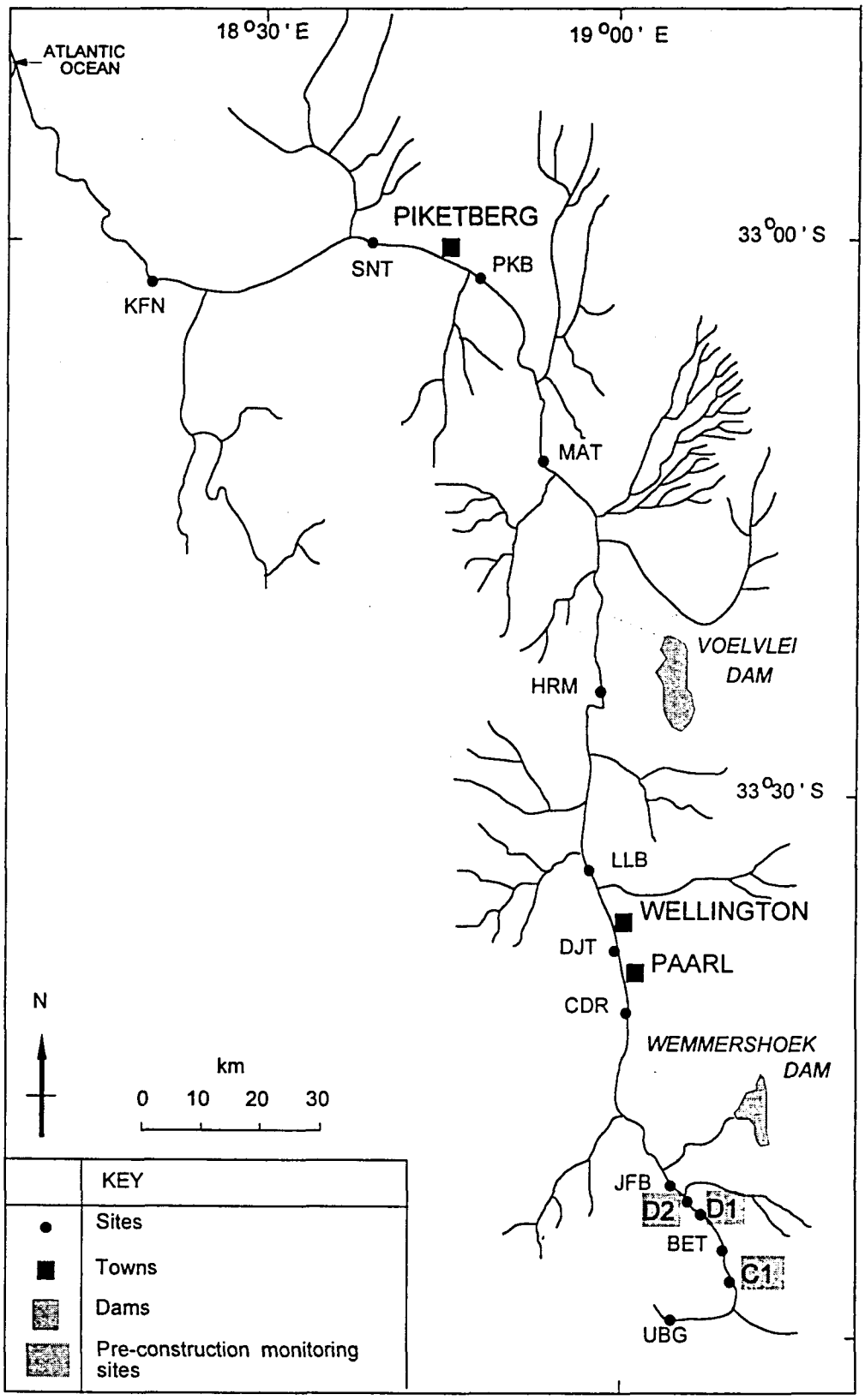
7.2 INTRODUCTION

7.2.1 General description of the Berg River

Situation and physical characteristics

The Berg River (Figure 7.1) rises in the Franschhoek and Drakenstein Mountains, approximately 60

Figure 7.1. Map showing locations of the three pre-construction monitoring sites in the upper reaches of the Berg River (C1, D1 and D2), as well as SASS sampling sites used by Dallas (1996) along the length of the Berg River. C1 and D1 correspond to sites referred to in Dallas (1996) as ABT and BTF, respectively.



km east of Cape Town, and flows in a northerly direction through the towns of Paarl and Wellington, and the village of Hermon, before swinging westwards past Gouda, Piketberg and Hopefield. Some 300 km from its source, it enters the Atlantic Ocean at Veldrif, on the west coast of South Africa.

The Berg River catchment lies within the winter rainfall region, with 80% of total rain falling as short, intense showers during winter. Rainfall is not evenly distributed throughout the catchment, but is highest (up to 5000 mm y^{-1}) in the mountain ranges of the upper river, dropping to as little as 400 mm y^{-1} in its lower reaches (Dallas 1992). The Berg River itself, and six of its nine major tributaries (Wemmers, Dwars, Franschhoek, Klein Berg, Twenty-Four and Kuils Rivers), are perennial rivers, but prone to reduced flows in summer. The remaining tributaries are all aseasonal, and dry up during the summer. Natural flow in the Berg River is highly regulated, with the Wemmershoek Dam tapping flow from the Wemmers tributary, and Voelvlei Dam supplementing its inflow with abstraction from the Leeu, Twenty-Four and Klein Berg Rivers, via canals. Misverstand Weir is located on the lower reaches of the Berg River itself, while the upper reaches form part of the Riviersonderend-Berg River Interbasin Transfer Scheme. This scheme releases water from Theewaterskloof Dam in the Riviersonderend catchment, into the upper Berg River during summer, via the Berg River Siphon.

Geological influences

In its upper reaches, the Berg River cuts through quartzitic Table Mountain Sandstone (TMS), which forms part of the Table Mountain Group of the Cape Supergroup. As such, water in these reaches is expected to be low in mineral content, acidic and poorly buffered (Dallas *et al* 1995). In the lower reaches near Piketberg, the erodible Malmesbury shales become the dominant rock formation. These shales, comprising ancient marine sediments, are both easily erodible, and high in mineral content, and it is the river's passage across this erodible substratum that largely accounts for both the high mineral content, and the meandering nature of the lower Berg River.

Historical records

The Berg River is unusual in that a particularly rich historical data base already exists as to riparian vegetation, macroinvertebrate fauna, conditions of instream habitats and water quality down the length of the river. In some cases, these data date back as far as 1950, when the first survey of the Berg River was initiated by Harrison and Elsworth (1958). This early study included a comprehensive assessment of the water chemistry and the aquatic macroinvertebrate communities at sites extending between the upper reaches of the river, and the start of the tidal influence, about 30 km upstream of the river mouth. This forms an invaluable record of historical faunal distributions and zonation patterns within the river. Since then, other studies have centred on various aspects of the chemistry and biology of the Berg River. Fourie and Steer (1971) and Fourie and Gorgens (1977) carried out studies on water quality and mineralisation in the Berg River, respectively, between 1963 and 1970, while Coetzer (1978) surveyed the macroinvertebrate fauna of the river over three seasons in 1974. Dallas and Day (1992) resurveyed the Berg River in 1992, and compared existing macroinvertebrate communities and water quality with those reported in the historical literature. During this study, they observed a marked deterioration in both water quality

and faunal community structure, particularly in previously unimpacted reaches upstream of Paarl, which suggested an increase in organic pollution into the river. In the lower reaches, changes in community structure were indicative of an increase in salinity in this region. Dallas *et al.* (1995) and Dallas (1995) have since re-surveyed selected sites along the Berg River, measuring both water quality variables and macroinvertebrate community composition during a study based on field verification of the SASS4 methodology. Other work in progress by members of the Freshwater Research Unit, at the University of Cape Town, includes an investigation of the impact of the Riviersonderend-Berg River inter-basin transfer system, on the riverine ecosystem of the upper Berg River (K. Snaddon, Freshwater Research Unit, *pers. comm.*).

7.2.2 The Berg River in the region of the proposed Skuifraam Dam

Existing land-use

The site of the proposed Skuifraam Dam is in the upper reaches of the Berg River, within the La Motte Forest Reserve, and downstream of the Berg River Siphon. Present land-use in the area comprises mainly forestry, while the Dewdale Trout Farm is located upstream of the proposed dam wall in the area expected to be submerged by the dam.

Ecological patterns observed in previous studies, upstream and immediately downstream of the proposed Skuifraam Dam

As recently as 1993, Dallas (1995) found that the Berg River upstream of the forestry plantations was still relatively unimpacted, and indeed, largely comparable with conditions recorded by Harrison and Elsworth (1958) during their survey of this reach in 1951 (Harrison and Elsworth 1958, Dallas and Day 1992). Once into the plantations, however, a deterioration from the natural river condition was observed, and changes in faunal composition were attributed to the increase in silt deposits, and a substantial decrease in marginal vegetation within this reach. Further downstream, in the region likely to be flooded by Skuifraam dam, the river was impacted by the Berg River Siphon, and the Dewdale Trout Farm, both of which were developed subsequent to the 1951 survey of Harrison and Elsworth (1958), and both adversely affecting instream faunal diversity and community composition (Dallas 1996).

These historical records thus form an important background to any future surveys undertaken within the Berg River, and allow additional changes to the structure or functioning of the Berg River ecosystem to be viewed in the context of previous conditions.

7.3 METHODS

7.3.1 Study sites

Three sites were selected in the upper reaches of the Berg River, to be used as pre-construction monitoring sites for the proposed Skuifraam Dam. As such, two of these sites (D1 and D2) were selected so as to lie downstream of the proposed site of the dam wall, and thus reflect future impacts of the dam, while the control site (C1) was located upstream of the anticipated upper

extent of the dam. All three sites fall within the upper foothill, stony run zone described by Harrison and Elsworth (1958), but their exact location, and particular characteristics are outlined in the following section, and illustrated in Figure 7.1. Two of these sites correspond to Dallas (1996)'s sites in the following manner: C1 = ABT; D1 = BTF, and data from both Dallas (1996) and previous studies in reports prior to this assessment suggested that the three sites selected for pre-construction monitoring in this report were likely to show *a priori* differences in overall ecological condition, given that the lower two sites were already impacted by a combination of the trout farm, afforestation, and aseasonal discharge brought about by the opening of the Berg River Siphon. By contrast, the upper site was impacted only by forestry activities (Dallas 1992).

C1

This site corresponds with that described by Dallas and Day (1992) as Station 2, and Dallas (1996) as ABT, and is situated immediately upstream of the causeway in the La Motte Forest Reserve, above the Berg River Siphon outlet. The river was approximately 6 m wide in this area, and flowed over a combination of boulders and large cobbles. Instream biotopes comprised mainly riffle, with patches of run, and limited backwater areas. Marginal vegetation was restricted to a few clumps of palmiet reed (*Prionium serratum)*, although debris in the form of branches and twigs accumulated in the stream between boulders. Riparian vegetation was dominated by pine trees (*Pinus* spp.) and species of invasive alien acacias although some residual indigenous riparian vegetation was still present (Boucher 1996).

D1

This site is located downstream of both the Berg River Siphon releases, and the Dewdale Trout Farm. The siphon comes into operation on a seasonal basis, releasing water from Theewaterskloof Dam at sporadic intervals between late spring and early autumn (K. Snaddon, Freshwater Research Unit, pers. comm.). By contrast, Dewdale Trout Farm (now believed to be under different management) cycled river water through its ponds throughout the year, releasing the enriched effluent back into the river downstream of its intake pipes. During low-flow periods, relatively high proportions of the river's flow were likely to be channelled through the farm (Dallas 1996). The river here comprised a single channel, with areas of fast flowing boulder and cobble riffle, as well as run and limited backwater biotopes. Marginal vegetation was limited to patches of *Prionium serratum,* while riparian vegetation comprised primarily alien invasives (*Acacia* spp.) with some pine trees. This site lies immediately downstream of the site of the proposed Skuifraam Dam wall.

D2

This site is approximately one hundred metres upstream of the confluence of the Berg and Franschhoek Rivers. It is thus two hundred metres downstream of IFR Site 1, (DWAF 1996b), and is situated about 3.4 km downstream of the proposed location of the Skuifraam Dam wall. The river here comprised a single, unbraided channel, with deep pool biotopes separated by cobble riffles and runs. Marginal vegetation included patches of Palmiet reed (*Prionium serratum),* as well as the sedge *Isolepis prolifer.* Riparian vegetation comprised alien species (e.g. *Acacia longifolia, A. mearnsii, Pinus* sp.), interspersed with remnants of former indigenous communities (*Brabejum stellatifolium, Ehrata vilosa and Ischyrolepis subverticullatus)* (Boucher 1996).

7.3.2 Monitoring programme

A monitoring programme was initiated at the above three sites in September 1994, and ran until August 1996. Samples were collected at approximately quarterly intervals, although the actual dates of sampling can be seen in Table 7.1. To simplify analysis and subsequent interpretation of data obtained during the course of this programme, samples were analysed by season. The assignment of different months into particular seasons was compatible with the assignations used in the compilation of the WRC Biological and Chemical Database (Dallas *et al.* 1995, and Chapter 2 of this report), and comprised the following:

Autumn March, April, May
Winter June, July, August
Spring September, October, November
Summer December, January, February

Sampling of the lower monitoring site, D2, was confounded during the first two sampling sessions by the initial choice of a site, within a zone impacted by active tree-felling down to the river banks. The consequent bank erosion, and rates of sedimentation into the river at this site were such that virtually no macroinvertebrates were found within the riffle areas, and the site was thus abandoned as a monitoring site in favour of the less-impacted D2 site upstream, which is described above. This resulted, however, in the absence of any usable data for the third monitoring site during the first two sampling sessions of the programme.

Since one of the major factors influencing community structure, both spatially and seasonally, downstream of C1, appears to be the timing of releases from Theewaterskloof Dam, via the Berg River Siphon, the periods during which this siphon was in operation are also indicated in Table 7.1, courtesy of K. Snaddon (Freshwater Research Unit, University of Cape Town, pers. comm.). This information is of great importance in assisting the interpretation of different biological communities, sampled at different sites, and in different seasons.

Table 7.1. Monitoring dates and seasons, at each site.

SITE	SAMPLING DATE	SEASON	SIPHON CONDITION
C1, D1	September 1994	Spring	Closed
C1, D1	November 1994	Spring	Open
C1, D1, D2	March 1995	Autumn	Open
C1, D1, D2	July 1995	Winter	Closed
C1, D1, D2	October 1995	Spring	Open
C1, D1, D2	February 1996	Summer	Open
C1, D1, D2	May 1996	Autumn	Closed
C1, D1, D2	August 1996	Winter	Closed

The following sections provide a brief outline of the types of variables collected at each site, and the broad techniques followed in each case. Further details as to the exact methodologies pertaining to the measurement of both biological and chemical variables may be found in Appendix 3.1 of this report.

Water quality and discharge

In situ measurements of temperature, conductivity and pH were taken at each site, using a mercury thermometer, a Crison CDTM-523 conductivity meter and a Crison pH/mv meter 506 respectively. Measurements of both depth and flow were also made, at 1 m intervals along a cross-section of the river width, using an OTT c 2 Small Current Meter. Readings were taken at 30 second intervals, and the revolutions per minute converted into a measure of flow, using the formula: V = 0.2407n +0.015, as specified in the instrument handbook (OTT 1986), where V is the volume of water in m s^{-1}, and n is the number of revolutions of the flow gauge per second. These measurements were converted into an estimate of discharge, using the formula:

$Q = + (w_2 * d_2 * v_2) + (w_3 * d_3 * v_3) + \ldots (w_n * d_n * v_n)$

as described by Gordon *et al.* (1992), where Q = discharge ($m^3 s^{-1}$); d = depth (m); w = the sum (m) of half the widths on either side of the measuring point , and n is the number of readings taken across the cross-section.

Water samples for water quality analyses were taken from rapidly-flowing areas, and filtered *en site*, using Whatman 45 µm GF/F filter papers. All such samples were frozen within 12 hours of collection, and analysed for the following variables:

- Total dissolved solids (TDS), expressed in mg l^{-1}
- Total suspended solids (TSS) expressed in mg l^{-1}
- Anions [comprising sulphate (SO_4^{2-}) and chloride (Cl^-)] converted to mmol l^{-1}
- Cations [comprising calcium (CA^{2+}), sodium (Na^+), potassium (K^+) and magnesium (Mg^{2+}) ions] converted to mmol l^{-1}
- Nutrients [comprising phosphates (PO_4-P), nitrite (NO_2-N) and nitrate (NO_3-N) ions), converted to µg l^{-1}]. These nutrients were measured on the HPIC anion-exchange column, which does not have a particularly low detection limit (0.1 mg l^{-1} NO_3). As such, only NO_3-N was found in detectable quantities at any of the sites sampled.
- Total alkalinity, expressed in meq l^{-1}.

Aquatic macroinvertebrates

These communities were assessed both qualitatively, using the SASS4 rapid bioassessment technique (explained in detail in Appendix 3.1), and quantitatively, using a 0.1 m^2 box sampler. The former method was used to sample all available biotopes at each site, and no attempts were made to distinguish between fauna of different biotopes. Box samples were used only in the riffle habitat, and five replicate samples were taken at each site, on each sampling occasion.

Dallas (1995) compared the results of rapid bio-assessment sampling, based on SASS, with those obtained from quantitative box-sampling. Although both methods were clearly able to distinguish between impacted and unimpacted sites, each had different strengths and weaknesses. SASS, for

example, while rapid and cost-effective, is nevertheless less likely to detect rare taxa, than is the box-sample method. For this reason, Dallas (1995) cautions against the indiscriminant use of SASS for environmental impact assessments, when the detection of rare or endangered fauna is a priority. In terms of routine biomonitoring programmes, however, the ability of SASS to detect changes in water quality within hours of sampling make it an ideal bio-assessment technique. Moreover, although Dallas (1995) found that higher numbers of taxa were obtained from the same biotope from box samples, rather than from SASS samples, the routine use of SASS as a multi-biotope sampling methodology should outweigh these problems, as SASS is able to draw samples from a wider range of biotope types, where they are available. The two methods are, however, complementary, and the use of both in this initial, pre-construction monitoring programme means that the data provided should be compatible with any method decided on for future monitoring programmes at this site. Moreover, the two sets of data are open to comparison, and should thus facilitate future decisions as to the choice of the most suitable, yet cost-effective biomonitoring technique for during- and post-construction phases of Skuifraam.

Samples collected by means of box samplers were preserved in 7% formaldehyde, and returned to the Freshwater Research Unit, University of Cape Town, for identification as was possible within the time constraints of this project. Individual samples were separated into a >950 µm size fraction, <950 µm to >500 µm and <500 µm to >250 µm. The >950 µm size fraction was analysed separately, and combined with the rest of the sample, the latter combination being referred to hereafter as the Total Group. Dallas *et al* (1995) found, however, that, when working at the taxonomic level of family, size fraction was not a major factor in ensuring adequate replication of samples, and thus of sites. Data were expressed as densities of animals (numbers per 0.1 m^2).

In addition to the sampling carried out at the three pre-construction monitoring sites, SASS samples were also collected quarterly between spring 1994 and winter 1995 from selected sites along the length of the Berg River. These data, published in Dallas (1996), were used in the present report to give an overview of the Berg River, from headwaters to the upper reaches of the estuary, and thus place the pre-construction monitoring sites in a broader context.

7.3.4 Statistical analysis

Biological data

Since the biological data collected during this programme were primarily community-based, multi-variate procedures were deemed most appropriate for their analysis. The advantage of such procedures over univariate analyses is that they consider each species/family to be a variable, and the presence/absence, or abundance of each to be an attribute specific to each site, or sampling period (Dallas *et al* 1995). For this reason, subtle changes in community composition will not be masked by the need to summarise combined site characteristics into a single value (Norris and Georges 1993).

Data were thus analysed using the classification procedures contained in version 4 of Primer (1994). Macroinvertebrate data from SASS were initially transformed into presence/absence data,

and analysed using the Bray-Curtis coefficient, as recommended for biological data in Primer (1994) and by Field *et al* (1982). In addition to this, abundance data from both the 950 µm and the Total Groups were fourth root transformed, and similarly analysed. The quantitative data were analysed in sub-sets comprising individual sites, to assess seasonal trends within sites, as well as in subsets containing data from all three sites, but divided into seasons, to emphasise differences between sites, occurring over different seasons. These analyses were all performed using data taken to the lowest taxonomic level possible, in the time provided. In addition, sites were analysed, using data reduced to family level only, to get some idea of whether species-level identification of macroinvertebrates in a monitoring programme such as this one is strictly necessary. This has been the subject of considerable debate, with authors such as Chesters (1980) advocating that environmental monitoring must be done at the level of species, while Chessman (1995), Warwick (1993) and Wright *et al.*(1995) argue that family-level bio-assessments are more likely to reflect realistic patterns of community changes as a response to impacts in aquatic ecosystems. SASS itself uses family-level identifications of invertebrates, although it does incorporate a sliding scale of scores for two families, namely Baetidae and Hydropsychidae. Each of these families include both taxa which are pollution tolerant, and those that are highly sensitive, and the sliding scale of scores allows for scores to be weighted in favour of samples in which more than one type, or species occur.

Cluster analyses were performed on all data sets, using the Bray-Curtis coefficient. Cluster analysis produces hierarchical groupings of samples, such that samples within a group are more similar to each other, than to samples in outside groups. These hierarchical clusters are presented in the form of dendrograms.

In addition to cluster analysis, biological samples were also ordinated, using multi-dimensional scaling (MDS). This analysis produces ordinations of the samples being analysed, such that distances between samples reflect the similarity of the biological communities comprising each sample (Clarke and Warwick 1990). MDS is particularly suitable for use in biological analyses, being undistorted by missing data, and data of "non-uniform reliability" (Field *et al.* 1982). The reliability of each MDS ordination is open to assessment, based on the calculated "stress" value of each ordination. Clarke and Warwick (1990) recommend that stress values < 0.1 correspond to good ordinations, with little chance of misinterpretation. By contrast, stress values between 0.1 and 0.2 may be used cautiously, although no real conclusions should be based on the results of such ordinations on their own. In such cases, ordination groupings should be interpreted in the light of some additional form of analysis, such as the hierarchical cluster groupings shown in dendrograms. Used in conjunction, the two methods thus provide a useful analytical tool.
A final analysis run on the biological data was the similarity percentage breakdown process employed by SIMPER (Primer 1994). This analysis allows an *a posteriori* identification of the species that are primarily responsible for the clustering of similar sites.

Physical and chemical data

Discharge and water quality data were analysed using the Principal Components Analysis (PCA) (PRIMER Ver. 4). While PCA is not recommended for use on biological samples (Primer 1994), it is

highly appropriate for analysis of environmental variables, which do not require particular treatment of absent ("missing") values. PCA does, however, require vigorous transformation of environmental variables, both to normalise data, and to render the different measurement scales used on different variables comparable to each other. All data were thus log transformed, prior to analysis, with the exception of pH (already in log form). To enable use of the statistical procedures outlined below without risk of auto-correlation between conductivity, and concentrations of individual anions and cations, the following equations were used to represent anions and cations in terms of their ionic ratios.

$$\text{CATIONS} = \frac{[Na] + [K]}{[Na] + [K] + [Mg] + [Ca]} \qquad \text{ANIONS} = \frac{[Cl]}{[Cl] + [TAL]}$$

This transformation of anion and cation concentrations into component ratios meant that they could be analysed in conjunction with conductivity, without fear of auto-correlation. TDS was not included in the analysis, however, due to its high degree of correlation with conductivity.

PCA produces ordinations showing spatial groupings of samples, based on the similarity of their environmental variables. It also produces eigen vectors for each variable, corresponding to the directional effect of each variable, in producing the overall ordination of samples. These vectors were overlain on the PCA site ordinations, to enable some degree of interpretation of the driving forces behind site differentiation on the basis of physical and chemical variables.

To establish some kind of a link between biological and environmental variables, each environmental variable was plotted as an overlay of the biological MDS ordinations, scaled in proportion to its dimensions within each sample, when compared to its dimensions in other samples. Such ordinations allowed a more visual assessment of the possible importance of different variables in determining community structure. It should be remembered, however, that these data are purely correlational.

7.4 RESULTS AND THEIR SIGNIFICANCE

7.4.1 Physical and chemical data

The chemical data, measured for different sites and grouped in order of seasons, are presented in Figures 7.2 and 7.3. It should however be borne in mind, that although data are presented in terms of seasonal patterns, data were in fact collected over a two-year period, and those that appear to be temporally sequential may, in reality, reflect values measured in different years.

Before entering into any analysis of the results of the water quality and quantity measurements, it should be noted that these values are all the results of once-off sampling efforts. As such, it is possible that samples might reflect short-term pulses of a particular chemical constituent down the river, or, alternatively, might fail to detect such pulses, if they do not exactly coincide with the time of measuring. Furthermore, it should also be stressed that the lack of replication of water samples for measurement of different variables means that any errors which are incurred as a result of post-

sampling contamination, or analytical error, are thus unlikely to be detected. Chemical analysis is costly, however, and the lack of replication of samples was largely due to financial constraints.

Conductivity

Conductivity levels at C1 indicated a relatively constant range of conductivity levels throughout the year, but with a slight increase in winter and late spring (Figure 7.2 A). By contrast, conductivity at D1 and D2 showed pronounced fluctuations, which largely corresponded to periods when the Berg River Siphon was operational. Conductivity was at a maximum at these sites during late summer and autumn, before decreasing in winter to values that were more comparable with those measured at C1. Thereafter, in late spring, conductivity levels increased again, to levels well above those recorded at C1. These increases once more coincided with periods of siphon releases.

pH

The patterns of measured pH at the three sites followed a similar pattern to that described for conductivity. pH at C1 was consistently low, never rising above pH 6, and dropping to a minimum of 4.3 in winter (Figure 7.2 B). By contrast, pH levels at D1 and D2 fluctuated between 7.3 and 4.8, with the former alkaline values occurring during late summer, and again largely coinciding with periods of siphon releases. However, even during periods when the tunnel was not discharging water, pH values downstream of C1 were generally elevated. This fact suggests that either other impacts downstream of C1, over and above those due to the siphon, may have had an effect on riverine pH levels, or, alternatively, that the effect of siphon discharges on river pH outlasted the siphon release phase. Data from K. Snaddon (Freshwater Research Unit, University of Cape Town) suggest that close links do exist between discharges from the siphon and raised pH levels in the river. It is possible, however, that more than one impact produced the same result, and different impacts might be of more significance during different seasons. During winter, pH dropped to levels more in line with those recorded at C1, before increasing in late spring, again in conjunction with periods of siphon releases. The slightly lower pH levels observed during winter and early spring at all sites are consistent with increased rates of leaching of acid polyphenols from the surrounding vegetation (Midgeley and Schafer 1992).

TSS

Although TSS concentrations fluctuated on quite a dramatic scale, both between seasons and between sites, overall trends may still be discerned, with TSS levels at C1 being generally lower than those recorded at the two downstream sites (Figure 7.2.C). During winter, however, TSS values at this site increased slightly, possibly as a result of increased erosion of sediment into the river from the forestry plantation during the winter season. Dallas and Day (1992) observed that TSS levels at this site were higher than those at the largely unimpacted site monitored upstream of the plantations. By contrast to the low TSS levels recorded at C1, TSS values at D1 and D2, particularly during summer and late spring, and coincidental to releases from the Berg River Siphon, were consistently, and dramatically elevated. In winter, these concentrations declined, however, and were more comparable with the winter range of concentrations measured at C1.

Figure 7.2. Results of water quality analyses, conducted on samples from the three pre-construction monitoring sites, over a two-year period. * refers to periods when the Berg Siphon is discharging.

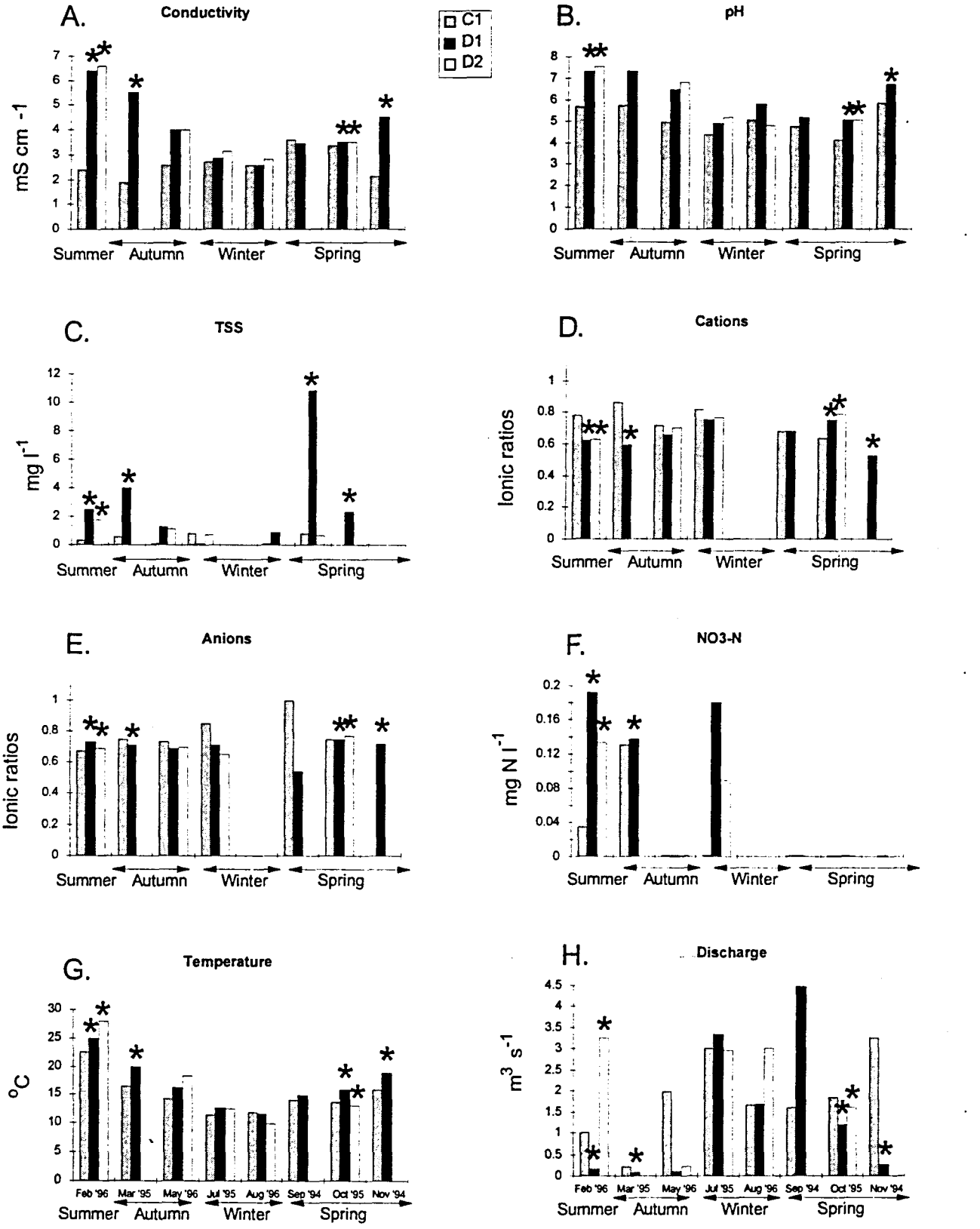
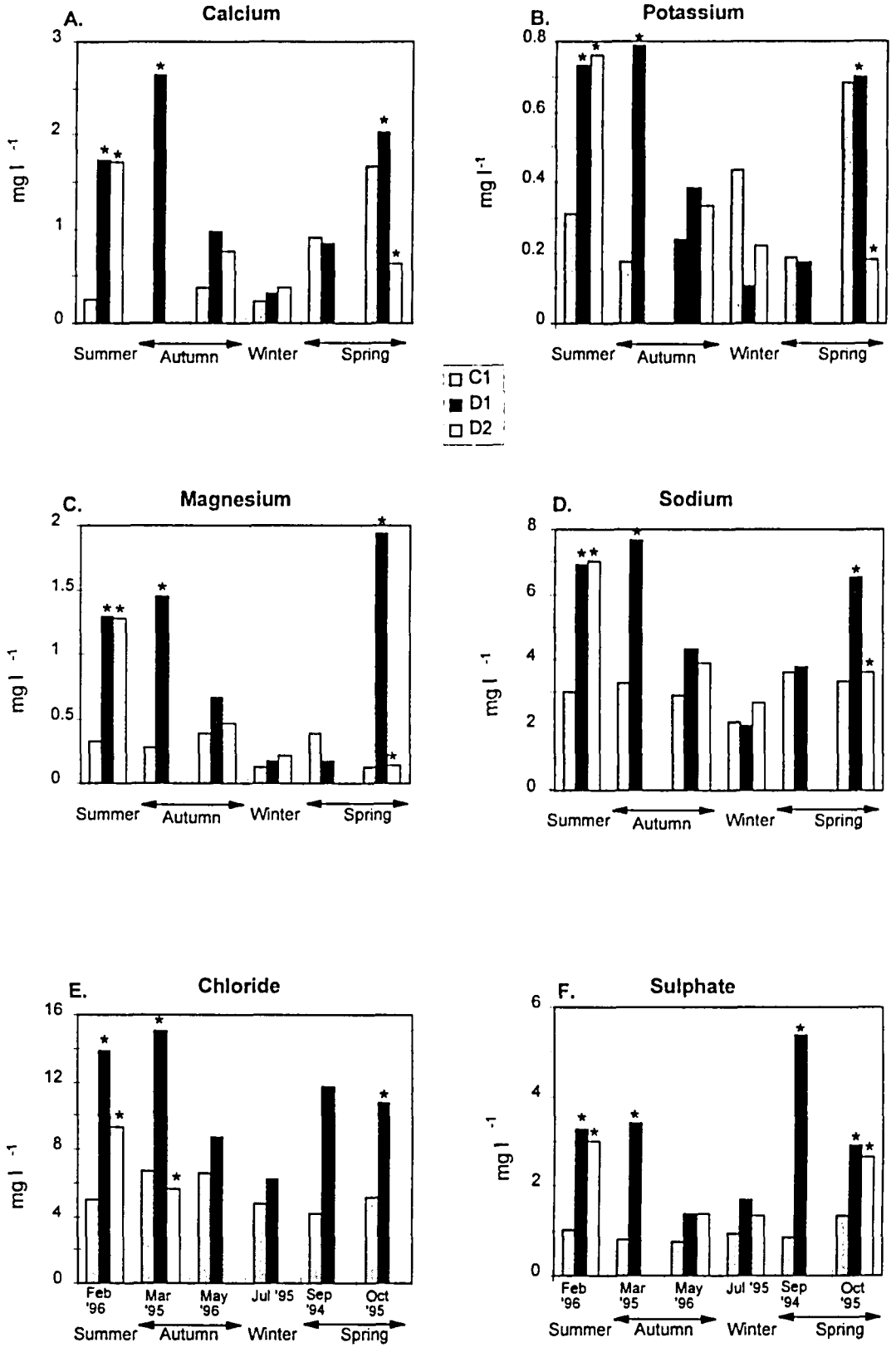


Figure 7.3. Actual concentrations of anions and cations sampled from the three pre-impoundment monitoring sites, over a two year period. * refers to periods when the Berg Siphon is discharging.



Cations

No pronounced differences in cation ratios were observed between sites, although summer and autumn values for C1 were elevated above those observed at the other two sites (Figure 7.2 D). When these ratios are split into their original components, however (Figure 7.3 A), it can be seen that, while the cation ratios did not change between sites, the actual concentrations of all four cations measured increased markedly at sites D1 and D2 during siphon discharge periods. During winter, concentrations decreased, and were only slightly higher than those found at C1, with the exception of potassium, the concentration of which was slightly elevated at C1 during winter.

Anions

Anions followed a similar pattern to that displayed by cations, with anion ratios (including total alkalinity) remaining relatively constant throughout the year (Figure 7.2 E), but with concentrations of individual anions increasing markedly between sites, during summer and late spring siphon release periods (Figure 7.3 B).

Nutrients

It was unfortunate that the levels of detection used to measure nutrients were too low to detect any nutrients other than nitrate, thereby preventing comparison of other nutrient levels between sites, and limiting nitrate comparisons to a few samples only. Since detection is, however, above 0.01 mg NO_3 - N l^{-1}, or PO_4-P l^{-1}, the failure to detect these nutrients implies that their concentrations at these sites are generally low. Detectable levels of nitrates were, however, found in all samples collected over summer, and late autumn, and again in winter. In each case, nitrate concentrations at C1 were considerably lower than those at D1 and D2, and indeed, nitrates fell below detection levels at C1 during winter (Figure 7.2 F). Although nitrate levels at sites downstream of C1 were elevated in summer during periods of discharge from the Berg River Siphon, marked increases were also evident during winter, when the siphon was not discharging. These data thus indicate possible dual contributions from both the trout farm and the siphon discharges.

Temperature

Temperature in the Berg River fluctuated primarily between seasons, rather than between sites, with a general trend of higher temperatures being recorded during summer than in winter (Figure 7.2G). Slight differences between sites on each sampling occasion may be interpreted as mainly due to differences in the time of day at which each site was sampled. In general, however, the data here show that water temperature may be used as a reasonable surrogate for season.

Discharge

Discharge measurements showed no clear patterns, and, in fact, appeared to reflect errors in sampling, rather than real differences in discharge between sites (Figure 7.2 H). This interpretation is based on the fact that discharge data do not reflect periods when the Berg Siphon was open, and increased volumes of water were known to be released into the river downstream of C1. The failure of the discharge data to reflect such variation points to the inherent problems entailed in the sampling method used. Gordon *et al.* (1992) warn that such errors are likely to increase in cobble or boulder-based streams, adding that decreasing the distance between successive measuring on

the cross-section is one way to decrease this problem. It is possible that the measurement interval of 1 m used in the present survey was inadequate.

For these reasons, discharge data were not used in any further analyses in this study, as no real degree of confidence could be attached to their values.

Principal Components Analysis (PCA)

Figure 7.4 shows the overlay of eigen vectors derived for each chemical variable, on a PCA-derived ordination of each sampling event, at each site. The distance between samples is a measure of their similarity, based on standardised Euclidean distance (ter Braak 1988), and the more similar samples are, the closer they will lie together. Eigen values are used to give some indication of how much of the variation between sites is explained by the ordination produced. Using two axes in the analysis outlined above, eigen values explained 64.58% of the variation between samples. This implies that the two-dimensional ordination displayed in Figure 7.4 provides a fairly strong picture of sample similarities (Primer 1994). Moreover, the eigen values themselves that are obtained for this ordination are both above 1.0, for the first two axes of the ordination. Statistica (1996) suggests that eigen values above 1 are reliable predictors of ordinations, and the fact that eigen values in the third axis drop to below 1, indicates that the use of only two axes in the ordination shown here is justified. The eigen values themselves are displayed in Table 7.2.

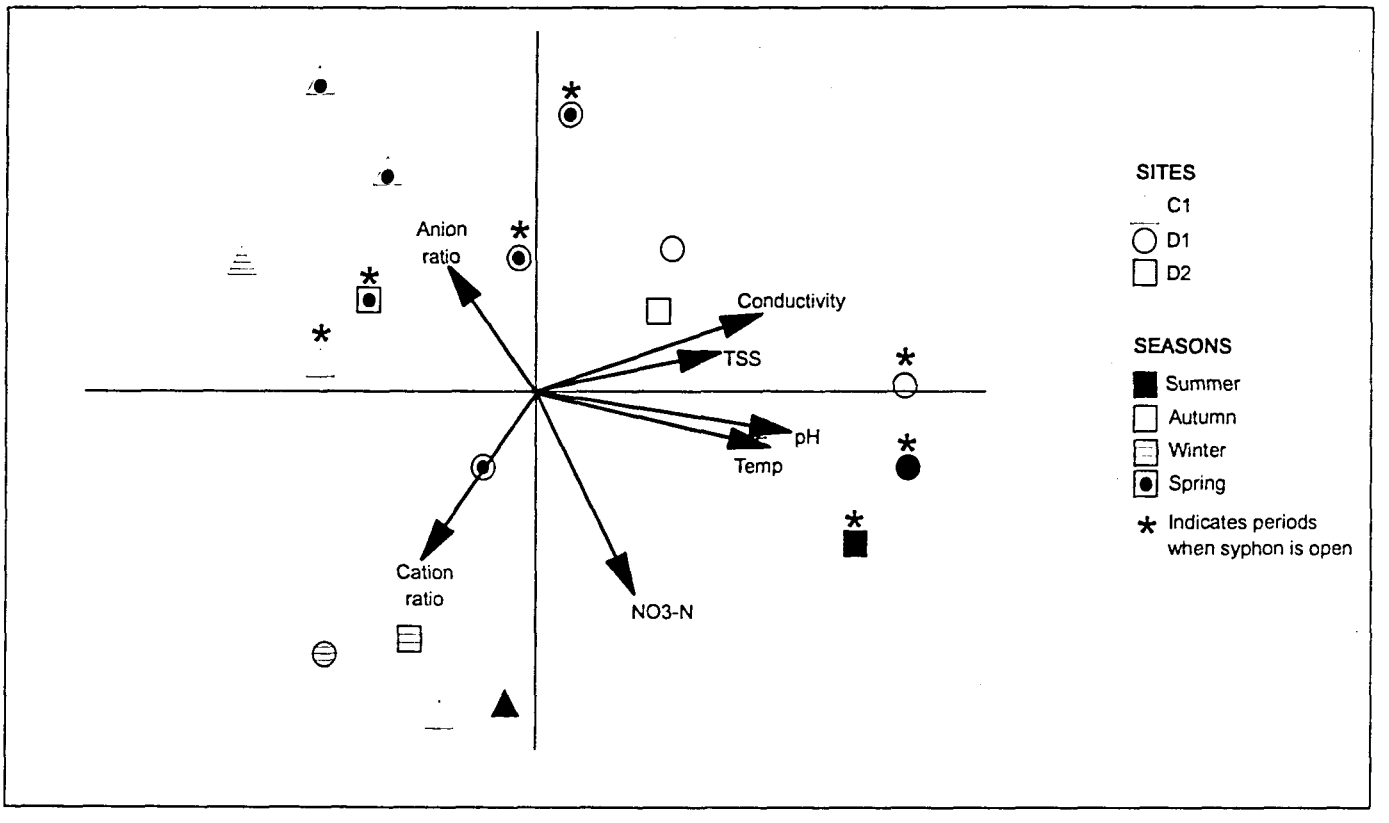
Table 7.2. Results of the PCA ordinations of sites, according to the environmental variables present at each site, and during each sampling period.

EIGEN VALUE	AXIS	% VARIATION EXPLAINED	CUMULATIVE % VARIATION
3.88	PC1	48.52	48.52
1.284	+ PC2	16.06	64.58
0.962	+ PC3	12.49	77.07
0.783	+ PC4	9.8	86.87
0.517	+ PC5	6.48	93.35

Eigen vectors were plotted for each variable in Figure 7.4, to allow some directional interpretation of the sample ordinations. Further analysis is limited, however, by the fact that vector strength is not indicated on the overlay. Nevertheless, there does appear to be some meaningful grouping of samples along the two axes. C1 samples group in the upper and lower left-hand quadrants, with summer and early autumn samples clustering in the bottom, and winter, spring and late autumn clustering above. By contrast, D1 and D2 samples are distributed throughout the ordination, with summer and autumn (Berg Siphon open) samples distributed in the right-hand quadrants (pH, conductivity, TSS and temperature dominated), and winter and spring samples scattered in the left hand quadrants. A point of note is the comparison between spring D1 samples. The two samples in the upper quadrant were taken during periods of siphon discharge, while the lower (cation-dominated) spring D1 sample was taken when the siphon was not in operation. These analyses provide further circumstantial evidence for the effect of aseasonal discharges of water from the

Berg River Siphon on the downstream riverine environment, and indicate differences in the water chemistry at the three monitoring sites, which may be largely the results of differences in these impacts. The following section assesses the effect of these differences between sites, on the fauna themselves.

Figure 7.4. PCA ordination of sites, according to environmental variables present at each site, and during each sampling period. Eigen vectors for each chemical variable have been overlaid onto these axes.



7.4.2 Biological data

SASS samples

The results of the SASS samples taken at each site, over time, are illustrated in Figure 7.5, in terms of SASS4 Score, Number of Taxa, and Average Scores Per Taxon (ASPTs). Interpretation of these data is facilitated by the use of the guidelines suggested in Chapter 3 (Table 3.1) for interpreting SASS data obtained from the foothill reaches of rivers.

In the light of these guidelines, the data shown in Figure 7.5 illustrate a general trend of decreasing water quality downstream of C1, which appears most marked during summer and early autumn. C1 itself, although known to be impacted by the surrounding forestry plantation (Dallas 1992), still obtained scores which fall within, or close to, Chutter's criteria for near-natural water quality. Even when SASS4 Scores at this site fell below 120 (for example, during winter), ASPT values were

consistently above 7.5, a fact that suggests that impacts at this site were unlikely to be serious, and that the low scores obtained were probably attributable to limited biotope availability at this site.

In marked contrast to C1, the two downstream sites, D1 and D2, exhibited clear signs that their natural ecological functioning, at least during part of the year, had been impaired. These trends were particularly evident during summer and early autumn, when SASS4 Scores at D1 dropped to below 60, accompanied by ASPTs well below 7. In late autumn, some recovery between sites was, however, evident, with scores at both sites increasing above 100, and ASPT at D1 at least rising to 7. During winter, ASPTs at these sites increased such that, using the criteria specified in Table 3.1, the impacts reflected during summer and spring appeared considerably reduced.

Thus the seasonal trends in invertebrate community structure suggested by the SASS scores at C1 were reversed at D1 and D2. Whereas species diversity (indicated by number of taxa) as well as SASS4 Score showed a summer peak and a winter low at C1, at the lower sites, both SASS4 score and number of taxa were highest during winter, and very low in summer. Indeed, during one sampling period (August 1996), SASS4 Score at D2 was well above those recorded at either C1 or D1. On the whole, however, SASS data suggested that C1 was the least impacted of the three sites assessed. The high scores obtained at this site were generally due to the presence of pollution-sensitive fauna, with high SASS scores, such as Notonemouridae, Athericidae, Ephemerellidae, Leptophlebiidae and a few case-dwelling Trichoptera. All sites had chironomids and simulids present, while low-scoring oligochaetes were found primarily at sites D1 and D2. The odonate nymphs, such as libellulids, coenagrionids and aeschnids were also found with greater regularity at the lower two sites, possibly due to the greater biotope diversity, particularly the increase in marginal vegetation which characterises these sites (Boucher 1996).

The use of ordination and cluster analysis allowed further analysis of the SASS data, which up to now has been examined mainly in terms of the scores allocated to different taxa, and not in terms of the taxa themselves. Figure 7.6 shows an ordination in which SASS presence/absence data have been grouped into clusters of similar samples, based on the hierarchical groupings shown in the dendrogram of Figure 7.7, from which sample groups were clustered on the basis of 50% similarities.

Such a presentation of data illustrates several broad trends in the seasonal community composition both within and between sites. Since the stress level of this ordination is low (0.12), the distributions indicated in the ordination may be regarded with some degree of confidence, particularly when interpreted in the light of Figure 7.7. Of particular interest is the fact that all C1 samples, regardless of season, cluster together. Similarities between the other two sites appear to be more seasonally based, with summer and autumn samples grouping together (right hand cluster), while winter samples are grouped with C1 samples. The spring community at D1 is of particular interest, and suggests, as do the PCA water chemistry overlays (Figure 7.4), that the timing of discharges from the Berg River Siphon may play a significant role in determining community structure at sites immediately downstream. In September 1994, for example, when the siphon was

Figure 7.5. Results of SASS rapid bioassessments, showing (A) SASS4 Scores, (B) No. of taxa and (C) ASPTs at each of the three pre-construction monitoring sites on the upper Berg River, over a two-year period.

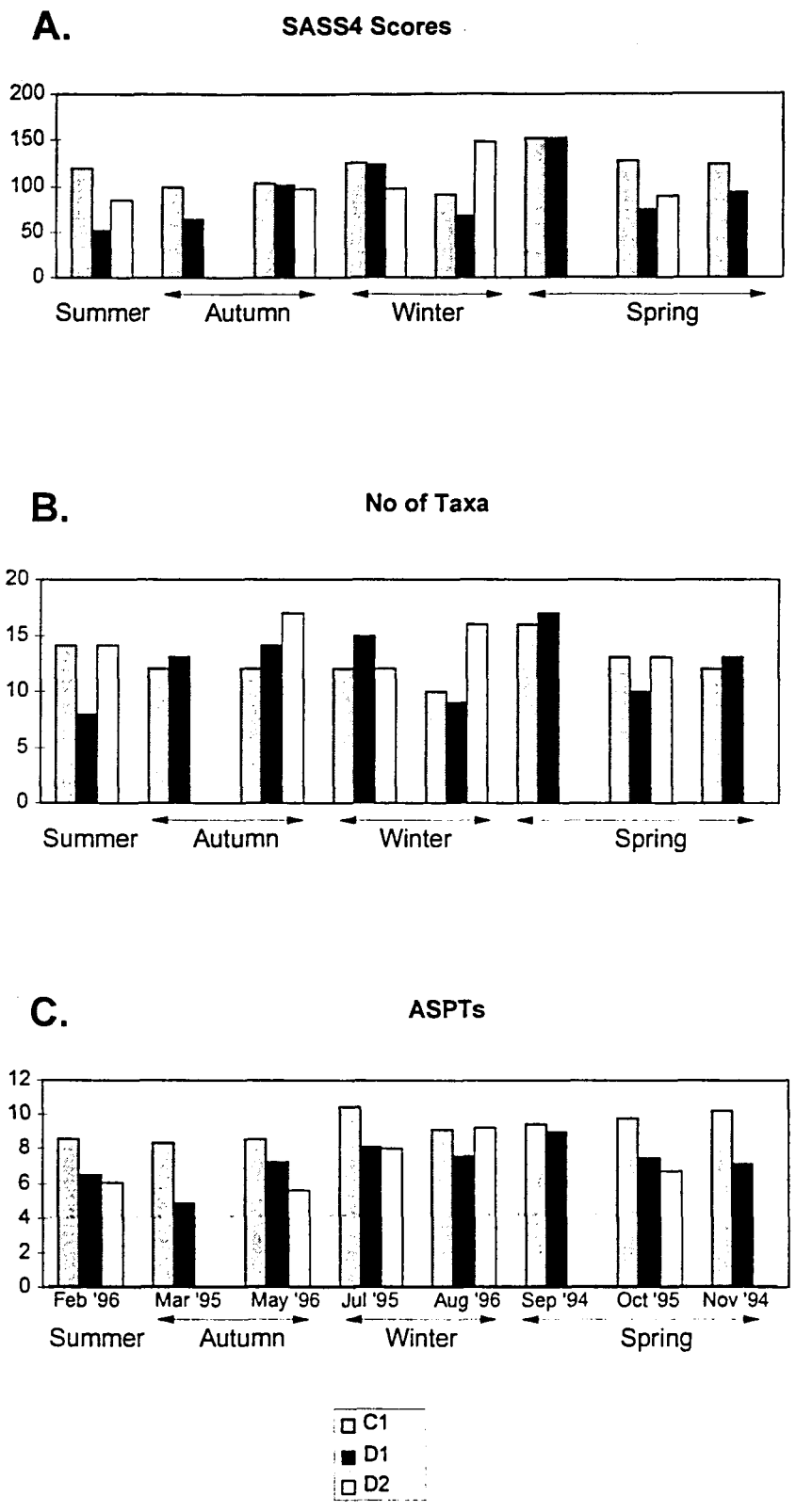
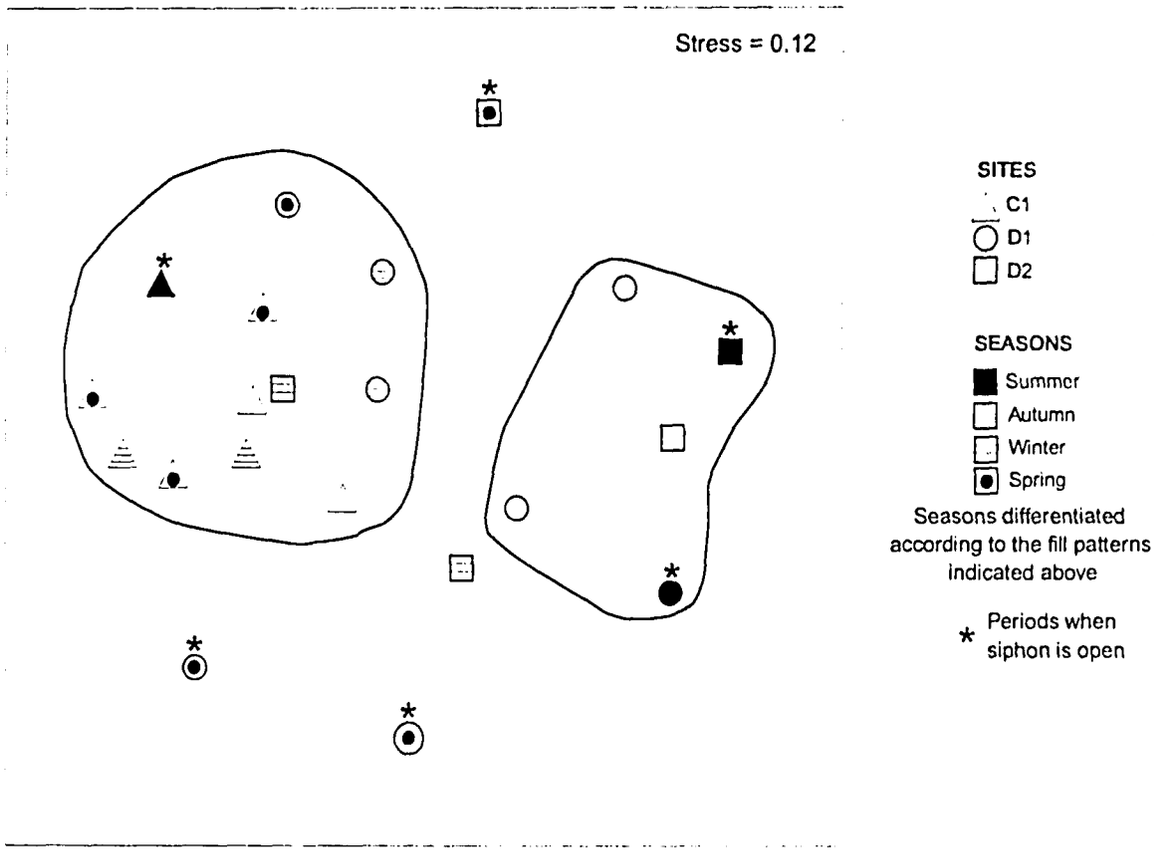


Figure 7.6. Ordination of SASS presence/absence data, for samples collected over two years, from the three pre-construction monitoring sites.



not discharging, the D1 spring sample grouped with samples from C1, as well as the winter D1 and D2 sites (also under conditions of natural flow). In terms of SASS scores, this site also has a high SASS4 Score (Figure 7.5). By contrast, spring D2 and D1 samples collected during siphon discharge periods, separate out from the remaining sites at less than 50% similarity, and are thus not included in any of the clusters outlined in the figure.

In an attempt to relate the ordination of Figure 7.6, which is based on between-site similarities of presence or absence family-level data, to the environmental variables collected for these samples, the MDS biological ordination was overlain by scaled plots of each environmental variable. These are displayed in Figure 7.8. Each environmental data point relates spatially to the site and date when it was collected, and hence the position of individual samples, shown in the ordination of Figure 7.6. These overlays allow some interpretation of which environmental variables may be of importance in determining groupings of biological data. For example, the consistent overlay of high pH samples, over D1 and D2 summer and autumn (siphon discharging) samples, shown in Figure 7.8A, suggests a potentially important link between pH and community composition. Conductivity overlays produce a similar picture (Figure 7.8 B). Similar links were found between conductivity, pH and biological community structure in the surveys of the Breede River catchment, described in Chapter 4 of this report. No clear trends were evident from overlays of nitrates, TSS, and anion and cation ratios (Figure 7.8, D-G). It should, however, be warned that the high stress levels

Figure 7.7. Dendrogram showing the classification of SASS presence/absence data, for samples collected from the three pre-construction monitoring sites, over a two-year period. Dotted lines separate groups below 55% similarity level.

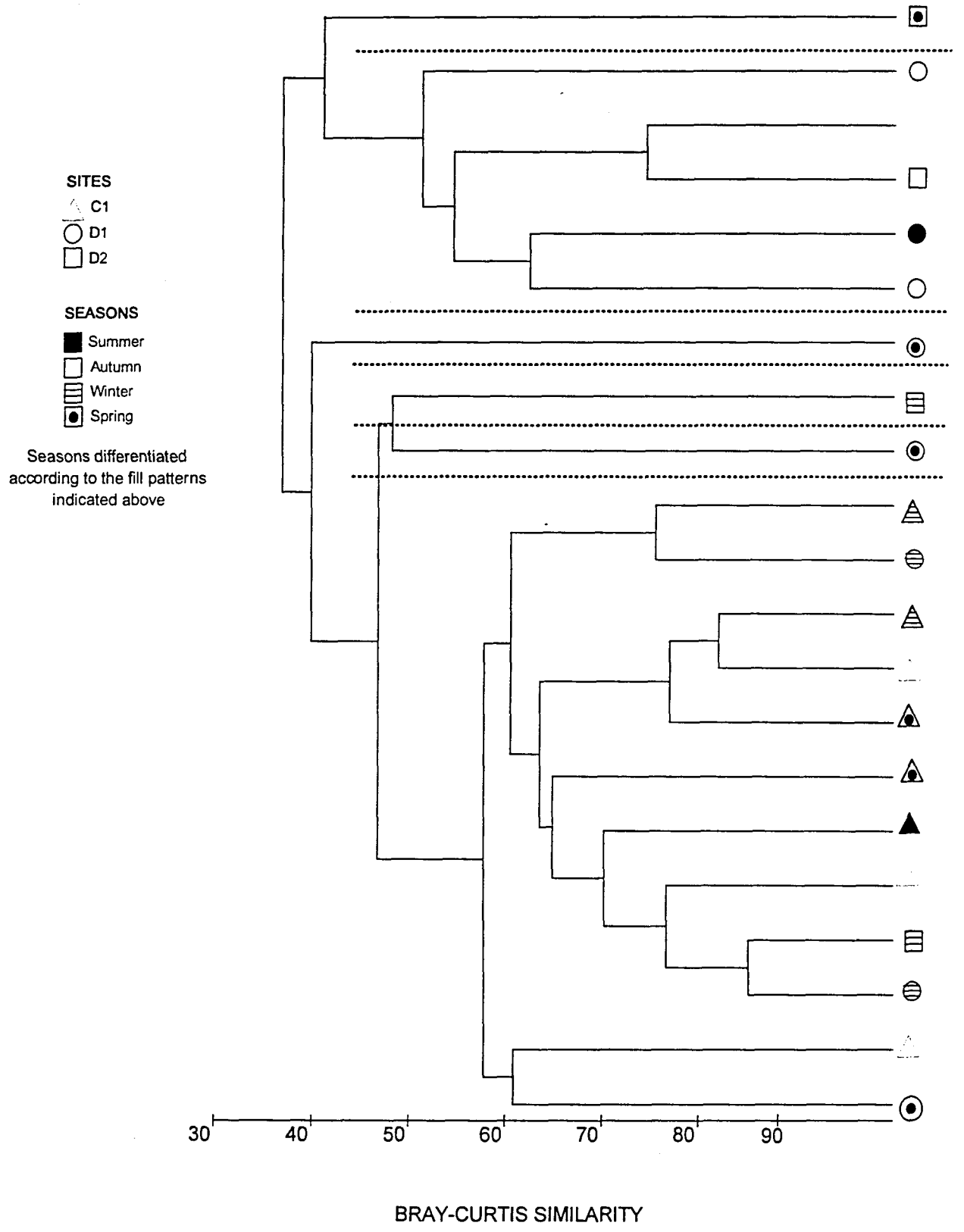
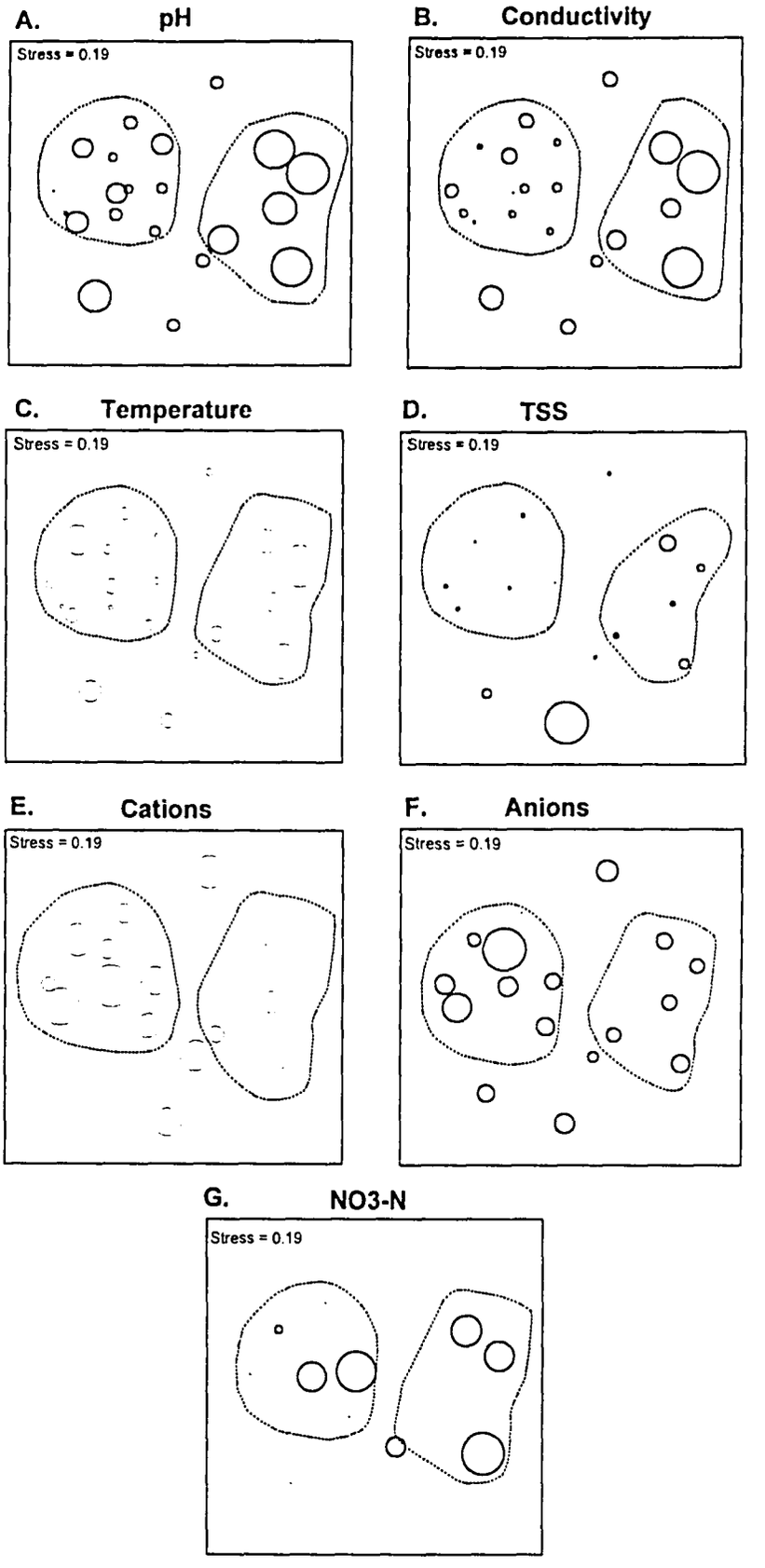


Figure 7.8. Overlays of biological ordination of SASS presence/absence data, by environmental variables. These figures relate spatially to the ordination shown in Figure 7.6.



obtained for these overlays mean that their interpretation should proceed with caution. Moreover, such overlays are of correlative value only, and do not imply causation.

Quantitative box-samples

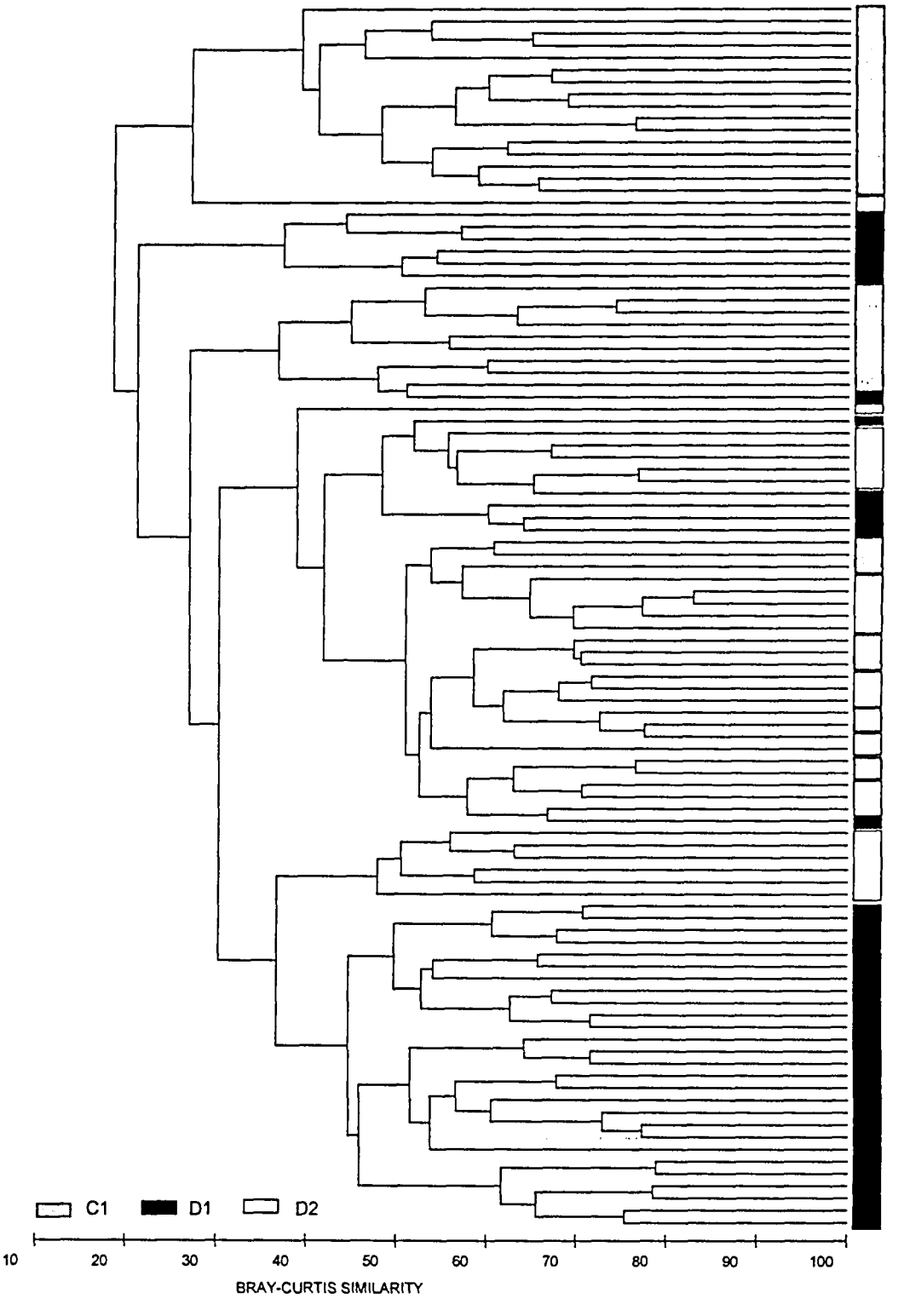
Quantitative data, analysed to species level where possible, and obtained from box-samples collected in the stones-in-current habitats were used to supplement the information supplied by SASS. Although initially these data were analysed en masse, using the multi-variate techniques outlined above, the large numbers of samples involved (five replicates per site) meant that the patterns which emerged were less clear than those obtained by presence-and-absence analysis of SASS data. Moreover, stress levels were high (0.24), and interpretation of two-dimensional ordinations was thus uncertain, even when accompanied by dendrograms showing hierarchical clusters (Primer 1994). The MDS dendrogram is, however, shown in Figures 7.9, where it can be seen that, on a very broad level, biological data appear to separate primarily on the basis of sites, and thereafter within sites, at higher levels of similarity. The high numbers of samples involved, coupled with high degrees of similarity, meant, however, that further analysis of these data was not productive.

To improve the confidence of interpretation, data were subsequently divided into meaningful, smaller groups, and then analysed. These groupings were at the level of both sites, and seasons, and thus allowed comparison of seasonal changes in community composition within sites, as well as comparison of different sites, during the same season (i.e. when seasonal variability had been reduced). In order to identify important distinguishing taxa, responsible for the separation of different sites or sampling events into discrete clusters, Simper analyses were performed on data from each season, grouping data in terms of sites, and, in the case of the spring data, in terms of periods of siphon discharge or closure within site samples. The results of these analyses are referred to in the following sections, where appropriate. Furthermore, the data themselves are provided in Appendices 7.1 to 7.4, where the percentage contribution by each taxa to the total number of animals found in each sample, are compared for each season. To facilitate comparison, these tables have been coded, so as to highlight those species in each sample which accounted for more than 10% of the number of animals found at each site.

Seasonal differentiation within sites

C1: The MDS ordination of biological data from the 950 μm samples taken at C1 are shown in Figure 7.10 (A). Samples have been grouped according to the relationships indicated by the cluster analysis performed on data from this site, at the Bray-Curtis 45% level of similarity. Within these major clusters, sub-groups have been illustrated, at a similarity level of 60%. Overall, seasonal variation is apparent between samples, with summer and winter samples clearly separated from each other. Winter samples are, however, highly variable, as indicated by their occupation of separate cluster groups. Autumn and spring are less well-defined, clustering in mixed groups, both with each other, and amongst winter and summer samples. This is probably a reflection of the fact that spring and autumn are transitional seasons between summer and winter, and overlap of invertebrate communities with both seasons is thus likely. Please note that although biota at C1 would not be affected by siphon discharges downstream, periods when the siphon is open have

Figure 7.9. Ordination of all quantitative biological data, using the species-level data-sets.



nevertheless been marked, to facilitate comparison with similar samples taken at downstream sites.

D1: A comparison of the ordination obtained for D1 (Figure 7.10 B), with that of C1 reinforces the idea, already suggested by the SASS ordinations, that clear differences exist between these sites, in terms of seasonal variability. In particular, unlike at C1, less differentiation of summer communities is evident D1. This change in ordination may be tentatively attributed to the influence of the Berg Siphon, in altering natural summer flow regimes, and producing aseasonal discharge and its associated changes in water quality, downstream of the siphon. Similarly, spring and autumn samples cluster in terms of whether or not the Berg Siphon is discharging, rather than in terms of like seasons. Thus winter samples are grouped only with natural-flow spring samples, while summer and autumn (siphon-flow) samples are clustered together. The additional separation of spring, (siphon-flow) samples into a separate cluster on the left is indicative of the overall variability displayed within this impacted system.

Clustering of spring (open-siphon) communities near to those from winter (natural flow) communities is not altogether surprising, as it is feasible that sufficient winter fauna remain in the river in spring, to survive what would initially appear to the organisms as merely a prolonged rainy season. By contrast, in summer and autumn, riverine fauna are less likely to be adapted to sudden increases in discharge, and the effect of the siphon would probably be such that more of the summer/autumn fauna were affected.

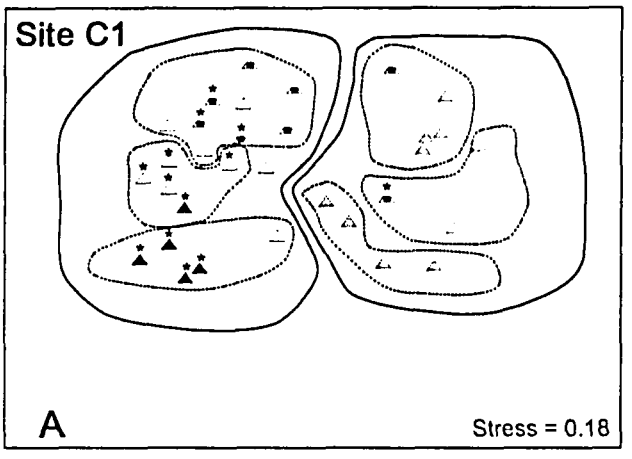
D2: As in the case of D1, the clustering of samples of D2 community data indicate that impacts appear to be marring the more natural seasonal distributions of communities assumed to exist at C1. In the case of D2, however, the resultant clusters are less mixed than those of D1, possibly as a result of the fewer number of samples available for this site. In general, samples group in terms of periods of siphon discharge or natural flow, with winter and autumn (natural flow) samples also forming a cohesive unit. The fact that seasonal groupings at D2 are different not only from those at C1, but also from those at D1, suggests, however, that impacts experienced at the two downstream sites might differ, either in magnitude or in the kinds of impacts affecting the biota. For example, some recovery from the impacts of both the trout farm and the siphon releases might be expected at D2, given its distance downstream of D1. At the same time, however, D2 is probably subjected to more habitat degradation and scouring by loose sediment, as a result of erosion from the forestry area than is D1.

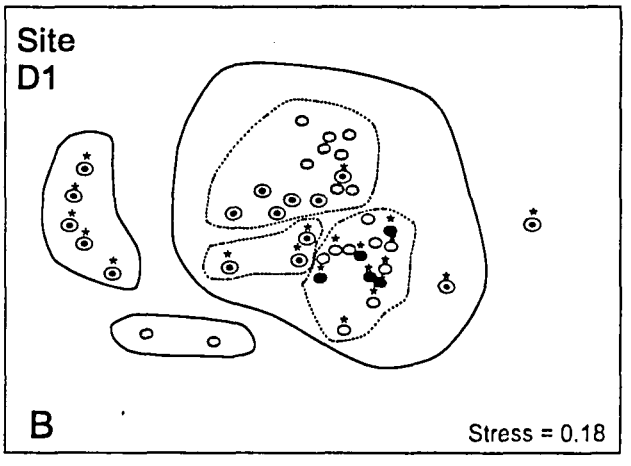
In spite of considerable variation, these data do show that, downstream of C1, seasonal differences between samples appear to be altered by other impacts, particularly during summer. The timing of these impacts appear to correlate with periods when the river is receiving aseasonal discharge from the Berg River Siphon.

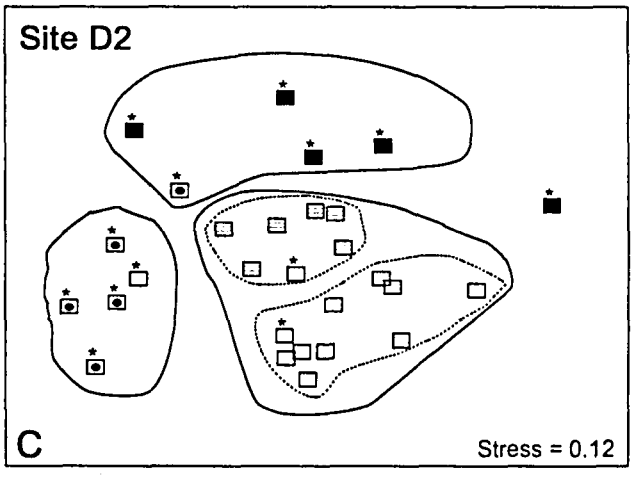
Differentiation between sites, within seasons

The ordinations illustrated in Figure 7.11 have been interpreted with the assistance of hierarchical dendrograms. Their stress levels are, however, low, and more confidence may thus be displayed in the natural spatial arrangements apparent in the ordinations themselves. All four ordinations **Figure**

7.10. Ordination of quantitative biological data, separated according to site, and using species-level data sets. Samples are grouped according to the hierarchical clusters displayed by cluster dendrograms. Solid lines linking groups are the 45% Bray-Curtis similarity level, while dotted lines are at 60% similarity.







SITES
C1
D1
D2

SEASONS
Summer
Autumn
Winter
Spring

Seasons differentiated according to the fill patterns indicated above

* Periods when siphon is open

illustrate differences between the upper site, C1, and the lower two sites, in terms of seasonal groupings. These trends corroborate patterns that have already been suggested by both the chemical analyses and the SASS samples.

Differences between communities during the same season are most marked in summer (Figure 7.11 A), when the three sites separate out at 45% similarity levels. As has already been suggested, the fact that D1 and D2 are largely separated from each other, as well as from C1, suggests that impacts at these sites might be different. Simper analyses indicated that the principal elements responsible for Bray-Curtis dissimilarities between sites during summer were, for all site groupings, the presence or absence of the hydropsychid taxa, *Cheumatopsyche afra and Cheumatopsyche thomasetti.* The former species was found at C1, while the latter was present only at D1 and D2. Simuliidae (more abundant at D1 and D2, than at C1) accounted for the third most important cause of dissimilarity between sites, followed by Heptageniidae (more abundant at C1 than at the other two sites). As far as differences between D1 and D2 are concerned, 34% of the dissimilarity between sites was accounted for by differences in abundances of Hydraenidae, Simuliidae, *C. thomasetti*, and elmid beetle larvae, all of which, with the exception of Simuliidae, were more abundant at D2 than at D1. Since Simuliidae are not sensitive to organic pollution, their higher abundance at D1 is a further indication of organic pollution entering the river downstream of C1, via the Berg siphon and/or through the trout farm at Dewdale.

In autumn, C1 samples continued to differentiate from samples of the other two sites (Figure 7.11B). Within D1 and D2, however, samples separated again on the apparent grounds of whether or not the siphon was discharging. Once again, Simper analyses elaborated on these results, showing dissimilarity between C1 and D1 to be primarily due to the presence of *C. thomasetti* at the latter site only, along with higher abundances of Simuliidae. These two taxa, along with Heptageniidae and Tricorythidae, both species that were more abundant at C1, accounted for 30% of the dissimilarity between C1 and D1 in autumn. D2 was distinguished from C1 by the absence of Baetidae, Chironomidae and Heptageniidae, and from D1 by the low abundances of Simuliidae, *C. thomasetti* and Chironomidae at D2. The low numbers of taxa recorded at D2 during this sampling session suggest that this site may have been impacted by factors downstream of D1.

By contrast to the autumn ordinations, the stress levels shown in the seasonal ordinations shown in Figure 7.11 increased sharply in winter, indicating that variability within these samples was leading to a lowering of confidence levels in the ordination. Such increases are a common phenomenon for winter communities, when the natural increase in disturbances leads to an increase in sample variability. In general, however, winter patterns indicate much less overall differentiation between sites, as indicated by the number of C1 samples clustering with samples from the other two sites. Simper analyses performed on two groups of winter samples, namely C1, versus D1 and D2, showed that Chironomidae, Tricorythidae and Simuliidae account for 35% of the dissimilarity observed between these two sample groups, with the more sensitive Tricorythidae being the only one of these differentiating taxa to be more abundant at C1.

By contrast to the winter ordinations, in spring (Figure 7.11 D), C1 once again separates out

distinctly, while D1 and D2 cluster in mixed groups. Of interest in this ordination is the fact that, of all seasons, differentiation of samples taken during siphon releases appears to be at a minimum, and C1 and D2 samples intermingle. This fact bears out earlier suggestions that spring fauna, which includes some winter fauna, might be better able to survive sudden increases in flow regime, than would the summer and autumn communities. Simper analyses performed on the groups illustrated by the ordinations in Figure 7.11D suggest that 31% of the differences between C1 and the other two sites are due, in both cases, to higher abundances of Chironomidae, Gyrinidae, Tricorythidae and Baetidae at C1.

Differences between species- and family-level community analysis

All data-sets were analysed at the level of both family and species, bearing in mind that not all taxa in so-called "species level" data were identified to species or even to genus. Instead, Leptophlebiidae, Notonemouridae and Trichoptera were all taken to species level, while elmid adults were grouped morphologically in terms of "species" numbers. Where other taxa could be identified further than family level, they were. A comparison of differences in results between the species- and family-based analyses revealed, however, that surprisingly few differences arose from data from the two methods, although it is possible that, if the entire community had been identified to species level, different results would have been obtained. By the same token, however, at the species level, abundances of individual taxa, particularly rare taxa, decrease dramatically from the abundances which would have been obtained at family level, for each taxonomic group. This means that trends that might have been more apparent at the level of family, are often diluted at species level.

It was particularly interesting to note that identification to species level of both Notonemouridae and Leptophlebiidae revealed no additional trends between sites, and might, in fact, even mask differences which would have been more apparent at the family level, given that splitting of families into further taxonomic categories resulted in decreased abundances of each taxonomic level. This said, species-level identification of hydropsychid larvae did prove informative, with distinct trends being shown in *Cheumatopsyche thomasetti* and *Cheumatopsyche afra* distributions between sites. *Cheumatopsyche afra* for example, was recorded only upstream of the siphon, at C1, while *C. thomasetti* was found downstream. Both these species were identified by the Simper analysis of summer data as being largely responsible for determining the differences between C1, D1 and D2.

7.4.3 Monitoring sites in the context of the Berg River as a whole

The ecological condition of the Berg River at the selected pre-construction monitoring sites (C1, D1 and D2) may be seen in relation to the rest of the Berg River, by drawing on SASS data collected between 1994 and 1995, and already presented in Dallas (1996). The locations of these sites are illustrated in Figure 7.1. Figure 7.12 summarises the data themselves, and indicates that, although in comparison to C1, sites D1 and D2 appear degraded, when compared with other sites further downstream they are, in fact, in considerably better ecological condition. Indeed, Figure 7.12 shows that there is a strong trend of deteriorating water quality with distance down the river.

Figure 7.11. Ordination of quantitative biological data, separated according to seasons using species-level data-sets. Samples are grouped according to the hierarchical clusters displayed by the cluster dendrograms.

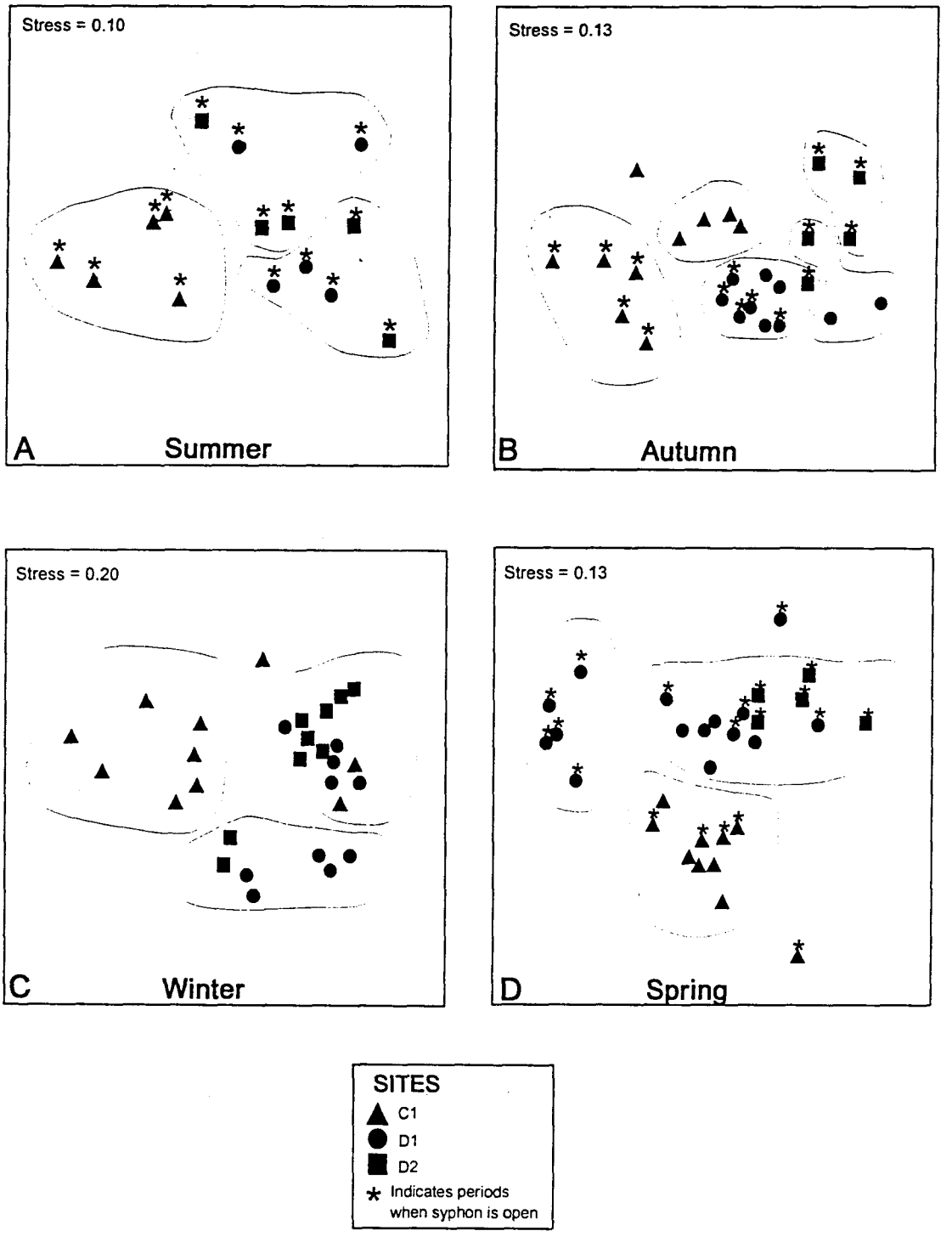
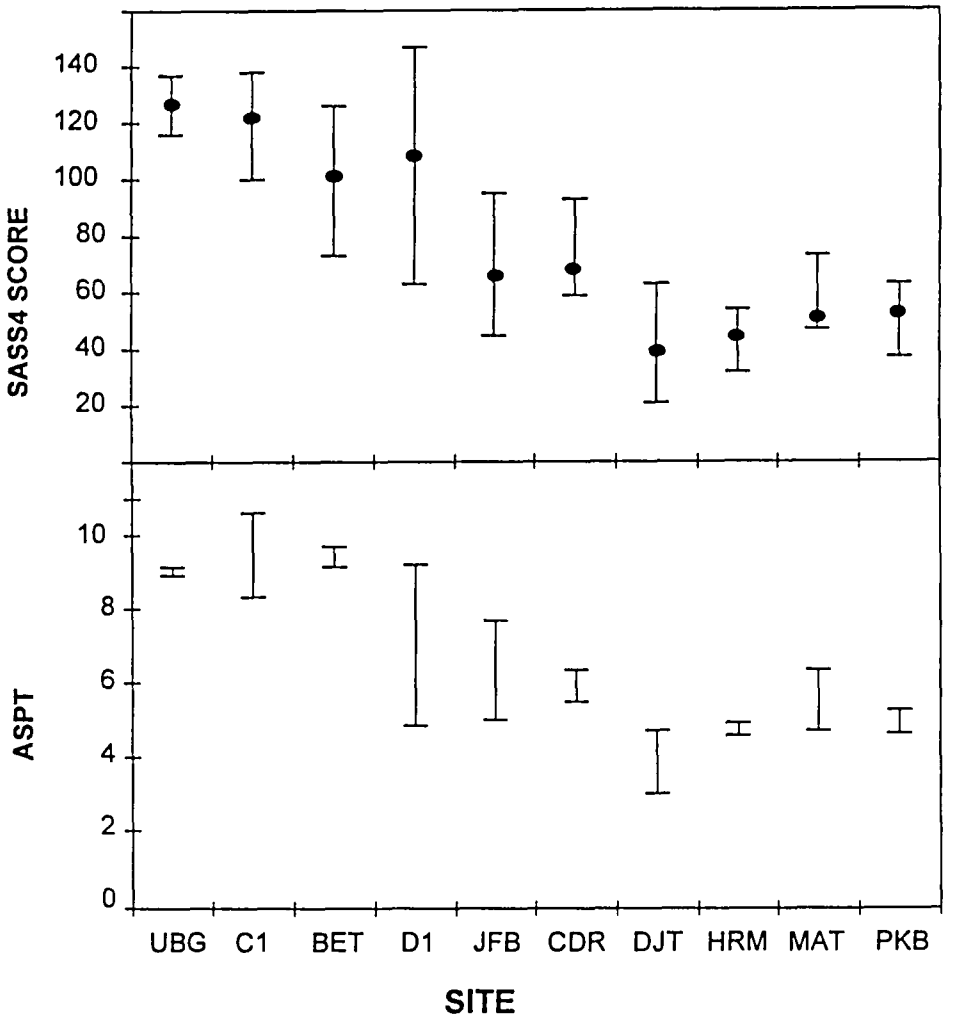


Figure 7.12. Average, minimum and maximum SASS4 Scores, and minimum and maximum ASPT values, calculated from seasonal 1994/5 SASS4 data for ten sites on the Berg River (from Dallas 1996).



7.5 GENERAL DISCUSSION

7.5.1 Monitoring methodologies

The data presented in this study reflect the results of a combination of sampling techniques, namely the rapid bioassessment technique, SASS, which was used to sample all available instream biotopes, and the more quantitative box sampling method, used only in riffle areas. Each of these methods thus contributed a different aspect to the overall information gained from this study. SASS, for example, allowed a broad overview of community structure, at the taxonomic level of family. Ordinations based only on presence-absence analysis of sample similarities, using SASS data alone, showed that the sites surveyed were distinguishable from each other, on the basis of taxonomic composition. The combination of SASS total scores, ASPTs and species richness data (number of taxa) also facilitated interpretation of the SASS samples, allowing the three monitoring sites to be assessed in terms of the extent of the impact. Qualitative box-sampling, by contrast,

allowed a more detailed investigation into patterns of community composition on a seasonal level, as well as between sites. The data used for such analyses were taken from the 950 μm samples, where species level identification was at its best. Although Dallas (1995) found that this fraction was responsible for explaining a substantial proportion of variability between sites, it did mean that some taxa were not fully represented in analysed samples. The Hydracarina, for example, were found mainly in the 500 and 250 μm size classes. They were, however, included in the initial analyses, which used total numbers of taxa found in each sample, and did not appear, to contribute significantly to any additional groupings of similar samples.

As far as long-term monitoring of during- and after-construction impacts of Skuifraam Dam on the riverine ecosystem is concerned, the results of the surveys presented here suggest that SASS should be adequate for detecting changes in community composition as a result of changes in water quality. Quantitative samples have, however, been of value in this study, in allowing the detection of specific trends in some taxa, as a result of changes in water quality such as pH. Subsequent monitoring programmes might benefit by collecting certain taxa, such as Hydropsychidae, from SASS samples, for identification to generic or species levels where possible. Such a tactic would be a compromise between the time and cost-effectiveness of a bioassessment technique such as SASS, and the more detailed, but more time-consuming, quantitative box-sampling method.

7.5.2 Pre-construction assessment of the Berg River in the vicinity of Skuifraam

The results presented here of the initial, pre-construction monitoring of the Skuifraam Dam, allow an assessment of the present ecological state of the Berg River in the area of the proposed dam, as well as permitting some comparison of the effects of existing impacts on the aquatic macroinvertebrate fauna of the river. In general, both chemical and biological data suggest that the riverine ecosystem is moderately impacted downstream of C1. Moreover, seasonal data show that these effects are most severe during summer, when the Berg Siphon is operational, with spring and autumn discharge periods also leading to changes in natural community composition.

It should be admitted, however, that this study does not provide concrete evidence that the deterioration in biological diversity, coupled with a decline in abundances of sensitive taxa, such as Leptophlebiidae, Notonemouridae, and riffle-dwelling elmid beetles (Elmidae) from the lower sites, is wholly due to the effects of the inter-basin transfers effected via the Berg Siphon. The choice of monitoring sites was constrained by the need for the same sites to be used both during and after construction of Skuifraam, and, as such, D1 was the most upstream site still feasible for monitoring, that would nevertheless be downstream of the dam wall. For this reason, sampling was not effected between the siphon outlet and the Dewdale Trout Farm outlet, and the effects of the two impacts could not be distinguished. However, the marked changes in community composition coincident with recorded periods of discharge from the siphon, suggest that these discharges are largely responsible for observed impacts. Differences in species composition observed between sites when the siphon was not operational may, however, be attributable to other impacts, such as the trout farm. By the same token, however, such impacts may merely represent a post-impact lingering effect. For example, changes in species composition, coupled with increased nitrate levels

found in May (1996) samples could be the result either of accumulated nutrients from the siphon discharge, which have not yet been flushed out of the system by the first rains, or of the result of high nutrient discharge into the river from the trout farm. Given, however, that trout farm releases are usually associated with elevated nutrient levels (Brown 1993) , it is probable that the observed impacts reflect both the effects of the trout farm, and the siphon discharges. Both these impacts would potentially attenuate slightly towards D2, given that it is some distance downstream. The latter site is, however, subject to additional impacts, stemming largely from forestry, so any attenuation that does occur remains undetected.

The effects of the siphon appear to be detrimental in two main ways. First, the quality of water discharged differs markedly from that natural to the upper Berg River. Water quality data presented in this report indicates that, downstream of the siphon outlet, pH, conductivity, and nutrient levels all increase dramatically. That these changes are probably largely attributable to the effects of the Theewaterskloof discharge is given impetus by data collected over a similar time frame by K. Snaddon (Freshwater Research Unit, University of Cape Town). These data, collected from sites upstream of the trout farm release point, indicate similar trends in all three variables. Although conductivity increased (correlated with the increased concentrations of major anions and cations entering the river through the siphon), ratios of anions and cations did not change. This is not surprising, as such changes would be indicative of differences in underlying geology between the two catchments involved in the inter-basin transfer (Day and King 1995). Since the Riviersonderend catchment is underlain by similar geological formations to the Berg River, at least in the upper reaches, such changes are unlikely to occur.

The effects of changes in pH and conductivity rendered by siphon discharges are more evident on some taxa than on others. For example, Scott (1983) noted that larvae of two species of Hydropsychidae appear to have different tolerance ranges to pH. *Cheumatopsyche afra*, found in this study only at C1, is limited to acid waters, between pH 4.7 and 6.8. By contrast, *C. thomasetti* occurs primarily in waters having a slightly higher pH range, between 6.4 and 8.2. The latter species was found at sites downstream of C1, and particularly during the summer months, when pH levels were consistently elevated, apparently by siphon discharges.

The second major impact of the Berg Siphon discharges on the riverine biota, namely the effect of aseasonal discharge into the river, is of more relevance to this study. After construction of Skuifraam, the siphon discharges will cease to impact on the river. The Skuifraam feasibility study (DWAF 1996b) did highlight, however, a growing concern that the timing and magnitude of summer releases from Skuifraam, for agricultural uses, would entrench the seasonal reversal already effected in the river by the aseasonal releases from the Berg siphon. The results of the present study confirm previous findings, that show marked impacts of these aseasonal flows on macroinvertebrate species composition. Comparisons of ordinations for different sites, for example, show that, downstream of the siphon releases, summer communities are more similar to winter communities, than those exposed to natural low-flow regimes, at C1. The effect of high summer discharges is to eliminate, or reduce the abundance of, species adapted to periods of low flows. This impact is compounded by the fact that such sites are out of synchrony with re-colonising adult insects. In

summer, even though flows might resemble winter flows, the winter fauna are not present, and impacted sites thus have communities which represent neither high flow, nor low-flow conditions, but show a tendency to group with autumn and spring communities.

The masking of seasonal trends in invertebrate communities at sites experiencing aseasonal high summer discharges is not only a reaction to the flow regime. Several authors (e.g. Quinn and Hickey 1993, Warwick 1993) have observed that seasonal trends in community structure are muted at impacted sites. The trends observed in this study, of a decrease in differentiation of communities on a seasonal level, with distance downstream of C1, also reflect this observation.

In general, the pre-construction monitoring of the Berg River, both up- and downstream of the proposed Skuifraam Dam should provide useful baseline data for comparison with data collected in the future. Although some of the data presented here are dogged by the inevitable problems of sample variability, and sampling and analytical error, they do nevertheless provide a fairly comprehensive description of the fauna present in the river prior to construction. For these data to be of value in future comparisons, it is thus recommended that, if possible, future monitoring of the Berg River in connection with Skuifraam, be conducted at the same sites.

Appendix 7.1. Taxon percentage abundance at the three upper Berg River pre-construction monitoring sites, during summer months.

ORDER	FAMILY	GENUS	SPECIES	Summer				
				C1				
				FEB96 1	FEB96 2	FEB96 3	FEB96 4	FEB96 5
Arachnida	Hydrachnellae			0.57	0.63	1.32	5.04	6.29
Coleoptera	Dytiscidae							
Coleoptera	Elmidae	Elmid adult	Beetle A	6.25	5.05	0.44	0.66	1.71
Coleoptera	Elmidae	Elmid adult	Beetle B				0.44	0.57
Coleoptera	Elmidae	Elmid adult	Beetle C	0.85				
Coleoptera	Elmidae	Elmid adult	Beetle D					
Coleoptera	Elmidae	Elmid adult	Beetle E					
Coleoptera	Elmidae	Elmid adult	Beetle F		0.32		0.22	
Coleoptera	Elmidae	Elmid adult	Beetle G					
Coleoptera	Elmidae	Elmid adult	Beetle H	1.70				
Coleoptera	Elmidae	Elmid adult	Beetle Z					
Coleoptera	Elmidae	Elmid larvae		18.75	12.93	10.13	3.51	10.29
Coleoptera	Hydraenidae			3.41	1.58	0.44		6.29
Coleoptera	Hydraenidae	Hydraenidae X						
Coleoptera	Hydrophilidae							
Coleoptera	Limnichidae							
Collembola								
Diptera	Athericidae			0.28	4.73		1.10	5.71
Diptera	Chironomidae			4.55	12.93	3.52	18.42	5.14
Diptera		Cone worm						
Diptera		(pupae)						
Diptera	Dolichopodidae							
Diptera	Empididae							
Diptera	Sciomyzidae							
Diptera	Simuliidae			6.53	14.20	19.38	34.65	8.57
Diptera	Tipulidae							
Ephemeroptera		(juveniles)		5.68	3.15	13.22	4.39	5.71
Ephemeroptera	Baetidae			14.20	18.93	30.84	28.51	28.57
Ephemeroptera	Caenidae							
Ephemeroptera	Ephemerellidae							
Ephemeroptera	Ephemeroptera							
Ephemeroptera	Gyrinidae						0.22	
Ephemeroptera	Gyrinidae	(larvae)		1.99	1.26			
Ephemeroptera	Hemiptera							
Ephemeroptera	Heptageniidae			9.94	6.31	11.01		11.43
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A		0.32			
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A	1.14	0.63	0.44		
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B	0.28	0.63			0.57
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A	2.27	0.32	0.44		
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B					
Ephemeroptera	Leptophlebiidae			4.26	3.15	0.88		
Ephemeroptera	Tricorythidae			5.68	3.15	1.76	0.44	
Hemiptera	Pleidae	Plea	Plea sp.					
Hemiptera	Veliidae							0.57
Megaloptera	Corydalidae							
Mollusca	Cyrenidae							
Odonata	Aeschnidae							
Odonata	Cordulidae							
Odonata	Libellulidae							
Oligochaeta	Lumbricidae				0.63			
Oligochaeta	Naididae	Slavina			1.58			
Oligochaeta	Naididae	Pristina			1.58			
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi		0.32			
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida					
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp					
Plecoptera	Notonemouridae	Desmonemoura						
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis	0.85	1.58	1.76	0.22	
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp	0.85	0.32			
Plecoptera	Notonemouridae							
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp	0.57	0.32			
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti					
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra	0.85	0.95	2.64	1.54	0.57
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp					
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.			0.88	0.22	2.29
Trichoptera	Leptoceridae	Parasetodes						
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis	8.24	2.52		0.22	3.43
Trichoptera	Leptoceridae							
Trichoptera	Philopotamidae							
Trichoptera	Polycentropodidae					0.88		0.57

Appendix 7.1 (contd.)

ORDER	FAMILY	GENUS	SPECIES	Summer				
				D1				
				FEB96 1	FEB96 2	FEB96 3	FEB96 4	FEB96 5
Arachnida	Hydrachnellae			0.30	0.11			
Coleoptera	Dytiscidae							
Coleoptera	Elmidae	Elmid adult	Beetle A					
Coleoptera	Elmidae	Elmid adult	Beetle B				0.44	
Coleoptera	Elmidae	Elmid adult	Beetle C		0.45	0.28		
Coleoptera	Elmidae	Elmid adult	Beetle D					
Coleoptera	Elmidae	Elmid adult	Beetle E					
Coleoptera	Elmidae	Elmid adult	Beetle F					
Coleoptera	Elmidae	Elmid adult	Beetle G					
Coleoptera	Elmidae	Elmid adult	Beetle H			0.28		
Coleoptera	Elmidae	Elmid adult	Beetle Z					
Coleoptera	Elmidae	Elmid larvae		0.60	1.14	0.28	8.89	5.62
Coleoptera	Hydraenidae			7.15	0.23		1.78	
Coleoptera	Hydraenidae	Hydraenidae X						
Coleoptera	Hydrophilidae							
Coleoptera	Limnichidae				0.45			0.80
Collembola								
Diptera	Athericidae			0.70	0.23	0.28	2.22	1.20
Diptera	Chironomidae			31.52	11.59	38.95	13.78	43.37
Diptera		Cone worm						
Diptera		(pupae)						0.40
Diptera	Dolichopodidae							
Diptera	Empididae							
Diptera	Sciomyzidae							
Diptera	Simuliidae			46.22	74.77	45.86	39.11	10.04
Diptera	Tipulidae							
Ephemeroptera		(juveniles)						
Ephemeroptera	Baetidae			4.03	4.55	5.52	17.78	16.06
Ephemeroptera	Caenidae							
Ephemeroptera	Ephemerellidae							
Ephemeroptera	Ephemeroptera							
Ephemeroptera	Gyrinidae							
Ephemeroptera	Gyrinidae	(larvae)						
Ephemeroptera	Hemiptera							
Ephemeroptera	Heptageniidae							
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A					
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A					
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A					
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B					
Ephemeroptera	Leptophlebiidae							
Ephemeroptera	Tricorythidae							
Hemiptera	Pleidae	Plea	Plea sp					
Hemiptera	Veliidae							
Megaloptera	Corydalidae			0.10				
Mollusca	Cyrenidae							
Odonata	Aeschnidae			0.40	0.23		0.44	0.40
Odonata	Cordulidae							
Odonata	Libellulidae			0.30				
Oligochaeta	Lumbricidae				0.91			
Oligochaeta	Naididae	Slavina		0.20				10.84
Oligochaeta	Naididae	Pristina		0.10				
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida					
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp					
Plecoptera	Notonemouridae	Desmonemoura						
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis					
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp					
Plecoptera	Notonemoundae							
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp					
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti	7.65	4.77	8.01	12.89	8.84
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra					
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp	0.10		0.28	1.78	2.01
Trichoptera	Leptoceridae	Oecetis	Oecetis sp	0.60	0.45	0.28	0.89	
Trichoptera	Leptocendae	Parasetodes						
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis		0.11			0.40
Trichoptera	Leptocendae							
Trichoptera	Philopotamidae							
Trichoptera	Polycentropodidae							

Appendix 7.1 (contd.)

ORDER	FAMILY	GENUS	SPECIES	SUMMER D2				
				FEB96 1	FEB96 2	FEB96 3	FEB96 4	FEB96 5
Arachnida	Hydrachnellae				0.16			
Coleoptera	Dytiscidae							
Coleoptera	Elmidae	Elmid adult	Beetle A					
Coleoptera	Elmidae	Elmid adult	Beetle B		0.16			
Coleoptera	Elmidae	Elmid adult	Beetle C					
Coleoptera	Elmidae	Elmid adult	Beetle D					
Coleoptera	Elmidae	Elmid adult	Beetle E					
Coleoptera	Elmidae	Elmid adult	Beetle F					
Coleoptera	Elmidae	Elmid adult	Beetle G					
Coleoptera	Elmidae	Elmid adult	Beetle H					
Coleoptera	Elmidae	Elmid adult	Beetle Z					
Coleoptera	Elmidae	Elmid larvae				2.30	1.77	1.06
Coleoptera	Hydraenidae			4.82	2.52		0.88	
Coleoptera	Hydraenidae	Hydraenidae X					0.88	
Coleoptera	Hydrophilidae							
Coleoptera	Limnichidae							
Collembola								
Diptera	Athericidae			0.64	0.16			1.59
Diptera	Chironomidae			21.22		58.36	33.63	11.64
Diptera		Cone worm						
Diptera		(pupae)		4.82				
Diptera	Dolichopodidae							
Diptera	Empididae							
Diptera	Sciomyzidae				0.16			
Diptera	Simuliidae			50.16	89.75	16.07	21.24	50.79
Diptera	Tipulidae			0.32				
Ephemeroptera		(juveniles)						
Ephemeroptera	Baetidae			12.86	4.73	13.11	26.55	26.46
Ephemeroptera	Caenidae							
Ephemeroptera	Ephemerellidae							
Ephemeroptera	Ephemeroptera							
Ephemeroptera	Gyrinidae							
Ephemeroptera	Gyrinidae	(larvae)						
Ephemeroptera	Hemiptera							
Ephemeroptera	Heptageniidae							
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A					
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A	0.64				
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A					
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B					
Ephemeroptera	Leptophlebiidae			0.64				
Ephemeroptera	Tricorythidae							
Hemiptera	Pleidae	Plea	Plea sp.					
Hemiptera	Veliidae							
Megaloptera	Corydalidae				0.16			
Mollusca	Cyrenidae						0.88	
Odonata	Aeschnidae			0.32		0.33		
Odonata	Cordulidae							
Odonata	Libellulidae					1.31		0.53
Oligochaeta	Lumbricidae							
Oligochaeta	Naididae	Slavina					5.31	
Oligochaeta	Naididae	Pristina						
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida					
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp					
Plecoptera	Notonemouridae	Desmonemoura						
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis		0.47			
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp					
Plecoptera	Notonemouridae							
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.					
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti	2.25	1.42	2.95	4.42	3.70
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra					
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp			0.33	0.88	
Trichoptera	Leptoceridae	Oecetis	Oecetis sp	0.96	0.32	4.59	3.54	3.70
Trichoptera	Leptoceridae	Parasetodes						
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis	0.32		0.66		0.53
Trichoptera	Leptoceridae							
Trichoptera	Philopotamidae							
Trichoptera	Polycentropodidae							

Appendix 7.2. Taxon percentage abundance at the three upper Berg River pre-construction monitoring sites, during autumn.

ORDER	FAMILY	GENUS	SPECIES	Autumn									
				C1									
				MAR95					MAY96				
				1	2	3	4	5	1	2	3	4	5
Arachnida	Hydrachnellae			3.92	0.40	2.69	1.53					2.31	0.33
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A		2.78	0.6	6.11			0.54			1.23
Coleoptera	Elmidae	Elmid adult	Beetle B	1.31			0.38						
Coleoptera	Elmidae	Elmid adult	Beetle C		1.98	1.5							
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z										
Coleoptera	Elmidae	Elmid larvae		12.6	5.56	8.1	3.2		11.1	5.05	4.35	10.989	13.28
Coleoptera	Hydraenidae			8.50	13.89	1.20	12.79		0.71	1.44			4.13
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae												0.11
Collembola													
Diptera	Athericidae			4.79	3.57	0.60	2.10		1.18	0.54			
Diptera	Chironomidae			12.64	6.35	6.89	15.08	3.35	5.90	1.44	3.26	11.55	3.68
Diptera		Cone worm											
Diptera		(pupae)											
Diptera	Dolichopodidae												
Diptera	Empididae												
Diptera	Sciomyzidae												
Diptera	Simuliidae			0.22		1.20	7.44			11.01	1.09	3.63	1.23
Diptera	Tipulidae												
Ephemeroptera		(juveniles)					3.82		2.36	9.03	16.30	16.50	5.58
Ephemeroptera	Baetidae			17.4	7.94	11.	13.	41.8	58.9	36.3	71.7	49.5	44.6
Ephemeroptera	Caenidae												
Ephemeroptera	Ephemerellidae												
Ephemeroptera	Ephemeroptera												
Ephemeroptera	Gyrinidae												
Ephemeroptera	Gyrinidae	(larvae)			1.98	1.20	0.38		7.08	9.93	1.09	0.33	4.69
Ephemeroptera	Hemiptera												
Ephemeroptera	Heptageniidae			10.89	15.87	11.98	7.63	8.37		3.07			
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A	6.75	11.51	13.1	5.53	9.21	1.42	6.14			2.90
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B	1.53	1.59	2.99	1.34	4.18	0.24	0.18			0.78
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A	1.53	2.78		1.72	14.23		0.36			
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans	0.44	0.79	1.20	0.38	0.84		1.08			
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B	0.22	1.98	1.50	0.95	4.18					0.67
Ephemeroptera	Leptophlebiidae			10.8	15.87	11.9	5.73	8.37		8.84			5.36
Ephemeroptera	Tricorythidae			4.36	3.97	8.98	2.29	0.42					
Hemiptera	Pleidae	Plea	Plea sp.										
Hemiptera	Veliidae												
Megaloptera	Corydalidae						0.19		0.24				0.11
Mollusca	Cyrenidae												
Odonata	Aeschnidae									0.18			1.45
Odonata	Corduliidae	(larvae)											
Odonata	Libellulidae												
Oligochaeta	Lumbricidae									0.18			0.45
Oligochaeta	Naididae	Slavina			0.79								
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi			0.60	0.57						
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata			0.30	0.38						
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp.										
Plecoptera	Notonemouridae	Desmonemoura											
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis	0.22	0.40	0.30	0.19	0.42					
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp					0.42					
Plecoptera	Notonemouridae			1.0		2.9		0.84					
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.			1.2	0.2		0.24				0.11
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra	0.6		0.3	1.9		0.24			2.64	1.34
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp									0.33	
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.			1.20					1.09	0.33	
Trichoptera	Leptoceridae	Parasetodes											
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis			4.4	2.4		10.3	4.15	1.09	0.99	6.47
Trichoptera	Leptoceridae												
Trichoptera	Philopotamidae						2.2						0.67
Trichoptera	Polycentropodidae					0.9						0.99	0.11

Appendix 7.2 (contd.)

ORDER	FAMILY	GENUS	SPECIES	Autumn D1 MAR95 1	2	3	4	5	MAY96 1	2	3	4	5
Arachnida	Hydrachnellae			1.02	0.13	2.47	2.63		0.82	0.35	1.78	2.05	0.12
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A										0.12
Coleoptera	Elmidae	Elmid adult	Beetle B										
Coleoptera	Elmidae	Elmid adult	Beetle C				0.29					0.14	
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z		0.13								
Coleoptera	Elmidae	Elmid larvae		0.77	0.33	0.41	2.05		3.46	0.70	1.02	2.73	0.87
Coleoptera	Hydraenidae				0.33	1.03			2.97	0.59	1.53	2.18	0.37
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae			1.53	0.07					0.12			
Collembola													
Diptera	Athericidae			0.26		1.44	0.29		0.49				0.62
Diptera	Chironomidae			31.12	7.70	19.34	6.73	5.77	33.61	67.17	41.27	58.80	16.71
Diptera		Cone worm											
Diptera		(pupae)					0.58						
Diptera	Dolichopodidae												
Diptera	Empididae												
Diptera	Sciomyzidae												
Diptera	Simulidae			9.69	64.3	13.5	53.5	82.9	17.3	5.51	34.14	16.64	59.65
Diptera	Tipulidae												
Ephemeroptera		(juveniles)		5.10	2.01		2.92		3.29	2.34	1.27	4.09	
Ephemeroptera	Baetidae			20.4	3.35	8.23	17.5		24.7	17.58	3.18	5.46	9.90
Ephemeroptera	Caenidae					2.06							
Ephemeroptera	Ephemerellidae												
Ephemeroptera	Ephemeroptera												
Ephemeroptera	Gyrinidae										0.25		0.12
Ephemeroptera	Gyrinidae	(larvae)											
Ephemeroptera	Hemiptera												
Ephemeroptera	Heptageniidae												
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B										
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A										
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans										
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B										
Ephemeroptera	Leptophlebiidae												
Ephemeroptera	Tricorythidae												
Hemiptera	Pleidae	Plea	Plea sp			0.21							
Hemiptera	Veliidae												
Megaloptera	Corydalidae					0.21							
Mollusca	Cyrenidae												
Odonata	Aeschnidae				0.07	1.03				0.12			
Odonata	Corduliidae	(larvae)			0.07	0.62		1.37					
Odonata	Libellulidae						0.29	0.27	0.33	0.12	0.38	0.27	0.62
Oligochaeta	Lumbricidae					0.21							
Oligochaeta	Naididae	Slavina											
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopsis	Aphanicercopsis sp.										
Plecoptera	Notonemouridae	Desmonemoura											
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis										
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp										
Plecoptera	Notonemouridae												
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti	29.	20.	48.	13.	8.5	13	4.9	15	7.6	10.89
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra										
Trichoptera	Hydroptilidae	Orthotricha	Orthotricha sp										
Trichoptera	Leptocendae	Oecetis	Oecetis sp.	0.3				0.8	0.2	0.5	0.1		
Trichoptera	Leptocendae	Parasetodes											
Trichoptera	Leptocendae	Athripsodes	Athripsodes bergensis										
Trichoptera	Leptocendae												
Trichoptera	Philopotamidae												
Trichoptera	Polycentropodidae					0.2		0.3					

Appendix 7.2 (contd.)

ORDER	FAMILY	GENUS	SPECIES	Autumn D2									
				MAR95					MAY96				
				1	2	3	4	5	1	2	3	4	5
Arachnida	Hydrachnellae								0.29	1.18	0.71	0.38	0.71
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A									0.13	
Coleoptera	Elmidae	Elmid adult	Beetle B										
Coleoptera	Elmidae	Elmid adult	Beetle C										
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z									0.13	
Coleoptera	Elmidae	Elmid larvae						7.14	0.15	0.18	0.71	0.13	0.24
Coleoptera	Hydraenidae									0.18		0.50	0.59
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae												
Collembola													
Diptera	Athericidae								0.07				
Diptera	Chironomidae							85.71	18.43	26.58	18.25	29.04	32.12
Diptera		Cone worm											
Diptera		(pupae)											
Diptera	Dolichopodidae												
Diptera	Empididae											0.13	
Diptera	Sciomyzidae												
Diptera	Simulidae			100.00					75.24	59.76	74.41	61.45	53.41
Diptera	Tipulidae												
Ephemeroptera		(juveniles)										1.25	
Ephemeroptera	Baetidae								3.28	6.33	4.15		5.88
Ephemeroptera	Caenidae												
Ephemeroptera	Ephemerellidae												
Ephemeroptera	Ephemeroptera												
Ephemeroptera	Gyrinidae												
Ephemeroptera	Gyrinidae	(larvae)						1.43					
Ephemeroptera	Hemiptera										0.12		
Ephemeroptera	Heptagenidae												
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B										
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A										
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans										
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B										
Ephemeroptera	Leptophlebiidae												
Ephemeroptera	Tricorythidae												
Hemiptera	Pleidae	Plea	Plea sp.							0.18			
Hemiptera	Veliidae												
Megaloptera	Corydalidae									0.18			
Mollusca	Cyrenidae												
Odonata	Aeschnidae								0.07				
Odonata	Cordulidae	(larvae)											
Odonata	Libellulidae								0.36	0.27		0.88	0.59
Oligochaeta	Lumbricidae												
Oligochaeta	Naididae	Slavina											
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp.										
Plecoptera	Notonemouridae	Desmonemoura											
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis										
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp										
Plecoptera	Notonemouridae												
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti					5.71	2.04	4.25	1.66	5.88	6.12
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra										
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp										
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.						0.07	0.90		0.13	0.24
Trichoptera	Leptoceridae	Parasetodes											
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis										
Trichoptera	Leptoceridae												
Trichoptera	Philopotamidae												
Trichoptera	Polycentropodidae												0.12

Appendix 7.3. Taxon percentage abundance at the three upper Berg River pre-construction monitoring sites, during winter months.

				Winter									
				C1									
				AUG96					JULY95				
ORDER	FAMILY	GENUS	SPECIES	1	2	3	4	5	1	2	3	4	5
Arachnida	Hydrachnellae												
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A										
Coleoptera	Elmidae	Elmid adult	Beetle B										
Coleoptera	Elmidae	Elmid adult	Beetle C										
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z										
Coleoptera	Elmidae	Elmid larvae		0.23			0.66			16.6			7.37
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydraenidae												
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae												
Collembola													
Diptera	Athericidae			7.26									
Diptera	Chironomidae			90.1	94.8	91.7	95.6	97.1					
Diptera	Dolichopodidae												
Diptera	Empididae						0.33						
Diptera	Sciomyzidae												
Diptera	Simuliidae				1.36	0.83	1.66		66.6	2.38	16.9		
Diptera	Tipulidae												
Diptera		Cone worm											
Diptera		Pupae				2.48							
Ephemeroptera	Baetidae								16.6	23.8	16.9	20.0	10.5
Ephemeroptera	Caenidae												
Ephemeroptera	Ephemerellidae												
Ephemeroptera	Ephemeroptera												
Ephemeroptera	Gyrinidae	Gyrinidae (larvae)			3.26	3.31	0.33			4.76			7.37
Ephemeroptera	Gyrinidae												
Ephemeroptera	Hemiptera												
Ephemeroptera	Heptageniidae								5.56	2.38	1.69	4.00	2.11
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A		0.27						1.69		
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A			0.83	1.33	0.35		4.76	8.47	16.0	
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B		0.27	0.83		1.75		4.76	3.39	4.00	18.95
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A									4.00	
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans							4.76			
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B								3.39	4.00	
Ephemeroptera	Leptophlebiidae									5.95	8.47	20.0	10.5
Ephemeroptera	Tricorythidae									15.4	25.4	20.0	10.5
Ephemeroptera		(juveniles)		2.34									
Hemiptera	Pleidae	Plea	Plea sp.										
Hemiptera	Veliidae												
Megaloptera	Corydalidae												
Mollusca	Cyrenidae												
Odonata	Aeschnidae												3.16
Odonata	Cordulidae												
Odonata	Libellulidae												
Oligochaeta	Lumbricidae												
Oligochaeta	Naididae	Slavina											
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis					0.70			6.78		12.6
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp						11.1	7.14	1.69		
Plecoptera	Notonemouridae	Aphanicercella	Aphanicerca barnardi									4.00	
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp							2.38			
Plecoptera	Notonemouridae	Desmonemoura											
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra										
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp										
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis										
Trichoptera	Leptoceridae												
Trichoptera	Leptoceridae	Oecetis	Oecetis sp										
Trichoptera	Leptoceridae	Parasetodes											
Trichoptera	Philopotamidae												
Trichoptera	Polycentropodidae												

Appendix 7.3 (contd)

ORDER	FAMILY	GENUS	SPECIES	Winter									
				D1									
				AUG96					JULY95				
				1	2	3	4	5	1	2	3	4	5
Arachnida	Hydrachnellae												
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A	0.23			1.28	0.39					
Coleoptera	Elmidae	Elmid adult	Beetle B										
Coleoptera	Elmidae	Elmid adult	Beetle C		0.49			0.39	0.57				
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z										
Coleoptera	Elmidae	Elmid larvae		0.47	4.88	1.31	2.56	2.33	5.14				
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydraenidae				0.98	0.65	3.85						
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae							0.39					
Collembola													
Diptera	Athericidae							0.39	1.71				
Diptera	Chironomidae			96.48	93.17	84.31	87.18	94.55	62.86	89.84	92.76	93.75	91.89
Diptera	Dolichopodidae												
Diptera	Empididae			0.23									
Diptera	Sciomyzidae												
Diptera	Simuliidae			1.17		8.50		1.17	9.14	6.10	1.97	2.08	2.70
Diptera	Tipulidae												
Diptera		Cone worm							0.57				
Diptera		Pupae											
Ephemeroptera	Baetidae								8.57	4.07	1.97	4.17	5.41
Ephemeroptera	Caenidae												
Ephemeroptera	Ephemerellidae												
Ephemeroptera	Ephemeroptera												
Ephemeroptera	Gyrinidae	Gyrinidae (larvae)							1.14				
Ephemeroptera	Gyrinidae												
Ephemeroptera	Hemiptera												
Ephemeroptera	Heptageniidae												
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A			0.65			0.57				
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B			0.65							
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A										
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans										
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B										
Ephemeroptera	Leptophlebiidae								1.14				
Ephemeroptera	Tricorythidae								0.57		0.66		
Ephemeroptera		(juveniles)											
Hemiptera	Pleidae	Plea	Plea sp										
Hemiptera	Veliidae												
Megaloptera	Corydalidae												
Mollusca	Cyrenidae												
Odonata	Aeschnidae												
Odonata	Cordulidae												
Odonata	Libellulidae												
Oligochaeta	Lumbricidae								1.14				
Oligochaeta	Naididae	Slavina											
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis						4.57		1.32		
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicerca barnardi										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp.										
Plecoptera	Notonemouridae	Desmonemoura				1.96					1.32		
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti	1.17		1.96	3.85	0.39					
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra										
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp										
Trichoptera	Leptoceridae	Athripsodes	Athrisodes bergensis				1.28						
Trichoptera	Leptoceridae												
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.										
Trichoptera	Leptoceridae	Parasetodes											
Trichoptera	Philopotamidae			0.23									
Trichoptera	Polycentropodidae												

ORDER	FAMILY	GENUS	SPECIES	D2									
				AUG96					JULY95				
				1	2	3	4	5	1	2	3	4	5
Arachnida	Hydrachnellae												
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A										
Coleoptera	Elmidae	Elmid adult	Beetle B										
Coleoptera	Elmidae	Elmid adult	Beetle C										
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z										
Coleoptera	Elmidae	Elmid larvae				0 81							
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydraenidae				0.95	1 63	22 22						
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae												
Collembola													
Diptera	Athericidae						11 11						
Diptera	Chironomidae			93 14	89 52	91 06	22 22	85 71	82 16	100.00	83 56	77 88	
Diptera	Dolichopodidae												
Diptera	Empididae												
Diptera	Sciomyzidae												
Diptera	Simuliidae			6 86	7.62	4 07	22 22	12 61	2.70		16 44	22 12	
Diptera	Tipulidae												
Diptera		Cone worm											
Diptera		Pupae											
Ephemeroptera	Baetidae												
Ephemeroptera	Caenidae												
Ephemeroptera	Ephemerellidae												
Ephemeroptera	Ephemeroptera												
Ephemeroptera	Gyrinidae	Gyrinidae (larvae)			0.95		11.11						
Ephemeroptera	Gyrinidae												
Ephemeroptera	Hemiptera												
Ephemeroptera	Heptageniidae												
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A						8 11				
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B						13 51				
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A						8 11				
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans										
Ephemeroptera	Leptophlebiidae	Apnonyx	Apnonyx B										
Ephemeroptera	Leptophlebiidae												
Ephemeroptera	Tricorythidae												
Ephemeroptera		(juveniles)											
Hemiptera	Pleidae	Plea	Plea sp.										
Hemiptera	Veliidae												
Megaloptera	Corydalidae												
Mollusca	Cyrenidae												
Odonata	Aeschnidae												
Odonata	Cordulidae												
Odonata	Libellulidae												
Oligochaeta	Lumbricidae												
Oligochaeta	Naididae	Slavina											
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis										
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicerca barnardi										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp										
Plecoptera	Notonemoundae	Desmonemoura						0 84					
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra										
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp		0.95								
Trichoptera	Leptoceridae	Athripsodes	Athrisodes bergensis			2.44	11.11	0 84					
Trichoptera	Leptoceridae												
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.										
Trichoptera	Leptoceridae	Parasetodes											
Trichoptera	Philopotamidae												
Trichoptera	Polycentropodidae												

Appendix 7.4. Taxon percentage abundance at the three upper Berg River pre-construction monitoring sites, during spring months.

				Spring									
				C1									
				OCT95					SEP94				
ORDER	FAMILY	GENUS	SPECIES	1	2	3	4	5	1	2	3	4	5
Arachnida	Hydrachnellae				0.17			1.32				0.27	
Coleoptera	Dytiscidae												
Coleoptera	Elmidae	Elmid adult	Beetle A										
Coleoptera	Elmidae	Elmid adult	Beetle B										
Coleoptera	Elmidae	Elmid adult	Beetle C										
Coleoptera	Elmidae	Elmid adult	Beetle D										
Coleoptera	Elmidae	Elmid adult	Beetle E										
Coleoptera	Elmidae	Elmid adult	Beetle F										
Coleoptera	Elmidae	Elmid adult	Beetle G										
Coleoptera	Elmidae	Elmid adult	Beetle H										
Coleoptera	Elmidae	Elmid adult	Beetle Z										
Coleoptera	Elmidae	Elmid larvae		6.04	4.18	5.51	3.85	15.79	2.38	1.36		11.53	3.91
Coleoptera	Hydraenidae			2.26	2.26	1.24	1.92					0.27	
Coleoptera	Hydraenidae	Hydraenidae X											
Coleoptera	Hydrophilidae												
Coleoptera	Limnichidae							1.32					
Collembola									0.79			0.27	
Diptera	Athericidae								0.13			0.27	0.22
Diptera	Chironomidae			32.83	17.07	32.41	19.23		69.58	72.51	70.53	57.10	55.69
Diptera		Cone worm						1.32	1.46			0.27	0.11
Diptera		(pupae)											
Diptera	Dolichopodidae											0.54	
Diptera	Empididae												
Diptera	Sciomyzidae												
Diptera	Simuliidae			10.38	3.66	4.09							
Diptera	Tipulidae				0.35								
Ephemeroptera		(juveniles)		3.77		4.75	19.23	26.32		3.90	3.31		1.12
Ephemeroptera	Baetidae			24.53	52.26	20.91	48.08		14.55	11.70	19.87		12.28
Ephemeroptera	Caenidae												
Ephemeroptera	Ephemerellidae												
Ephemeroptera													
Ephemeroptera	Gyrinidae												
Ephemeroptera	Gyrinidae	Gyrinidae (larvae)		6.04	7.32	3.33	2.88		4.23	2.73		22.52	18.97
Ephemeroptera	Hemiptera												
Ephemeroptera	Heptageniidae												
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A										
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A	1.32	0.17	0.38		7.89	1.06	1.36	0.66		1.34
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B	0.75	0.52	0.29		7.89	0.26	1.95	0.33		0.45
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A	0.57		0.10		9.21	0.26	1.75		3.22	0.22
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans	1.13	1.74	1.05		19.74		0.97		1.07	
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B	1.70	0.35			5.26		0.58			0.67
Ephemeroptera	Leptophlebiidae								1.85				
Ephemeroptera	Tricorythidae												
Hemiptera	Pleidae	Plea	Plea sp.		0.17								
Hemiptera	Veliidae												
Megaloptera	Corydalidae			0.57		0.10							0.11
Mollusca	Cyrenidae												
Odonata	Aeschnidae												
Odonata	Corduliidae	(larvae)											
Odonata	Libellulidae												
Oligochaeta	Lumbricidae			0.38		1.71							0.11
Oligochaeta	Naididae	Slavina		3.40		16.83	1.92						
Oligochaeta	Naididae	Pristina											
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi		1.57	3.80			0.13		0.66		
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata										
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida										
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp.		0.52								
Plecoptera	Notonemouridae	Desmonemoura			0.35						0.33		
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis			1.90					1.32		
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp		1.57		1.92		0.53		0.99		
Plecoptera				1.51	4.01				0.79				
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.	1.89	0.52	1.05	0.96	1.32	1.06	0.78	0.66	2.41	4.13
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti										
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra										0.11
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp										
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.										
Trichoptera	Leptoceridae	Parasetodes											
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis	0.94	0.87	0.48			0.26		1.32		0.56
Trichoptera	Leptoceridae												
Trichoptera	Philopotamidae												
Trichoptera	Polycentropodidae				0.17	0.10							

Appendix 7.4 (contd.)

ORDER	FAMILY	GENUS	SPECIES	Spring D1 NOV94 1	NOV94 2	NOV94 3	NOV94 4	NOV94 5	OCT95 1	OCT95 2	OCT95 3	OCT95 4	OCT95 5	SEP94 1	SEP94 2	SEP94 3	SEP94 4	SEP94 5
Arachnida	Hydrachnellae						5.33		5.43	2.58	8.49	2.14	10.58					
Coleoptera	Dytiscidae								0.15				0.25					
Coleoptera	Elmidae	Elmid adult	Beetle A						0.15							0.28		
Coleoptera	Elmidae	Elmid adult	Beetle B															
Coleoptera	Elmidae	Elmid adult	Beetle C								2.83		0.25					
Coleoptera	Elmidae	Elmid adult	Beetle D															
Coleoptera	Elmidae	Elmid adult	Beetle E															
Coleoptera	Elmidae	Elmid adult	Beetle F															
Coleoptera	Elmidae	Elmid adult	Beetle G															
Coleoptera	Elmidae	Elmid adult	Beetle H															
Coleoptera	Elmidae	Elmid adult	Beetle Z															
Coleoptera	Elmidae	Elmid larvae			1.09	2.87	0.67	0.60	0.15	1.80	1.42	0.49	3.53	0.54	11.11	0.84	1.35	
Coleoptera	Hydraenidae			0.14					1.61	2.58	2.36	1.32	1.51			0.28		
Coleoptera	Hydraenidae	Hydraenidae X																
Coleoptera	Hydrophilidae					0.21												
Coleoptera	Limnichidae									0.52		0.16				0.28		
Collembola																0.28		
Diptera	Athericidae			0.14														
Diptera	Chironomidae			16.11	5.27	45.36	83.33	9.91	49.12	41.49	50.00	66.89	55.67	95.68	44.44	88.48	88.94	98.95
Diptera		Cone worm																
Diptera		(pupae)																
Diptera	Dolichopodidae																	
Diptera	Empididae					0.21							0.25		0.85	0.28	0.23	
Diptera	Sciomyzidae																	
Diptera	Simuliidae			81.94	92.73	47.23	5.33	87.09	10.26	26.80	28.30	23.56	4.03	2.70	30.77	5.34	4.74	0.81
Diptera	Tipulidae																	
Ephemeroptera		(juveniles)							1.47	10.31		1.65						
Ephemeroptera	Baetidae								21.99	5.15			17.63					
Ephemeroptera	Caenidae																	
Ephemeroptera	Ephemerellidae																	
Ephemeroptera																		
Ephemeroptera	Gyrinidae			0.14		0.62		0.75	0.44		0.47	0.16			0.85		0.23	
Ephemeroptera	Gyrinidae	Gyrinidae (larvae)				0.41	1.33			0.26		0.16			0.85	0.28	0.23	
Ephemeroptera	Hemiptera												0.25					
Ephemeroptera	Heptageniidae																	
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A											0.54				
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A					0.15							2.56	0.28		
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B															
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A															
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans												0.85			
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B															
Ephemeroptera	Leptophlebiidae																	
Ephemeroptera	Tricorythidae								0.15									
Hemiptera	Pleidae	Plea	Plea sp.															
Hemiptera	Veliidae																	
Megaloptera	Corydalidae			0.14	0.36								0.25				1.58	
Mollusca	Cyrenidae																	
Odonata	Aeschnidae					0.21												
Odonata	Corduliidae	(larvae)																
Odonata	Libellulidae								0.15					0.54				
Oligochaeta	Lumbricidae			0.28		0.41					3.77							
Oligochaeta	Naididae	Slavina							8.21	7.22		1.81	2.77					
Oligochaeta	Naididae	Pristina																
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi		0.18													
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata														0.45	
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida															
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp.															
Plecoptera	Notonemouridae	Desmonemoura										0.16			0.85			
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis			2.46						0.49			1.71	0.28	0.68	
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp	1.11				1.50				0.33	0.25			0.56		
Plecoptera																		
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.														0.23	
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti				2.67		0.44	1.03	0.94	0.49	0.50		2.56		1.13	0.23
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra				0.67										0.23	
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp															
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.							0.26			1.01		0.85	1.12		
Trichoptera	Leptoceridae	Parasetodes					0.67											
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis		0.36				0.29		0.94	0.16	1.26			1.40		
Trichoptera	Leptoceridae																	
Trichoptera	Philopotamidae										0.47							
Trichoptera	Polycentropodidae														1.71			

Appendix 7.4 (contd.)

ORDER	FAMILY	GENUS	SPECIES	SPRING D2 OCT95				
				1	2	3	4	5
Arachnida	Hydrachnellae			10.45	4.48	3.93	4.46	0.63
Coleoptera	Dytiscidae							
Coleoptera	Elmidae	Elmid adult	Beetle A					
Coleoptera	Elmidae	Elmid adult	Beetle B			0.70		
Coleoptera	Elmidae	Elmid adult	Beetle C					
Coleoptera	Elmidae	Elmid adult	Beetle D					
Coleoptera	Elmidae	Elmid adult	Beetle E					
Coleoptera	Elmidae	Elmid adult	Beetle F					
Coleoptera	Elmidae	Elmid adult	Beetle G					
Coleoptera	Elmidae	Elmid adult	Beetle H					
Coleoptera	Elmidae	Elmid adult	Beetle Z			0.14		
Coleoptera	Elmidae	Elmid larvae		0.45	0.32	0.28	0.84	
Coleoptera	Hydraenidae				1.12	1.26	0.56	0.79
Coleoptera	Hydraenidae	Hydraenidae X						
Coleoptera	Hydrophilidae							
Coleoptera	Limnichidae							
Collembola								
Diptera	Athericidae							
Diptera	Chironomidae			67.27	40.80	28.05	48.47	27.04
Diptera		Cone worm						
Diptera		(pupae)		6.82				0.31
Diptera	Dolichopodidae							
Diptera	Empididae							
Diptera	Sciomyzidae							
Diptera	Simuliidae			7.27	44.96	54.56	20.89	58.81
Diptera	Tipulidae			0.45			0.28	
Ephemeroptera		(juveniles)				2.81		
Ephemeroptera	Baetidae				6.40			7.86
Ephemeroptera	Caenidae							
Ephemeroptera	Ephemerellidae							
Ephemeroptera								
Ephemeroptera	Gyrinidae						0.56	0.16
Ephemeroptera	Gyrinidae	Gyrinidae (larvae)						
Ephemeroptera	Hemiptera							
Ephemeroptera	Heptageniidae							
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes A					
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia A					
Ephemeroptera	Leptophlebiidae	Castanophlebia	Castanophlebia B					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx A					
Ephemeroptera	Leptophlebiidae	Choroterpes	Choroterpes elegans					
Ephemeroptera	Leptophlebiidae	Aprionyx	Aprionyx B					
Ephemeroptera	Leptophlebiidae							
Ephemeroptera	Tricorythidae							
Hemiptera	Pleidae	Plea	Plea sp.					
Hemiptera	Veliidae							
Megaloptera	Corydalidae							
Mollusca	Cyrenidae							
Odonata	Aeschnidae							
Odonata	Corduliidae	(larvae)						
Odonata	Libellulidae						0.28	
Oligochaeta	Lumbricidae			0.45	1.60		0.56	
Oligochaeta	Naididae	Slavina		6.36		7.43	21.73	3.93
Oligochaeta	Naididae	Pristina						
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella barnardi					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella bifurcata					
Plecoptera	Notonemouridae	Aphanicercella	Aphanicercella cassida					
Plecoptera	Notonemouridae	Aphanicercopcis	Aphanicercopcis sp.					
Plecoptera	Notonemouridae	Desmonemoura						
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca capensis					0.16
Plecoptera	Notonemouridae	Aphanicerca	Aphanicerca sp					
Plecoptera								
Trichoptera	Ecnomidae	Parecnomina	Parecnomina sp.					
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche thomasetti		0.16	0.14	0.28	
Trichoptera	Hydropsychidae	Cheumatopsyche	Cheumatopsyche afra					
Trichoptera	Hydroptilidae	Orthotrichia	Orthotrichia sp					
Trichoptera	Leptoceridae	Oecetis	Oecetis sp.	0.45			0.84	0.31
Trichoptera	Leptoceridae	Parasetodes						
Trichoptera	Leptoceridae	Athripsodes	Athripsodes bergensis		0.16	0.70	0.28	
Trichoptera	Leptoceridae							
Trichoptera	Philopotamidae							
Trichoptera	Polycentropodidae							

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The overall objective of this project was to increase our knowledge of the water quality requirements of riverine biota (invertebrates). All of the component chapters, whilst rather varied, contribute to this overall objective. The Biological and Chemical Database initiated as part of a previous WRC project expanded during the development process to incorporate recent advances in spatial differentiation of rivers and subregions within rivers. In this way it is hoped that biological (invertebrate) and chemical data incorporated in the BCD is made accessible in a useful and meaningful form. The system has been designed such that it is relatively simple to query either chemistry or biology, or a combination of the two. Whilst the BCD has its limitations with respect to the establishment of the "cause and effect" relationship between biota and water quality, it provides a platform for a number of queries related to invertebrates and water quality, including the establishment of:

- tolerance ranges for invertebrate taxa based on recorded observations,
- regional, subregional and seasonal patterns and variability in invertebrate distribution,
- biotope preferences of invertebrate taxa, etc.

These queries will enhance our knowledge of the relationship between water quality and invertebrates and thereby contribute to the use of invertebrates as a surrogate for water quality, e.g. in bioassessment techniques such as SASS. The widespread use of SASS and future incorporation of SASS into the National Biomonitoring Programme for Riverine Ecosystems highlights the importance of continually exploring and advancing such methods to ensure that they are robust and scientifically-based.

The development of the BCD facilitated the establishment of regional water quality guidelines for non-toxic inorganic constituents, namely total dissolved solids or conductivity, total suspended solids and pH. The national water quality guidelines, which are essentially a specification of the instream water quality required to protect aquatic ecosystems, for these constituents are given as numerical ranges or as proportional changes from local background conditions. The Target Water Quality Range, which is a management objective, is set within the No Effect range, i.e. such that the ecological integrity and functioning of the aquatic ecosystem is maintained. The method proposed for the establishment of regional or site-specific incorporates the following steps:

- establish which Water Quality Management Region the site is in,
- establish which subregion the site is in,
- ascertain if background concentrations or ranges have been established for "least impacted" or reference sites within this subregion,
- conduct a SASS4 assessment to establish the current condition of the site with respect to the aquatic community.

On this basis, the extent of water quality impairment of the site may be established as reflected by SASS Scores. Depending on the availability of water chemistry data for the site or that of a

reference site in the same WQMR and subregion, the median concentration or value, seasonal and diurnal variation, and percentage of observed data for each season which falls within the proposed TWQR can be calculated. For reference sites, if the TWQR is reflective of the observed data, seasonal values may be set, and if the TWQR is not reflective of the observed data, the TWQR may be adjusted such that 80% of the observed data are incorporated. For impacted sites: the same process is followed, but where the TWQR is not reflecting the observed data, remedial measures need to be taken and a monitoring programme, incorporating a biological and chemical component, initiated. The percentage observed data within the TWQR may then need to be recalculated and sites condition re-evaluated on the basis of SASS4 Scores.

Following this process should enable the extent of water quality impairment at a site to be established in relation to what would be expected under natural or background conditions. To ensure that the guidelines are effective in protecting the aquatic ecosystems from further degradation, monitoring need to be undertaken. As mentioned previously, the SASS method is being used extensively and its use in the future is likely to increase. The use of SASS as a tool for testing the effectiveness of the water quality guidelines has been tested within the southern and western coast water quality management region in this study. SASS reference sites have been identified and preliminary categories of water quality impairment for subregional groups within this WQMR established. These categories and reference sites should facilitate future monitoring of the effectiveness of the guidelines within this WQMR. The technique with which these reference sites were identified and water quality categories established can potentially be applied to other regions in South Africa.

In addition to the above research components aimed at establishing and monitoring regional water quality guidelines for non-toxic inorganic constituents, a laboratory-based study was undertaken on the combined effect of three metals, namely aluminium, copper and manganese, to a local south-western Cape endemic, the amphipod *Paramelita nigroculus*. Results suggest that, even in combination, the current TWQR for each of these metals would afford protection to this organism. Examination of background concentrations for these metals also showed that concentrations for aluminium and copper were higher than the TWQR in acidic south-western Cape streams, which none-the-less supported an abundant and diverse aquatic fauna.

Finally, the pre-construction monitoring of the biota, physical attributes and chemical parameters of the upper Berg River, should facilitate future monitoring during and after construction of Skuifraam Dam. The opportunity to undertake monitoring of the biota of a river, prior to the construction of a dam, is an unusual but fortunate one, and which will hopefully advance our knowledge on the effects of construction on the aquatic ecosystems downstream of such activities.

8.2 RECOMMENDATIONS

1. The approach proposed for the development of regional water quality guidelines for non-toxic inorganic constituents needs to be further developed and tested by DWAF and regional guidelines established for other Water Quality Management Regions.

2. A biomonitoring programme for the southern and western WQMR and which is suitably linked to the national initiative, needs to be established. The many studies undertaken by members of the Freshwater Research Unit, UCT, provide an ideal backbone for the future development of this very important programme. Ultimately regional DWAF should be responsible for the routine monitoring of our aquatic resources but members of FRU are ideally placed to assist in the developmental phases. The techniques documented in this report should also feed into the national initiative and be compared to other techniques or methodologies currently being used.

3. It is recommended that continual low-intensity sampling be undertaken on the Berg River until a decision is reached on the construction of Skuifraam dam. It would be advisable for this to be conducted by regional DWAF personnel who are becoming familiar with the SASS technique, but who could receive additional field supervision by members of FRU if required.

4. The synergistic and antagonistic effects of toxins needs to be further examined with a view to revising the interim water quality guidelines if appropriate, including other combinations of metals and using other invertebrate taxa.

5. The BCD has already proved to be most useful in establishing both chemical and biological characteristics of riverine ecosystems. Further interrogation should enhance our understanding of both aspects. It is therefore important that the BCD be maintained through the incorporation of new studies, and its use be encouraged, albeit it a controlled manner.

6. Additional testing and development of the SASS technique needs to be undertaken.

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GLOSSARY AND LIST OF ACRONYMS

AEV	acute effect value: concentration of a constituent above which there is expected to be a significant risk of measurable acute toxic effects in aquatic communities
ASPT	average score per taxon: in the SASS system,
BCD	Biological and Chemical database: the database, developed in the course of this project, that houses data on South African riverine systems for which both biological and chemical information is available
benthic macroinvertebrates	animals, such as insects and crabs, that live on the beds of streams and are large enough to be seen with the naked eye
biomonitoring	the use of living organisms to monitor the biological integrity or 'health' of an ecosystem
bioregion	one of the geographical areas of South Africa, defined mainly on the basis of various biotic characteristics
CEV	chronic effect value: that concentration of a constituent above which there is expected to be a significant risk of measurable chronic toxic effects in aquatic communities
DWAF	South African State Department of Water Affairs and Forestry
diel	occurring over a period of 24 hours
ecotoxicology	the study of the effects of toxins on ecosystems and their inhabitants
foothill	the zone of a river where it runs through foothills
HABS1	an index for evaluating habitat quality by assessing the number of different types of biotope in a stretch of river
HAM	habitat assessment matrix: an index of the extent to which the physical habitat of a stream has been degraded
lower river	the zone of a river near the sea
mountain stream	the zone of a river in its uppermost mountainous reaches
MDS	multi-dimensional scaling: a multivariate ordination technique in which plotted distances between samples reflect the degree of similarity between the biological communities of each sample
NAEBP	South Africa's National Aquatic Ecosystem Biomonitoring Programme
NTU	nephelometric turbidity unit: a unit of measure of turbidity

PCA	Principle Components Analysis: a multivariate analytical technique in which spatial groupings of samples are based on the similarity of their environmental variables
reference site	in a biomonitoring programme, a 'least impacted' or 'pristine' site against which others can be compared
riparian	of the river bank
SASS	the South African Scoring System: a method for the rapid, field-based assessment of water quality as reflected in the invertebrate biota at a site
SASS4	the particular version of SASS used in the present study
subregion	a sub-category of the Bioregions that takes the longitudinal zonation of rivers into account
TAL	total alkalinity
TDS	total dissolved solids
TSS	total suspended solids
TWQR	target water quality range: the desired or 'ideal' concentration range that will ensure protection of aquatic ecosystems (usually set as equal to the 'no effect' range)
taxonomy	the hierarchical classification of living organisms in families, species, etc.
transitional zone	the zone of a river between the foothills and the lower river
water quality	the combined effects of the physical attributes and chemical constituents of a sample of water on its 'users'; in the context of the present work, the 'users' are the river and its biota
water quality regions	geographical regions with waters similar in their physical attributes and chemical constituents
WQMRs	water quality management regions: in South Africa, regions in which water quality is similar enough that the rivers can be managed using the same criteria and guidelines