ASSESSMENT OF THE INSTREAM FLOW INCREMENTAL METHODOLOGY, AND INITIAL DEVELOPMENT OF ALTERNATIVE INSTREAM FLOW METHODOLOGIES FOR SOUTH AFRICA

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EXECUTIVE SUMMARY

1. INTRODUCTION

There is growing concern worldwide regarding the increasing rate of deterioration of the natural environments of rivers. In the past, much of this concern has focussed on water-quality problems, and only recently has the manipulation of flow regimes been recognised as a major factor affecting the health of rivers. Some countries, including South Africa, have now initiated activities to address the damage caused by modified flow regimes that do not cater for the water needs of the riverine ecosystem. From these activities has developed the new science of instream flow assessments, whereby recommendations are made on modified flow regimes for rivers involved in water-resource developments. Although such assessments are usually made when new developments are planned, they can equally well be done for extant developments in order to guide moves to halt or reverse deterioration of the river concerned.

South Africa's first acknowledgement of the problem at the national level came in 1987, with two major workshops on assessing the water requirements of rivers. One, organised by the Department of Water Affairs and Forestry (DWAF) to address the water requirements of the rivers of the Kruger National Park, was the precursor to the Kruger National Park Rivers Research Programme. This programme, presently running, is the most comprehensive attempt ever organised in this country to develop both an understanding of the functioning of rivers and ways of managing them and their waters in a sustainable way. The other workshop, organised by the Foundation for Research Development, alerted the wider national community of river scientists and managers to the need for methodologies to assess the water requirements of rivers.

The project reported on here evolved directly from the activities related to these two workshops. Its objective was to initiate the establishment in South Africa of one or more scientifically acceptable methodologies for assessing the instream flow requirements of the country's rivers.

2. PROJECT AIMS

The project aims, as agreed in the original contract between the University of Cape Town and the Water Research Commission, and amended by the Steering Committee for the project, are summarised below.

- Compile a synthesis report of present worldwide knowledge on methodologies for instream flow assessments.

- Develop local expertise on the Instream Flow Incremental Methodology (IFIM), through a research programme of field work and computer training, using the Olifants River (western

Cape) as a test case. IFIM is currently the most well-known and used methodology worldwide for instream flow assessments.

- Test and assess IFIM, present possible solutions to problems encountered, and suggest further research.
- Use IFIM to establish the instream flow requirements of the Olifants River.
- In a separate exercise, assess the usefulness of the historical flow records held by DWAF for determining the instream flow requirements of South African rivers.
- Compare the results of the investigations of IFIM and the historical flow record approach, and discuss their ecological and management implications.
- Begin development of alternative local methodologies, if this is deemed necessary.
- Provide recommendations on how instream flow assessments should be undertaken in South Africa in future.

In the following sections, the nature of IFIM is explained and its application in South Africa is described. Conclusions are drawn regarding the methodology. Two alternative initiatives in the field of instream flow assessments are then described. Finally, recommendations are made on how the science of instream flow assessments should be further developed in South Africa.

3. THE NATURE OF THE INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM)

IFIM was devised by the United States Fish and Wildlife Service. It comprises a collection of analytical procedures and computer programs (Chapter Three) and includes the Physical Habitat Simulation Model, PHABSIM II, which is its best known component. In its entirety IFIM is said to evaluate the effects of incremental changes in stream flow on channel structure, water quality, temperature and availability of physical microhabitat for selected target species. Information on the availability of this physical microhabitat, which is simulated by PHABSIM II, is actually the principle product of applying the methodology, and is used in negotiations for an acceptable modified flow regime for the river of concern.

The focus of IFIM is PHABSIM II, which acts much like any hydraulic model by simulating hydraulic conditions over a range of discharges, but is unusual in that these simulations are then linked to habitat information on selected riverine species. The model uses the concept that physical flow-related conditions at the microhabitat level can be measured and, using this information to calibrate the model, then simulated over a chosen range of discharges; that the instream areas where the selected target species most often occur, termed the preferred habitat(s), can also be measured at the microhabitat level, using the same variables; and that these two kinds of information can then be linked, to illustrate how much flow-related microhabitat is available to the species over the chosen range of discharges.

To produce this output, the model uses measured data on channel morphology at selected sites, and on the hydraulic characteristics of flow through those sites, to simulate conditions of water depth, water velocity, substrate and hydraulic and vegetal cover over the range of discharges. The substrate and cover conditions are together termed the channel index (CI). Simulations are done at a level of resolution deemed to be ecologically relevant, by compartmentalising the study site, within the model, into a grid of cells. Once the hydraulic simulations are complete, each cell within PHABSIM II has a value for water depth, water velocity and CI for each of the discharges which the model was programmed to simulate.

In parallel, data are collected on the preferred microhabitat of the selected species and used to construct "habitat curves". Libraries of such curves, each showing the preference of a named species for specific water depth, water velocity and substrate and cover conditions, have been compiled in the United States of America, and are continually being refined as new data become available. The curves have values of the measured variable on the X-axis and suitability as habitat on the Y-axis, with the Y values ranging between 0.0 (unsuitable habitat) to 1.0 (most suitable habitat). Such curves are commonly called "suitability index curves" or SI curves. The project reported upon here initiated the collection of SI curves for South Africa.

PHABSIM II then links the information on the hydraulic conditions within each cell with that on the preferred habitat of the species, by using the SI curves to assess how suitable the depth, velocity and CI in each cell are at each discharge. These three suitability values for each cell at any one discharge are then combined, to give the cell's composite suitability at that discharge. The procedure is repeated for the full range of chosen discharges, to show how microhabitat is lost or gained as the discharge changes. The standard output from PHABSIM II is a plot of available flow-related microhabitat (called Weighted Usable Area or WUA), in units of area per unit length of river, versus discharge. This output is used when negotiating an acceptable modified flow regime for a flow-regulated river, and now has legal standing in the United States of America.

To extend the relevance of the PHABSIM II output, IFIM makes provision for extrapolation of WUA at a study site, to total WUA over the whole river length of concern. This provides a more global picture of the likely effects of a water-resource development, by comparing the present and predicted future distribution of preferred macrohabitat for the species over the whole river. To do this, the concept of macrohabitat is introduced. Variables which do not change at the microhabitat level and are therefore termed macrohabitat variables, such as hydrology, water quality, temperature and gross channel morphology, are assessed in order to identify macrohabitat zones of similar conditions along the river. PHABSIM II study sites should be located in each macrohabitat zone that is based on channel geomorphology, and through which its hydraulic simulations can validly be extrapolated. The model is then used to predict available microhabitat at the study site, and the results extrapolated over the whole (geomorphological) macrohabitat zone to produce a prediction of total available habitat. However, either within the zone, or covering one or more zones, are changes in water quality and temperature which will restrict species distributions and thus modify the final figure for total WUA.

Completing the original set of activities encompassed within IFIM were methods for clarifying the objectives of the instream flow assessment, choosing the study area, study sites and target species, and using the PHABSIM II results in negotiations for water. Recent additions not available for use in this project are a time-series library, a stream temperature model, and a program to assist understanding of the institutional and legal framework of the U.S. Fish and Wildlife Service.

4. LEARNING AND APPLYING IFIM IN SOUTH AFRICA, USING THE WESTERN CAPE OLIFANTS RIVER AS A TEST CASE

The project staff were river ecologists with no training in hydrology, hydraulics, hydraulic modelling, land-surveying or fluvial geomorphology. Skills in all of these disciplines, as well as ecological skills and others such as computer literacy, are needed to apply IFIM (Chapters Four to Nine). The staff also had no contact with the creators of IFIM, or the regular updates emanating from those specialists for American users of IFIM, until very late in the project. Both the methodology and the skills it requires were therefore self-taught. Vital roles were played in this process by Mr W. R. Rowlston, an experienced hydraulics engineer with DWAF who guided the learning and use of PHABSIM II, and by the author of PHABSIM II, Dr R. T. Milhous, who visited South Africa in 1992 to work with river scientists using IFIM. The assessment of IFIM presented in Chapters Four to Nine is in sufficient detail to provide a comprehensive manual of the basic steps in applying IFIM. This was done with the aim of reducing much of the confusion inherent in the documentation on the methodology, for the benefit of other users.

The Olifants River was chosen for learning and applying IFIM because it presents the classic conflicts over water that the methodology was designed to help resolve. Most of the catchment lies in a semi-arid area, but the river is quite large because it rises in a high-rainfall mountain range. Citrus farms along the river valley constitute one of the two main areas in the country producing citrus fruit for the export market. The orchards are expanding, other fruit and vegetable crops are also produced, and historical water rights have not yet been fully utilised so further increases in the demand for water are likely. A further dam is planned in the headwaters of the river, to complement the existing two in its middle reaches. The river also has the highest conservation priority of any river in the Cape Province, and ranks in the top few nationally. This is mainly because of its eight endemic fish species, which are now all on the country's Red Data list of endangered species. Some of these species are close to extinction, with the main causes identified as habitat destruction, fragmentation of the river continuum by dams, massive abstraction of water which is changing the middle reaches of the river from perennial to seasonal, and predation by the alien smallmouth bass *Micropterus dolomieui*.

The objective thus identified for learning and applying IFIM was to assess its usefulness in establishing the instream flow requirements of the Olifants River, so that this knowledge could be used in future negotiations for water between DWAF and off-stream users such as the farmers. It was felt that the problems faced in this project, of limited expertise, time, and biological and other data, would be similar to those present when undertaking an instream flow assessment for almost any river in South Africa. Thus, the project activities would be a good test of the methodology's applicability in this country.

The project team established PHABSIM II study sites in the three major zones of the river, created fixed transects surveyed in to trigonometrical beacons which were used to describe channel morphology, and on three occasions collected cell-by-cell data along the transects on water depth, velocity and CI, as well as relevant discharge-related data, in order to calibrate and run the model. At the same time, seven additional sites along the mainstream and three on selected tributaries were established. These and the three PHABSIM II sites were used together for two purposes.

First, samples of bottom-living (benthic) aquatic invertebrates were collected at each of the 13 sites, and their flow-related microhabitat conditions recorded, in the four seasons winter, spring, summer and autumn. This information was used to create three SI curves of preferred microhabitat (one each for velocity, depth and CI) for each of several selected invertebrate target species, to be used in PHABSIM II. The target "species" chosen were "the community of highest diversity", *Rheotanytarsus* sp. A, *Pelorioius granulosus* and *Polypedilum ?articola*.

Secondly, water-quality samples and additional data on features of the sites were collected at every site on every visit. These were used in conjunction with the information on invertebrate distributions gained from the field trips, and office data on the general hydrology and geology of the catchment, to refine the delineation of macrohabitat zones within the three major zones initially identified.

Fish are the traditional choice as target species for use in IFIM, and are the ecosystem component of most concern in the Olifants River. The preferred microhabitats of selected fish species were thus also recorded and the data used to create SI curves, for use in PHABSIM II. The fish species used as target species were *Austroglanis gilli*, *Barbus calidus*, *Barbus serra* and the alien *Micropterus dolomieui*. From the field data, similar SI curves could be created for all the other fish and invertebrate species studied but not named here, but this has not been done for this report.

The field data on channel morphology, cell-by-cell hydraulics and CI, and SI curves for the fish and invertebrate target species were combined using PHABSIM II. The output from the model consisted of plots of Weighted Usable Area versus Discharge (WUA-Q) for each target species. In this project, the outputs were predictions of how WUA changes for each target species at any one of the three PHABSIM II sites as discharges increase or decrease, and how WUA for each target species differs between the three sites because of differences in channel morphology and substrate particle size along the river. These predictions illustrate both present WUA and, assuming channel morphology and substrates do not change with a water-resource development, the future availability of WUA after such a development. As the biological data used were collected only in summer, the results would be applicable only for that season.

Theoretically, it should be possible, through the use of macrohabitat zones, to then extrapolate the WUA results to show both the present total WUA for a target species over the whole river and the predicted future total WUA after the water-resource development.

This was not possible in this project, however, because the determination of macrohabitat zones could not be done. Though useful in concept, it was found in practice that an acceptably accurate prediction of future conditions along the river in terms of these variables would probably have doubled the cost and duration of the project. Even if such work could have been done and had produced an acceptably accurate prediction, there is virtually no knowledge in South Africa of what the species are responding to in their environment and so which of the predicted changes might be expected to change the length of river that they can inhabit. Further, there remains the problem that each species may perceive longitudinal changes in the macrovariables differently, and so defining macrohabitat zones that are common to all species seems to be an unrealistic objective. Thus, the extrapolation from PHABSIM II output on WUA to the larger picture of changes in total WUA could not be made.

Without a link between microhabitat and macrohabitat, the most that seemed acceptable was to recognise that the hydraulic simulations done by PHABSIM II were representative of short sections of river of unknown length upstream and downstream of the study sites. If the hydraulic-habitat link-up was then made in the model, and there is much scientific debate on whether or not this is valid, the WUA-Q output could be used to assess, at the study site, the present effect of changing discharges on WUA. This could then be used to help choose an acceptable range of discharges for the future, on the untested assumption that none of the macrovariables except discharge would be changing. All scientific literature dealing with IFIM available to this project dealt with the problem in this way, that is, by ignoring the macrohabitat assessment and the fact that variables other than discharge might be changing with a development. Under those restrictions, however, the PHABSIM II output can safely only be used to simulate present WUA at the study site. It does not seem valid to then use this to determine total present WUA, nor to determine future WUA at the study site or future total WUA.

In this project, the most that it seemed possible to recommend from the data collected and its use in IFIM terms was that discharges along the Olifants River should not fall below 1.0 to 1.0 $m^3 s^{-1}$ during the summer months, this being the point at which wetted area and thus WUA began to sharply decrease. Invertebrate samples collected during the other seasons, but as yet unprocessed, would allow a similar recommendation to be made for those seasons, while not helping determination of when the recommendation for one season should give way to that for the next. There was little within the IFIM process to aid identification of the highest acceptable discharge in summer should irrigation releases begin from the proposed dam, for the plots of WUA-Q showed that WUA was lost and gained as discharges increased, in a way that was not obviously linked to channel shape or bankfull level. Nor could anything be gleaned regarding which flow surges or floods should also be incorporated into a modified flow regime, and IFIM does not guide on how this could be determined.

Indeed, structured links between IFIM and the hydrological record of the river of concern are almost non-existent, and do not seem to be used in any way to aid the final flow recommendation. Yet this same record is the first, and often the main, guide that South African river scientists have when making a flow recommendation and is thus used extensively locally (Chapter Twelve). For this reason, and because of IFIM's limited output of predictions of microhabitat at the species level, it thus became clear that the methodology could not be used in South Africa, at least at the level of development learnt during this project, to provide recommendations on a comprehensive modified flow regime for maintenance of a river ecosystem. Despite its great vision and potential, and the very useful data collected during its implementation, IFIM should in reality be seen as only one of the suite of tools required when assessing the instream flow requirements of rivers.

5. CONCLUSIONS ON IFIM

IFIM is a complex and very difficult methodology to grasp conceptually, because it draws together many different disciplines. It is quite visionary in context and contains an extraordinary wealth of information within its many manuals. It is an outstanding training tool in a range of topics, if not in its clarity, creating a framework for studying catchments, river flow, water quality, river channels, biotopes and species in a structured way. In doing so, it guides researchers into a more comprehensive understanding of the relationships between these variables.

However, the methodology is confusing and, as was only realised during the project, incomplete. PHABSIM II is the only part of it that is used regularly, and the whole macrohabitat assessment module remains largely at the theoretical level. Its developers now see IFIM as more of an umbrella concept, providing a broad view of how one should proceed when attempting an instream flow assessment, and not as a comprehensive and pragmatic guide of what to do. As far as could be determined, there has been no attempt (until now) to apply it in its entirety.

The model PHABSIM II is user-unfriendly. The theoretical concepts incorporated into the model's programs were not presented in any text available to this project and so, for instance, there was limited understanding of how the model used data, how the "acceptable range" for the coefficients used in the various hydraulic equations were decided upon, or why it produced WUA in units of area when units of "worth" or "suitability" would seem to be more appropriate from the way the data seem to be used. The model contains invalid, undeveloped or redundant options without much or any indication of which are which, and produces large numbers of output files, much of the contents of which are repetitious. Although there is an option for using metric units, this does not work in practice, and so field data collected in metric units must be converted to imperial units for PHABSIM II and then converted back to metric units for presentations of its outputs.

It became clear that although the model presents the opportunity for possible misuse, it has considerable potential in the hands of an experienced hydraulic modeller. The complex series of options that it contains for manipulating the data enable such a modeller to produce the best possible description of the hydraulics of a site. Once this has been done, a less-experienced modeller could usefully experiment with the data to search for trends in the habitat-discharge relationships. To reach a high-quality description of the hydraulics of the river, however, it seems essential that an hydraulics engineer is involved from the beginning of the project, aiding the choice of sites, the placing of transects, the appropriate collection and manipulation of data, and the assessment of the quality of the hydraulic simulations. By the end of the project, the authors of this report felt that they understood the model sufficiently to start exploratory manipulations of data, but would still need help from an hydraulician to achieve a good hydraulic description of a study site.

There is much scientific discussion as to whether or not the three microhabitat variables used in PHABSIM II (depth, velocity, CI) are the only, or the correct ones, for describing microhabitat, or are used in the right way for this purpose in the model. It was not possible in this project to attempt to resolve the above issues but, accepting that a fairly simplistic picture is created by most models, depth, velocity and CI do seem to be the most obvious variables to choose to describe microhabitat. Equally important, however, is that data of this kind collected for the model are valuable in their own right. Whether or not they are ultimately used in PHABSIM II, attention is focussed, and knowledge gained, on the how the riverine biota react to flow. Gradual creation of a library of SI curves for important riverine species thus seems a worthwhile target for South African researchers. This will have to run in parallel with research on how transferable such curves are between sites, rivers and seasons.

6. INITIAL DEVELOPMENT OF ALTERNATIVE METHODS FOR ASSESSING INSTREAM FLOW REQUIREMENTS

During the project, as it became obvious that IFIM was incomplete and could not provide a recommendation for a comprehensive modified flow regime, the development of two alternative potential methodologies began.

6.1 THE USE OF DAILY FLOW RECORDS

In the first initiative (Chapter Eleven), the daily flow data held by DWAF were used to search nationwide for rivers with similar flow patterns. This has been done before in South Africa, but by using rainfall data and catchment characteristics. It has not been attempted at the level of resolution required for ecological work, where the specific flows that the biota are experiencing are more relevant than some coarser statistic of flow. It was hoped that similar rivers would group regionally, so that extrapolations regarding flow patterns could be made from known to unknown rivers within a region. Considering the time and data constraints pertaining whenever a new water-resource development is proposed, such extrapolations would improve the ability to make a sensible recommendation for a modified flow regime for the river of concern.

Two different methods were used to analyse the data. Method One used cluster analysis and discriminant analysis, in which the computer programs use fixed algorithms to form the groups of similar rivers, and the results are objective and reproducible. Method Two used correspondence analysis and covariance biplots, which are exploratory techniques the results of which require interpretation and subjective decisions at many stages of the analysis. They allow information which is not in the data set, such as geographical location or catchment boundaries, to be taken into consideration, but the results are not necessarily repeatable by another researcher. Method One can be used to group rivers that are similar, while Method Two can be used to group rivers that are, perhaps, less similar but occur within defined geographic regions.

Using both Methods, the daily flow data for almost 300 gauging stations recording near-natural flow were investigated in two forms. First, similarities in seasonal flow patterns were sought by comparing the proportions of annual flow occurring in each calendar month. Secondly, similarities in flow types were sought, using derived variables of flow which were thought to be ecologically significant, such as the coefficient of variation and the number of days of zero flow.

The research revealed that, based on the monthly proportions of flow, only three major geographical super-regions could be identified: the winter rainfall area in the south-west Cape, the aseasonal rainfall area in the southern Cape, and the summer rainfall area in the rest of the country. Method Two, because of its iterative approach, was then used to create regions within the summer-rainfall super-region, which were based on catchment boundaries and somewhat similar flow patterns. Both Methods produced statistics of flow which described each of their groups.

When the derived variables of flow were analysed to search for similar flow types, stations were grouped differently by the two Methods. Each method placed the stations into different flow-type groups and these groups were described differently. Method Two produced supergroups called 'perennial', 'quasi-perennial-seasonal' and 'extreme seasonal', which could further be described as tending to have high, medium or low flood frequencies or high, medium or low flood durations. Method One produced groups which could be placed in categories such as, for example, 'perennial and predictable', 'long flood durations' or 'unpredictable floods'. Both methods produced mosaics of different flow types within any one geographical region, but showed tendencies for certain flow types to dominate particular areas. The different flow types occurring within a region are probably due to the effect of using gauging stations from different parts of the river system.

The results support the findings of similar research in other countries, showing that several types of flow patterns occur within any one geographical area. Nevertheless, it is highly likely that there will be a future need to group similar rivers, in order to extrapolate from known to unknown situations. It is therefore recommended that methodologies be further developed that do not necessarily require such groups to have geographical boundaries.

6.2 THE BUILDING BLOCK METHODOLOGY

The second initiative concerns a methodology that is being developed by river scientists involved in the Instream Flow Assessment workshops run by the Environment Studies sub-directorate of DWAF. As DWAF has moved to adopt the guidelines of Integrated Environmental Management, a routine sequence to the initial scoping and screening exercise for any proposed dam (or ROIP) has become a workshop to determine the Instream Flow Requirements of the river downstream of the dam.

The Building Block Methodology (Chapter Twelve) is designed to be used in such workshops, in situations where time, finances and relevant biological data are limited. It is based on the assumption that species associated with a river can cope with baseflow conditions that naturally occur in it often, and may be reliant on higher flow conditions that occur in it certain times (e.g. specifically-timed floods). It is further assumed, though largely untested as yet, that identifying such flow conditions and ensuring that they are incorporated as part of a modified flow regime will allow some semblance of the natural biota and associated functioning of the river to be maintained. Finally, it is also assumed that certain kinds of flow influence channel geomorphology more than others, and that incorporating such flows into the modified flow regime will aid maintenance of the natural channel structure. Thus, the recommended modified flow regime is envisaged as encompassing a framework of commonly-occurring low flows, interspersed with selected higher flows each of which adheres to natural limits of magnitude, duration and timing, and performs certain functions.

The methodology has been developed over the last two years, through use in South Africa in four workshops addressing the instream flow requirements of specific rivers. It represents, at best, a first attempt to determine the modified flow regime needed to maintain a river at some pre-determined state, but most of those involved in the workshops feel that, as a statement on behalf of the river, it is better than the two possible alternatives: to leave the assessment to those with no understanding of riverine functioning, or to make no provision at all for the river's requirement for water. Improvement of the Building Block Methodology continues through its application at DWAF workshops and through focussed research projects presently underway in the country.

7. EXTENT TO WHICH THE CONTRACT OBJECTIVES WERE REACHED

With reference to the project aims:

- The synthesis report on methodologies presently available for instream flow assessments is available in draft form. After inclusion of further literature acquired during the project, it will be finalised.

- The Instream Flow Incremental Methodology was learnt, and applied and tested in a South African situation which represents the local realities of assessing the water requirements of rivers. Problems encountered were described and some solutions offered.

- Selected daily flow records were obtained from DWAF, and analysed to assess their usefulness in grouping like rivers based on similar flow patterns.

- Neither IFIM or the daily-flow analyses provided the means of producing a recommendation of a comprehensive modified flow regime for a regulated river in the way required by DWAF. Both approaches can provide part of the answer, however, and both produce flow-related data on rivers which are valuable in their own right. They should both be seen as members of the suite of tools available to those making recommendations on modified flow regimes.

- Development of an alternative methodology has begun for situations where little time, finances or data are available. This is being done in liaison with other river scientists and DWAF personnel. At the same time, the newly-developed Kruger National Park Rivers Research Programme is providing a more comprehensive approach to assessment of the water requirements of rivers.

- With initiatives such as these already underway in South Africa, the main recommendations for further developing the science of instream flow assessments are that these initiatives be supported, while not losing sight of the experience and knowledge of those who developed IFIM or are presently engaged in similar work in other countries.

8. RECOMMENDATIONS FOR FUTURE WORK

Links between South Africa and those scientists developing and using IFIM should be maintained, because new developments are continually taking place. Links should also be created or strengthened with other large river research programmes in other countries, as well as with researchers in the science of instream flow assessments in southern Africa and Australia.

Assessment of the various methodologies for instream flow assessments currently used or available in South Africa should be made by the national community of river scientists and water managers, and recommendations made regarding which should be used in any specific circumstance.

Links should be strengthened between river ecologists, fluvial geomorphologists and hydrologists, so that ecological-meaningful flows can be defined, used in hydrological simulations and ultimately incorporated into recommendations for modified flow regimes. Further development of hydrological models that can simulate daily flows to an acceptable degree of accuracy for ecological purposes, should also be done.

Research should be intensified on the reactions of riverine biotas to unnaturally high or unnaturally low low-flows. It should also be focussed on the roles played by floods in the maintenance of riverine ecosystems.

The creation of a national data base, listing the conditions in which riverine species are most often found, should be co-ordinated. Some work of this kind is already underway, for both water quantity and water quality criteria.

With appropriate flow-related data so scarce for South African riverine biotas, an interim management option for the country might be to manage river flow at the biotope level (that is, at the level of the riffle, the pool, and so on). The potential for inter-disciplinary work at the level of the biotope should thus be explored.

TABLE OF CONTENTS

TERMS OF REFERENCE

The overall aim of this study, in terms of the agreement between the Water Research Commission and the University of Cape Town, was to establish in South Africa one or more scientifically acceptable methodologies for assessing the instream flow requirements of the country's rivers.

More specifically, the original aims were:

1. To compile a synthesis report of present worldwide knowledge on methodologies for assessing instream flow requirements, including a review of methods for addressing instream flow requirements not catered for by the Instream Flow Incremental Methodology (IFIM) (e.g. the requirement for flushing flows or a particular water quality).

2. To develop local expertise in IFIM through a research programme of field work and computer training, using the Eerste (south-western Cape) and Olifants (western Cape) Rivers as experimental rivers.

3. To critically assess the strengths and weaknesses of IFIM, identify which of its assumptions and techniques were amenable to testing, and carry out feasible short-term and long-term tests. Additionally, to present possible solutions to problems encountered during these activities and make suggestions for further research.

4. To use IFIM to establish the instream flow requirements of the Olifants and Eerste Rivers. Later, at the request of the Water Research Commission, an additional aim was to liaise with certain researchers working on the Letaba and Sabie Rivers in the eastern Transvaal, and aid their application of IFIM to their study rivers. The research on the two Transvaal rivers is the subject of separate reports to the Water Research Commission.

5. To establish, in a separate exercise, the usefulness of the historical flow records of the Department of Water Affairs and Forestry in determining the minimum, maintenance and maximum monthly instream flow requirements of South African rivers.

6. To compare results from the IFIM and Historical Flow Record approaches for the rivers studied, discuss the ecological and management implications of the results and make recommendations on how instream flow assessments should be undertaken in future.

During the course of the project, the following amendments to these aims were approved:

1. The Eerste River was excluded from the programme, and all experimental work in the Cape was focussed on the Olifants River. This was due to time constraints becoming

obvious as the extent and complexity of the IFIM methodology was revealed, and also to the wish to concentrate all biological work on one river so that results for different components of the biota could be compared.

2. In the research on historical flow records, the search for a methodology for assessing minimum, maintenance and maximum flows for regulated rivers was deferred until a thorough analysis of regional flow patterns had been done. The need for this analysis had been recognised, but initially it had been envisaged as a fairly simple preliminary task.

3. The proposal to use IFIM to make a preliminary assessment of the instream flow requirements of the Letaba River was abandoned. This was because the researchers working on that river could not spare the time to collect the specific field data required for the link-up.

LIST OF TABLES

(table captions are abbreviated) *PAGE*

LIST OF FIGURES

(figure captions are abbreviated) *PAGE*

LIST OF APPENDICES

(appendix captions are abbreviated) *PAGE*

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We have turned to Mr Bill Rowlston and Dr Robert Milhous for help many times throughout this project. Bill Rowlston learned to use PHABSIM II in order to contribute to this work, spent a large amount of private time testing it on our behalf, and guided our efforts to learn it. Bob Milhous visited South Africa in 1992 to teach local river scientists about IFIM. Much of the success of this project is due to their support, for which we are very grateful, while any errors in interpreting their work and advice remain ours.

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1. INTRODUCTION

There are several different climatic regions within South Africa, ranging from Mediterranean to desert, and peak rainfall times range from summer to winter to unpredictable; much of the country is semi-arid. Average annual rainfall is less than 500 mm, little more than half the world average of 860 mm (Department of Water Affairs (DWA) 1986). Sixty-five per cent of the country receives less than 500 mm of rain annually, while 21% receives less than 200 mm per annum. These phenomena are reflected in river flow, with only 8.6% of rainfall reaching the rivers compared with, for instance, 66% for Canada (Alexander 1985). Additionally, river flow in almost all unregulated (undammed) rivers exhibits high seasonal variability and, in many parts of the country, high temporal unpredictability (DWA 1986).

Creating reliable sources of water for South Africa's burgeoning human population becomes essential under such conditions, and most major rivers are now dammed. The tendency has been to commence water storage as soon as the wet season begins, with the minimum releases that occur at this time being compensation flows for downstream users. There is, understandably, a marked reluctance to allow appreciable amounts of water down the rivers while dams are filling. Major releases from dams usually occur later in the wet season when the storage reservoirs are close to full. In regulated rivers the first floods may thus come down the river some time after the beginning of the wet season, and wet-season flows may be greatly reduced from the natural levels. At the beginning of the dry season, with most domestic and industrial requirements for water continuing at about the same level as in the wet season and irrigation requirements increasing, water releases into rivers for downstream users may increase their flows above the normal dry-season level. In regulated rivers there is thus a general tendency, to varying degrees, toward retardation of the onset of high flows and a reversal of seasonal flow patterns.

With projected further high increases in human population numbers, continuation of these trends seems inevitable. Already, the major dams in South Africa have the capacity to harness about 52% of the mean annual runoff (MAR) (DWA 1986), while the inter-basin transfer schemes which are extant, under construction or in an advanced stage of planning, will have the ability to transfer about 14% of the economically utilizable MAR between catchments (W.S. Rowlston, Department of Water Affairs and Forestry (DWAF), pers. comm.).

Until recently, though the effort put into the development of the country's water resources has been enormous, scant attention has been paid to the ecological requirements of the riverine ecosystems providing most of the water. The many functions provided by the living components of rivers, such as bank stabilisation, flood attenuation and water purification, have been readily acknowledged, but often the components themselves have not, and so have remained uncatered for in terms of water quality and quantity. The financial costs of reparation as a result of ignoring the requirements of these living systems, such as dredging silted-up dams, repairing flood damage, combatting toxic blue-green algal blooms, shoring-up eroding banks and so on, are enormous. In addition, there are inevitable ecological consequences, such as loss of habitats and species. In the past, the links between all of these kinds of long-term costs and the initial acts of disturbance to the riverine ecosystems have rarely been recognised by water managers and decision-makers.

DWAF has recently recognised that water-development schemes may have potentially large impacts on the environment. For this and other reasons, it has shifted its policy from one of the provision of water, more or less on demand, to one of comprehensive management of water systems (DWAF 1992a). This enlightened move has resulted in, among other things, debate as to whether rivers are "the resource", the water needs of which should be met first, or "competing users of water" that should be considered in line with all other potential users of their water. Whatever is resolved, it is clear that guidance as to the water requirements of rivers is now needed. These requirements, often described using such terms as **instream flow requirements, ecological flow requirements** or **environmental water allocations**, should be quantified in terms of the magnitude, timing, duration and frequency of different flows.

The onus is on river scientists to provide this information, which can be done through an instream flow assessment. The essence of such an assessment is to identify those fundamental components of a river's flow regime that are considered essential for perpetuation of its valued ecological or water-resource features, and to negotiate for these to be built into a modified flow regime.

Development of the relatively new science of instream flow assessment has been well documented, especially in North America, where early work in this field was begun as far back as the 1950s (Trihey & Stalnaker 1985). Such assessments can be based primarily on hydrological data or on hydrological, hydraulic and biological data; most are variations on the theme that changing amounts of physical habitat become available with changes in flow, and are aimed at the preservation of target species (O'Keeffe *et al.* 1989). In North America, where most instream flow assessment have been done, the very narrow objective of most such studies has been to determine how the physical habitat (mostly in hydraulic terms) preferred by game fish such as trout could be maintained or reproduced in the river of concern. In other countries, such as South Africa, the United Kingdom and Australia, there has been less concern about safe-guarding single species, perhaps because the sports-fishing lobby groups have been less vociferous or the species of game fish less important. In these countries, then, the accent is more on the maintenance of whole riverine ecosystems than of single species (King *et al.* in press).

Instream flow assessments are still in their infancy in South Africa, but water managers, hydrologists, hydraulics engineers and river scientists are already developing a common language and a working relationship with regard to the management of rivers. Their joint recognition that the water requirements of ecosystems involved in water-resource development needed to be addressed led directly to this project being proposed. There was a need both to learn and assess existing methodologies for determining the water requirements of rivers and, if necessary, to begin development of new methodologies suited to local conditions. Thus, this project became the first attempt in South Africa to comprehensively study the field of instream flow methodologies. It started at a time when the country's river scientists, water engineers and water managers alike were focussing on new ways of studying and describing river flow, and forming new teams to guide sustainable management of the country's rivers.

Referring to the Terms of Reference for this project, the literature review on existing methodologies forms a separate document (Tharme in prep.). The other objectives listed in the

Terms of Reference are reported on in this document. Chapter Two provides an historical background on the development of instream flow assessments in South Africa. In Chapter Three the concepts and practicalities of the Instream Flow Incremental Methodology (IFIM) are focussed on, for this is the most developed and well known methodology worldwide for such assessments. Chapters Four to Ten record project activities in learning and assessing IFIM, the problems encountered in applying the methodology, the lessons learnt and the conclusions drawn. Alternative approaches to instream flow assessments that are being developed in South Africa are described in Chapters Eleven and Twelve. In Chapter Thirteen recommendations are made for the further development of instream flow methodologies in South Africa.

2. THE HISTORICAL DEVELOPMENT OF INSTREAM FLOW ASSESSMENTS IN SOUTH AFRICA

2.1 GROWING AWARENESS OF THE NEED FOR ENVIRONMENTAL WATER ALLOCATIONS

In 1983, Roberts, in projecting the future freshwater demands in South Africa, introduced the idea of "11% for conservation", this referring to a percentage of the estimated total water requirements of all sectors in the year 2000 (Roberts 1983). This proposal, by an engineer, was designed to introduce the country's engineering community to the idea of allocating water for environmental management.

Robert's figure of 11% for conservation, however, was based not on the water requirements of rivers, but on a coarse estimate of the countrywide water needs of estuaries, lakes and nature reserves. Thus, it could not be used to calculate the requirements of individual rivers, although it was a useful catalyst for future research on the topic. Roberts acknowledged that his estimate was simplistic, and recommended that engineers and scientists undertake intensive research as soon as possible to obtain more accurate values.

At least one such study had already been done. With construction of the Pongolapoort Dam in Zululand in 1969, ecologists warned that the extensive inland floodplain of the Pongola River was threatened (Coke 1970). The comprehensive series of investigations that followed (Phélines *et al.* 1973; Bruton & Cooper 1980; Heeg & Breen 1982) was designed to determine and minimise the likely impacts of the dam on the floodplain. Existing data on water quality, hydrology and biological studies were collated and new studies undertaken. As a result, recommendations were made for flood releases from the dam (W.J.R. Alexander, University of Pretoria, pers. comm.; unpublished DWA report). These recommendations were aimed at creating a specific flooding regime for the floodplain pans, and do not appear to have necessarily catered for the flow requirements of the other components of the riverine ecosystem outside the floodplain. It was not possible to trace published literature giving a detailed explanation of how the recommended modified flow regime was derived from the gathered hydrological and biological data, and so these vital stages of an instream flow assessment cannot be commented upon. Many lessons on how to undertake such an assessment must have been learnt during this research, and a record of these, plus an outline of a workable methodology, would have been invaluable for others.

Some years later, in 1987, the problem of how to assess the flow requirements of river ecosystems was again addressed in South Africa. Two multidisciplinary workshops were held, organised by DWAF and the Foundation for Research Development (FRD), respectively. DWAF wished to make decisions on future water allocations in the eastern Transvaal, an area which includes the Kruger National Park. Participants in that workshop were mostly those already active in that region in the fields of water management, engineering, nature conservation and freshwater ecology (Bruwer 1991). The FRD workshop was of a more generalised nature, designed to bring together, and assess the relevant knowledge of, the wider national community of river scientists, engineers and managers (Ferrar 1989).

At the time of these workshops many of the participants, although prominent in their respective fields, still knew little of the theory and practice of water allocations for the environment. Also, many had little experience of multidisciplinary workshops catering for such widely different fields as civil engineering and freshwater ecology. The products of the two workshops included two suggested approaches for arriving at preliminary estimates of instream flow requirements (King & O'Keeffe 1989).

Both approaches represented conceptual frameworks within which instream flow assessments could be developed, rather than detailed descriptions for achieving them. The "Flow Simulation Method" used a combination of hydrological data on virgin daily flow and any relevant ecological knowledge to identify monthly limits between which base flow should remain; additional ecological requirements, such as flushing flows, were superimposed on this basic pattern. The "Skukuza Method" identified those ecological components of riverine ecosystems which were consumptive and non-consumptive users of water, and allocated amounts of water to each; the users could be identified by first recognising certain depths of water which fulfilled different ecological requirements, and then determining the timing, duration and magnitude of the flow events needed to produce these water depths.

Elements of almost any approach to instream flow assessments can be seen in these methods and in the Pongola study, because some combination of the same basic sets of information seems to be needed irrespective of the approach adopted. The crucial next step, however, is the adoption of structured methodologies for assessing instream flow requirements or, if present ones are unsuitable, the development of new methodologies. This step would encourage a deeper understanding of the ecological processes being catered for, require the development of more sophisticated methods for manipulating data and ensure that experience and expertise are handed on. No co-ordinated efforts were made to adopt or develop any formal methodologies for instream flow assessments at that time.

2.2 LOCAL RESEARCH ON METHODOLOGIES FOR INSTREAM FLOW ASSESSMENTS BEGINS

New research initiatives in the field of instream flow assessments began in about 1989 and have grown through the early 1990s. Engineers and planners from DWAF have joined forces with river ecologists, fluvial geomorphologists and hydrologists from the University of Cape Town, Rhodes University, the University of the Witwatersrand and the Division of Water Technology, Council for Scientific and Industrial Research; with scientists from Provincial Nature

Conservation Departments and the National Parks Board; with several groups of consulting engineers; and with others, to initiate assessments of the ecological water requirements of important rivers targetted for development of their water resources. Major funders of the effort are DWAF, the Water Research Commission (WRC), the Department of Environment Affairs (DEA) and FRD.

Most effort is presently being concentrated on the recently established Kruger National Park (KNP) Rivers Research Programme. Several approaches to assessing instream flow requirements are being tested on the rivers of the Kruger National Park, and especially on the Sabie River, the least modified of its rivers. Intensive studies of, *inter alia*, sediment transport, habitat requirements of the aquatic biota, and the relationships between groundwater movement and the riparian zone are being done by researchers on the KNP programme. At present, test applications of IFIM (Bovee & Milhous 1978) and the "Skukuza Method" are being made, and many of the projects underway are collecting data in a form suitable for use in one or other of these approaches. Additionally, O'Keeffe & Davies (1991) described a method of assessment which used simulated monthly hydrological data for the Sabie River under natural and developed conditions to create a range of possible flow regimes. These regimes were then assessed for acceptability, using a conservation status model (O'Keeffe *et al.* 1987).

The detailed information emanating from the KNP programme should result in high-resolution estimates of the instream flow requirements of the KNP rivers. In addition, it is hoped that one or more clear methodologies for assessing instream water requirements can be distilled from this intensive, long term, multidisciplinary research effort; these could be applied to the many other rivers in South Africa requiring such information for management purposes.

In parallel with the KNP Rivers Research Programme, and in many cases preceding it, there have been other major activities related to the application of methodologies for instream flow assessments. The project reported upon here arose from ideas originating at the FRD workshop in 1987 and developed during a visit in 1989 of Dr James Gore to the first author of this report. Dr Gore, who is the leading North American scientist using riverine invertebrates in instream flow studies, first brought IFIM to South Africa, thereby providing the initial literature and computer programs used in this project. The author of the IFIM model PHABSIM II, Dr Robert Milhous, also visited South Africa in 1992, working with project members and members of the KNP programme (King *et al.* in prep.). Activities surrounding both of these visits greatly broadened scientists' knowledge about methodologies for instream flow assessments as well as helping create a wider awareness of the subject among water managers and engineers.

Project members have also worked with the Environmental Studies sub-directorate of DWAF, which has an ongoing programme of assessing the water requirements of rivers earmarked for water-resource development. Often working with rivers about which little is known, and with budget restrictions and severe time restrictions, members of the sub-directorate have brought together teams of specialists to provide guidance on instream flow requirements based on the best available knowledge (e.g. DWA 1989 (Orange River estuary); DWA 1990a (Orange River); DWAF 1992b (Lephalala River); DWAF 1993a (Berg River); and DWAF 1993b (Berg River estuary). They have also been outstanding in their encouragement of the development of new methodologies. One such local approach to instream flow assessments (see Chapter Twelve) was first applied at the DWAF workshop on the water requirements of the Lephalala River (DWAF 1992b). Designed to cope with the fact that only minimal amounts of data, time and finances are usually available for instream flow assessments in South Africa, this methodology will continue to be developed in a new project beginning with the Water Research Commission in 1993 (King & Tharme: The effects of different magnitude flows on South African riverine ecosystems). The experiences of members of the Environmental Studies sub-directorate of DWAF regarding the kinds of data and understanding that were urgently needed for their assessments but not available, would be as valuable an input to the KNP Rivers Research Programme as detailed information emanating from that programme would be to their work.

There are some more isolated local activities related to the development of methodologies for instream flow assessments. Of particular interest is the work of Kleynhans, who is studying the effects of groundwater abstraction on the nearby Limpopo River ecosystem and developing a structured approach for judging when such abstractions should be halted. Faced with the common problems of limited time, data and finances, he has recorded a series of data on conditions in the river and used this to draw up interesting and useful guidelines for controlling water abstractions (Kleynhans 1992a, 1992b, 1992c).

Good communication between all disciplines involved in instream flow assessments has become a strong feature of such work in South Africa, and is largely due to the very effective facilitating activities of the funding bodies. These have enabled most interested parties to keep in touch with each other and with developments in the field, and have promoted the formation of new teams designed to develop relevant theory and practice. All of these activities have been aided by the recognition by DWAF that "the natural environment is a legitimate water user with specific needs" (DWAF 1992a). Further discussion on this and on the future development of instream flow methodologies appears in Chapter Thirteen.

3. CONCEPTS AND PRACTICALITIES OF THE INSTREAM FLOW INCREMENTAL METHODOLOGY AND ITS MODEL PHABSIM II

3.1 INTRODUCTION

The Instream Flow Incremental Methodology (IFIM) and its model PHABSIM I (now upgraded to PHABSIM II) were devised by the United States Fish and Wildlife Service to assist in the assessment of instream flow requirements of rivers (Bovee 1982). An instream flow requirement may be described as the quantity of water required for a particular use within a river; historically it has usually described that required for maintenance of a specific aquatic species, but it may be used to refer to the water requirements for other needs, such as recreation or maintenance of the complete river ecosystem.

In the last two decades, as IFIM and PHABSIM II have been developed, a plethora of information on them has been written. More than twenty manuals, many quite long, have been compiled on specific aspects such as Probability of Use Criteria, Stream Network Habitat Analysis and the Techniques and Theory of Hydraulic Simulations; the manual for PHABSIM II alone is more than 500 pages long.

These manuals track the development of the methodology and so contain not only valuable information, but also a variety of terms, ideas and techniques that later became redundant. Much of the later literature was compiled in response to earlier criticisms, and so the information as a whole has to be pieced together rather like a jigsaw puzzle. There is presently no detailed synthesis of the current state of the methodology that allows one to assess which of the earlier information is redundant. Nor is there a brief but clear step-by-step description of the methodology in its entirety that helps one both to gain an overview of the sequence of tasks to be done and to understand why they are needed. The amount of information that has to be absorbed before the methodology makes practical sense is formidable, and the amount of learning that has to occur, no matter which discipline one starts from, is extensive.

In this Chapter, a step-by-step overview of the concepts and practicalities of IFIM and PHABSIM II has been compiled. Brevity is aimed at, so that the complete methodology can be understood, but with sufficient detail for it to be judged. Throughout, the information is presented in a way that is hopefully user-friendly to those learning their way into this new field from either the engineering or ecological disciplines. It would be impossible to cover all details provided by the IFIM manuals, and so literature with a more in-depth treatment of specific subjects is referenced. Additionally, Tharme (in prep.) provides a detailed review of the international literature dealing with IFIM and PHABSIM II.

The Water Research Commission funded a visit in October 1992 by the author of PHABSIM II, Dr Robert T. Milhous, which helped clarify many areas of confusion. Dr Milhous' explanations, some of which may not occur in any published literature, are included where appropriate as personal communications.

3.2 OUTLINE OF THE INSTREAM FLOW INCREMENTAL METHODOLOGY (IFIM)

A general outline of IFIM is given in this Section. Sections 3.3 to 3.18 then provide greater detail of each step of the methodology.

IFIM is considered to be the most sophisticated methodology available for quantitatively assessing the instream flow requirements of rivers (Gore & Nestler 1988). It comprises a collection of analytical procedures and computer programs, including the Physical Habitat Simulation Model, PHABSIM II (Milhous *et al.* 1989), which is its best known component.

In its entirety IFIM is said to evaluate the effects of incremental changes in stream flow on channel structure, water quality, temperature and availability of suitable microhabitat (see glossary) for selected target aquatic species (Orth 1987). Incrementalism is an approach to problem solving that involves slightly modifying procedures or positions from those previously established (Bovee 1982) and assessing the effects. In the context of IFIM it is usually used to assess the impacts on a river of a water-resource development such as a dam, by predicting changes in the amount of physical microhabitat available to chosen aquatic organisms with increments of flow change. The output from the methodology is used to negotiate for water allocations for the river, for some identified purpose. Other quite far-reaching uses are claimed for the methodology, such as the translation of changes in land use to changes in the stream environment (Bovee 1982).

The procedures within IFIM are designed to allow a complete evaluation of the effects of incremental changes in flow. Included are procedures or information for considering the study objective(s), selecting study reaches and target species (see glossary), assessing the suitability of the macrohabitat ("environment"; see glossary), and assessing microhabitat availability, as well as techniques for decision-making once the rest of the IFIM approach has been completed. Details of how to carry out each of these procedures range from very comprehensive for some, to no more than a mention that they should be done, for others. The **macrohabitat** referred to in the methodology appears to relate to those variables which are more or less consistent over the full width of the river, such as water temperature and water quality, while **microhabitat** (more accurately defined as **physical microhabitat**, for observations are limited to this) relates to variables that can vary significantly across the channel, such as water depth, velocity, substrate (see glossary) character and hydraulic and overhead cover.

The first tasks in an IFIM study are selection both of the study objectives and the extent of the river to be investigated, and identification of the target species; all of these will relate to the question to be answered by the study. Attention then focuses on the catchment and the macrohabitat. The catchment has to be shown to be in "dynamic equilibrium" or, if it is not, a prediction of its new equilibrium conditions has to be made - either way, the intention is to ensure that the channel conditions modelled later using PHABSIM II will remain valid. Then, the macrohabitat variables used in the IFIM procedures are recorded, to show where in the river such conditions are presently suitable for the target species, and predicted, to show where they will still be suitable after the water-resource development. This is done so that the assessment of microhabitat availability using PHABSIM II will be valid, for no species can live in a suitable microhabitat if the wider environmental conditions are unsuitable.

PHABSIM II is then used to simulate the amount of physical microhabitat available over a range of flows. PHABSIM II is an integral part of IFIM, but is often incorrectly used as being synonymous with it. Thus, many instream flow studies in the literature deal only with the microhabitat assessment, without giving prior attention to conditions in the river on a larger scale.

PHABSIM II is an hydraulic-environmental model that simulates the amount of physical microhabitat available for chosen target species over a chosen range of flows. It requires input data on channel morphology and on within-channel conditions at known calibration discharges, all of which are obtained from a series of channel cross-sections (transects). Using these, conditions over a wider range of unmeasured flows are simulated. The results are combined with data on the preferred physical microhabitat of the target species to assess how much of this microhabitat is available at any particular flow.

This output is the tool within IFIM that is used when making recommendations on future flows in the regulated river. At the simplest level, these recommendations usually involve the modeller/negotiator identifying, on a scale of decreasing flows, that at which the amount of available microhabitat sharply decreases and by recommending that flows do not drop below this value. More complicated and integrated techniques do exist, such as time series analyses, but these were not available to us at the time of this project.

The "target species" referred to in the above procedures is a generic term that can refer to a single species, species guild, community or life stage; a more detailed discussion on the topic is given in Section 3.5. Data on the microhabitat requirements of the target species are used to provide input to PHABSIM II. It is recognised that the species to be used should be selected by an experienced river ecologist with first-hand knowledge of the river concerned, with the choice of species depending on the objective to be achieved by an instream flow allocation. For instance, if it is wished to conserve rare fish species, they will become the target species, while if there is a more general wish to maintain a reasonably healthy river, the most diverse benthic invertebrate community within the river might be chosen, "most diverse" often being accepted as a substitute for "healthiest". Whatever is chosen as the target species, from then on its flow requirements represent the flow required in the river. Data collected on the hydraulic conditions it prefers become the input to PHABSIM II and simulated losses and gains of its microhabitat are the model's output. Negotiations for the required modified flow regime of a river are often based solely on this output even though it may not represent a comprehensive picture of the flow requirements of the river. Other components of the flow regime, such as flushing flows for instance, may have to be dealt with outside PHABSIM II because the model cannot adequately simulate conditions in, or help assess the required number and duration of, such flows.

The several sequential steps that constitute a complete IFIM analysis are detailed in Figure 3.1.

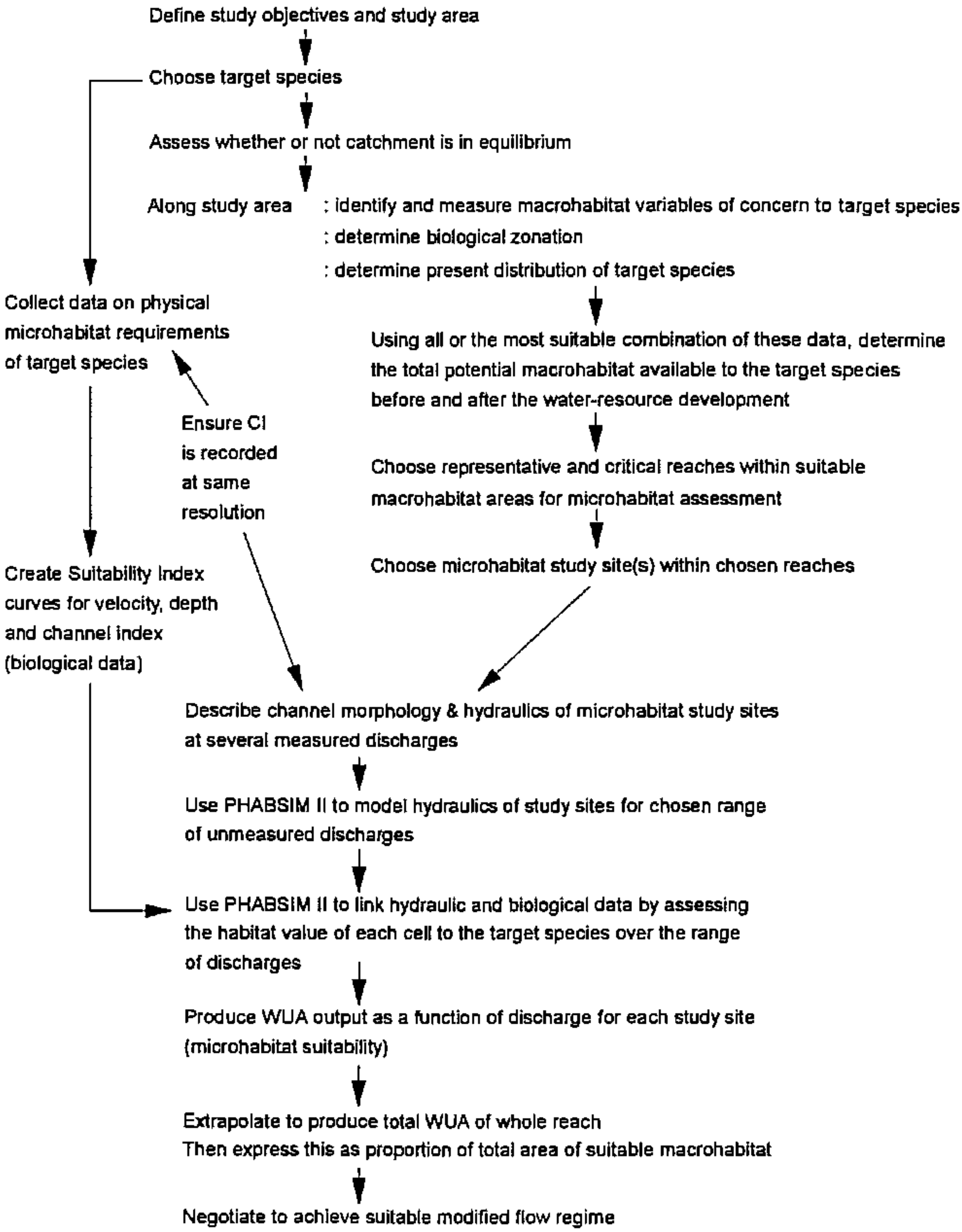


Figure 3.1 Steps involved in a comprehensive IFIM assessment (see text for details)

3.3 STEP ONE - IDENTIFICATION OF THE STUDY OBJECTIVES

> *In a dry country such as South Africa, any request for a water allocation must be well motivated. When the request is for water for a river ecosystem (i.e. reservation of some of the river's water for its own maintenance), the objective to be achieved within the system by the water allocation must be clearly stated. This ultimate objective which, for instance, may be the maintenance of the river in a near-pristine condition or maintenance of stable riparian strips to protect land from eroding, will dictate the objectives of the study and the target species chosen.*
>
> *IFIM appears to focus only on the study objectives, that is, the simulation of available microhabitat for a target species over a range of flows, and does not necessarily clearly address any greater objective than the immediate preservation of that species.*

Bovee (1982) states that the study objectives should be explicit, for they reflect the kind of study that will be conducted, determine the study approach and describe the way the results will be analysed. He gives an example of the detail required: "The objective of this study is to determine the impact of the proposed Miller Creek dam on the habitat potential for game fishes downstream of the dam site".

This kind of objective illustrates the limitations of a methodology that claims (Bovee 1982) to allow assessment of "instream flow problems" and to be applicable to "virtually any kind of disturbance to a riverine ecosystem", but really only allows assessment of possible changes in the physical microhabitat (described in a simplistic way) of selected species that must live in open water. These limitations appear to be less important in North America, where concern for commercial fish species largely dictates what will be studied and protected, than in South Africa, where the aim is maintenance of the integrity of river ecosystems rather than of specific species. The topic is dealt with in more detail in later Chapters on the study river and alternative approaches to assessing instream flow requirements.

3.4 STEP TWO - IDENTIFICATION OF THE STUDY AREA

The length of river to be included in the study area is dictated by the study objectives. The study area tends to be at one of three scales: river basin studies; site specific instream flow allocation studies, where the flow allocation must refer to an actual location on the river; or, at intermediate scales, project impact studies where the study area can contain several study sites (see glossary), all of which are within that portion of the river actually affected by the activity to be investigated (Bovee 1982).

3.5 STEP THREE - SELECTION OF TARGET SPECIES

The choice of target species is dictated by the study objectives. Where a specific species, guild, community or life-stage of a species is defined within the objectives, this will usually become the target species (e.g. for an objective such as "the flows that would provide most microhabitat for game fish species X", species X becomes the target species). On the other hand, where the general impact of a development on a river is to be investigated, species may be chosen using other criteria (e.g. for an objective such as "the flow that maintains the most diverse invertebrate community", either the most diverse community or an invertebrate with similar microhabitat requirements to this most diverse community could become the target species.

Major game, sport or commercial species are often chosen, as are endangered species, or species may be chosen by ranking them in order of their (a) importance from a management perspective and (b) vulnerability, and also (c) on the availability of information on them. Bovee (1982) stresses that all interpretations on environmental change are based on what happens to the target species. Thus, if the wrong species are evaluated, or an insufficient diversity or number of species is used, the analysis would be of little value.

3.6 STEP FOUR - THE ASSESSMENT OF CATCHMENT EQUILIBRIUM AND MACROHABITAT SUITABILITY

> *Independent of PHABSIM II, and as an essential pre-requisite to its application, is the implementation of the next stage of IFIM, which forms an assessment of (a) whether there is an existing problem associated with macrohabitat conditions that would be exacerbated by a water-resource development, and (b) where macrohabitat conditions are presently suitable, whether this will continue to be true after the development. Application of these early stages of IFIM are discussed by Tharme & King (1991), dealt with in depth in Chapters Four and Five, and summarised below.*

The assessment is reliant on the concept of "catchment equilibrium" *sensu* Bovee (1982), where dynamic changes in catchment factors such as water and sediment yields, and hence in associated macrohabitat conditions, are about some steady state (see glossary). Bovee stresses the importance of establishing whether or not the catchment is in equilibrium prior to commencing a full instream flow study. If it is in disequilibrium, the future new equilibrium conditions should be determined, for only then can the continued suitability of macrohabitat be judged. Bovee (1982) provides little practical information on how to assess if a state of catchment equilibrium exists or, if it does not, what time scales are likely to be involved in reaching a new equilibrium. The exercise seems to mainly involve a comparison of past and present information on both the annual flow regime and the sources and magnitudes of sediment inputs, but there are no guides as to satisfactory levels of resolution to work to, or what to do if, as in many South African cases, such information is simply not available. Bovee and co-workers, and others in North America using IFIM, apparently do not routinely attempt the exercise of catchment assessment (R.T. Milhous pers. comm.), even though they stress its importance.

Assuming for the present that the catchment is in equilibrium, the next step is to determine, for the part of the river that will be affected by the development (hereafter called 'the river'), present macrohabitat conditions and predict those likely to pertain after the development. This is necessary in order to ensure the validity of subsequently modelling the availability of microhabitat. Macrohabitat analyses concentrate on four variables related to the river: the hydrological regime, channel morphology and sediment dynamics, water quality and temperature. The first two of these variables, at least, are also part of the assessment of catchment equilibrium, although the link between the two kinds of analyses is not well explained and the required information seems to differ. The catchment assessment appears to concentrate on past and present conditions, with some attention paid to projected land-use changes (i.e. has the catchment changed in the past and is it still changing?), while the macrohabitat assessment concentrates more on present and future conditions (i.e. what are macrohabitat conditions at present and what are they likely to be after the development?).

In the macrohabitat assessment, data on the present values of these four variables are used to divide the river into longitudinal stretches with similar conditions, and to provide data input for the calibration of models outside IFIM that will simulate future macrohabitat conditions. They would also provide information for use in other techniques for assessing future conditions, should modelling not be chosen.

Using the data on present conditions, longitudinal segments of similar flow and channel morphology are identified along the river and, through the placing of macrohabitat study sites, the conditions of water temperature and water quality within each segment are determined in order to assess its suitability as macrohabitat. Later in IFIM, microhabitat sites are established in some or all of these segments and results from the analyses of microhabitat (i.e. the PHABSIM II output) can then be extrapolated over whole segments.

Bovee (1982) initially defines a segment as that length of river with a "common channel morphology and flow regime, but not necessarily the same water quality, temperature or species composition". However, he later states that segment boundaries occur wherever the flow regime changes significantly and subsegment boundaries occur wherever channel morphology changes significantly. Segments and subsegments are thus poorly distinguished and here both are encompassed in the term segment (see glossary). Indeed, the whole approach for dividing the river into units for further study is wordy and confusing, and the underlying concepts difficult to extract.

To take this further, Bovee's (1982) stated ideal is to:

- create a segment to represent every major change in channel morphology or where the average base flow changes by more than 10% (either through addition by a tributary or aggregate of tributaries, or loss by diversion).
- create a microhabitat study site in each of the segments.
- assess the number of segments, or parts of segments, that have the correct macrohabitat conditions for the target species, in terms of water quality and temperature.

- superimpose the PHABSIM II output of available microhabitat at the study site onto the segments (or parts thereof) with suitable macrohabitat conditions, to give total available habitat for the target species.

There is the potential for creating a high number of segments, sites for assessment of macrohabitat, and study sites for microhabitat analysis, which could become prohibitive in terms of time and other costs. Before these numbers could be reduced, however, the underlying concepts of segments and macrohabitat need to be considered.

Dealing first with segments, the requirement for a high number of segments based on flow is presumably to ensure that PHABSIM II does not describe hydraulic conditions (microhabitat) at a fine resolution which are then extrapolated to segments (macrohabitat) hydraulically delineated at a coarser resolution (that is, segments that have a wider range of hydraulic conditions). Similarly, the requirement for further segmentation based on channel morphology is presumably to ensure that PHABSIM II does not describe substrate conditions at a fine resolution that are then extrapolated to segments geomorphologically delineated at a coarser resolution.

The reality for all but the wealthiest agencies, however, probably is that segments will not formally be delineated or will be delineated and then clumped together in some way, and few rather than many study sites will be established. There is thus the potential that segments will be described at a coarse level which may negate the more refined output of PHABSIM II.

While segments seem designed to accurately describe hydraulic and geomorphological conditions in the river and thus allow a valid link-up with PHABSIM II at the level of the hydraulic programs, the macrohabitat assessment appears designed to determine the total length of the study area in which the target species can live, and thus allow a link-up with PHABSIM II through extrapolation of available microhabitat to a larger area. However the use of mainly or only a limited set of physical and chemical data to assess available macrohabitat seems inappropriate. This is because the riverine biotas react to the sum of many environmental variables, including biological ones, rather than to changes in a few physical and chemical variables. Unless one knows well the limits of tolerance of the chosen target species to each and every variable (many of which may not have been measured), this approach is of questionable value in delineating macrohabitat areas that are meaningful in terms of these species. Bovee (1982) occasionally mentions "species composition" in his discussion on identifying suitable macrohabitat areas, but does not explain how these kinds of data could fit into his scheme.

It is interesting to compare Bovee's approach with the "hydrobiological zones" long used by river ecologists to describe longitudinal downstream changes in biological communities (e.g. Illies 1961; Harrison 1965). Hydrobiological zones have traditionally been delineated along rivers in terms of the distribution of benthic aquatic invertebrate communities or fish communities, and have then been linked to measured changes in physical and chemical conditions. If the river is delineated in this way, most target species will correlate well with the distribution of one (or more) of these zones. In South Africa, as the range of tolerance of the target species to the measured variables of water quality and temperature will almost always not be known, establishment of suitable macrohabitat by Bovee's route would be difficult. Here and elsewhere hydrobiological zones would seem to provide a more realistic assessment of available macrohabitat for a target species than Bovee's approach, and it is assumed that this route was not followed because of the wish to restrict the variables used to those for which future conditions could most easily be modelled. Probably the best approach is to use all available information, including that on hydrobiological zones, to identify available macrohabitat.

Final confusions regarding this issue are the size of a segment and the degree of synonymity between segments and zone. In different parts of the manual on habitat analysis (Bovee, 1982), a segment is defined as being more than 10% of the total length of river under study (page 45) - it is not clear if this means total river length or total length of study area - while elsewhere (page 48) it is stated that a representative reach (see Section 3.7) can consist of a whole segment and in length should be 10 to 14 times the width of the channel. The former description implies that a segment may be many kilometers long, while the latter suggests it could be a few hundred metres long at most. As rivers tend to have few hydrobiological zones (usually between three and about eight) a segment appears to be shorter than an hydrobiological zone. In practice and bearing in mind the practical need to limit the number of study areas, it seems reasonable to assume that the hydrobiological zone consists of a group of segments and can be used as a guide to help decide the extent of available macrohabitat.

Whatever approach is used, following establishment of the present macrohabitat zonation in the river, it is necessary to simulate future macrohabitat conditions after development has taken place and assess if the zones will still cover the same stretches of river. This would normally be done through modelling water quality, water temperature and sediment dynamics. Other approaches are possible (Tharme & King 1991), but are usually less precise or require historical or empirical data that are not usually available in South Africa. With regard to the models currently available for this type of modelling, the time and expertise needed to run them is beyond the reach of all but the best-funded agencies. Although R.T. Milhous (pers. comm.) and J.A. Gore (Center for Environmental Research and Service, Troy State University, pers. comm.) state that this type of modelling is routinely performed at the outset of IFIM studies in North America, no literature could be found that reported on such an exercise as part of an IFIM study. According to Bovee (1982), there should be a preliminary screening to determine whether or not present or projected future macrohabitat conditions warrant such costly investigations, but he gives no guidance as to how this screening could be done and instead stresses that failure to accurately predict future macrohabitat changes could nullify all subsequent steps in IFIM.

If the modelling of macrohabitat change could be done, there remains the question of whether the simulations of future conditions would be at a level of accuracy justifying a subsequent in-depth analysis of microhabitat. If the modelling cannot be done, one is left with gathered data on the present macrohabitat condition of the river, but only a sketchy knowledge (if that) of what the future river zonation and macrohabitat conditions within those zones are likely to be. Finally, even if future conditions could be determined with sufficient accuracy, one still needs to know the range of conditions tolerated by the target species so that the suitability of these future conditions can be assessed. No guidelines are given regarding a satisfactory level of knowledge of these tolerance ranges and there seems to be the assumption that such data are available in the literature. There is very little information on the ranges of tolerance of any South African riverine species, however, and in its absence the whole exercise could become a costly and pointless exercise.

For these and, presumably, other reasons, most reports in the literature either assume that present conditions are suitable and future conditions will not differ significantly from them (e.g. Gore *et al.* 1991), or simply ignore the whole macrohabitat assessment (e.g. Bullock *et al.* 1991). Further details of both the approach and the critiques of it are reviewed by Tharme (in prep.).

3.7 STEP FIVE - THE LINK BETWEEN MACROHABITAT AND MICROHABITAT

> *To recap, the longitudinal zones delineated in the river represent different macrohabitat conditions, that is, different conditions of one or more of the following: water quality, water temperature, channel morphology, sediment dynamics and flow regime. Together these will influence and restrict the distribution of the riverine species, many of which may occur in only one zone. Within its zone or zones, the amount of microhabitat available to a species will alter with changes in discharge, as more or less channel becomes wetted.*

The objective of the next major part of IFIM is thus to use PHABSIM II to assess the changes in available microhabitat with changes in discharge, and define them, for any specified discharge, in terms of available microhabitat per unit length of stream. Subsequently, this is integrated with the macrohabitat that is suitable for the target species, as described in Section 3.6, to produce a statement of the total amount of microhabitat available to the species over a range of discharges.

Bearing in mind that the term "zone" is used to represent a collection of similar "segments" (see glossary), any reach within a zone should theoretically be very similar to any other, and so could act as that zone's representative reach in which the microhabitat studies will be done. Several techniques can be used to select representative reaches, of which the most commonly used is random selection. In this approach, a number of potential representative reaches are marked on a map, each of which is 10-14 times as long as the average width of the channel. As the cycle of riffles, pools, meanders and other geomorphological features are said to be repeated along a river at a spacing of 5 to 7 times the width of the channel (Leopold *et al.* 1964, cited in Bovee 1982), a representative reach as described above should include the full sequence of microhabitats existing in the zone. From these potential representative reaches one (or more) is chosen, theoretically randomly, but more usually with considerations of the practicalities of access in mind. The topic is dealt with more fully by Bovee (1982).

Critical, or unique, reaches are also recognised by Bovee (1982). These are portions of rivers containing a particular type of microhabitat that is absolutely essential for the completion of one or more life stages of the selected target species, but which is poorly represented in the representative reaches.

The final step in establishing the microhabitat study area(s) is to determine the total length of river represented by each representative reach (see glossary) and each critical reach (see glossary), each of which is called a reach length. The reach length will often be the same as the zone length, except where more than one reach is established per zone. Eventually, the reach length is multiplied by the available microhabitat per unit length of stream (the PHABSIM II output for that reach or zone), to show the total available microhabitat at any discharge. As far as is understood, any critical reach occurring within a zone is treated separately from the representative reach in all calculations and negotiations, otherwise its importance could go unnoticed. However, if the critical reach is only applicable for a certain time of the year (e.g. a spawning period) the representative and critical reaches can be combined in calculations for the rest of the year (Figure 3.2).

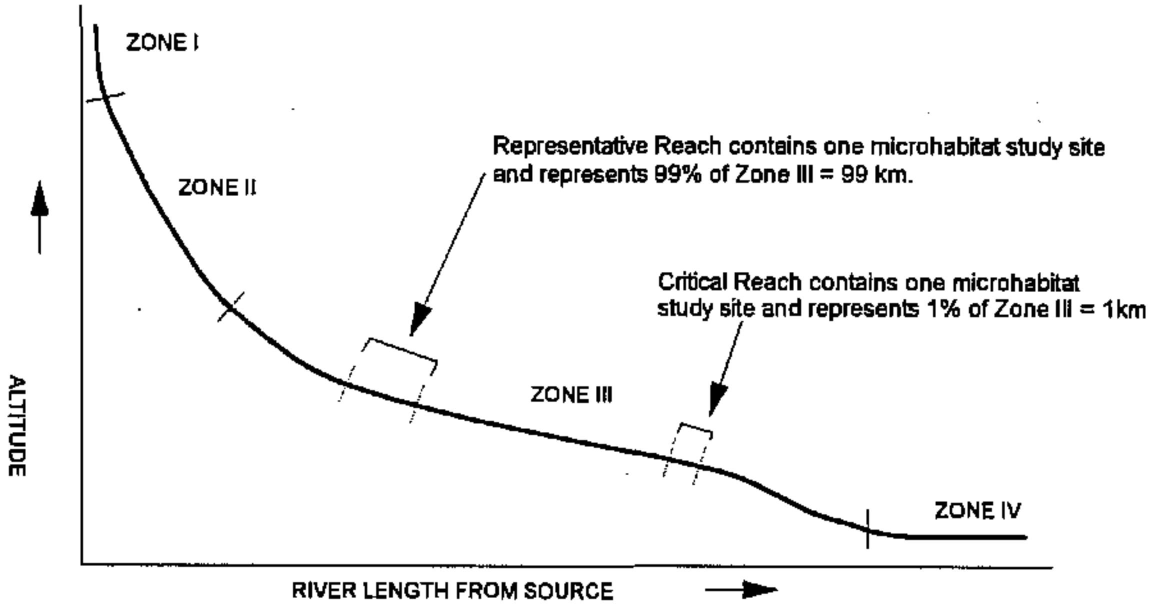
Bovee (1982) recommends, in a check list of procedures, that three to five representative reaches be chosen at random for each zone, though elsewhere in the manual it is stated that only one such reach is needed to represent the microhabitat for the entire zone, if all reaches are similar. As the amount of work involved in studying any one site is considerable, most researchers seem to establish a series of study sites in parts of the river that are obviously different, but without following any formal procedure (e.g. Orth & Maughan 1982; Shirvell & Dungey 1983). In these cases, the reach length equals the zone length.

3.8 STEP SIX - DESCRIBING A MICROHABITAT (PHABSIM II) STUDY SITE

> *Within each of the recognised reaches a study site is established which may be the length of the whole reach, or shorter, if the reach is similar throughout its length. Studies of channel morphology and channel hydraulics will be carried out at the study site to provide data input for PHABSIM II. The same site may be used for the biological studies required (see Sections 3.11 and 3.12).*
>
> *From this point on, the details within the IFIM manuals of what to do, and how to do it, become far more comprehensive than for the early stages of IFIM, reflecting the greater accent on the microhabitat studies in the methodology.*

The channel morphology and hydraulics of each site are described using a number of transects (cross-sections), which together represent all the kinds of in-channel conditions and microhabitats found within the study site - and thus, by inference, within the representative reach and relevant zone. A combination of depth and velocity readings, taken sequentially along each transect, and at several different known discharges, provides the basic information on how water is flowing through the channel (i.e. the hydraulic conditions). This information is the input data used to calibrate PHABSIM II, which then can produce simulations of hydraulic conditions over a specified range of unmeasured discharges. The simulations are linked with data on the microhabitat requirements of the target species, as described in Section 3.14.

Transects should stretch through the wetted channel to well above the highest known flood level on both banks. The most downstream transect must be at an hydraulic control (see glossary) in order for some of the hydraulic simulation routines in PHABSIM II to run.



1. MACROHABITAT

Length Zone III = 100 km
Channel width Zone III = 20 m
Total available macrohabitat = 2 km^2

2. REPRESENTATIVE REACH

Length = 99 km
Total wetted area = 1.98 km^2
WUA for Target Species (PHABSIM II output) = 800 m^2 per 100 m of stream
= 792 000 m^2 in 99 km
Total WUA of Representative Reach = 0.792 km^2 of a possible 1.98 km^2

3. CRITICAL REACH

Length = 1 km
Total wetted area = 0.02 km^2
WUA for Target Species (PHABSIM output) = 1500 m^2 per 100 m of stream
= 15 000 m^2 in 1 km
Total WUA of Representative Reach = 0.015 km^2 of a possible 0.02 km^2

NB. In terms of macrohabitat conditions, target sp. X can only live in Zone III.

NB. Total WUAs of Representative and Critical Reach cannot simply be added to give total WUA for Zone III (see text).

Figure 3.2 Calculation of total available microhabitat (WUA) for target species X at any one discharge, for an hypothetical river

Hydraulic controls can be defined as physical features in the channel, natural or man-made, which cause a change in the stage-discharge relationship - that is, they cause a break or inflection in the slope of the water surface (Bovee & Milhous 1978). Indeed, these authors stated that every hydraulic control within the study site should be described by a transect, and that additionally, "habitat transects" should be created to describe every type of microhabitat not described by an hydraulic transect. However, there is no guidance about how to cope with the facts that increasing numbers of hydraulic controls appear as discharges decrease, and that microhabitats appear and disappear as discharges change, which may result in the number of transects established becoming a function of the flow pertaining on that field trip. It is also not clearly explained in the manuals that the most commonly used hydraulic simulation routines do not require that every hydraulic control be described. If they are described, however, the number of options for manipulation of the data is increased, which would probably lead to fewer modelling problems and an increase in the accuracy of the hydraulic simulation. The hydraulic options within the model are discussed in Section 3.16.

Bovee & Milhous (1978), when describing the setting up of transects, advised against creating too many, but balancing this is the fact that too few or improperly placed transects will give a distorted view of both channel morphology and hydraulic conditions. Careful placement of transects is thus vital, and consultation with an hydraulics engineer at this stage would be invaluable. Between five and ten transects per study site seems to be an acceptable number, but there is no set number, and it is left to the researcher to judge the requirement for each site.

After selection of the transects, both end points (headstakes) of each one are surveyed in and all referenced to some common benchmark which may be an arbitrary datum or a recognised trigonometric point. It is strongly advised that the headstakes be marked with permanent survey beacons on which are recorded the site name, the number of the transect and whether it is on the right or left bank.

3.9 STEP SEVEN - COLLECTION OF PHYSICAL DATA

> *Several types of data collected along each of the transects are common to all of the hydraulic simulation routines encompassed in PHABSIM II, and their collection requires a variety of equipment and skills. Comprehensive instructions are given in Bovee & Milhous (1978).*

The data sets required are:

- The distance between transects (stationing)
- Height of the headstakes (headstake elevations)
- Sequential measurements of the height of the ground along each transect (ground elevations)
- Height of the water surface at each transect (water surface elevation - WSL)

- Discharge at each transect or the mean for the site (Q in $m^3 s^{-1}$)
- At each surveyed point: descriptions of substrate particle size and proportions; vegetal and other cover, both instream and overhead; and any other feature deemed to be an important component of the microhabitat of the target species (channel index - CI)

For most of the hydraulic programs, the following is also required:

- Sequential measurements of velocity across the river at each transect (velocity distributions). Depths are usually recorded at the same time, and are necessary if the transect is to be used for discharge calculations, but are not required as input to PHABSIM II. In practice, it was found that depth data were very useful for checking WSLs and the changing location of the edges of the wetted channel, and it is recommended that they always be recorded with velocity measurements.

Further details of each of these data sets are given below.

3.9.1 STATIONING

The distance between headstakes of successive transects is recorded on each bank and averaged; alternatively thalweg distances may be used. The transects are then allocated index numbers correlating with the cumulative distance upstream, starting with 000 for the most downstream one. The index number of the most upstream transect will equal the total length of the study site.

3.9.2 HEADSTAKE ELEVATIONS

Level loop closure, or some similar practice of cross-checking the elevations of all surveyed headstakes, is recommended. This could save later anguish with rivers that appear to flow up cliffs or down mine shafts.

3.9.3 GROUND ELEVATIONS

The profile of each transect is measured from headstake to headstake. All measurements should start from the same side of the river, but beware, as the left bank is variously stated as being the left side looking downstream (Bovee & Milhous 1978) or the left side looking upstream (Milhous *et al.* 1989). It does not seem to matter which is used, as long as everyone involved uses the same one and remembers which it is.

The transect profile is described by surveying in a series of horizontal distances, each linked to a ground elevation. The resultant survey points, or verticals, each form the centre or edge of a rectangle of channel called a cell (Figure 3.3). Parallel cells stretch up- and downstream of the transect for specified distances, meeting cells linked to neighbouring transects. Descriptions of the conditions within each cell are derived in various ways from the measurements taken at the verticals.

An early choice has to be made as to whether verticals will be established where there is an obvious change in gradient or channel index or be evenly spaced. Usually 20 to 30 are established, and are closer together within the wetted channel, where more detail is desirable. Thus, cells are wider on the dry banks and narrower within the wetted channel. Velocity and depth are measured at each vertical and information for the channel index is recorded. Details of the methods used are given in the following relevant Sections, but it is important to note here that if a channel index suitable for the target species has not yet been devised, or if several target species are to be used for which different components of the substrate and vegetal cover might be important, all potentially relevant features should be recorded at each survey point, so that suitable indices can be worked out later.

3.9.4 WATER SURFACE ELEVATIONS

> *In order to calibrate the hydraulic routines within PHABSIM II at least one set of readings of WSLs is required, which consists of the WSL at each transect. Some of the hydraulic simulation routines require more than one set of WSLs, taken at discharges that are as dissimilar as possible. The selection of an appropriate simulation routine is discussed in Section 3.16.2. The discharge pertaining to each set of WSLs must be known.*

The recommended technique for measuring WSLs is to repeatedly dip the staff to the water surface and lift it again as soon as it forms a meniscus with the water. The person holding the staff shouts each time contact with the water is made, and the surveyor takes the average of several readings. In reality, with the staff often extended to its full five meters because of working in steep-sided channels, and with a strong wind blowing, the technique is not accurate. Usually, the staff was stood in the water and water depth read off to link up with the survey reading, but when this is done in sandy-bed rivers care has to be taken to avoid the staff sinking in the sand. Three or more WSL readings should be taken along each transect on each visit, or at least three per channel in multi-channel rivers. The values should be assessed carefully, before deciding which values, or combination of values, to use.

3.9.5 DISCHARGE MEASUREMENTS

> *A discharge value has to be linked to the WSL reading for each transect, for calibration of PHABSIM II.*

If there is no reason to suspect that water is being introduced or abstracted either between transects or anywhere upstream between the times spent at different transects, one discharge value will suffice for all of the transects at a site, on any one visit. With luck, this value can be read from a nearby gauging station, if this is deemed valid. If not, discharge has to be measured in the field. Any of the surveyed transects can be used for this, but usually that with the most uniform flow is chosen. A separate transect for discharge measurements can be established if all the others are unsatisfactory. In practice, it was very useful to have a discharge value for each transect on each visit, as this helped judgement of whether or not flow patterns were changing during the site visit and so helped to explain unexpected WSL readings.

At 20 or more points within the wetted channel along the discharge transect, readings are taken of average current velocity. If one of the established transects is being used, and 20 or more verticals occur within the wetted channel, these surveyed points may be used for the

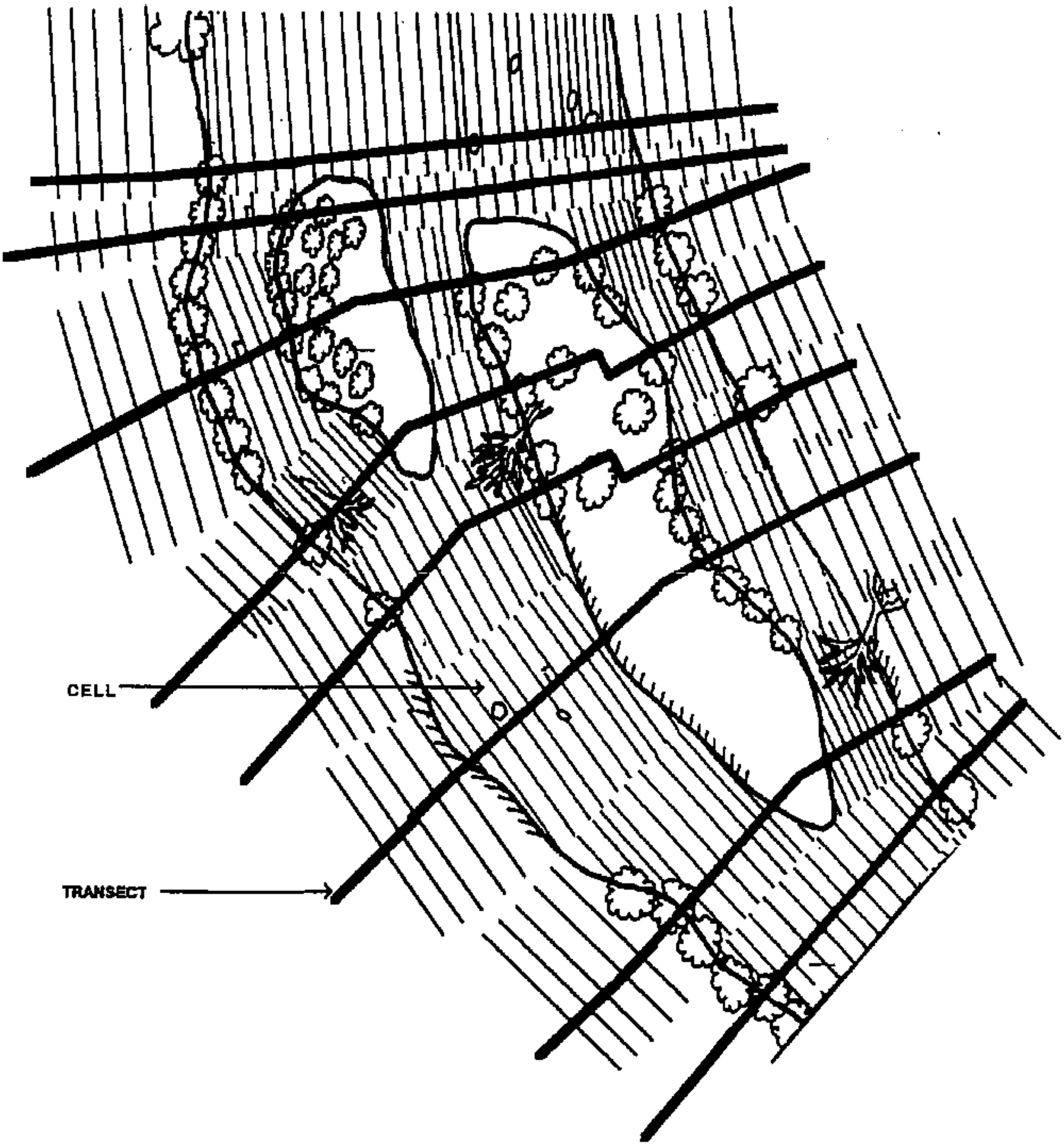


Figure 3.3 Placement of transects and verticals to define stream cells. These are used to describe the distribution of different microhabitats in a stream reach (modified from Bovee 1982)

discharge measurement as the distances between them will already be accurately known. Average current velocity usually approximates that occurring at 0.6 of the water depth, measured from the water surface. However, in waters deeper than 0.75 m, readings at 0.2 x depth and 0.8 x depth are necessary, half the sum of these velocities being a more accurate measure of average current velocity (Bovee & Milhous 1978).

These authors also give equations for calculating average current velocity of waters with more complicated hydraulics:

$$\text{Average velocity} = \frac{\{V0.2d + V0.8d + (2V0.6d)\}}{4} \quad \text{(Equation 3.1)}$$

Where Vx is the depth measured from the water surface

As the authors of this report are not trained to judge the complexity of the hydraulics of water, it was decided to use Equation 3.1 for all waters greater than 75 cm depth.

It is strongly recommended that a bucket current meter with top-setting wading rod (such as the Price-type AA and Mini) be used, as the Mini is sensitive to very low flows and is necessary for measurements in very shallow water, while the wading rod automatically sets the meter at 0.6 depth.

Total discharge can be calculated from the series of readings in several ways, one being the use of the partial section concept (Bovee & Milhous 1978). Each partial section (or "cell") is defined by a surveyed-in vertical and consists of half the space to the two adjacent verticals. The discharge through a partial section is given as:

$$q_1 = a_1 \times v_1 = w_1 \times d_1 \times v_1 \quad \text{(Equation 3.2)}$$

Where
q_1 = the discharge through a cell
a_1 = the area of the cell
v_1 = mean column velocity, measured at the vertical
d_1 = mean depth of the cell, measured at the vertical
w_1 = width of the cell = the sum of half the distances to each of the two adjacent verticals

The total discharge through the transect (Q) is the sum of all the individual cell discharges:

$$Q = \Sigma q_1 \quad \text{(Equation 3.3)}$$

3.9.6 VELOCITY DISTRIBUTIONS

Measurements of velocity are taken at each vertical of the transects used for discharge calculations. They are also an essential component of the data sets used in most of the hydraulic simulation programs in PHABSIM II where they are used to help calibrate the model.

The velocity readings taken at each vertical of each transect at a study site during one visit constitute a velocity data set. In all cases, mean column velocity (i.e. at 0.6 depth) is measured. Depending on which options are used when running PHABSIM II, one or more velocity data sets are needed, taken at discharges that are as dissimilar as possible. This range is necessary because Bovee & Milhous (1978) state that the limits of accurate simulations of WSLs and velocities by PHABSIM II are 0.4 times the lowest measured discharge to 2.5 times the highest measured discharge. Thus, the greater the measured range of discharges, the greater will be the range over which discharges can be accurately simulated.

If more than one velocity data set is collected, the verticals used for the velocity measurements must be at exactly the same locations on all trips, so that each velocity value relates to a described cell within the model. Thus, each point of measurement of velocity should be located in terms of its distance from the headstake of its transect and with reference to its original location, rather than its distance from the water's edge. **This is important** - the data cannot be entered into the model if the cells do not match up.

3.9.7 CHANNEL INDEX

The final information on physical conditions that is required as input to PHABSIM II relates to the nature of the substrate and the hydraulic or overhead cover occurring along each transect. This information is recorded at each vertical during the initial surveying-in of the transects, and not normally recorded again on subsequent calibration trips; care should be taken, however, as one needs to be alert to possible seasonal changes both in the distribution and abundance of aquatic vegetal cover, and in the location of sand and other small-sized substrates.

The information on channel index is used in the link-up with the target species (habitat-simulation component of PHABSIM II) and not in the hydraulic simulations, but an entry of some description for each cell is necessary before the hydraulic simulations will run. The entry may initially be zero if the code has not been decided on; however, if the specialist running the hydraulics programs has not visited the sites that are being modelled, an actual description of the substrates, either in or separate from the code, can be very useful for understanding channel roughness. The link-up with the target species is dealt with in Section 3.17, but in part it involves coding the species' preferred microhabitat in terms of substrate and cover and matching these with similarly-coded cells described from the survey/calibration trips.

The methods for describing and analysing substrate and cover data have probably undergone more evolution than any other aspect of PHABSIM II (Bovee 1982). This is because fairly standard techniques of description and analysis exist for hydraulic and hydrological data but not for biologically-related data such as substrate and cover. The methods described below are not the only ones or necessarily the best ones, but they are tested and compatible

> *with IFIM and PHABSIM II. They are dealt with fully by Bovee (1982).*

The field data are coded to create what were originally called substrate and cover codes, and later called channel indices (CI). A CI value is entered into PHABSIM II for each cell, **including all the dry ones**, and stays linked to its cell through all the following simulations of the cell's hydraulic conditions at different flows.

CIs consist of a series of one or more numeric digits, with each digit describing a specific aspect of the substrate or cover and being independent of the others. Up to four digits per CI can be accepted and read by PHABSIM II and each digit can have values from zero to nine as long as the complete index is larger than 0.00. However, it is advisable to avoid the use of zero, to use three or fewer digits and to restrict the options available within each digit, because the high number of permutations possible with a four-digit, many-value code would create a complex descriptive mosaic of cells within the river bed. In the hydraulic simulations, very few of these cells would match up with the coded requirements of the target species.

Traditionally, the CIs have described some combination of such features as classes of bed material, dominant and sub-dominant particle sizes of the substrate, degree of embeddedness, percentage of sand and other fines, percentage of overhead or instream vegetal or hydraulic cover, undercut banks and root wads. It is difficult to describe more ephemeral features such as the fine organic silt or algal mats that appear on rocky beds at times, though these are recognised as important habitat features for some species of both fish and invertebrates. Nevertheless, the code for the CI is compiled bearing in mind, as far as possible, the microhabitat features that are important to the target species so that the link-up between biological requirements and available microhabitat can be made. It is of little use describing the cells along each transect in terms of the percentage of sand in the substrate if the target species spends its life in the top 10 cm of water among overhanging vegetation.

An example of a coding system is given in Table 3.1. There, the tens represent the percentage of overhead vegetal cover, while the units represent classes of bed material. Using this code, a value of 34 would indicate that the characteristics of a cell (used in the hydraulic program), or the preferred microhabitat of a target species in terms of substrate and cover (used in the habitat program), were 51-75% overhead cover over a cobble bed.

Table 3.1 Example of a channel index (CI) incorporating information on cover and substrate

CODE (tens)	PERCENT OVERHEAD COVER	CODE (units)	SUBSTRATE COMPOSITION
1	0-25	1	clay and silt
2	26-50	2	sand
3	51-75	3	gravel
4	76-100	4	cobble
		5	boulder
		6	bedrock

Once a code has been decided upon, it is used to describe every cell in the initial survey exercise and every microhabitat studied when compiling the microhabitat preference (see glossary) curves (see Sections 3.10 and 3.12) for the target species. If more than one target species is used, a different code may have to be created for each; in such cases, care must be taken to ensure that the same code is being used both for species microhabitat curves and, within PHABSIM II, to describe the cells. Clearly, a great deal of forethought needs to be dedicated to creating suitable codes **before** the surveying of transects begins. Probably the wisest course is to record comprehensive details in the field, bearing the microhabitat of the target species in mind, but to leave actual compilation of the code until later. In this way a variety of data is available if subsequent changes to the code are deemed necessary.

3.10 STEP EIGHT - DEFINING PHYSICAL MICROHABITAT

> *The link between the physical and biological data takes place at the level of the surveyed cells, that is, the microhabitat.*
>
> *Each cell will have a certain depth and velocity at any one discharge and a CI that is assumed to stay the same at all discharges. Before the link-up with the biological data can occur, the combination of these three variables must be known for each cell, at each discharge within the range to be considered. PHABSIM II simulates these combinations, thereby describing how the microhabitat changes as flow changes.*

Physical microhabitat is defined by Bovee (1986) as a composite of hydraulic and structural features, specifically described by the depth and velocity of the water, the nature of the substrate and the proportions of any instream hydraulic or overhead cover, whether these are provided by vegetal or geological features. No argument is presented as to why these features were chosen to represent microhabitat or how adequately they may be assumed to do so. Clearly, they are important components of microhabitats, and they have the advantage of being amenable to being described within a model such as PHABSIM II, but some justification of their importance would seem to be needed when so many subsequent links in IFIM depend upon them.

Collecting methods for data on these physical features are given in Section 3.9. The resultant field data give cell-by-cell descriptions of the size and CI of each cell and its water depth and velocity at one or more measured discharges. Knowing the WSL related to each measured discharge, PHABSIM II can be calibrated and then will produce simulations of the depth and velocity occurring in each cell at any specified discharge. These are then matched with the microhabitat preferences of the target species (see Section 3.11) to compute the amount of microhabitat available for it at these discharges.

3.11 STEP NINE - THE CHARACTER OF THE BIOLOGICAL DATA USED AS THE INPUT TO PHABSIM II

Two kinds of biological data are needed for implementation of IFIM in its entirety, but usually only one kind is collected. The first kind deals with the ranges of tolerance of the chosen target species to macrohabitat variables such as water quality and temperature. These data are needed in order to assess the distribution limits of suitable macrohabitat in the river as per Bovee's approach and are discussed in Section 3.6. These are the kind of data that usually are not collected or, in South Africa, often available.

The second kind of data describes the microhabitat used by the target species in terms of depth, velocity and CI. These descriptions, or their processed versions, are called by a variety of terms such as ***microhabitat suitability criteria and suitability curves,*** *and represent the biological input to PHABSIM II. The following discussion deals only with this second kind of data. Bovee (1986) describes in detail the collection and manipulation of such data to provide input for PHABSIM II.*

Bovee (1982) defines criteria as characteristic behavioural traits of a species that are established as standards. In the context of IFIM, microhabitat suitability (see glossary) criteria describe the range and optimal conditions preferred by the target species in terms of depth, velocity and CI.

Underlying their use are three assumptions: (a) that different stages in the life histories of most species exhibit preferences within the range of microhabitat conditions that they can tolerate; (b) that these ranges and preferences can be defined, and (c) that the area of river providing these conditions can be quantified as a function of discharge (Bovee 1982). PHABSIM II is the tool used to quantify the changes in available physical microhabitat that occur with changes in discharge. Not stated within the part of the manual dealing with criteria, and only recognised incidentally elsewhere in the methodology, is a fourth implicit assumption. This is that the microhabitat is adequately described by the three physical variables used (see Section 3.10).

Within IFIM, microhabitat suitability criteria can be derived in different ways (categories) and expressed in different forms (formats). These differences affect the precision with which the preferences of the target species are represented.

3.11.1 CATEGORIES OF CRITERIA

Three categories of microhabitat suitability criteria are recognised:

- **Category I criteria** are derived from information in the literature or professional experience and judgement.

- **Category II criteria** are based on analyses of the microhabitat conditions utilised by the target species, and are called "utilisation functions".

- **Category III criteria** take into account the fact that optimal conditions might not have been available at the study site, and attempt to correct this bias so that the criteria can be used in other streams. These are called "preference functions".

3.11.2 FORMAT OF CRITERIA

Criteria may be created from the collected data in three ways (Figure 3.4):

- **Binary format** - A measured value for each of the three variables depth, velocity and CI may be rated as suitable (1.0) or not suitable (0.0), with no gradations in between (Figure 3.4a).

- **Univariate curves** - More detailed than the binary format, the univariate curve shows a gradation in the suitability of conditions from optimal at the peak, to unsuitable at the base. The tails of the curve represent the bounds of suitability. The peak is valued at 1.0 and its base at 0.0, with the intermediate points usually interpolated linearly along the vertical axis (Figure 3.4b).

- **Multivariate response surfaces** - represent two or more univariate curves multiplied together, indicating interactions between variables. Values along the vertical axis are allocated in the same way as for univariate curves (Figure 3.4c). Also called "joint suitability functions" and "multivariate suitability functions", these are generally difficult to derive and are still the subject of study.

During the development of IFIM a confusing array of terms has been created. Suitability, preference, utilisation and availability have all been linked to the terms curves, functions, indices or criteria, and sometimes used inappropriately. "Suitability" seems to be a catch phrase that represents either "utilisation" (category II) or "preference" (category III) information, often without clear reference as to which is meant. Curves, functions, indices and criteria seem to be liberally interchanged, though the curve could be described as a graphical representation of a criterion, while the function is presumably a mathematical description of that curve. "Suitability index curve" or "Suitability curve", abbreviated to SI curve, seems to be the phrase most often used in the recent literature to describe the microhabitat characteristics associated with a target species, but there should be clarity on whether it represents utilisation or preference of microhabitat.

3.12 STEP TEN - COLLECTING BIOLOGICAL DATA FOR THE CREATION OF SUITABILITY CURVES

The different categories of criteria described above require different approaches for collecting the data, and thus slightly different SI curves may be produced. Data collection for category I criteria is largely an office exercise and produces relatively coarse SI curves, while extensive field work is required to obtain the data necessary for

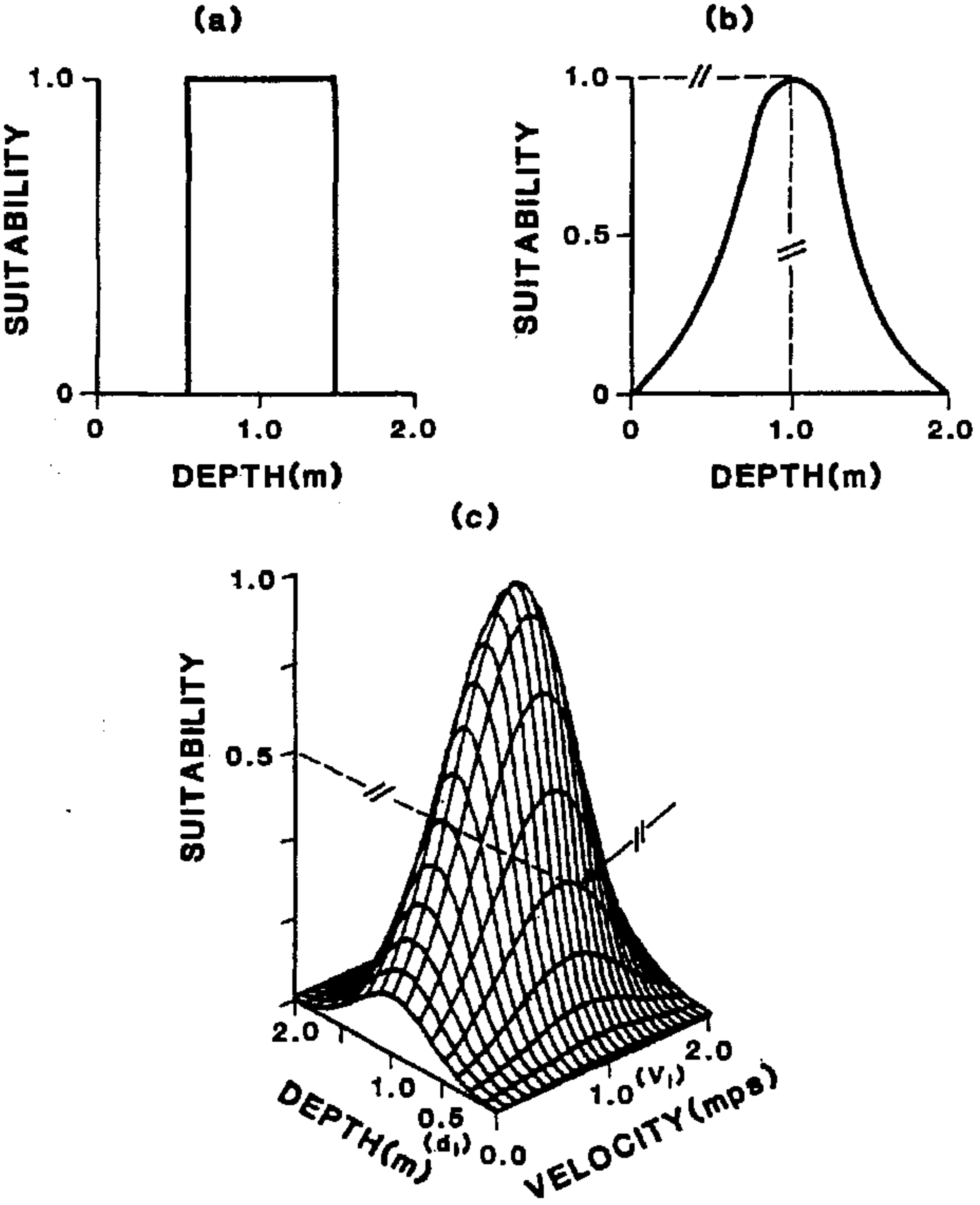


Figure 3.4 Three kinds of habitat criteria: (a) binary (b) univariate curve and (c) multivariate response surface (from Bullock *et al.* 1991)

> *categories II and III criteria and so the resultant SI curves are at a finer level of resolution. Bovee (1986) describes in detail how to collect data for all three categories of criteria.*
>
> *In each case, the objective is to obtain a large number of specific values for the conditions of water depth, velocity and CI in which the target species was found or is known to occur; additionally, for category III criteria, similar data are required on where it does not occur. These values are analysed to produce the best possible statement of the range of conditions (i.e. the physical microhabitat) in which the target species occurs and, within that range, the physical microhabitat in which it occurs most often (usually referred to as "preferred habitat").*
>
> *It should be remembered that the term "target species" is being used as a generic term to describe a species, a life stage of a species, a guild or a community. This has important implications for understanding the following explanations. For instance, when assessing the impact of a development on a species, three or more life stages of that species may be recognised, all with different microhabitat requirements. As the species cannot survive unless all of its life stages survive, each life stage becomes a "target species" and is treated separately in the assessment.*

Category I criteria are gleaned from the general literature or expert opinion. As such, they are seen as the least accurate of the three categories of data, though experience has shown that they should not be underestimated (Bovee 1986). On the other hand, as much of the historical research in streams has not produced data of the kind required for IFIM, category I criteria may be the best that can be compiled for many species at short notice. They could thus be the main type available in South Africa into the foreseeable future.

Category II criteria produce SI curves that show microhabitat utilisation by the target species within the studied stream; in other words, they describe the conditions in which the species was actually found. As no assessment is made of whether or not the full range of microhabitats available in the target species' geographical distribution range is available within the studied stream, the SI curves produced may give a misleading picture of its preferred microhabitat. Category II curves should thus only be used for assessment of the stream where the data were collected.

Category II data may be collected by a variety of techniques, such as direct overhead observation, snorkeling, underwater video, biotelemetry, electrofishing or area sampling with samplers such as nets. All of these techniques have advantages and drawbacks and the sampling design should be very carefully thought out in order to avoid biases in the resulting data sets (see Bovee 1986). Using the chosen technique, it is recommended that at least 150-200 data points of linked depth, velocity and CI data be recorded, in order to produce a satisfactory Category II SI curve. Each data point should represent an observation rather than a record of where one individual occurred, and so may relate to more than one individual. Observations rather than individuals are counted, because gregarious species such as schooling fish could produce a large number of identical data points. However, the number of individuals related to each data point should be recorded, as this may be used in the subsequent analyses.

Category III criteria produce SI curves that aim to show true microhabitat preference, and so are theoretically transferable from stream to stream. They are based on category II curves that have been adjusted to factor out any bias resulting from limited microhabitat availability in the study stream. To transform category II criteria to category III criteria, information is needed not only on the conditions in which the target species was found, but also on those pertaining at the same time and site in parts of the channel where it was not found. This is accomplished through random or proportional sampling of all parts of the study stream, to produce records of the full range of microhabitats available. The exercise should be repeated every time that data on microhabitat utilisation are collected. Data on microhabitat utilisation and microhabitat availability are then combined (see Section 3.13) to produce an SI curve of microhabitat preference. Transferability of data remains a contentious issue, however (Bovee 1986; Thomas & Bovee unpub.). SI curves compiled from species microhabitat data for different reaches of the same river, for different seasons, or for the same species for different rivers, regions or countries, may be very different; this topic is dealt with further in Chapters Seven and Eight.

It is generally recognised that inappropriate sampling methods, inappropriate data processing, and poor sampling design, have a far greater potential for producing a bias in the collected data than the actual activities involved in the field. Different sampling techniques may work best for different life stages of the same species, and should be standardised for any one life stage and species. Selection of an appropriate study site is important, with a very long stretch of river perhaps being required, because records of the utilisation and availability of microhabitat should be done, if possible, in a reach containing the full range of possible microhabitats. Pooling data from different sites can produce biases in the form of over-representation if the sites were of different sizes and were sampled for different lengths of time, or if different field techniques were employed. It is therefore crucial to ensure, if possible, standardisation of the data collected from different sites, or the number of observations per site, preferably at the outset of the study. Time spent on design in the beginning of the project is clearly very well spent.

3.13 STEP ELEVEN - ARRANGING THE BIOLOGICAL DATA TO PROVIDE INPUT TO PHABSIM II

The raw data on microhabitat utilisation are either used alone, or combined with data on microhabitat availability to produce preference data. Microhabitat utilisation and preference are presented as simple graphical displays that represent the behavioural response of the species to the measured variables water depth, velocity and CI (Figure 3.5). These three graphic displays, or SI curves, per species, form the habitat input to PHABSIM II. Bovee (1986) provides full details.

To create the curves, the data on velocity, depth and CI for each target species are usually ranked by frequency of observation or of number of individuals in any size class or category of the variable, or they may be plotted as a simple x-y scatter of data. Based on the resulting histograms, bar graphs or data points, a curve is drawn that best describes the functional relationship between the species and the variable of concern. The co-ordinates of the curves, or SI curves, form the basic information on the physical microhabitat requirements of the target species and are the input data for PHABSIM II.

3.14 STEP TWELVE - THE LINK-UP BETWEEN PHYSICAL AND BIOLOGICAL DATA USING PHABSIM II

> *Knowing from the hydraulic simulations the conditions of depth, velocity and CI for each cell at each simulated discharge, PHABSIM II is then used to evaluate each cell at each discharge to determine its overall quality as microhabitat. The resultant quality value of the cell at any one discharge is a composite number based on its hydraulic and structural characteristics, with a value of 1.0 indicating that it is completely suitable microhabitat, while 0.0 indicates it is completely unsuitable microhabitat. Within PHABSIM II the composite quality value is then multiplied by the surface area of the cell to produce an index of microhabitat termed Weighted Usable Area (WUA). The composite quality values of all surveyed cells are calculated and summed to ultimately produce a WUA for the whole study site. The sequence is then repeated for other discharges.*

Within a stream, at any one discharge, the microhabitat within a cell can be expressed in its simplest or standard form (modified from Nestler *et al.* 1989) as:

$$F[v,d,CI] = f(v) \times f(d) \times f(CI) \quad \text{(Equation 3.4)}$$

Where
F[v,d,CI] = function that combines information on velocity, depth and CI to produce a composite number representing the microhabitat quality value of that cell at that discharge for the target species
f(v) = function used to transform stream velocity (v) of a cell into a measure of its value for a target species (value is taken from the SI curve for velocity)
f(d) = function used to transform depth (d) of a cell into a measure of its value for a target species (value is taken from the SI curve for depth)
f(CI) = function used to transform the CI of a cell into a measure of its value for a target species (value is taken from the SI curve for CI)

F[v,d,CI] describes the composite (net) suitability of the cell for a target species at a given discharge, and is sometimes called the microhabitat quality value of the cell. It is usually expressed as the product of the three values read from the SI curves (as above), but can also be expressed as the geometric mean or as a minimum preference formulation. Expressed as the product, it implies synergistic action (Gan & McMahon 1990), with high amounts of microhabitat only existing if all three variables have high values. Use of the geometric mean implies compensation effects, whereby if two of the three options have high values, the value of the third is relatively unimportant unless it is zero. Use of the minimum preference formulation accents the importance of the minimum of the three values, implying that the microhabitat is no better than its worst component. Professional judgement has to be used to decide which option best reflects the situation to be described.

To explain the derivation of the cell's net suitability, Gan & McMahon (1990) give the example of a cell of 10 m^2 which, at a given discharge, had values (taken from the SI curves) of 0.90, 0.85 and 1.0 for velocity, depth and CI respectively. If the method of analysis chosen involves use of the product of these values, then the net suitability of the cell at the discharge under consideration would be 0.9 x 0.85 x 1.0 = 0.765. When multiplied by the surface area of the cell to give the WUA, this results in 7.65 m^2 of the cell being suitable for use by the target species. Summation of the WUA for each surveyed cell would give the overall WUA of the study site at that discharge, while repetition of the procedure for many discharges would produce a picture of the losses and gains of WUA with changing discharges. This is the final output of the model PHABSIM II (Figure 3.5).

3.15 STEP THIRTEEN - THE NATURE OF PHABSIM II

> *In this Section a description of the model is given. Sections 3.16 and 3.17 then outline how it can be used. The manual for the model (Milhous et al. 1989) provides all necessary information on the hardware needed to run PHABSIM II on a mainframe or microcomputer. Details of all programs are given, as are the layouts of various data inputs and sample outputs from several programs. The manual is long and difficult to use, however, because the sequence of tasks to be done is not easy to understand or well explained, and much information is repeated several times in different guises. Additionally, the theoretical basis of the model is barely dealt with, making it very difficult for even an experienced hydraulic modeller to judge the importance of the many options.*

PHABSIM II can be run on IBM-compatible micro-computers (preferably AT), which should have
- at least 512K of available RAM memory
- at least one floppy disk drive
- MS-DOS version 3.00 or later
- an editor with ASCII file compatibility

It is also strongly recommended that there is:
- a hard drive with at least 20K of storage memory
- an 8087 or compatible numeric coprocessor
- a monitor with 640 x 200 graphics and Colour Graphics Adaptor (CGA) or compatible graphics card

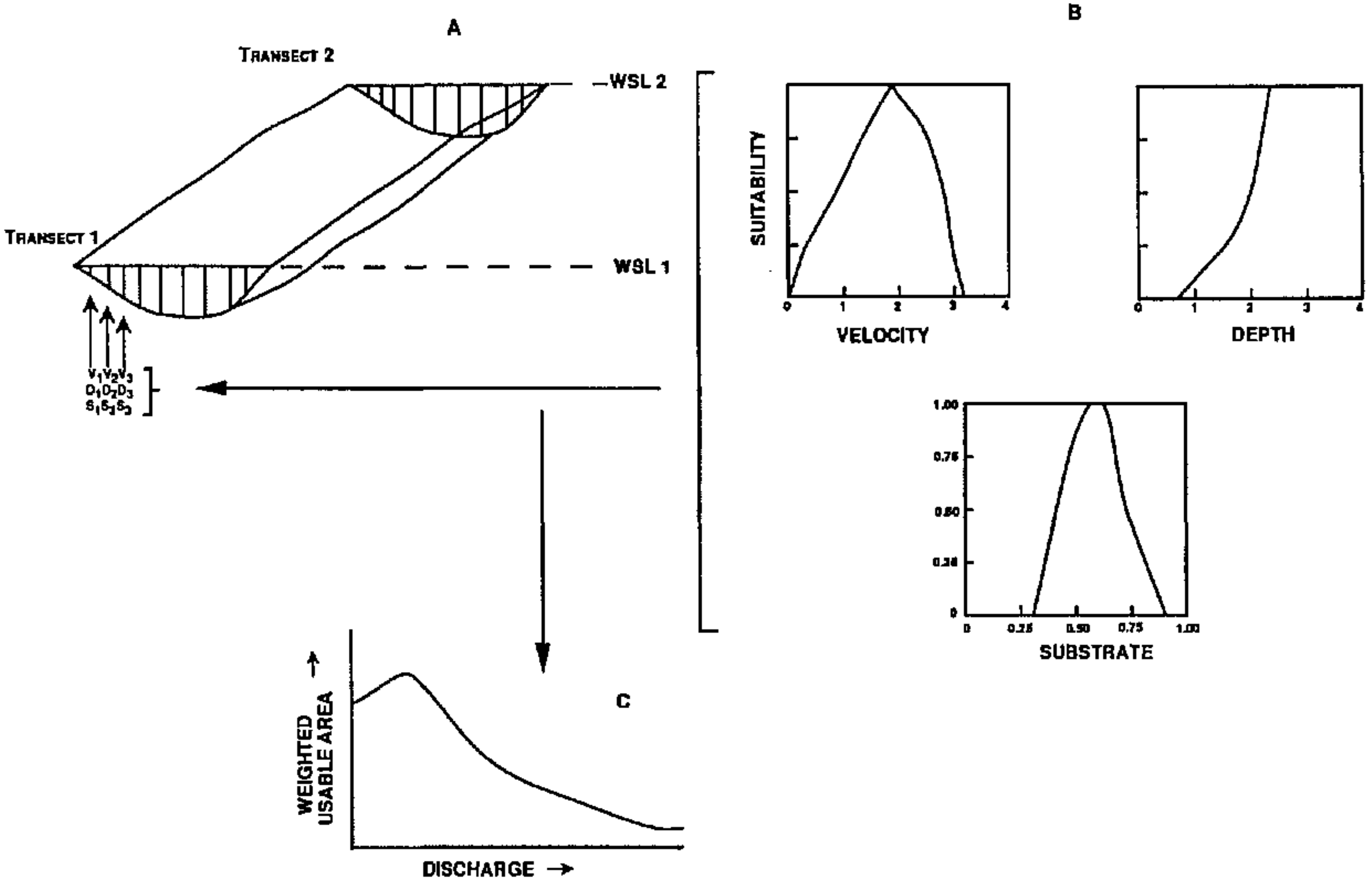


Figure 3.5 The three steps of a PHABSIM II study: data on (A) velocity (v), depth (d) and substrate index (s) from the surveyed transects are linked to measured WSLs and discharges to provide calibration data for the hydraulic programs within PHABSIM II. The habitat suitability data (B) are linked with the simulated hydraulic data to predict changes in WUA with changes in discharge (C)

- a printer with graphics capability and the ability to print 132 characters per line
- some facility for displaying a 132-column output on an 80-column screen would also be very useful

PHABSIM II is a collection of 240 separate programs, packaged on 25 floppy disks (each 360K). Half of the programs are executable files while the rest are batch files which control the running of the executable files. The executable files are derived from source codes written in Ryan-McFarland FORTRAN 77, while the batch files are written in Microsoft batch language (Gan & McMahon 1990).

There are two main sets of programs, those for hydraulic simulation and those for habitat simulation. Two other small sets of programs deal with inputting information from the SI curves (curve maintenance programs) and with simulating physical microhabitat when two or more discharges are linked, such as a spawning discharge followed by an incubation discharge (effective habitat programs). Additionally, there are many support programs concerned with data manipulation - the creating, checking, modification, listing, comparing, adding, re-arranging, extracting and plotting of information contained in the data sets (Gan & McMahon 1990). Many of these support programs are not essential, and serve as a convenience for various data manipulations that could otherwise be done manually. Additionally, many of them contain a variety of combinations of the same routines, and so there is much needless repetition. Milhous *et al.* (1989) and Gan & McMahon (1990) list in detail the name and function of each file, and these are not repeated here.

The manual for PHABSIM II (Milhous *et al.* 1989) contains sections on an Introduction, the Hydraulic Simulation Programs, Cross-section and Hydraulic Properties (Tape 3 and Tape 4) Programs, Curve Maintenance Programs, Habitat Simulation Programs, Effective Habitat Analysis Programs and Report Generation Programs. There are appendices containing file formats and sample data sets, an alphabetical summary of batch and procedure files, details of how to run PHABSIM II on various kinds of computer link-ups, and how to develop SI curves.

Gan & McMahon state that "as a program suite, PHABSIM II is neither easy to comprehend or to use. The beginner must be prepared to expend extensive time and effort in its study before a production run can be considered". Only a few files are required for any one run of PHABSIM II, but for the beginner it is not clear which should be used and how they differ, nor is there an obvious route to follow through the programs; different sets of programs run independently, though their outputs have to be rigorously linked. The lack of instruction is at least partly deliberate, so that the user can choose the most appropriate route and programs for the study being done. However, within each set of programs there is a formidable number of choices to be made of which programs, or which options within programs, to use. These choices require considerable theoretical background knowledge in both the hydraulic and ecological fields, a combination unlikely to be present in any one person. The large manual contains little guidance in this regard, and where the reader is guided to other literature (e.g. the appendices or tutorial) for a more in-depth treatment of a topic, basically the same information is given again.

Many of the programs within PHABSIM II were written or modified in response to earlier criticisms of PHABSIM I, but programs are still being added whenever another valid criticism or a new study situation arises (R.T. Milhous pers. comm.). This is done without any overall plan being produced of their place in the model and without appended literature referencing or describing the new option. Many of the obsolete programs, or obsolete options within programs, remain in PHABSIM II because researchers used to the earlier version demand them, but there is no indication in the literature and packages received for this project of which parts are now considered obsolete. Within North America a network of PHABSIM-users keeps in touch with the continuing development of PHABSIM II and IFIM, but there is no structured means for users elsewhere to do so. There is a recognised need for some stringent housekeeping of the model, to eradicate confusing redundancies and explain new additions, but this is unlikely to be done (R.T. Milhous pers. comm.).

3.16 STEP FOURTEEN - HYDRAULIC SIMULATION USING THE MODEL PHABSIM II

> *The sequence of tasks to be done for a complete PHABSIM II run is (1) creation and checking of the data input files for the hydraulic simulation of WSLs and velocities (2) completion of the hydraulic simulations, which will provide a velocity and depth value for each cell at each discharge (3) checking the quality of the hydraulic simulations (4) creation and checking of the data input files for the habitat simulation, and (5) linkage of the hydraulic simulation with the habitat data to calculate WUAs, using a habitat simulation routine (Figure 3.6). Optional later tasks are to simulate effective habitat and perform time series analyses, neither of which is dealt with in this report. The first three tasks are dealt with in this Section.*

3.16.1 CREATION OF THE DATA INPUT FILES FOR HYDRAULIC SIMULATION

The tutorial for PHABSIM II (Milhous *et al.* 1990) was written recently in response to the demand from potential users of PHABSIM II for a simpler guide than the manual. It is a rigid step-by-step set of instructions for following a limited number of paths through the model, but is far simpler to follow than the manual and allows a clearer, if simplistic, understanding of the sequence of steps to be taken. It gives most of the necessary guidance for creating the data files, and omitted parts, such as how to determine the stage of zero flow for each transect, can be figured out; the tutorial was found to be invaluable. However, it provides no more theoretical background knowledge than the manual or other associated literature, and so is of limited use for assessing the quality of either the data or the resulting hydraulic simulations.

With guidance from the tutorial, customised programs within PHABSIM II can be used to create data files of the channel characteristics recorded in the field. The files can also be created with an editor in free-format, as long as they comply with the specified fixed format. The data required for hydraulic simulation depends upon which model within PHABSIM II is used, but some combination of the following is used:

- a list of the discharges to be simulated (QARDs). These should be within the limits of accuracy set by the values of the calibration discharges. That is, within the range 0.4 x the lowest calibration discharge to 2.5 x the highest measured discharge.

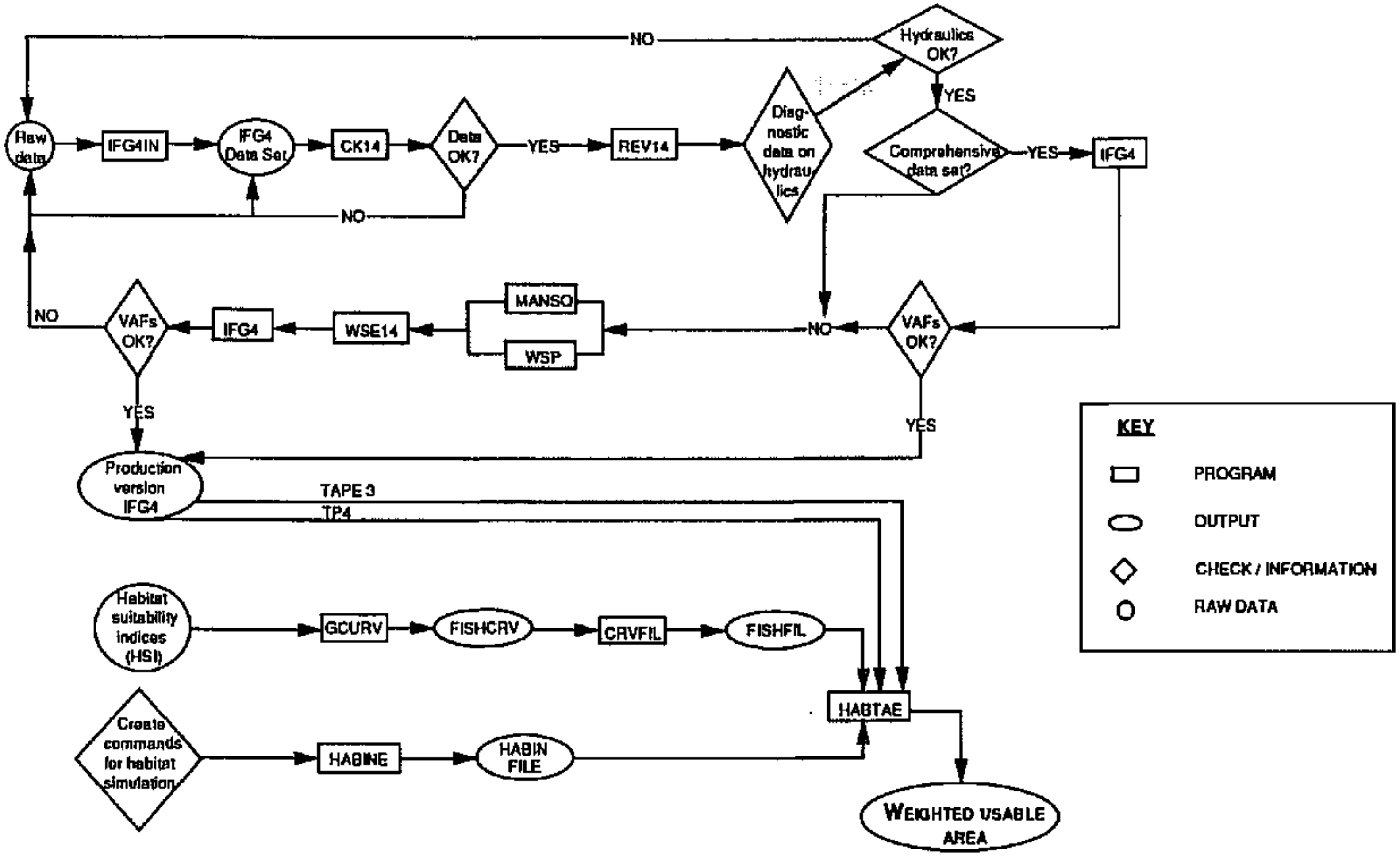


Figure 3.6 The flow of data through PHABSIM II (assumes three stage-discharge pairs and one velocity set)

- the transect identity number (stationing), linked to:

    the distance to the adjacent **downstream** transect (confusingly called "reach length" in the tutorial and used in the hydraulic simulation), and also to

    the proportion it represents of the distance to the adjacent **upstream** transect (reach length weight - used in habitat simulation).

- the stage of zero flow for each transect, which indicates what the WSL would be at each transect if there was no flow in the river.
- the slope for each transect - preferably the energy slope, but this can be approximated by the water surface slope.
- the X and Y co-ordinates of each transect vertical.
- Manning's n for each vertical or each transect, depending on the hydraulic model to be used, and substrate/cover values for each vertical. Manning's n values can be calculated within the PHABSIM II runs or provided, but substrate values always have to be provided. The Manning's n values calculated by the model bear little resemblance to real Manning's n values, and would probably better be referred to as "velocity distribution coefficients" (R.T. Milhous, pers. comm.); if the values calculated by the program are not used, alternative values should not be entered by the modeller until the way in which the model uses them is thoroughly understood (see Chapter Nine).
- the WSL and discharge for each transect on each calibration field trip = (CAL) sets.
- a velocity reading for each wetted vertical of each transect (= (VEL) sets) to link with each (CAL) set. The hydraulic model which uses the (VEL) sets can be calibrated with three (CAL) sets and only one (VEL) set, but it is wiser to collect a (VEL) set for each (CAL) set if possible, as this increases the options for manipulating the data.

Although there is theoretically the option of using either metric or non-metric data, the metric option has never worked and so all metric values have to be converted to imperial units.

3.16.2 COMPLETION OF THE HYDRAULIC SIMULATION

> *PHABSIM II incorporates the concepts of open-channel hydraulics to predict changes in depth and velocity for the area represented by each cell of each transect as a function of discharge. Field measurements made at one or more discharges are used to calibrate the model and then depths and velocities over the full range of specified discharges are simulated. WSLs are simulated first (Figure 3.6), in order to provide depth values for each cell, and then the distribution of velocities along each transect is simulated. The result is that each cell is allocated both a depth and a velocity value for each specified discharge, which will eventually be needed in order to assess its value as microhabitat. Full details of the hydraulic models and their use*

> *are given in Milhous et al. (1989), Gan & McMahon (1990), and Milhous et al. (1990).*

There are five basic programs which may be used for hydraulic simulation in PHABSIM II. These are IFG4, MANSQ, WSP, STGQS4 AND HEC-2. HEC-2 is an hydraulic program developed and used by the U.S. Army Corps of Engineers and is not part of the PHABSIM suite; it requires separate access and is not considered further here. STGQS4 is an abridged version of IFG4, generating only WSLs and average velocities for each transect, and is also not considered further here.

WSLs are simulated in a different way in each of the three remaining hydraulic programs. WSP uses a standard step backwater computation to simulate WSLs (Gan & McMahon 1990) and thus all transects are linked in the computation. In order for WSP to run successfully, every hydraulic control in the study site must be described by a transect. Additionally, the most downstream transect should be at an hydraulic control at which there is a unique, known stage-discharge relationship (i.e. with no backwater effects). On the other hand, IFG4 and MANSQ treat each transect separately, and so do not require such stringent coverage of hydraulic controls. The unlinking of transects in these two programs may be in response to the fact that very low discharges are difficult to model accurately using the standard step backwater method because an increasing number of hydraulic controls appear, and have to be described, as water levels drop (pers. obs.).

WSP assumes that flow conditions are steady and that the downstream water surface profile is controlled by hydraulic conditions at the most downstream transect. The concept of energy balance between transects is used. If hydraulic controls are missed, an experienced hydraulic modeller might be able to divide the surveyed transects into smaller groups, and run separate simulations for each group (R.T. Milhous pers. comm.).

IFG4 simulates WSLs by creating a stage-discharge relationship for each transect, using the calibration data collected on the field trips. Three data points are the minimum required for establishing the relationship, but care must be taken, as the relationship can change over the range of simulated discharges if WSLs rise to a level where the channel shape changes or secondary channels are flooded. If IFG4 fails to predict sensible WSLs due to poor calibration of the model, then these can be predicted by MANSQ. Manning's n can be adjusted by:

$$n = n_c \left(\frac{Q}{Q_c} \right)^{\beta} \quad \text{(Equation 3.5)}$$

Where
n = the roughness at discharge Q
n_c = the roughness at the calibration discharge Q_c
β = the beta coefficient, which must be supplied by the user

MANSQ simulates WSLs using Manning's equation independently for each transect. It assumes that flow is uniform, and fails under conditions of backwater effects. Though the theoretical basis for the model is not given, Gan & McMahon (1990) deduced that at each transect one set of stage-discharge data is used to derive the roughness coefficient of the transect (Manning's n), using the equation:

$$Q = \left(\frac{1.49}{n}\right) A\, R^{0.667}\, S^{0.5} \quad \text{(Imperial units)} \quad \text{(Equation 3.6)}$$

Where
Q = discharge
A = cross-sectional area
n = the Manning roughness coefficient
R = the hydraulic radius
S = the energy slope

Calibration of WSLs in MANSQ is achieved for any specified simulation discharge Q by means of the equation:

$$CF = CF_c \left(\frac{Q}{Q_c}\right)^{\beta} \quad \text{(Equation 3.7)}$$

Where
CF = the channel conveyance factor for discharge Q
CF_c = the channel conveyance factor at calibration discharge Q_c
β = is a coefficient

The value of the beta coefficient is unknown and is derived using the calibration stage-discharge data sets: MANSQ is run for these known discharges, using a value guessed by the user for the beta coefficient, the simulated and real WSLs are compared, and the coefficient is adjusted until the WSLs match.

Once WSLs have been simulated for all transects for the specified discharges, velocities are calculated (Figure 3.6). Velocity adjustment factors (VAFs) are also calculated for each transect to assist the user in checking the simulated velocities against those measured in the field. IFG4 predicts velocities on a cell-by-cell basis, using Manning's n and a simple mass balance adjustment (Gan & McMahon 1990). The manual does not state how the point velocities are derived in WSP, but Gan & McMahon (1990) deduce that they are probably simulated by applying Manning's equation to each vertical of each transect. MANSQ predicts only the mean velocity of a transect and not the point (cell) velocities necessary for microhabitat assessment. Thus, once it has been used to predict WSLs, IFG4 should be used to predict point velocities.

In addition to the above outputs, the three hydraulic models produce two unformatted files which are the hydraulic input to the habitat simulation programs. TAPE3 contains transect and reach data and TAPE4 discharge and velocity data. TAPE4 can be converted within PHABSIM II to an alternative form, TP4, depending on which habitat model will be used. As MANSQ only simulates mean, and not point, velocities, its TAPE4 output may be unsatisfactory for microhabitat modelling, and use of one of the other models for TAPE4 production, probably IFG4, would be preferable. Other restrictions are that the TAPE3 emanating from WSP has no CIs, and these have to be added using the program MODCI, and WSP does not have the TP4 option, so only one habitat simulation program can be linked to it.

In general, the hydraulic simulation programs are not easy to comprehend or the simulations easy to achieve. The selection of appropriate programs, and how to collect the required data, are major problems in themselves, requiring considerable knowledge of hydraulics. Following this, running of the chosen hydraulic model presents more areas of great uncertainty, with IFG4 requiring the setting of 22 options, MANSQ 12 options and WSP 10 options. These options are chosen using "input-output options commands" or IOCs. Some of the options deal with the printing of computational details or plots, but others relate to technical choices that have to be made and have up to five alternatives to choose from. Gan & McMahon (1990) conclude that some of the options would be impossible to implement without technical expertise, and that there is a presumption that the user has existing knowledge of hydraulics. Additionally, Osborne *et al.* (1988) conclude that WSP is impossible to calibrate under low flow conditions, presumably because of the number of hydraulic controls appearing, and difficult to calibrate even in hydraulically uniform channels. Of the 22 options in IFG4, it was found that one uses an equation now known to be invalid (R.T. Milhous pers. comm.), at least two deal with very unlikely situations and should be ignored, and one provides for different WSLs in multiple-channel streams but has no link-up to the habitat programs so it cannot be used. Other options are interlinked in such a complicated way that for people without a good hydraulics training they become incomprehensible.

In summary, while PHABSIM II is difficult to use, someone with the appropriate hydraulic training and enough time to learn the intricacies of the model should be able to produce good hydraulic simulations. While the large number of options in the model could be viewed as ways of fudging the results, they should more properly be regarded as an opportunity to derive from the field data, using expertise in hydraulics, the best possible description of the hydraulics of the study site over a range of flows.

3.16.3 CHECKING THE QUALITY OF THE HYDRAULIC SIMULATIONS

Several programs exist within PHABSIM II for assessing the hydraulic output from the model, but these concentrate almost exclusively on IFG4. Checking an IFG4 simulation, as laid out in the tutorial manual (Milhous *et al.* 1990), is dealt with here, in order to illustrate the options available. Initially the program CKI4 is used to check the data set for errors in data entry. Program REVI4 is then used to review the IFG4 data set and generate diagnostic data: relationships between variables are determined, roughness is calculated and displayed, the stage-discharge relationship is determined and WSLs are determined for all discharges selected for simulation (QARDs). The program LPTTWE plots thalweg values and WSLs from TAPE3 and TAPE4, and program SLOP34 lists the thalweg values, WSLs and slopes.

There are too many important points to check in the printouts for all to be mentioned here. Many are fairly basic, such as checking that the river is flowing downhill, that the WSL is above the river bed and that the discharge entered for each transect compares closely with that calculated by the model from given velocity readings. Some checks are more complicated, however, and require the expertise of an hydraulic modeller. This is partly because they contain technical hydraulic details, but also because some of the data given in the various printouts from PHABSIM II appear to be gratuitous and unnecessary, relating to elaborate or incorrect routines still utilised by some users in North America (R.T. Milhous pers. comm.); sorting the important from the irrelevant would be difficult for most ecologists. However, a sound knowledge of which parts of the output from the model are important, which parts are optional, and which parts can be ignored, is essential if the ultimate purpose of the hydraulic simulation is to be realised. This purpose is to arrive at a data set containing information on the number and location of cells and the water depth, velocity and CI of each cell over the range of flows to be simulated, for transmission to the habitat-simulation programs within the model.

3.17 STEP FIFTEEN - MICROHABITAT SIMULATION USING PHABSIM II

Once the hydraulic simulations are deemed acceptable they are presumed to satisfactorily reflect the physical microhabitat conditions in each cell over a range of discharges (QARDs). The next, and last, part of a standard PHABSIM II run deals with the evaluation of the net suitability of each cell at each QARD for the target species. As with the previous step, there are two tasks to be done: creation of the data input files and the actual microhabitat simulation.

3.17.1 CREATION OF THE DATA INPUT FILES FOR MICROHABITAT SIMULATION

The SI curves for depth, velocity and CI for each target species form the information on microhabitat requirements that must be introduced into the model. There is also an option to enter data on an SI curve for temperature, but how this could be used is unclear as there is no provision within the model for measured or simulated temperature data with which to link it.

The three programs used for entering information on SI curves are in a group of ten which are jointly called the curve maintenance programs group; the others in the group are used for listing data and other minor activities. The sequence of tasks (Figure 3.6) is:

- enter data from the SI curves using program GCURV
- check the data in the formatted FISHCRV file created, using program LPTCRV
- convert FISHCRV to an unformatted file FISHFIL, using program CRVFIL
- use FISHFIL in the habitat simulation

In order to enter data from SI curves into PHABSIM II, the X and Y co-ordinates for each curve must be determined, using only sufficient points to describe the curve (Figure 3.7). The X axis shows the value for the variable being represented and the Y axis the value of the suitability index. The first co-ordinate of the curve must have an X value of 0, and the last point a value of 100. Velocity and depth curves can usually be described by a maximum of four or five points, while CI curves may require more. GCURV is self-explanatory on how to enter these data points, the only other decision to be made being how to identify the set of three curves with a six-digit number; usually, the first two digits are used to indicate the family of the target species, the next two its species, and the last two its lifestage.

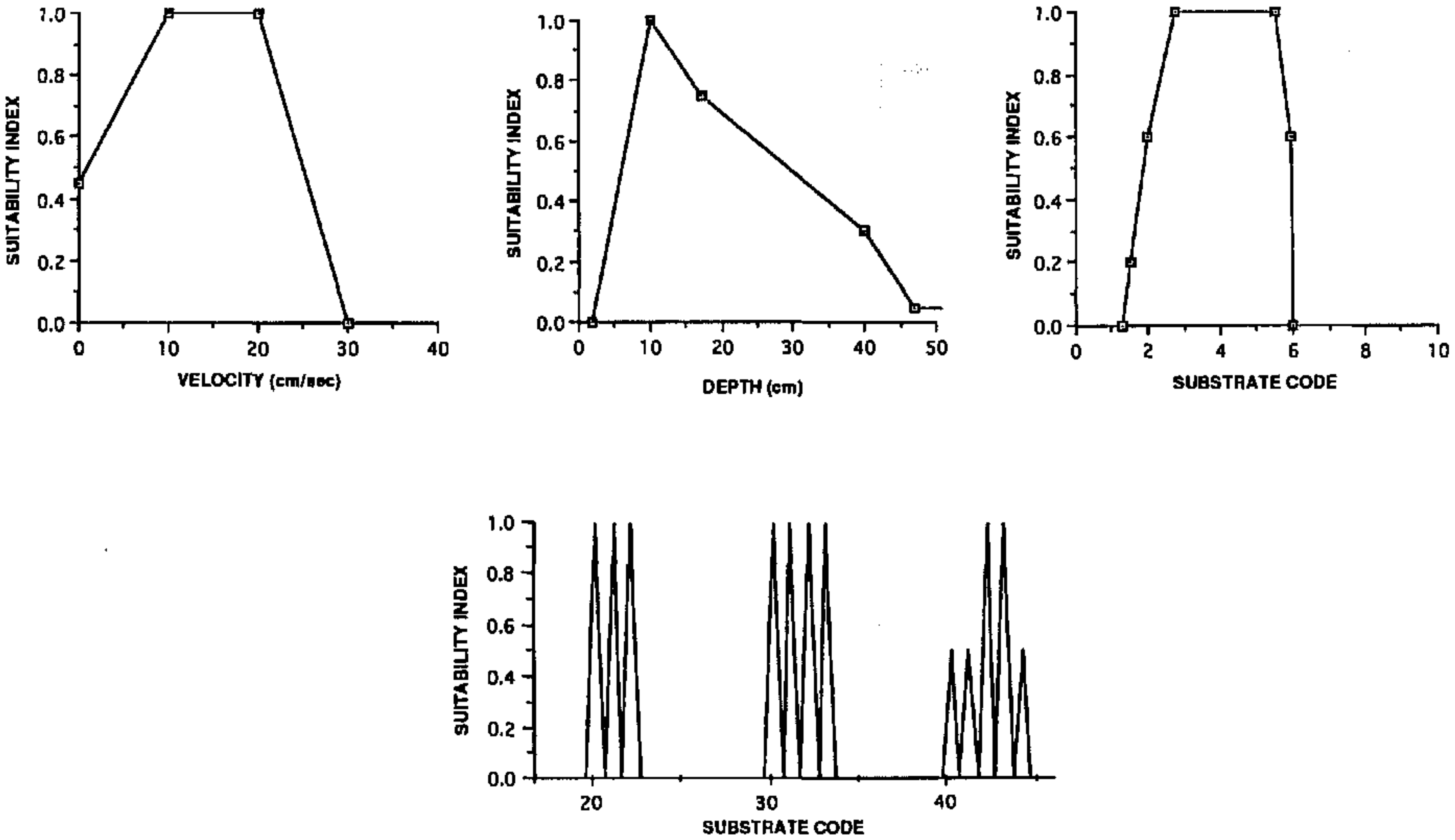


Figure 3.7 Examples of suitability index (SI) curves (from Bovee 1982; and Bullock *et al.* 1991)

Checking the created file with program LPTCRV is straightforward, any mistakes being corrected with a file editor, and conversion of it to an unformatted form is equally uncomplicated.

3.17.2 COMPLETION OF THE MICROHABITAT SIMULATION

> *The habitat simulation programs quantify available microhabitat within the study site, stratified by lifestage (e.g. adult, juvenile, larva) or activity (e.g. spawning, migration). This is done by linking the physical conditions present in each cell (TAPE3 and TAPE4/TP4 inputs) with the conditions required by the target species (FISHFIL input). The end product of the habitat simulation program is the description of WUA as a function of discharge, for each lifestage or activity (Figure 3.6).*

There are several habitat simulation programs available in PHABSIM II of which the most important are HABTAE, HABTAT, HABTAV and HABTAM. HABTAM and HABTAV define the cell boundaries as lying halfway between adjacent verticals, HABTAT defines them as lying at the verticals, and HABTAE offers either option. HABTAT "computes the available habitat area in a reach of stream" (Milhous *et al.* 1989), and is the basic simulation program, while the others provide various refinements. HABTAM, for instance, "simulates situations in which fish can migrate laterally within a transect, in order to make use of the available WUA when there is a change of velocity" and is designed for rapid fluctuations in flow, such as below hydropower stations (R.T. Milhous pers. comm.). HABTAV "simulates situations where fish habitat is determined by hydraulic parameters at the fish's location, as well as by velocities near the fish" and is principally designed for studies of trout and a few other well known species (R.T. Milhous pers. comm.). Less important programs are AVDEPTH and AVPERM, which are not habitat simulation programs as they do not calculate WUAs. They are used for calculating average hydraulic parameters for the whole reach when SI curves cannot be created, and are not dealt with further here.

HABTAE was not in the package reviewed by Gan & McMahon (1990), although it is dealt with in the PHABSIM II manual (Milhous *et al.* 1989). It appears to be the newest and most sophisticated option, and is described in the PHABSIM II manual as calculating the weighted usable area (surface or bed) (same as HABTAT, HABTAV and HABTAM), or weighted usable volume (WUV), for each transect. Where surface area is calculated, HABTAE produces the same results as HABTAT, provided the same simulation options are selected. HABTAE with the WUV option is used mainly for trout, which do not tolerate other fish above them in the water column, and is not applicable for schooling fish (R.T. Milhous pers. comm.). HABTAE and HABTAV are the two habitat programs dealt with in the tutorial, of which HABTAE is the more generally used and is the one that will be discussed here.

Each of the habitat simulation programs require an input options file, which specifies the options to be used when running the simulation. HABTAE has 21 options, HABTAM 14, HABTAT 19, and HABTAV 14. The options in HABTAE are more intelligible to an ecologist than those in the hydraulic programs, but many still confuse as there is no explanation as to why they are there. One is designed for recreational users of the river and has nothing to do with aquatic microhabitat (R.T. Milhous pers. comm.), while some others seem to have been designed for specific circumstances, such as linkage of cells to a specified total width for fish or canoe passage up or down river, but this is not explained in any of the literature available to this project.

The input options file for HABTAE is created by HABINE and contains indices specifying the preferences selected within each input-output command, the identification numbers of the sets of SI curves, and any information required by specific options. HABTAE requires as input the created HABTAE options file, TAPE3, TAPE4 and the unformatted file of SI curves FISHFIL. With these now all created, the habitat simulation can be done and WUA produced as output.

Total available area is the total wetted surface area of the studied representative or critical reach, expressed in ft^2 per 1000 ft of river length (which can then be converted by the user to the equivalent metric units) and as a function of discharge. The PHABSIM II output, WUA, is some smaller proportion of this area, and is expressed in the same units.

The simplest way of expressing total WUA is if one representative reach represents a complete zone (see Figure 3.2). Total WUA at any one discharge is then:

$TWUA = WUA \times ZL$ (Equation 3.8)

Where
TWUA = total weighted usable area for a target species within a zone (macrohabitat unit), in ft^2 or m^2
WUA = weighted usable area for a target species within a studied reach, in ft^2 per 1000 ft or m^2 per 1000 m
ZL = zone (macrohabitat unit) length, in ft or m

Variations on this equation are used if there is more than one studied reach per zone (see glossary) (Figure 3.2).

3.18 THE NEGOTIATION STAGE

The stated last step in IFIM is "evaluation of the alternatives to ensure that they meet management objectives and that internal conflicts and trade-offs have been resolved" (Bovee 1982). Various users recognise that the PHABSIM II output must be considered "in the context of water availability, water management constraints and ecological objectives" (Bullock *et al.* 1991). However, no literature emanating from the IFIM group is known that describes a formal procedure of negotiation. Lamb (1989) comes close to the topic when, using IFIM as an example, he considers the likely success of systems analysis in aiding decision makers. No specific explanations as to how to use the WUA-discharge output from PHABSIM II were found, nor even a guide to an objective way of determining the inflections point(s) on the plot that might help determine a "minimum recommended flow".

4. ASSESSING IFIM (STEPS 1-3): INTRODUCTION OF THE STUDY RIVER, AND IDENTIFICATION OF THE STUDY OBJECTIVES, TARGET SPECIES AND STUDY SITES

4.1 INTRODUCTION

The Olifants River system in the western Cape was chosen as the testing ground for assessing the general application of IFIM to South African rivers. In this Chapter, the river system and its catchment are described, as are the reasons for its selection for this assessment, with reference to the guidelines laid down within IFIM. The choice of study objectives is discussed, and reasons are provided for the selection and location of the study area and sites within it. The target species for the study are also introduced and their selection explained within the context of the study objectives. Furthermore, an assessment is made of the degree to which it was possible to follow the IFIM guidelines. Conclusions are drawn on the applicability of this component of the methodology in South Africa.

4.2 THE STUDY RIVER

To follow the steps within IFIM, the catchment of the study river and associated factors such as climate, geology and land-use have to be understood in some depth. Hence, the following sections provide descriptions of all features of the Olifants River system considered pertinent to the study.

4.2.1 DESCRIPTION OF THE CATCHMENT

The Olifants River system is located some 250 km north-west of Cape Town and has an estimated catchment area of 46 084 to 46 625 km^2 (Morant 1984) which makes it the second largest catchment in South Africa after that of the Orange River (Figure 4.1). Despite its large catchment size, it contributes only 2% of South Africa's mean annual runoff (MAR) (King *et al.* 1979). There are approximately 1100 km of river comprising the river system (Morant 1984).

Physiographically, the catchment is complex, with several ranges of high mountains running north-south, and with steep slopes over much of the area. Numerous smaller steep and mountainous valleys lie in a north-easterly direction and further dissect the catchment (McKenzie *et al.* 1990). Altitudes range from over 1800 m in the Groot Winterhoek mountains to 200 m at Clanwilliam Dam and about 20 m at Klawer. This physiographic diversity causes highly variable meteorological conditions throughout the catchment (McKenzie *et al.* 1990).

The catchment lies within the winter rainfall region of South Africa, with the majority of rainfall occurring between May and September. Snowfalls occur on the mountain peaks during winter, but have a minimal influence on streamflow. The eastern portion of the catchment, including the Doring River which is the principal tributary of the Olifants River, lies in a rain shadow area. Although most of the rainfall in this eastern area also falls during the winter months, considerable local rain can occur in summer as thunderstorms (Morant 1984). This part of the Olifants catchment is classed as semi-desert, as rainfall is unreliable overall and rarely exceeds 250 mm per annum (Morant 1984). The mean annual precipitation (MAP) for the catchment as a whole is estimated as 503 mm y^{-1} (Water Research Commission mean annual isohyetal maps 1989, cited in McKenzie *et al.* 1990). A marked reduction in MAP occurs along the length of the mainstream valley, and across the valley with the decline in altitude. For example, the MAP for the Groot Winterhoek mountains exceeds 1400 mm y^{-1} whereas at Clanwilliam Dam it is less than 300 mm y^{-1}. The large variation in altitude throughout the catchment is responsible for a wide range in ambient temperatures and hence in evaporation rates. The mean annual Symons pan evaporation in the headwater region of the Olifants River is approximately 1600 mm y^{-1} and increases to 2000 mm y^{-1} at Clanwilliam Dam (McKenzie *et al.* 1990).

Geologically, the catchment is varied, with the Olifants River itself draining an area consisting almost entirely of quartzitic sandstones and quartzites of the Table Mountain Group (Cape Supergroup) (Morant 1984). The Doring River, in the western and more southern parts of its catchment, drains similar sediments, but also Bokkeveld Group shales and Witteberg Group quartzites and shales (Cape Supergroup). The eastern and northern portions of the catchment of the Olifants River system consist of Dwyka Formation tillites and Ecca Group shales and

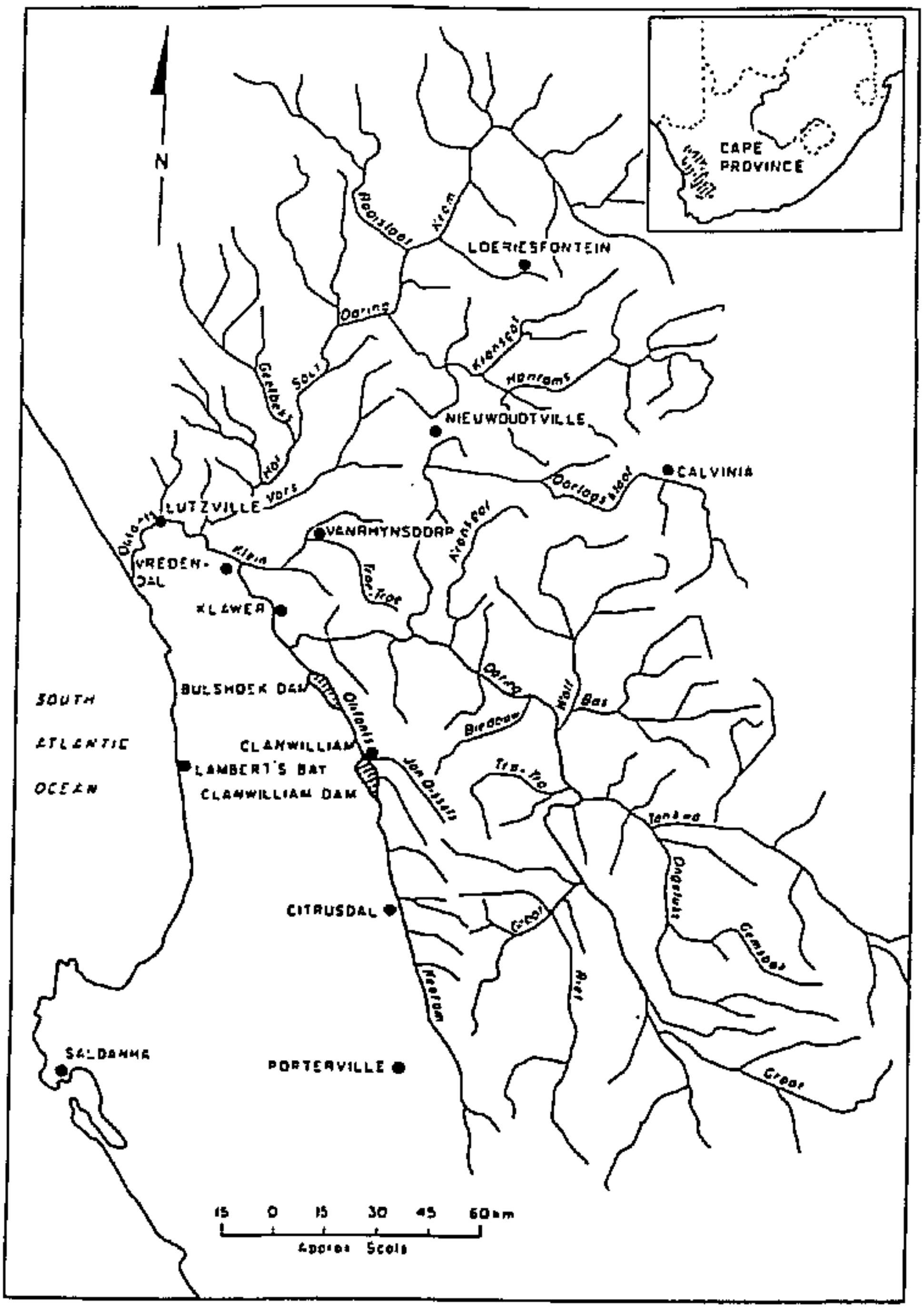


Figure 4.1 **Location and extent of the Olifants River catchment (from Morant 1984)**

sandstones (Karoo Supergroup). The central areas consist of shales, greywackes and limestones of the Malmesbury Group, and the north-western region of schists, gneisses and migmatites of the Namaqua Province. The geology of the area comprising the Olifants River valley is described further in Fourie (1977, cited in Griffiths 1990), and that of the entire catchment is depicted in geological maps of the region (1: 125 000 Ceres, 1: 250 000 Clanwilliam, 1: 250 000 Calvinia; Government Printer, Pretoria).

The catchment is almost entirely rural with highly variable amounts and types of vegetation cover, and little soil cover. Fairly sparse indigenous mountain fynbos dominates the mountain slopes while the natural vegetation at lower altitudes is more dense lowland fynbos (Acocks 1988, cited in Morant 1984). However, much of this area is now subject to intensive agricultural development, particularly along the relatively flat floor of the Olifants River valley with its deep soils. Semi-arid areas of the catchment are characterised by karroid vegetation such as succulent Karoo (J.P.H. Acocks 1951, 1: 1 500 000 map of veld types; Trigonometrical Survey Office 1951).

4.2.2 GENERAL HYDROLOGY

The MAR of the entire Olifants River catchment is 122 x 10^7 m^3 (Midgley & Pitman 1969, cited in Morant 1984). The runoff pattern reflects the marked seasonality of rainfall in the catchment, with little flow during the summer and peak flows during the period June to September. There tends to be extreme variability in the flood flows. Peak flow in the mainstream can range from 0.1% of the mean monthly runoff to 2.5 times this figure (Morant 1984). Monthly mean, maximum and minimum runoff data for Clanwilliam Dam hydrological gauging station are illustrated in Figure 4.2.

The MAR for the Olifants River specifically (a catchment area of 2825 km^2) is estimated as 527 x 10^6 m^3, and the mean annual rainfall over the area as 523 mm (Braune & Wessels 1981).

The erratic rainfall of the Doring River catchment results in an even more variable flood regime for this tributary, with a range from 0.1% to 4.5 times mean monthly flow in winter. Figure 4.3 illustrates this variability for monthly mean, maximum and minimum runoff data from the Aspoort gauging station. The MAR for the combined Doring and Sout River catchment, of area 45 765 km^2, is 449 x 10^6 m^3 and the mean annual rainfall only 188 mm (Braune & Wessels 1981).

Characteristically, runoff is rapid from most of the total catchment of the Olifants River system, due to water running off impervious sandstones and quartzites of the Olifants River region, and the sparse vegetation of the Doring River catchment (Morant 1984). The coefficient of variation of rainfall (CVP) and the coefficient of variation of runoff (CVR) for the Olifants River are 0.27 and 0.53 respectively. The CVP for the Doring and Sout Rivers is 0.25-0.29, and the CVR 0.61-0.73 (Braune & Wessels 1981). Braune & Wessels estimated the rainfall to runoff ratio for the Olifants River as 38.7, and for the Doring and Sout Rivers, in combination, as 5.2.

Information on the hydrological regime of the Olifants River system is extremely limited, and is discussed in Chapter Five. It includes simulated naturalised mean monthly discharges for various locations in the upper and middle reaches of the mainstream, and information on present and future flow patterns with both abstraction and water storage.

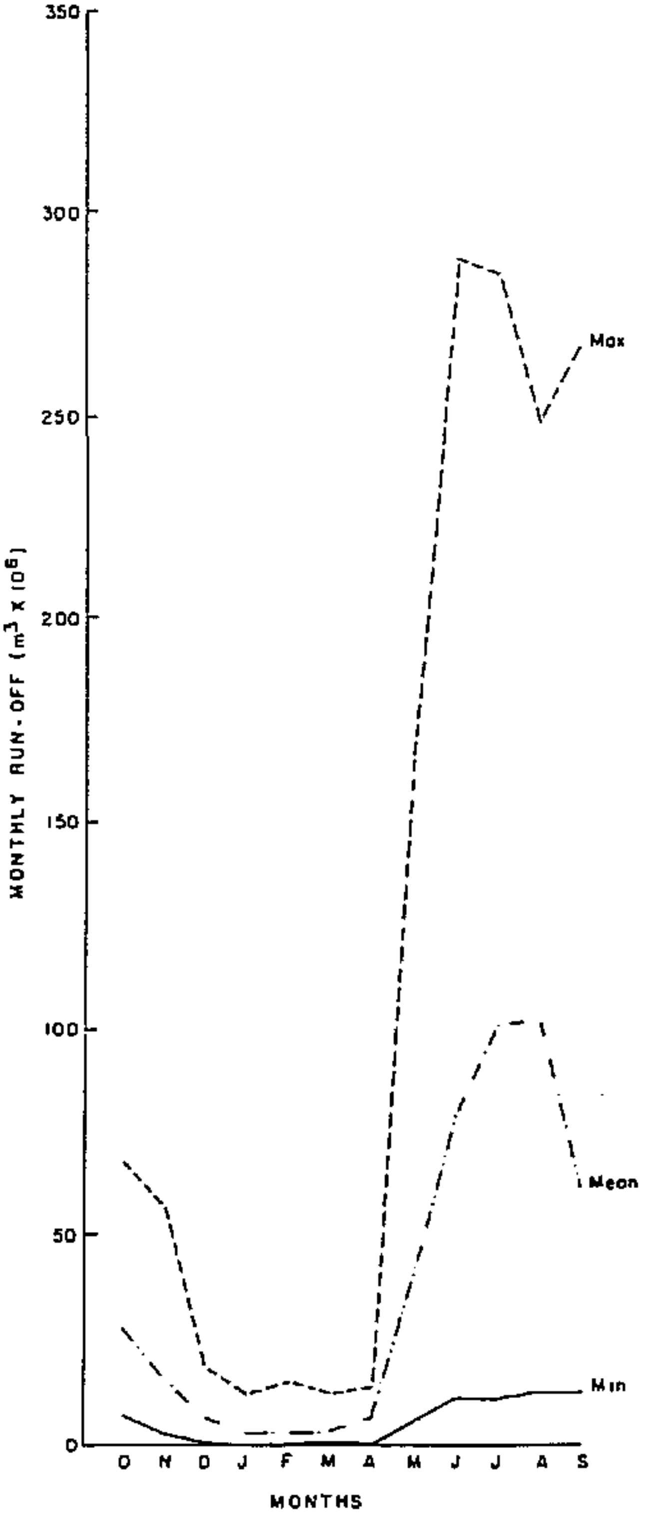


Figure 4.2 Mean, minimum and maximum monthly runoff for the Olifants River for the period 1934-1960, from Clanwilliam Dam gauging station (from Morant 1984)

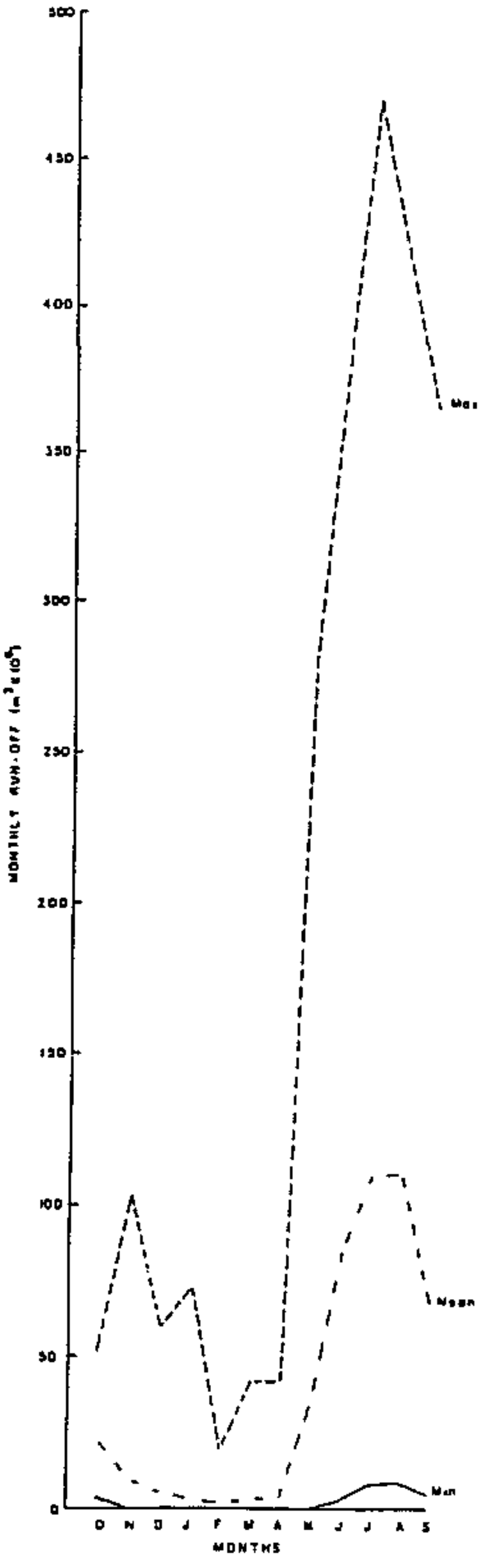


Figure 4.3 **Mean, minimum and maximum monthly runoff for the Doring River for the period 1922-1960, from Aspoort gauging station (from Morant 1984)**

4.2.3 DESCRIPTION OF THE OLIFANTS RIVER

The Olifants River mainstream has a total length estimated as 260 km (Morant 1984), 280.4 km (digitised GIS data, R. Wadeson, Geography Department, Rhodes University, pers. comm.), or 276.9 km (this study, source to sea) (Figure 4.4), and is naturally perennial. Its source is on the high Agter Witzenberg plateau, which is an agricultural area situated between the Skurweberge, the Groot Winterhoekberge and the Witzenberg. The source *per se* is difficult to pinpoint as it comprises a network of small mountain streams and associated wetland areas. Most of these streams do not flow in the summer (Tharme, pers. obs.). The highest reach of the Olifants River that is perennial is in an intensively farmed region of the plateau and exhibits clear signs of anthropogenic disturbance (Tharme, pers. obs.). The river flows northwards for about 12 km before entering a narrow gorge for 30 km and then emerging into a wide valley at Keerom. For the next 100 km it flows through a heavily cultivated region between the Olifantsrivierberge, Swartberg, Kouebokkeveldberge, Middelberg and the Cedarberg mountain ranges. There are two existing dams on this section of the river. Clanwilliam Dam, built in 1932 and raised in 1966, has a catchment area of 2033 km^2 and a storage capacity of 127×10^6 m^3 (Pitman *et al.* 1981). A canal leading off this dam supplies irrigation water for the Clanwilliam area. Bulshoek Dam, located 23 km downstream of Clanwilliam Dam, was constructed in 1919, has a storage capacity of 7.5×10^6 m^3, and is coupled with an extensive irrigation canal system that forms part of the Olifants River Government Water Scheme (ORGWS) (Pitman *et al.* 1981). This canal supplies irrigation water along about 90 km of the lower river and ends some 15 km before the estuary, which is at Papendorp (a description of the estuary can be found in Morant 1984). Bulshoek Dam functions mainly as a diversion weir for this lower river irrigation scheme, while Clanwilliam Dam is the principal storage dam designed to supply Bulshoek Dam and maintain a water supply for the middle-reach agricultural area.

The Doring River joins the Olifants River 20 km downstream of Bulshoek Dam. It is a seasonal river, with a highly variable flow regime. It and many of its tributaries drain the semi-arid areas of the Karoo, and contribute the largest proportion of sediment to the Olifants River mainstream. The Olifants River above the Doring River confluence carries low silt loads that are further reduced by the two dams in its middle reaches.

4.3 MOTIVATION FOR THE INSTREAM FLOW STUDY AND STUDY OBJECTIVES

4.3.1 MOTIVATION

The motivation for the instream flow study was based on two separate but interrelated concerns. The first dealt with present and projected changes in water resource allocations along the mainstream of the Olifants River, relative to growing water demands for agriculture. The second was principally a conservation concern pertaining primarily to the endemic fish of the river, and conflicted with the first. Both of these concerns are discussed below.

The Olifants River valley has become one of the three main citrus growing areas in South Africa, as well as being an important region for viticulture and the production of deciduous fruits, pastures and vegetables; there is some stock farming in the drier areas of the catchment

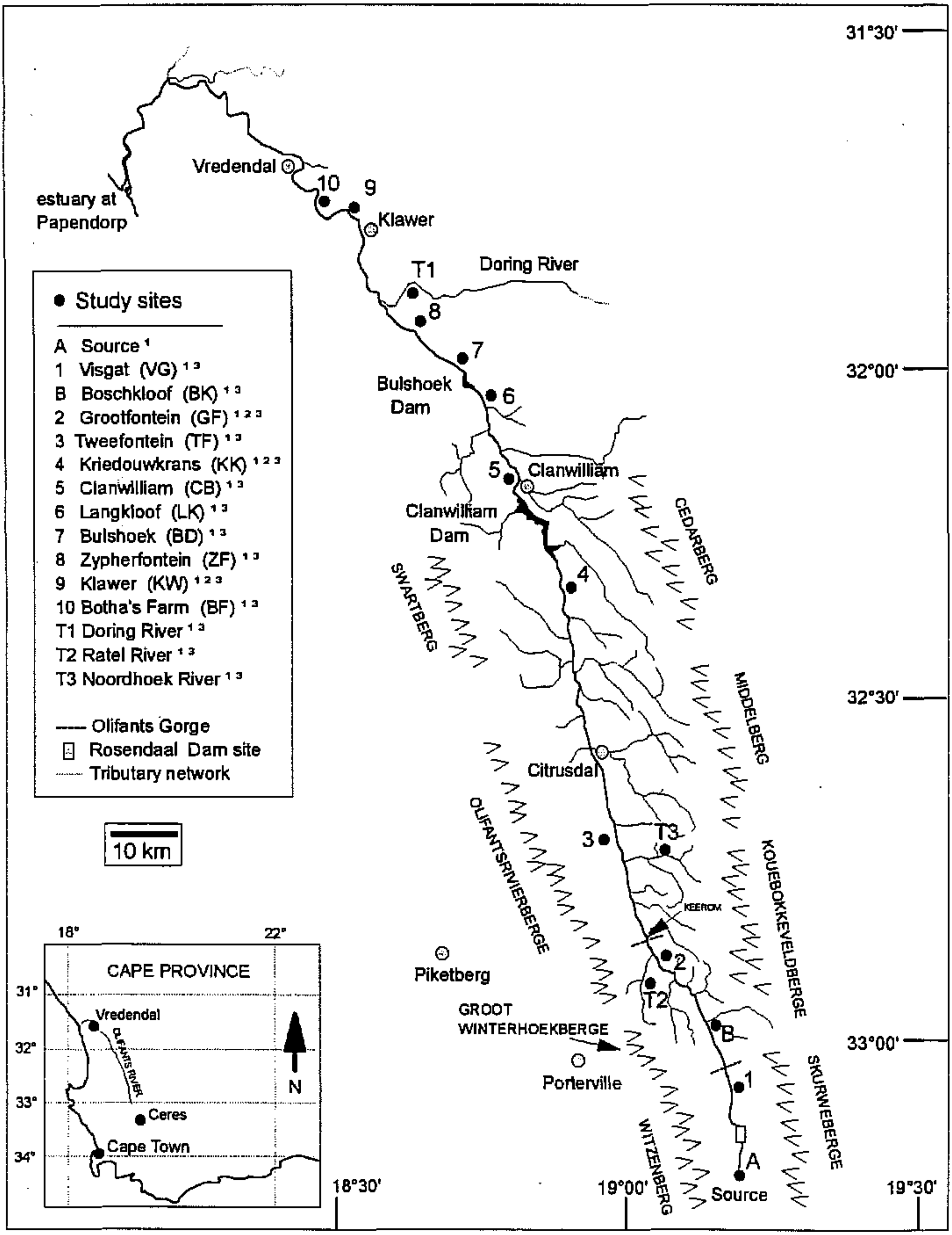


Figure 4.4 IFIM study area showing locations of macrohabitat ¹, PHABSIM II ² and benthic macroinvertebrate ³ study sites. Abbreviations of site names are given in parentheses

(Morant 1984; McKenzie *et al.* 1990). Rapidly expanding agricultural practices in the middle and lower reaches of the river within the past decade, particularly the expansion of citrus orchards, are leading to increased abstraction of river water for irrigation. Irrigation is undertaken during the summer months, from approximately October to March when there is very little rainfall. Water storage structures, such as farm dams, in the catchment are small and most crops are irrigated directly from run-of-river abstraction (McKenzie *et al.* 1990). Current and projected future demands for irrigation water in the area from Keerom to immediately upstream of Clanwilliam Dam (controlled by the Citrusdal Irrigation Board (CIB)), have resulted in the proposal of several water-development scenarios for the upper reaches of the river to satisfy these demands (McKenzie *et al.* 1990; DWAF 1991). There are also indications that the farming areas in the lower reaches, supplied by the ORGWS, are presently using all of their allocated water and will require larger quotas soon (McKenzie *et al.* 1990). Thus far, a dam with a capacity of 45-66 x 10^6 m^3 has been proposed for either Grootfontein or Keerom (Phase II), in the Olifants gorge, to be built in series with one upstream at Rosendaal (Phase I) on the Agter Witzenberg plateau (DWAF 1991). Although it has been calculated that both phases would be required to meet future offstream water demands by the CIB region in particular, (McKenzie *et al.* 1990), it appears likely that only the Rosendaal Dam will be built in the near future. The Grootfontein/Keerom Dam option is presently not considered to be a suitable option, due to environmental concerns, and may be shelved entirely or replaced by another option (D.I. van Wyk, Ninham Shand Inc. (NSI), pers. comm.).

In direct conflict with the above proposals for further regulation of the flow regime of the river, are several conservation issues. The river system contains eight endemic fish species all of which are listed in the Red Data book of fish (Skelton 1987) (Table 7.1). Although information on the biology and ecology of these fish species is extremely limited, a number of information sources, many anecdotal in nature, have suggested that the Clanwilliam and Bulshoek dams have been responsible for a sharp decline in population numbers of the migratory species in particular. Moreover, competition between an introduced alien predator, smallmouth bass, and the endemic fish has resulted in increased inaccessibility of former habitat for the endemic species in the mainstream, and a drastic reduction in their numbers. Several tributaries have provided refugia from the bass. However, most of these, such as Noordhoek River and the Ratel River, are under some form of environmental threat such as bulldozing of the river bed, water abstraction or deteriorating water quality.

The Olifants River is also important from a conservation perspective because of its unique gorge area. This is widely recognised for its aesthetic and recreational appeal, and includes Nature Conservation Wilderness areas and at least two natural heritage sites in its upper catchment (DWAF 1991). Possible historical links with the Orange River (Dingle & Hendey 1984), and its geological history (P.H. Skelton, JLB Smith Institute of Ichthyology, pers. comm.) make this river important from a scientific standpoint too. Further regulation of the river would seriously threaten all these valued attributes of the river.

The proposal to further develop the water resources of a river that is already subjected to large-scale regulation and abstraction, and the associated conflict with conservation issues, made the Olifants River an ideal testing ground for IFIM. Indeed, IFIM was designed to be used in such conflict situations. It is additionally suitable as a subject river for this kind of study as the problems faced when assessing its water requirements are likely to be common to most rivers in the country. These problems may include little time available before further development, poor current knowledge of the system, and limited available expertise and funding for the instream flow assessment. An investigation of how well the assessment can be made under these conditions would be a good test of the applicability of IFIM in South Africa.

4.3.2 STUDY OBJECTIVES

The study objectives are a reflection of the terms of reference for this project, and of the conflicts and motivation discussed in Section 4.3.1 (see also Section 3.3). The primary objective of attempting an instream flow assessment of the Olifants River was a general one: to learn all the existing components of IFIM and assess them in terms of their overall applicability to South African rivers. It was hoped to gain a clear understanding of the limitations and potential uses of the methodology relative to other possible approaches, whether these be new approaches developed to cater for the specific needs of South African rivers or alternative existing ones.

The second objective was to use IFIM, if possible, to determine the amount of total habitat available for selected target species over a range of flows, along those stretches of the Olifants River likely to be affected by the building of one or more of the proposed dams. As the location of the dam(s), their design, and operating release schedules had not yet been decided, their specific impact on the riverine ecosystem could not be assessed. This study was thus aimed simply at determining how changes in discharge would affect the amount of habitat available for the target species. This information could be made available to DWAF to aid decisions on water release schedules for the proposed dam(s).

The instream flow assessment was directed mainly at the upper and middle reaches of the river where the impacts of a dam(s) would most likely be greatest. However, it was considered important to include a set of sites representing the lower river reaches. This was because any water development scheme was likely to have an impact on all reaches of the river including the estuary, and because it was considered necessary to test the performance of IFIM by applying it in different parts of the same river.

4.4 TARGET BIOTA

4.4.1 SELECTION OF TARGET COMPONENTS

In selecting study organisms for the instream flow assessment, "target components" of the fauna or species groups were first chosen. In other words, the endemic fish species of the Olifants River were chosen as a target component for study and the benthic macroinvertebrates were selected as a second target component. This was done out of necessity, as there was insufficient known about any of the species to be able to select single species that are "sensitive to particular environmental parameters" and can "reflect the environmental constraints on their communities as a whole" (Bovee 1982). Distributions and abundances of the species were not known, nor, in the case of the macroinvertebrates, were the species present. There was no knowledge on the limits of tolerance to any environmental conditions of any of the species, nor was there a specific problem such as "potential changes in food supply for fish after water-resource development" to be studied.

The approach to the choice of target species had to be undertaken by combining the "basic research into habitat requirements", that Bovee (1982) stated should be done before an IFIM study, with collection of data for the IFIM study. Thus, a wide range of habitat data on all species of the two chosen target components was collected, as it was intended to use these data to focus in on specific target species at a later stage of the assessment.

4.4.2 BENTHIC MACROINVERTEBRATES AS TARGET SPECIES

The main target component of the riverine fauna selected for the instream flow study was the benthic macroinvertebrate community. For those reasons given in Section 4.4.1, the habitat requirements of the entire community were assessed first, by means of an index of species diversity. This type of approach has been used before in several studies, usually as a step towards the identification of an indicator species (Gore 1978; Gore & Judy 1981; Fouts 1990).

It involved identifying those physical conditions linked to the benthic macroinvertebrate samples with the highest biotic diversity index, and using these to represent the desirable condition to be achieved in the river. Ideally, later, specific species within the macroinvertebrate fauna could be chosen as indicator species. These would be species whose requirements best matched those of the community as a whole. Either the most diverse community or the most representative indicator species would eventually be selected as the target for the assessment and its, or indeed both sets of, requirements become the biological input to PHABSIM II.

4.4.3 FISH AS TARGET SPECIES

The Red Data fish species endemic to the Olifants River were selected as a second target component, because their water requirements were identified as the driving force, from the standpoint of conservation, in influencing future development of the water resources of the river. Additionally, an objective of this study was to make comparisons between the instream flow recommendations obtained using IFIM independently for the fish and the benthic macroinvertebrates. The comparison was felt to be important for three reasons.

Firstly, IFIM was initially developed to assess the flow and associated habitat requirements of game fish species such as the Salmonidae (Bovee 1986; Gan & McMahon 1990). Consequently, the methodology is presently most appropriate for the independent assessment of the instream flow requirements of single fish species rather than of species groups. It has only been used on a very limited basis for studies on benthic macroinvertebrates at the community and multi-species level within the past decade (Gore 1978; Gore & Judy 1981; Morin *et al.* 1986). It was anticipated that the use of the methodology for both components of the fauna would highlight those areas of IFIM where difficulties were likely to be experienced in its application for either component and would expose any weaknesses in the approach. As the methodology usually focuses on only one ecosystem component, namely single fish species, there was also the possible danger that critical flow requirements of other ecosystem components would be entirely neglected, or if assessed, would prove to be totally different. Thus, assessing the instream flow requirements of the benthic macroinvertebrate and fish fauna provided a further step in understanding the flow requirements of the whole ecosystem, and a further means of testing the applicability of the methodology. Certainly, the use of macroinvertebrates as target species for instream flow assessments appears to be rapidly gaining popularity. At present most studies using IFIM have not extended beyond the use of fish and/or macroinvertebrates as target organisms, and its use for other components such as riparian vegetation would require modification of the methodology beyond the capabilities of this research programme.

Information on the fish and benthic macroinvertebrate species used in the study is provided in Chapters Seven and Eight respectively.

4.5 STUDY AREA AND STUDY SITES

4.5.1 THE STUDY AREA

The study objectives listed in Section 4.3.2 required the study area to encompass all areas that might be affected in some way by increased upstream regulation. Further, the study area was extended to enable an assessment the performance of PHABSIM II in assessing microhabitat availability in various sections of the river that posed characteristically different sets of problems and challenges in applying the methodology.

The length of river selected for the study therefore, extended from the source to about 10 km downstream of the town of Klawer (Figure 4.4). Thus, approximately 200 km of an estimated total length of 277 km of river, was encompassed by the study area, and upper, middle and lower reaches of the river were represented.

4.5.2 THE STUDY SITES

Within this study area, fifteen sites were selected for the collection of data on macrohabitat and/or on the physical microhabitat requirements of the benthic macroinvertebrates (Figure 4.4 and Table 4.1). Three of these were on tributaries, including the Doring River. Three of the sites on the mainstream, namely Grootfontein, Kriedouwkrans and Klawer, also became PHABSIM II sites for the collection of all the hydraulic information required as input to PHABSIM II (see Chapter Six). Sites that were used for the collection of data on the microhabitat requirements of the endemic fish are listed in Table 7.2 and depicted in Figure 7.1 (see Chapter Seven), and included two sites on the mainstream.

4.5.3 CRITERIA FOR SELECTION OF STUDY SITES

Theoretical and practical considerations in the selection of both the macrohabitat and microhabitat study sites are discussed briefly in Chapter Three, and at length in Bovee (1982). The use of the kinds of criteria recommended in Bovee (1982) to facilitate site selection is discussed here in relation to the total of fifteen sites used for the assessment both of macrohabitat and of the microhabitat requirements of the macroinvertebrates. Those sites where data were collected for the assessment of fish microhabitat requirements are discussed further in Chapter Seven, as they were selected principally on the knowledge that they represented areas where endemic fish were likely to be found.

In the application of criteria, particular dependence is placed by Bovee (1982) on the use of existing information on the catchment, river system hydrology, channel morphology and sedimentation, water quality and temperature, and species biology. These are used to determine locations within the study area where significant environmental (or macrohabitat) changes occur. Change points in any of these macrohabitat variables considered significant enough to influence local macrohabitat conditions for the target species are used to divide the study area into a series of segments. Decisions then have to be made on how many of these segments are sufficiently different from the others to warrant the establishment of additional PHABSIM II sites.

Table 4.1 Location of IFIM sites for studies of macrohabitat and microhabitat for benthic macroinvertebrates, on the Olifants River system

SITE	MAP 1:50 000	LATITUDE	LONGITUDE	DISTANCE FROM SOURCE (km)	ALTITUDE (m a.m.s.l.)	
MAINSTREAM						
A. Source	3319 AA	33°09'33"	19°14'08"	0	760	
1. Visgat	3319 AA	33°04'37"	19°12'58"	11	630	
B. Boschkloof	3219 CC	32°58'30"	19°11'02"	23	350	
2. Grootfontein	3219 CC	32°53'14"	19°05'40"	36	248	
3. Tweefontein	3219 CA	32°45'06"	19°03'00"	65	168	
4. Kriedouwkrans	3218 BD	32°21'34"	18°56'50"	103	120	
5. Clanwilliam	3218 BB	32°10'26"	18°52'16"	125	80	
6. Langkloof	3218 BB	32°04'08"	18°49'34"	139	68	
7. Bulshoek	3118 DD	31°59'28"	18°47'20"	150	60	
8. Zypherfontein	3118 DC	31°56'26"	18°42'36"	157	32	
9. Klawer	3118 DC	31°46'10"	18°36'40"	186	20	
10. Botha's Farm	3118 DA	31°43'25"	18°32'00"	201	20	
TRIBUTARIES						
T1. Doring River	3118 DC	31°52'10"	18°41'02"	171[1]	20[1]	40[2]
T2. Ratel River	3219 CC	32°52'25"	19°05'00"	44[1]	232[1]	350[2]
T3. Noordhoek River	3219 CA	32°47'40"	19°05'40"	55[1]	192[1]	260[2]

1. At confluence with mainstream
2. Altitude for tributary reach site

An attempt was made at the outset of this study to use those criteria recommended in Bovee (1982), as summarised in Table 4.2. However, these criteria relied mostly on the availability of highly specific information and, in many instances, on long-term data bases. In the case of the Olifants River, and for many other South African rivers, much of this kind of information does not exist or is available in such a limited form that it cannot effectively be used as recommended to select study sites. As a result of this problem, attempts to apply the criteria ranged from moderately successful to quite or totally unsuccessful (Table 4.2). If site selection had been conducted based on field visits in addition to the office exercises suggested by Bovee, attempts to apply criteria may have proved more successful. Further constraints to the degree of success were imposed by limitations of finance, time and expertise. This forced the adoption of a combined *a priori* and *a posteriori* approach in the selection of study sites. Thus, instead of performing at least a preliminary assessment of catchment and macrohabitat conditions before choosing microhabitat sites, as recommended for a comprehensive IFIM assessment, microhabitat sites were chosen before macrohabitat sites. This procedure is described in Section 4.5.4.

4.5.4 STUDY SITE SELECTION

As the first step in site selection, scientists from Cape Nature Conservation (CNC) who were familiar with the ecology and geomorphology of the river system were consulted. Using 1:50 000 topographical maps of the entire river system and the professional judgement of these scientists, three main zones were identified along the study area. These zones were delineated based on a general knowledge of channel morphology, substrate and the distributions of fish and benthic macroinvertebrates. Within each of the three zones a single representative reach was provisionally chosen where a PHABSIM II (microhabitat) study site would be located.

A longitudinal profile of the entire river was then plotted from the maps. Locations of the following features were noted on this profile: the chosen zones; all changes in catchment land-use; dams or other channel regulation features; minor and major tributary confluences; access points to the river; all marked changes in slope; and any changes in channel form that were obvious from the maps. Based on these various criteria, more specific locations for the PHABSIM II microhabitat sites were selected within the representative reaches. The same criteria, and additionally, any likely or obvious change points in water quality or temperature variables such as point-pollution sources, were then used to select macrohabitat sites between the PHABSIM II sites. In addition, macrohabitat sites were located at the same places as the three PHABSIM II microhabitat sites.

The aims of including the macrohabitat sites between the PHABSIM II sites were twofold. Firstly, they were essential for the macrohabitat suitability component of IFIM (described in Section 3.6 and Chapter Five), where they were used to complete the suite of sites used for the collection of data on longitudinal changes in water quality, temperature, channel morphology, substrates and aquatic communities within the study area. Secondly, they provided sites for the collection of additional records on the distribution ranges, and limits of tolerance, of the target species to the macrohabitat and physical microhabitat conditions. The decision was made to include a macrohabitat site on the Doring River because it represented a very different part of the catchment both in terms of its geology and hydrology. As it was a known habitat area for some of the chosen target fish species (Morant 1984; K.C.D. Hamman, CNC, pers. comm.) it would provide further information on their tolerance ranges. Macrohabitat sites were also chosen on two of the smaller tributaries (Table 7.2) as the target fish species that had been eradicated from almost all the mainstream still occurred there (K.C.D. Hamman, CNC, pers. comm.). To meet the stated objectives (Section 4.3.2) fish data had to be collected in the tributaries and then used to model conditions in the mainstream.

The total number of sites representing the study area was restricted to those recognised as essential, based on the amount of time available for the study, the high degree of intensive

Table 4.2 **List of criteria and sources of information recommended for the selection of microhabitat and macrohabitat study sites, modified from Bovee (1982). Some of the information sources and limitations in applying these criteria for this study are listed, and the degree of success in their application indicated as successful (*), partially successful (#), or unsuccessful (X)**

CRITERION / SOURCE OF INFORMATION	SPECIFIED REQUIREMENTS AS PER BOVEE (1982)	INFORMATION SOURCES AND LIMITATIONS FOR THIS STUDY	DEGREE OF SUCCESS
CATCHMENT			
1. Topography	Significant changes in topographic relief	1:50 000 topographical maps only; Incomplete sequences of aerial photographs available and generally of poor quality; Orthophotographs available for only a few river reaches	*
2. Altitude	Obvious changes in altitudes	Known from longitudinal profile	*
3. Sediment source	Significant sources including areas of sediment-generating land-use	No detailed data base on land-use; Topographical maps indicating areas of agriculture of limited use for information on erosion or sediment generation; Sediment loads of rivers not known	#
4. Vegetation distribution patterns	Significant vegetation changes associated with altered land-use	coarse-level information on vegetation change available from generalised historical vegetation maps and topographical maps	#
5. Geology	Significant changes in geology of catchment	Geological maps of the area available	*
HYDROLOGY			
1. Tributary confluences	Accretion of > 10% of average base flow below the confluence	Base flow of mainstream not known in sufficient detail; Hydrology of most tributaries not known	#
2. Flow regulation structures and diversions	Removal of > 10% of total river flow above diversion	Some information on inpacts of two dams known; Hydrology of river upstream of smaller diversions (weirs) not known	#
3. Water abstraction points	Removal of > 10% of total river flow	Most abstraction directly from river and poorly documented	X

Table 4.2 continued

	CRITERION / SOURCE OF INFORMATION	SPECIFIED REQUIREMENTS AS PER BOVEE (1982)	INFORMATION SOURCES AND LIMITATIONS FOR THIS STUDY	DEGREE OF SUCCESS
	HYDROLOGY continued			
4.	Diffuse small tributaries	In aggregate adding 10% to average base flow of mainstream or adding 10% to drainage area-precipitation product	Hydrology of small tributaries not known	X
5.	Ground water sources	In aggregate adding 10% to average base flow of mainstream or adding 10% to drainage area-precipitation product	No information on groundwater supplies to the river	X
6.	Changepoints in flow regime	Other obvious changepoints in hydrological regime	River gauged only at inflow to Clanwilliam Dam	#
	CHANNEL MORPHOLOGY			
1.	Channel sinuosity	Locations where sinuosity changes appreciably (>25%)	Estimable from maps	*
2.	Width to depth ratio	Locations where ratio changes appreciably (>25%)	Width estimable from topographical maps	#
3.	Channel shape	Significant changes in general channel shape	Requires channel descriptions and field visit, not obvious from maps	#
4.	Channel pattern	Significant changes in pattern	Some changes in pattern obvious from maps; More subtle changes would require field visit	#
5.	Bed and bank particle size composition	Significant changes in composition	Not available in detail without field visit	#
6.	Bank (riparian) vegetation	Significant changes in composition and distribution	Not available, would require site visit	X
7.	Channel gradient	Sharp and gradual changes in slope	Calculable from maps	*
8.	Sedimentological regime	Identification of changes in sedimentological regime including sites of erosion and deposition, and supply and demand points	No information available	X

Table 4.2 continued

	CRITERION / SOURCE OF INFORMATION	SPECIFIED REQUIREMENTS AS PER BOVEE (1982)	INFORMATION SOURCES AND LIMITATIONS FOR THIS STUDY	DEGREE OF SUCCESS
WATER QUALITY / TEMPERATURE				
1.	Point sources of pollution or thermal effluent	Identification of point sources	Long-term water quality information only for dams and irrigation canals and not for mainstream	X
2.	Rapid or extreme changes in water quality/temperature loadings	Identification of significant changepoints or transition zones	Inadequate long-term water quality data	X
3.	Non-point pollution sources	Identification of areas of land-use affecting nonpoint pollution	Identification of sites of pollution such as agricultural return flow possible using maps; Degree of pollution not known	#
4.	Tributary confluences	Identification of those tributaries significantly altering water quality or temperature in the mainstream	No information from data bases, but possible to limited extent using information on geology	#
5.	Assimilation points for organic loads	Identification of such points	Inadequate historical data base	X
6.	Control sites for assessment of residual loadings of water quality variables	Establishment of control points for baseline information	Possible to establish with additional fieldwork	*
SPECIES BIOLOGY				
1.	Coldwater/warmwater species	Identification of populations of such species and transitional reaches	Ascertainable on basis of professional judgement and informal knowledge only	#
2.	Critical habitats	Identify critical habitats for life stages of the target species	Possible for fish spawning/migration for few species on basis of professional judgement and informal knowledge only; No data base	#
3.	Biological thresholds for target species	Identification of thresholds	Extremely limited information on species composition of river; No information on species limits of tolerance for water quality or temperature	X

sampling needed at each site, and the limited number of suitable access points to the river, particularly in the upper gorge area. Although this number of sites was probably fewer than the number that would have been identified had strict adherence to the techniques for site selection recommended by Bovee (1982) been possible, it was a realistic number from a practical viewpoint. Once all potential sites were marked on the maps, a reconnaissance field trip was undertaken to check on their suitability and to revise their locations or numbers if deemed necessary.

A longitudinal profile of the study area with the locations of all finalised study sites is depicted in Figure 4.5.

Tables 4.1 and 7.2 give approximate longitudes and latitudes for macrohabitat/invertebrate microhabitat and fish microhabitat study sites respectively, and Table 4.3 highlights the principal hydrological, geomorphological and ecological features of each site that ultimately resulted in its selection.

After the selection of all study sites was completed, both the macrohabitat and the microhabitat or PHABSIM II components of the methodology were initiated. The sampling approach and associated results and discussion for the macrohabitat component are given in Chapter Five, and for the microhabitat component in Chapters Six, Seven, Eight and Nine.

4.6 SUMMARY OF THE APPLICABILITY OF THIS COMPONENT OF IFIM

In summary, little practical guidance is given within the methodology on identifying the study area and defining the study objectives. The implementation of these steps is highly reliant on professional judgement anyway and varies considerably with the level of result required for the instream flow assessment. However, it would be useful to have a more comprehensive and structured form of outline to assist those researchers who are attempting to apply the methodology for the first time.

Information in Bovee (1982) on the selection of target species is directed primarily at single fish species, and reflects the historical development of the methodology as a means of determining the instream flow requirements of species of game fish. There is little information available in the literature on ways of designing studies to cope more effectively with the assessment of instream flows for benthic macroinvertebrates, and generally on ways of combining information on community requirements with information for individual indicator species. Also, there is limited information on how to do instream flow assessments for whole riverine ecosystems.

The selection of study sites for both the macrohabitat and microhabitat components of the methodology was made difficult by attempts to apply the types of criteria identified as necessary for site selection in Bovee (1982). Although the criteria seem to be the right ones and many of them are fairly reasonable in terms of their information needs, several were difficult or impossible to use in this study. Most of the information could theoretically have been obtained, albeit at a very coarse level, but it could have doubled the length and cost of this project, and would still have required various forms of specialist expertise. For instance, some criteria were dependent on the existence of large historical data bases or on sophisticated

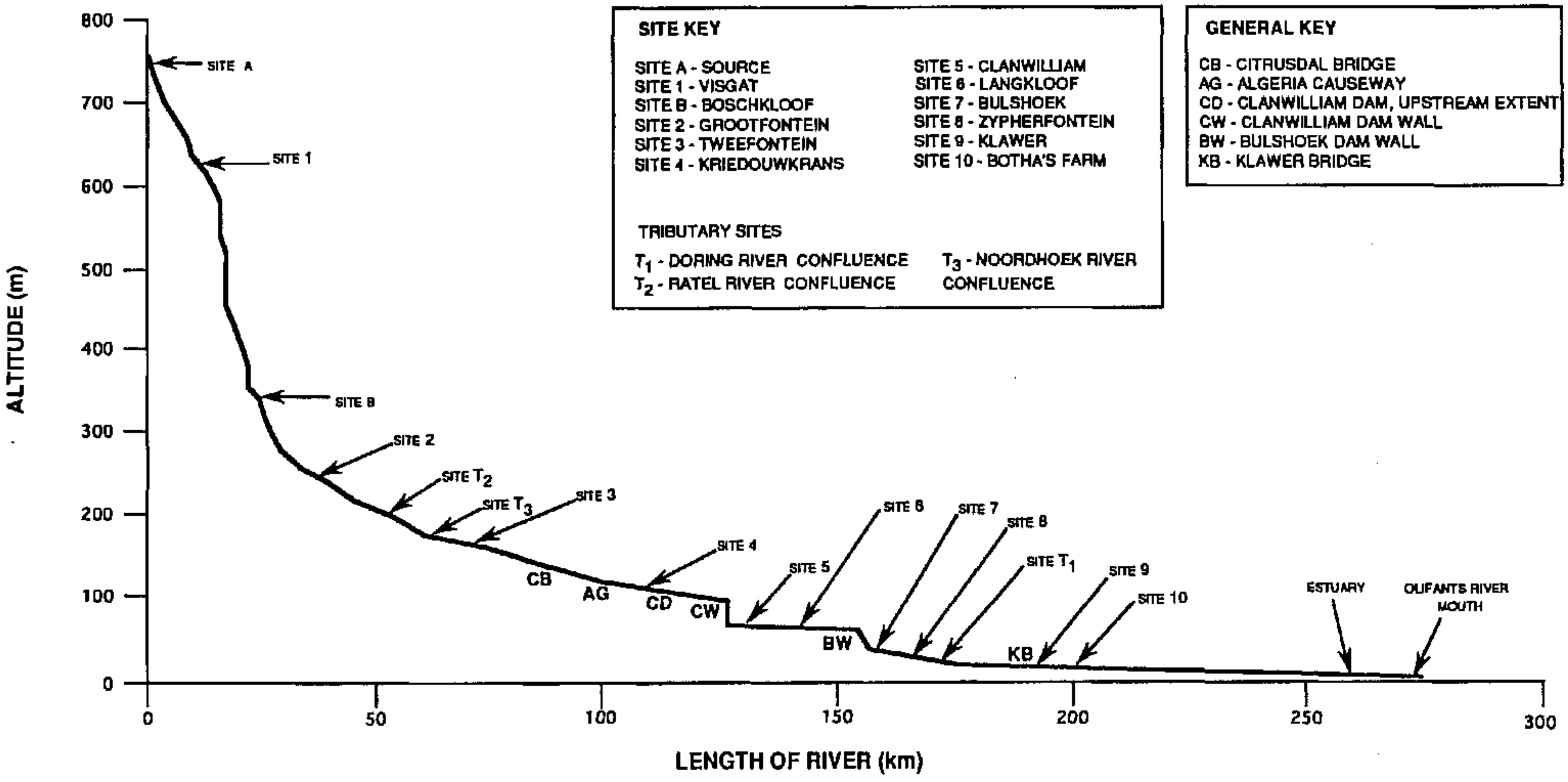


Figure 4.5 Longitudinal profile of the Olifants River showing locations of study sites

Table 4.3 General description of study sites selected for IFIM. Headings represent the main categories of criteria for site selection recommended by Bovee (1982); where possible, these criteria were used (see Table 4.2). Features indicated by asterices were assessed during this study and not during the initial mapping exercise for choosing sites, as information on them was not available without a field survey. In retrospect, certain criteria were found to be important in delimiting each site; these are underlined. BMI data - benthic macroinvertebrate data

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
MAINSTREAM							
Source	moderate intensity agriculture (fruit & vegetable crops); moderate potential for erosion & sediment production; high anthropogenic disturbance	flat, wide plateau with mountainous surrounds; upstream of gorge	location of perennial source fed by seasonal mountain streams & wetlands; farm dams; abstraction for irrigation; upstream of Rosendaal Dam site; no flow data	gradient 15.4 m km^{-1}; narrow, shallow channel; *bed mostly large cobbles covered with silt; low soil banks; *runs	cool water; *signs of organic enrichment (high nitrates & nitrites, fairly high conductivity); some historical data	*catchment fynbos; primarily alien vegetation overhanging banks, limited riparian fynbos	no specific BMI or fish data
Visgat	downstream of moderate intensity agricultural area; low potential for erosion & sediment production; natural heritage site with restricted access by permit; moderate anthropogenic disturbance	plateau steepening into start of gorge; low rocky cliffs in lower section	farm dams; abstraction for irrigation; fed by mountain streams; *downstream of Rosendaal Dam site; no flow data	gradient 20.0 m km^{-1}; rapidly steepening directly upstream of gorge, narrow shallow channel; *bed primarily bedrock slabs, *several bedrock pools with some cobbles & boulders; *banks low, high cliffs in lower reaches; pools, rapids, runs	*cool water; *very good water quality; no historical data	catchment fynbos; riparian fynbos; *occasional patches of palmiet (*Prionium serratum*)	no specific data; historically alien trout present; *BMI data collected

Table 4.3 continued

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
MAINSTREAM							
Boschkloof	natural heritage site with restricted acess by permit; few farms near gorge on surrounding mountainous plateau; very little agriculture in immediate vicinity; limited use of gorge for recreation; low potential for erosion & sediment production; very low anthropogenic disturbance	well-defined, steep gorge; extremely narrow in places	influenced to unknown extent by upstream water abstraction; numerous tributaries feed into mainstream from side gorges; no flow data	gradient 8.5 m km^{-1}; downstream of the steepest section of the gorge; *bedrock/cobble pools, cascades, several high waterfalls upstream; channel fairly narrow,; banks comprising high cliffs; *high biotope diversity	*cool to moderately warm water; *water quality excellent; no historical data	catchment fynbos; *occasional stands of palmiet instream	historically endemic fish present; only mainstream refuge where most endemic fish species coexist, high fish population numbers, critical habitat area for all fish life stages; *undescribed BMI species; *BMI data collected; alien smallmouth bass present in low numbers
Grootfontein (PHABSIM II site)	moderate intensity agriculture (fruit & vegetable crops); very low potential for erosion & sediment production; low anthropogenic disturbance	lower gorge, fairly narrow to wide valley between mountain ranges	*modelled flow data available; confluence of several tributaries with mainstream; *field flow data collected	gradient 2.8 m km^{-1}, moderately wide channel, *few deep sections; predominantly *cobble bed with occasional boulders & sandy areas; banks low but fairly steep sides to gorge; *some multiple channels with vegetated cobble islands; *high biotope diversity including riffles, runs, pools, shallow & deep backwaters	*variable temperatures with high summer diel values; *very good water quality; no historical data	catchment fynbos; riparian belt of riverine fynbos, occasional stands of palmiet and *Aponogeton* instream	historically endemic fish present; endemic fish present in very low numbers; presence of alien smallmouth bass in high numbers & other alien species; *BMI & fish data collected

Table 4.3 continued

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
MAINSTREAM							
Tweefontein	intensive farming area (citrus crops & livestock); start of CIB area; moderate potential for erosion & sediment production; high anthropogenic disturbance	downstream of gorge; wide alluvial mainstream valley with mountain ranges on both sides	intensive run-of-river abstraction; farm dams & boreholes; no flow data	gradient 2.2 m km^{-1}; foothill zone; moderately wide channel, *some multiple channels with vegetated islands; *predominantly cobble bed; riffle-run sequences	some historical data (upstream); *variable temperature regime including high summer diel values; *some evidence of agricultural activity (high nutrients)	catchment fairly sparse disturbed indigenous fynbos;* presence of alien *Acacia*	no specific data; historically endemic fish present; *BMI data collected
Kriedouwkrans (PHABSIM II site)	highly intensive citrus farming; lower section of CIB area; moderate potential for erosion & sediment production; high anthropogenic disturbance	wide alluvial valley with mountain ranges on both sides	intensive run-of-river abstraction; farm dams & boreholes; historical & modelled flow data available for downstream inflow to Clanwilliam Dam; directly upstream of Clanwilliam Dam; *field flow data collected; possible backwater effect from dam; flow ceases occasionally in summer	gradient ~2.2 m km^{-1}; channel wide, comprising *narrow multiple channels between palmiet islands; *bed composed of bedrock & boulder outcrops interspersed with sandy areas; *low sandy & occasionally rocky banks; *high biotope diversity, including riffles, runs, rapids	*evidence of agricultural activities (high nutrients & conductivity); some historical data (upstream)	catchment karroid broken veld (some fynbos); some indigenous riparian trees & shrubs, *aliens including *Acacia* & *Sesbania*; *stands of palmiet lining channel & forming instream islands	no specific data; historically endemic fish present; alien fish present; some historical BMI data (upstream); *BMI data collected

Table 4.3 continued

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
MAINSTREAM							
Clanwilliam	primarily citrus farming, rooibos tea & other crops; moderate potential for erosion & sediment production; high anthropogenic disturbance; near Clanwilliam Yellowfish Station (CNC); extensive bulldozing of sandy bed section; irrigation canal from dam	wide alluvial valley with mountain ranges on both sides	influenced by release schedule of Clanwilliam Dam; flow data for dam releases	gradient 0.7 m km^{-1}; directly downstream of Clanwilliam Dam; fairly wide channel with *sections of multiple channels separated by dense belts of palmiet; low rocky & soil-covered banks; *bedrock bed with some angular cobble (construction rubble) & gravel; *wide expanses of sand further downstream; *riffles, runs	*temperature & water quality influenced by hypolimnetic releases from Clanwilliam Dam; some historical data (downstream)	catchment succulent karoo (some fynbos); *dense palmiet islands between channels; little indigenous riparian vegetation; most natural vegetation replaced by crops or aliens	nursery area for several endemic fish species; critical spawning site below dam wall; *BMI and fish data collected; historically endemic fish present; alien fish species present
Langkloof	agriculture (various crops); moderate potential for erosion & sediment production; high anthropogenic disturbance	open valley with mountains on both sides	directly upstream of weir & Bulshoek Dam; experiences backwater effects from both; no flow data	gradient 0.7 m km^{-1}; *wide shallow channel; banks low; *bed entirely sand; *shallow runs, still waters	*evidence of agricultural activity (high nutrients, conductivity); no historical data	catchment succulent karoo (some fynbos); *grasses & *Phragmites* along banks; *some marginal stands of palmiet	no specific data; historically endemic fish present; *BMI data collected

Table 4.3 continued

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
MAINSTREAM							
Bulshoek	stock-farming & various crops; moderate potential for erosion & sediment production; high anthropogenic disturbance; start of ORGWS area and irrigation canal from dam	valley with hills on either side	directly downstream of Bulshoek Dam & influenced by spills & releases from dam; flow data for dam releases; no mainstream flow data	gradient 7.6 m km^{-1}; *wide multiple-channel; predominantly bedrock outcrops forming bed; banks low but bounded by valley sides; *occasional pools, runs, cascades & small waterfalls further downstream	*low degree of influence of dam on temperature & water quality; some historical data	catchment succulent karoo (some fynbos); *little riparian vegetation; *dense instream belts of palmiet lining narrow channels	historically endemic fish present; *BMI data collected
Zypherfontein	crop farming & livestock grazing; high potential for erosion & sediment production; high anthropogenic disturbance	valley with low hills either side	no flow data	gradient 1.0 m km^{-1}; low gradient after *series of cascades & waterfalls upstream over bedrock slabs; downstream section forming *long, deep pool; *fine sand & silt bed; sand & soil-covered low banks; mostly slow-flow pool habitat	*moderately warm; good water quality; some historical data (downstream)	*grasses & reeds along banks; alien vegetation; *waterlilies on surface waters; *catchment sparse succulent karoo characteristic of semi-arid areas	no specific data; historically endemic fish present; *BMI data collected; some historical BMI data (downstream)

Table 4.3 continued

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
MAINSTREAM							
Klawer (PHABSIM II site)	intensive agriculture (primarily viticulture) on floodplain terraces; high potential for erosion & sediment production; high anthropogenic disturbance	wide alluvial valley with low hills on either side; terraced floodplain	increased flow as downstream of confluence with Doring River; *field flow data collected	extremely low gradient (0.0002); wide (during floods) channel with *very high sand banks in places; *occasional sand bars & islands; *bed entirely sand; banks primarily sand with some soil; runs, some backwater areas	*both influenced by inflow from Doring River; water quality further influenced by irrigation return flows (high conductivity); some historical data (upstream)	catchment succulent karoo; *alien *Sesbania* along banks & on instream islands; *indigenous *Salix*; *occasional stands of *Phragmites*	no specific data; historically endemic fish present; *BMI data collected
Botha's Farm	intensive agriculture (primarily viticulture); high potential for erosion & sediment production; high anthropogenic disturbance	wide alluvial valley with low hills on either side	no flow data	extremely low gradient (0.0002); *channel of variable width; *low sand banks; *sand & gravel bed with localised areas of angular cobble (construction rubble); *riffles, runs	*influenced by local pollution from farming activities & irrigation return flows (high conductivity); no historical data	catchment succulent karoo; *grasses & aliens along banks; *indigenous *Salix*	no specific data; historically endemic fish present; *BMI data collected

Table 4.3 continued

SITE	CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	TEMPERATURE/ WATER QUALITY	VEGETATION	SPECIES BIOLOGY
TRIBUTARIES							
Ratel River	moderate agriculture (fruit & vegetable crops); low anthropogenic disturbance; low potential for erosion & sediment production	exposed mountainous slopes; *small gorge with low rocky cliffs in lower sections	perennial; no flow data; water abstraction for farming	gradient 31.6 m km^{-1} (middle reaches); *narrow channel dominated by bedrock rapids & wide deep pools, some cascades & waterfalls	*moderately cool to warm; *very good water quality	slopes with mountain fynbos; fairly well-developed riparian fynbos, *stands of palmiet	several endemic fish species present; *BMI and fish data collected; historically endemic fish present
Noordhoek River	limited anthropogenic disturbance; agriculture confined to region of confluence with Olifants; low potential for erosion & sediment production; some reaches bulldozed	exposed mountainous slopes; fairly narrow valley	perennial; no flow data; water diversion & abstraction for farming	gradient 17.4 m km^{-1} (lower reaches); *narrow to moderately wide channel with cobble bed; *riffle-pool sequences, runs	moderately cool; very good water quality	slopes with mountain fynbos; fairly well-developed riparian fynbos	many of endemic fish species present; *BMI and fish data collected; historically endemic fish present
Doring River	primarily stock farming & grazing; crops in upper reaches; high potential for erosion & sediment production; moderate anthropogenic disturbance; limited use of gorge for recreation; removal of sand for building	exposed mountainous slopes & valleys; some narrow gorge sections; wider valley upstream of confluence with mainstream	seasonal; historical & modelled flow data available; main tributary of Olifants River	gradient 1.5 m km^{-1} (lower reaches); *narrow channel in places; *alternating bedrock pools & sand pools & runs	moderately cool to warm; *good water quality but influence of agriculture (high nutrients); *high conductivities due to catchment geology & climate	catchment at site succulent karoo, typical of semi-arid region; *some *Phragmites* stands	several endemic fish species present; *BMI data collected; historically endemic fish present; alien species present; some historical BMI data

modelling techniques, particularly for sedimentology, hydrology, water quality, temperature regimes and species biology. The absence of such data bases for the Olifants River, and indeed for most other South African rivers for which instream flow assessments will need to be performed in future, makes necessary the use of coarser levels of information. This will probably require quite modified and more pragmatic sets of criteria. It is likely that decisions on the locations of study sites will often need to be made primarily on professional judgement, and ideally with reconnaissance field trips to the proposed study area.

It was clear from attempts to apply all the above steps that form a vital part of IFIM, that although the recommendations put forward in Bovee (1982) could not be firmly adhered to, they were based on sound scientific reasoning. Fairly good compromises were possible, however, in making the necessary decisions on site selection, study objectives and target species. Conclusions presented at the ends of the following chapters will indicate whether further compromises needed to be made and if they were deemed acceptable.

5. ASSESSING IFIM (STEP 4): MACROHABITAT ASSESSMENT

5.1 INTRODUCTION TO MACROHABITAT ASSESSMENT

An assessment of catchment equilibrium, the determination of the relationship between the status of the catchment and river macrohabitat conditions within the study area, and description of macrohabitat *per se* are essential components of an IFIM instream flow study which precede the application of PHABSIM II, and which are used to ensure that the rest of the study is not inappropriate. Essentially, macrohabitat refers to the large-scale longitudinal changes that occur along the river as described by hydrology, water quality and temperature, and channel geomorphology, in contrast to microhabitat which addresses physical characteristics of the channel and associated hydraulic conditions at point locations. The concepts forming the basis of this macrohabitat component of IFIM are explained briefly in theoretical terms in Chapter Three, and the entire component is described at length in Tharme & King (1991).

In this Chapter, the implementation of this pre-PHABSIM II phase of IFIM is focused on. Briefly, this involves determining present and future zones in the river, in terms of the specified macrohabitat variables, in order to be able to determine if these are likely to change with the water-resource development and thus change the total amount of macrohabitat available to the target species. Attempts to apply the guidelines to do this which are provided in Bovee (1982) are described, and the difficulties in their application are highlighted. Further, some reasons for, and solutions to, the types of problems encountered are proposed.

5.2 CATCHMENT EQUILIBRIUM

Bovee (1982), underscores the importance of establishing whether or not the study catchment is in equilibrium before commencing a full instream flow study using IFIM. If the catchment is in disequilibrium, Bovee recommends a number of alternative routes in the assessment; these routes and their links with the next set of procedures within the methodology are outlined in Figure 5.1.

The recommendations for coping with a situation of catchment disequilibrium are, however, mostly impractical. Firstly, it is suggested that it may be necessary to postpone the study until equilibrium is re-established. This is an unrealistic requirement where time is limited and where the water-resource development is likely to go ahead despite existing or projected catchment conditions. Secondly, Bovee (1982) proposes the implementation of remedial measures for the catchment before continuing with the instream flow assessment. This may only be possible if the changes in the catchment are well documented and understood, particularly in relation to the proposed development, and if the remedies can be enforced. The final option suggested is to predict the new equilibrium conditions. Where pertinent information on the catchment is available this may be possible, but the quality of the predictions obtained would be a reflection of the types of information used and of the constraints imposed in terms of finances, time, and the quality of the available information and expertise.

An evaluation of catchment must precede the rest of the macrohabitat assessment, as subsequent analyses of future conditions of flow, water quality, temperature, and microhabitat assume a persistence in channel structure and dimensions. This channel structure is dependent on the equilibrium status of the channel, which is a direct function of changes in catchment equilibrium associated with altered sediment loadings to, or flow patterns of, the river. The assumption of persistence of channel form is invalid if the river itself has not achieved a state of geomorphological equilibrium. Minimal information is provided in the manuals documenting IFIM, however, on what actually constitutes a state of catchment or channel equilibrium. For the purposes of this study, it was assumed to mean a condition of balance in the dynamics of the catchment (or channel), and to specifically refer to changes in land-use and associated changes in the hydrological, chemical and thermal and sedimentological regimes of the river (see Section 5.3.3.1 for comments on channel equilibrium), as implied by Bovee (1982).

These same regimes are also used in the macrohabitat assessment (see Section 5.3) and, although it is not stated within the available literature or by Bovee (1982), catchment equilibrium and macrohabitat are strongly inter-linked, for the former influences the dynamics, and directions and magnitudes of change of all macrohabitat variables (Figure 5.1). This is because catchment change will influence channel equilibrium by, for example, introducing sediments into the river, and the other macrohabitat variables by changing their various loadings from the catchment. Therefore, the action of catchment change may be an indirect or direct effect on macrohabitat.

With an assessment of catchment equilibrium, it is also important to determine whether or not the observed changes are the result of changes in land-use and therefore need to be dealt with as such, or could be mitigated using recommended instream flows. This is necessary to

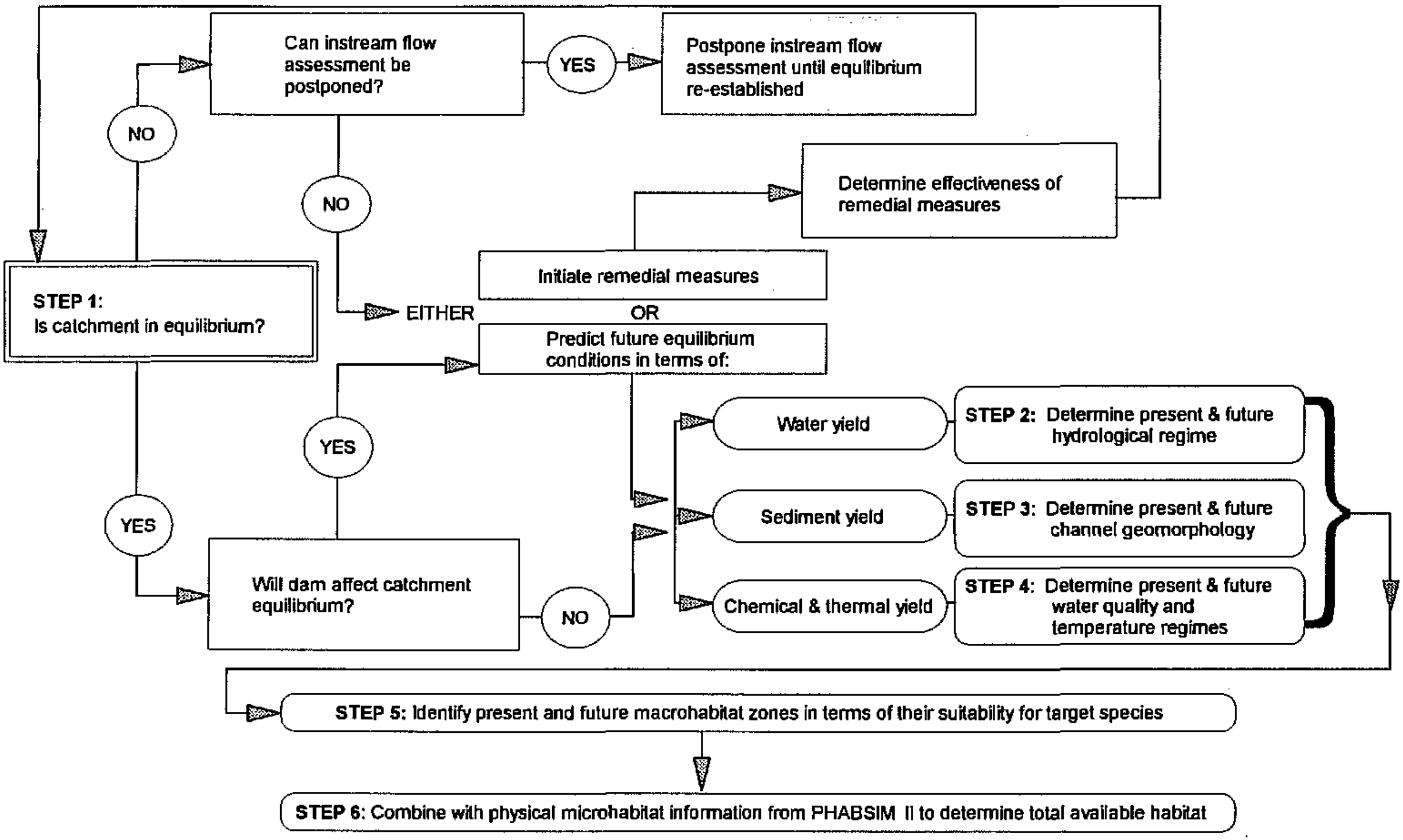


Figure 5.1 Flow chart of the procedures involved in an assessment of macrohabitat with a water development project such as a dam. Step 6 represents the theoretical link-up between predicted macrohabitat conditions and the output from PHABSIM II

provide a clear idea of which factors are most likely to be influencing macrohabitat conditions in the river, and thus need to be addressed.

Assessment of catchment equilibrium is done mainly through studies of the relationship between historical and present trends in macrohabitat conditions. However, if marked future changes in catchment equilibrium are anticipated, predictions of any possible effects of these changes on macrohabitat are also necessary. Assessment of macrohabitat conditions in the study river, in contrast, focus on present and projected future conditions (Figure 5.1), but as both exercises involve macrohabitat variables either directly or indirectly, they can be considered interdependent.

For the purposes of this study, the assessment of catchment equilibrium and macrohabitat is thus treated as a single issue, by first briefly reviewing the status of the catchment and then concentrating solely on macrohabitat. It is recognised that changes in macrohabitat may be partially a result of catchment-induced effects.

A preliminary assessment of the status of the catchment, solely on the basis of professional judgement, did not reveal any obvious large-scale changes in land-use occurring in the present or expected in the future, and it was anticipated that any potential changes in the sedimentological, chemical and thermal, and hydrological regimes associated with a water-resource development would become evident in the assessment of macrohabitat *per se*. Hence, the assumption was made that the catchment was in a state of equilibrium during this study, and that it was highly probable that it would remain stable in future.

5.3 ASSESSMENT OF MACROHABITAT VARIABLES

Macrohabitat assessment may be viewed as a scoping process, based on several important questions. The first is: what is suitable macrohabitat for the target biotic component or species being used in the study; for example, is the target species limited by water quality, temperature or some other factor? The second concerns whether or not there is an existing problem associated with macrohabitat conditions that would be exacerbated by a water development project such as the proposed dam(s) within the study area. The final question relates to whether or not, if macrohabitat conditions currently appear to be suitable for the target species, their suitability will alter after the project is implemented. This exercise is crucial to the study, as changes in macrohabitat could affect interpretation of the PHABSIM II output by changing the length of study river that is actually habitable for the target species or the proportions of different biotopes in a suitable reach, and therefore would affect the length of river over which the PHABSIM II results could be extrapolated. It also means that the PHABSIM II site might be describing a reach that will no longer exist after the development.

According to Bovee (1982), a preliminary screening of macrohabitat, specifically channel morphology, flow and water quality and temperature conditions, should first be made to determine whether existing limitations in macrohabitat or those changes anticipated with development are sufficiently significant for further more detailed analyses to be warranted; such detailed studies could prove extremely expensive in costs, time and expertise, particularly as predictive modelling would be needed. Yet, if the analyses do not proceed any further than a preliminary assessment and significant changes in macrohabitat do occur with further water-resource development, the remainder of the study using IFIM could be nullified.

For this study, as there was no indication in the methodology on where to draw the line between a coarse-scale preliminary assessment and the level of resolution required for a detailed study of macrohabitat, an attempt was made to conduct as detailed an assessment as possible within the constraints of this study. Within this assessment, river hydrology, sedimentology and associated channel geomorphology, and water quality and temperature were addressed using information collected at the same time as the information for the microhabitat component of IFIM, instead of prior to it (see Chapter Four).

Several objectives were identified for this component of the study, as follows (Figure 5.1). Firstly, an attempt would be made to independently identify present-day river zones of similar character, in terms of water quality, temperature, hydrology, channel geomorphology and biotic composition; these would then be compiled into composite macrohabitat zones if possible. Next, the future channel morphology and conditions in terms of the other macrohabitat variables would be predicted, and this information used to identify future macrohabitat zones for the study area. Finally, the information on present and future macrohabitat zones would be related to what was suitable, in macrohabitat terms, for the target species. To help address this problem of what constituted "suitable macrohabitat" for the biota, biological zones would also be identified, based on information collected during the study on the species composition of the benthic macroinvertebrate communities along the river. No assessment of the historical zonation of the study area was made, as information on historical conditions is only useful insofar as it indicates the degree to which present-day catchment and channel conditions differ from the past. All of the above aspects of the overall macrohabitat assessment are discussed in the following Sections 5.3.1 to 5.3.5.

5.3.1 MACROHABITAT TOLERANCE RANGES OF THE TARGET SPECIES

The problem of deciding which changes in macrohabitat are significant for the target species can only be resolved if the tolerance ranges of each of the target species are known for each of the macrohabitat variables under assessment, or if zones of suitable macrohabitat can be identified based on those criteria known to be critical or limiting for the species. Although the link-up between macrohabitat and the tolerance ranges of the target species forms the final stage of the process of macrohabitat assessment, it is discussed here because fundamentally, the entire determination of the extent of suitable present and future macrohabitat zones rests on knowing the macrohabitat requirements of the target species, and how the extent of macrohabitat available might be changed by the water-resource development. The exercise is further complicated in that the macrohabitat zones and responses might be different for every species, and the possibility of determining composite responses may thus be very low. Without this final link-up, though, much of the IFIM assessment becomes inappropriate and PHABSIM II can then only be used in a limited sense.

It was impossible to state for this study, with any degree of certainty, that a specific macrohabitat variable was or was not limiting for the chosen target species in the present or future. All that would be known at the end of the field work was that those target species presently living in the river could exist in the limited range of conditions measured. Hence, it was understood from the outset, that it would be difficult, for most target species, and impossible for those presently lost from the main channel, to state if macrohabitat zones based on, for instance, water quality, would be suitable in the future. In such a case, it was obvious that predictive modelling of future patterns of change in macrohabitat would be pointless and that the results from PHABSIM II would have to be treated with caution.

The assessment of macrohabitat was conducted here, even though it was clear that this link-up with the tolerance ranges of the target species would not be possible, because the study was aimed at applying and hereby assessing all components of the methodology. Furthermore, it was important to determine at what level IFIM could be implemented effectively within the context of most South African rivers. Certainly, the limitations faced in this study for this particular component of the methodology will be the rule rather than the exception for rivers in this country.

5.3.2 HYDROLOGY AS A DRIVING VARIABLE FOR MACROHABITAT

The assessment of macrohabitat as per Bovee (1982), requires an understanding of the dynamics of the hydrological regime within the study area. This is because the hydrological regime acts as a driving variable for macrohabitat, influencing the directions of change and interactions of all the other macrohabitat variables. It is not clearly explained in the methodology how the flow regime should be addressed in relation to the other macrohabitat variables. However, there is a stated requirement to ensure that any anticipated changes in the flow regime with regulation and/or abstraction will not either cause major changes in channel morphology and sediment dynamics or dramatically alter water quality and temperature regimes downstream, or that the effects of such changes can be assessed well enough to enable prediction of their effects on available physical habitat for the target species.

Ideally, the hydrological regime should be determined at each of the macrohabitat sites; in theory, it is also required as one of the main determinants of the locations of all macrohabitat and microhabitat study sites (see Chapter Four, Section 4.5.3 for explanations of both types of study site). The development and assessment of these hydrological regimes for the study area was, however, problematic in that the only flow gauge on the mainstream is located at the inflow to Clanwilliam Dam (DWA 1990b), which is 105 km from the source. This provided limited historical monthly flow data, and there was no record of virgin or near-natural flow conditions. Furthermore, the assessment was complicated by the poor quality of the rainfall records available for many parts of the catchment (McKenzie *et al.* 1990), and by the absence of gauging stations on most of the tributaries. A list of the gauging stations for the Olifants River system that are either mentioned in this report, or from which data were used for the instream flow assessment, is provided in Appendix 5.1.

As a result of these limitations, several types of hydrological data from a number of sources had to be collated by the authors of this report, and by BKS Consulting Engineers Inc. (BKS) and Ninham Shand Consulting Engineers Inc. (NSI). Members of BKS and NSI used this compiled information to model the runoff hydrology of the upper reaches of the Olifants River (D. Van Wyk and K. De Smidt, NSI, pers. comm.). Although the flow data were specifically generated as part of the Olifants River Systems Analysis, with the purpose of understanding flow yields and demands at a series of designated nodes in the upper river for the assessment of potential dam sites, they provided some information on the flow regimes at two of the study sites used in this study, namely Grootfontein and Kriedouwkrans (see Chapter Four, Table 4.1).

However, the data were not available in a format best suited to assessing instream flow requirements. The absence of daily flow records limited the expression of the hydrology of the river to monthly mean discharges. This resulted in the loss of information on flow variability, such as the recurrence intervals of floods or low flow periods, and, for example, the 10%, 50% and 90% exceedance thresholds on flow duration curves. All of these are identified by Bovee (1982) as important in understanding the impact future development could have on hydrology and, hence, on macrohabitat. Modelling flows at such a detailed level without comprehensive gauged data is too complex and inaccurate to be a worthwhile exercise (K. De Smidt, NSI, pers. comm.).

The hydrological simulation procedures employed in the Olifants River Systems Analysis, and used to produce the data for this study are outlined briefly below. Further details are provided in McKenzie *et al.* (1990). There were many limitations encountered with the hydrological data for the river, as detailed, which should be borne in mind as these data provided the only basic available information at the outset of this study.

5.3.2.1 Procedures for manipulation of the hydrological data

In simple terms, stochastic modelling of stream flow for the upper Olifants River mainstream was performed, which involved the division of the upper catchment into incremental subcatchments and the use of both rainfall figures, and patched and extended inflow data for Clanwilliam Dam. This produced monthly flow data for several sites in the upper catchment.

Historical monthly flow data were determined for the inflow to Clanwilliam Dam for the period 1935-1990 (DWA 1990b); they were calculated using a water balance approach, which included the use of the Acres Reservoir Simulation Program (McKenzie *et al.* 1990). The hydrological record was patched, and extended to 71 years using a deterministic stream flow simulation model, the Pitman model (1973, cited in McKenzie *et al.* 1990), to include the period 1920-1934 so that changes to the flow regime associated with increased river regulation could be identified over time.

Virgin flow conditions were simulated at mean monthly resolution, based on this extended data set, for Grootfontein (which matched site 2, Grootfontein, of this study) and Clanwilliam (specifically representing the inflow to Clanwilliam Dam, which is close to site 4, Kriedouwkrans, of this study). Present flow conditions were then synthesised for the same locations, with the inclusion of estimated historical irrigation demands and current water demands for the Citrusdal Irrigation Board (CIB) area. These data included an estimate of the future potential for abstraction by farm dams in the upper partial catchments (Agter Witzenberg plateau, Figure 4.4), that is, all total future maximum water demands and abstraction/storage capabilities of these farm dams were built into the current flow regime to provide water-resource engineers with the worst-case scenario (this was an essential step for obtaining upper and lower limits on the availability of water for dam storage). The present hydrological regimes were synthesised for the cases of no dam in the upper reaches at Rosendaal, and a dam at Rosendaal. Projected future hydrological regimes for the same locations on the river were then modelled, for the Rosendaal Dam and no Rosendaal Dam options, with the inclusion of estimates of future water abstraction demands in the CIB area. A list of the above simulated scenarios for the hydrological regime of the upper river is given in Table 5.1, and the raw flow data for all these scenarios are provided in Appendix 5.2. The information obtained from an assessment of these data is discussed below.

Table 5.1 Summary of hydrological data available for the upper Olifants River, at Grootfontein and at the inflow to Clanwilliam Dam, for virgin, present and projected future hydrological regimes. Data sets were derived from synthetic modelled data for the Olifants River Systems Analysis (from NSI). The reserve capacity of Rosendaal Dam was not considered in the generation of these A-hydrology data

HYDROLOGICAL DATA FOR GROOTFONTEIN AND INFLOW TO CLANWILLIAM DAM	ROSENDAAL DAM (CAPACITY $40 \times 10^6 m^3$)	DEMAND FROM CIB ($10^6 m^3 y^{-1}$)	AVERAGE SUPPLY TO CIB ($10^6 m^3 y^{-1}$)	YIELD FROM CLANWILLIAM AND BULSHOEK DAMS ($10^6 m^3 y^{-1}$)
virgin/naturalised	no	none	-	-
present without dam	no	present (1990) - 48	35.6	136
present with dam	yes	present (1990) - 48	46.6	133
future without dam	no	projected (2000) - 60	41.1	132
future with dam	yes	projected (2000) - 60	56.0	129

Within the Systems Analysis, both upper and lower estimates of all hydrological variables of concern were modelled by McKenzie *et al.* (1990) and NSI, due to the poor quality of much of the available data. The lower and hence, more conservative values, are referred to as A-hydrology, while the higher estimates accentuate runoff generated in the mountainous regions of the upper catchment, and are referred to as B-hydrology; both sets of hydrological data are based on the same total inflow to Clanwilliam Dam. Most hydrological information that has been generated for the Olifants River is based on A-hydrology, as is all the information presented here. Although much of the data generated are synthetic, they are considered to be fairly reliable, with an approximate 10% error margin (McKenzie *et al.* 1990).

5.3.2.2 Comparison of virgin, present and future hydrological regimes

As the primary objective in this project of assessing the hydrological regime was to compare historical virgin, present, and projected future flow regimes for the study area, sets of flow data were generated (Table 5.1) to enable comparison of the various scenarios relating to the proposed water-resource development for the upper reach of the river, viz. Rosendaal Dam. For the scenarios, which all illustrate changes in flow regime with and without a dam at Rosendaal, the present-day flow regimes are based on the assumption of maximum abstraction in the headwaters (worst-case scenario) and present abstraction demands in the CIB area, and the future flow regimes include projected increased abstraction levels in the CIB area (K. de Smidt, NSI, pers. comm.). The following discussion of these various scenarios serves to indicate the kinds of changes in the hydrological regime that have occurred up to the present, and to highlight possible future changes with further flow regulation.

The series of annual flow regimes for the reach represented by the Grootfontein study site indicate that the present and future flow regimes would be identical without the construction of a dam in the upper reaches (Figure 5.2). However, this is in reality, a function of the assumption of maximum water storage by farm dams in the modelling of the present hydrological scenario rather than the use of current farm dam storage figures. The annual flow regimes indicate a decrease in discharge for all months of the year, from historical to the present, and that this decrease would persist into the future. The decrease in discharge would be more marked during the winter months, especially during May (13.8% reduction in flow) and June (11.7% reduction in flow). The average annual discharge is shown to decrease by 9.6% from the virgin condition for these two scenarios, because of storage and abstraction of water for irrigation.

An upper reach dam at Rosendaal would have a considerable impact on the flow regime at Grootfontein (Figure 5.3). There would be a partial reversal of the seasonal flow regime from the natural situation for both present and future scenarios with a dam, with increased fairly constant supply of water for irrigation in the summer months and decreased flow in the winter months (although flows would still be highest in winter) due to dam storage.

In the simulated present-day scenario (Figure 5.3), average monthly discharge for the summer period of December to March would increase by a mean of 249.6% from the virgin discharge with a maximum increase of 509.9% in January. Varying decreases in discharge are likely to occur in winter, from April through to November. The greatest flow reduction would tend to occur in May, followed by June and then October; discharges would decrease by 25.3% in May and by 21.7% in June. The average annual discharge, in this scenario, would decrease by 10.8%.

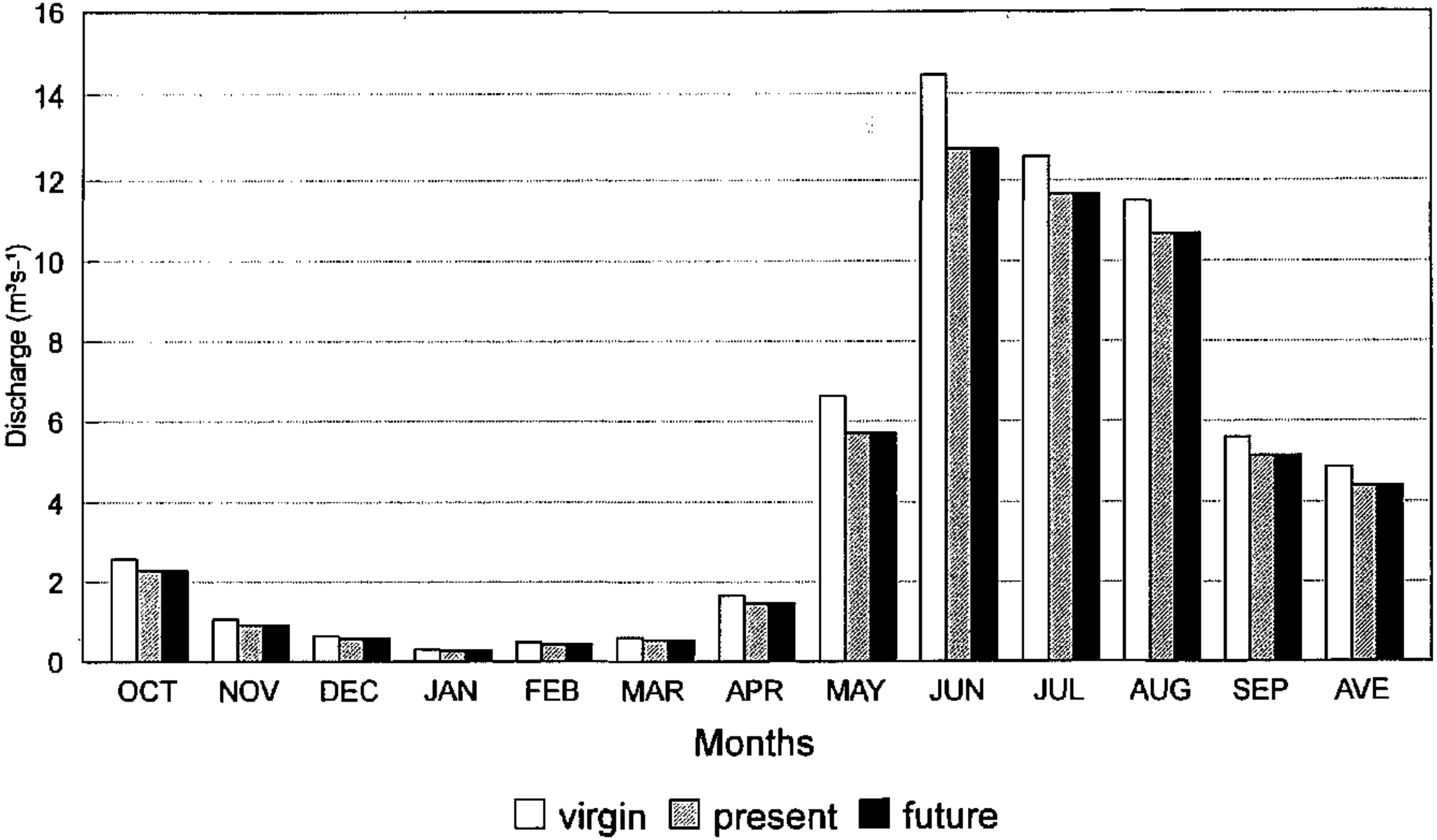


Figure 5.2 Comparative annual flow regimes based on average monthly discharge for virgin, present-day and future conditions at the Grootfontein PHABSIM II site, with no upper reach dam at Rosendaal (NSI data). AVE represents the average annual discharge

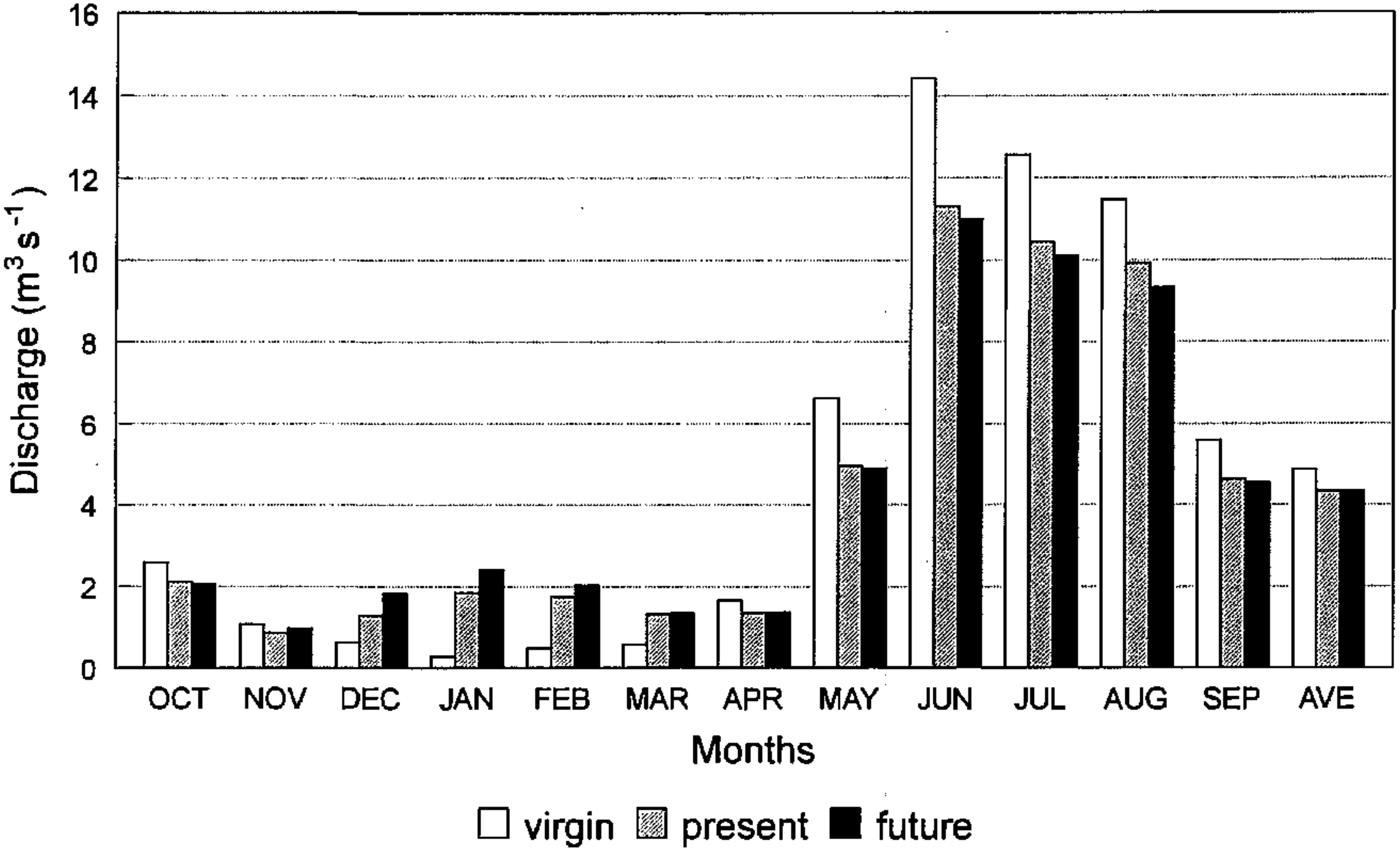


Figure 5.3 **Comparative annual flow regimes based on average monthly discharge for virgin, present-day and future conditions at the Grootfontein PHABSIM II site, with an upper reach dam at Rosendaal (NSI data). AVE represents the average annual discharge**

For the simulated future scenario, the general trends are similar to those for the present-day scenario, but are more marked. Summer flows would increase by an average of 331.4% from December to March and exhibit a 692.1% increase in January (Figure 5.3). Winter flows would decrease by 26.1% in May and 23.7% in June. The average annual discharge would decrease by 10.6%, which is a slightly lower decrease than would be experienced with the present-day scenario.

Similarly, Figures 5.4 and 5.5 enable comparison of the natural, present-day and future annual flow regimes without and with a dam at Rosendaal respectively, for the river at the inflow to Clanwilliam Dam. The flow regimes for the study site at Kriedouwkrans would be expected to exhibit slightly lower monthly discharges than those at the dam, due to the reduction in incremental catchment area, but the overall pattern of the hydrological regime would probably be very similar as the two sites are only a few kilometres apart. The flow regime at Kriedouwkrans could be simulated, using hydrologically-derived ratios for the adjustment of catchment area (K de Smidt, NSI, pers. comm.). This has not been done for this study, because it requires considerable hydrological expertise.

Without a dam at Rosendaal (Figure 5.4), average monthly flows would be severely reduced during the summer months for the present-day scenario, with only an average of 25.5% of the summer flow remaining downstream of the CIB area for November to March and a maximum flow reduction of 84.7% in February. Winter flows would remain similar to the virgin, but the average annual discharge would drop 11.7%.

In the future scenario (Figure 5.4), the situation would worsen due to increased water abstraction in the CIB area, and the average discharge for March would be the lowest of the summer discharges at only 10.4% of the virgin flow, followed closely by February and January. Flows would be reduced slightly at the end of winter relative to the present-day scenario and the average annual discharge decreased by a further 1.2%.

An upper-reach dam would improve present-day summer flow conditions during the height of summer (Figure 5.5). However, if this scenario is compared with that in Figure 5.4, it is clear that the improvement would be marginal and would be accompanied by a further reduction in flow in spring and autumn, and by some reduction over the winter months. The average annual discharge would also be lowered by 14.6% from the virgin discharge.

The projected future scenario indicates slightly more severe impacts on the flow regime at either end of summer, and a further loss of flow in the winter. Overall, this scenario would result in the greatest reduction in average annual discharge with 16.8% of the natural discharge being lost.

In summary, the above scenarios indicate the kinds of impact that would occur in the upper and middle reaches with increased river regulation. At Kriedouwkrans, there would still be very low flows in the summer as most water released by the dam would be abstracted for irrigation in the CIB area, and lower flows than previously in spring and autumn. The impact at Grootfontein would largely be an increase in summer flows to magnitudes far higher than would have occurred naturally.

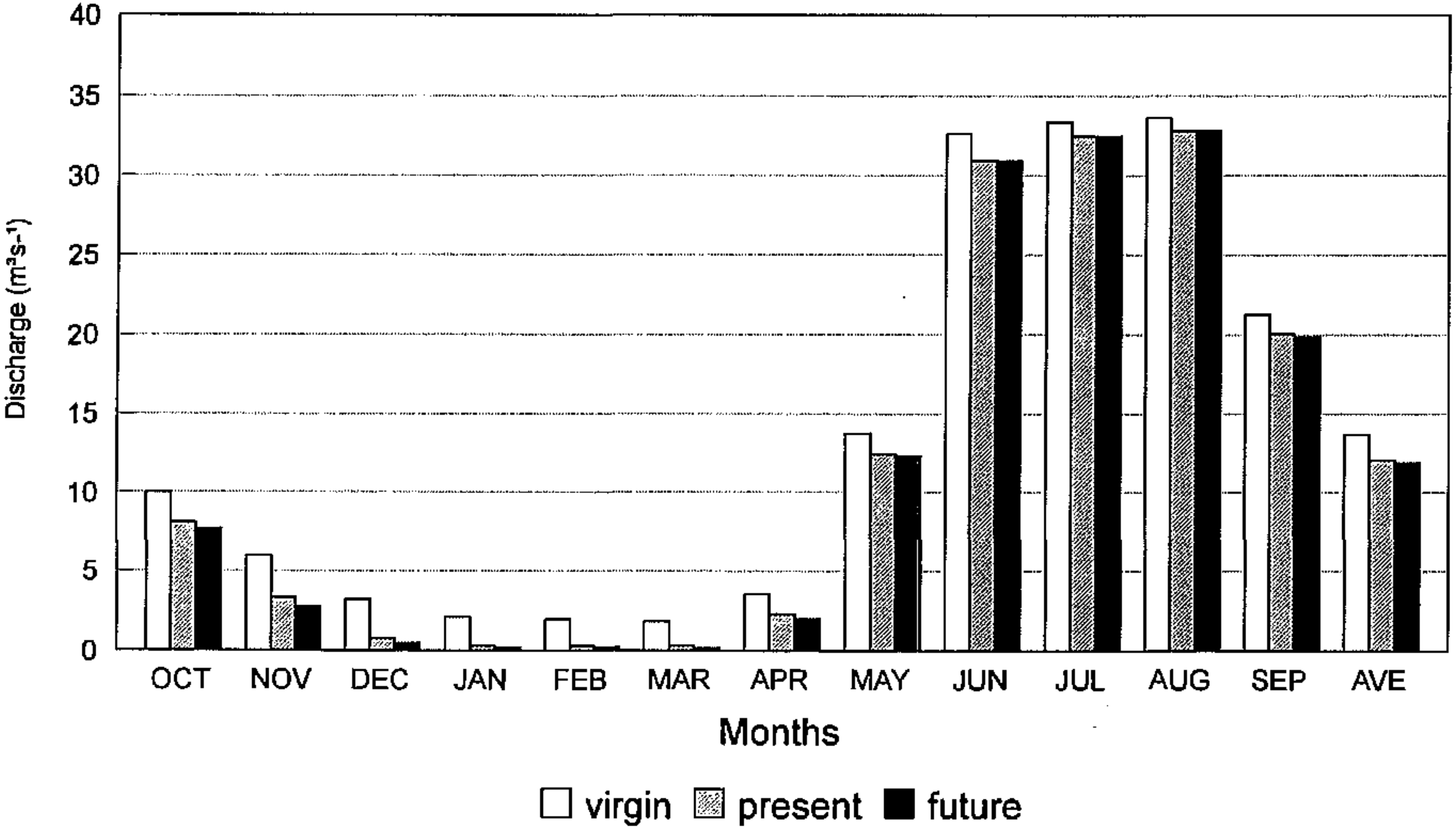


Figure 5.4 **Comparative annual flow regimes based on average monthly discharge for virgin, present-day and future conditions at the inflow to Clanwilliam Dam, representing the Kriedouwkrans PHABSIM II site, with no upper reach dam at Rosendaal (NSI data). AVE represents the average annual discharge**

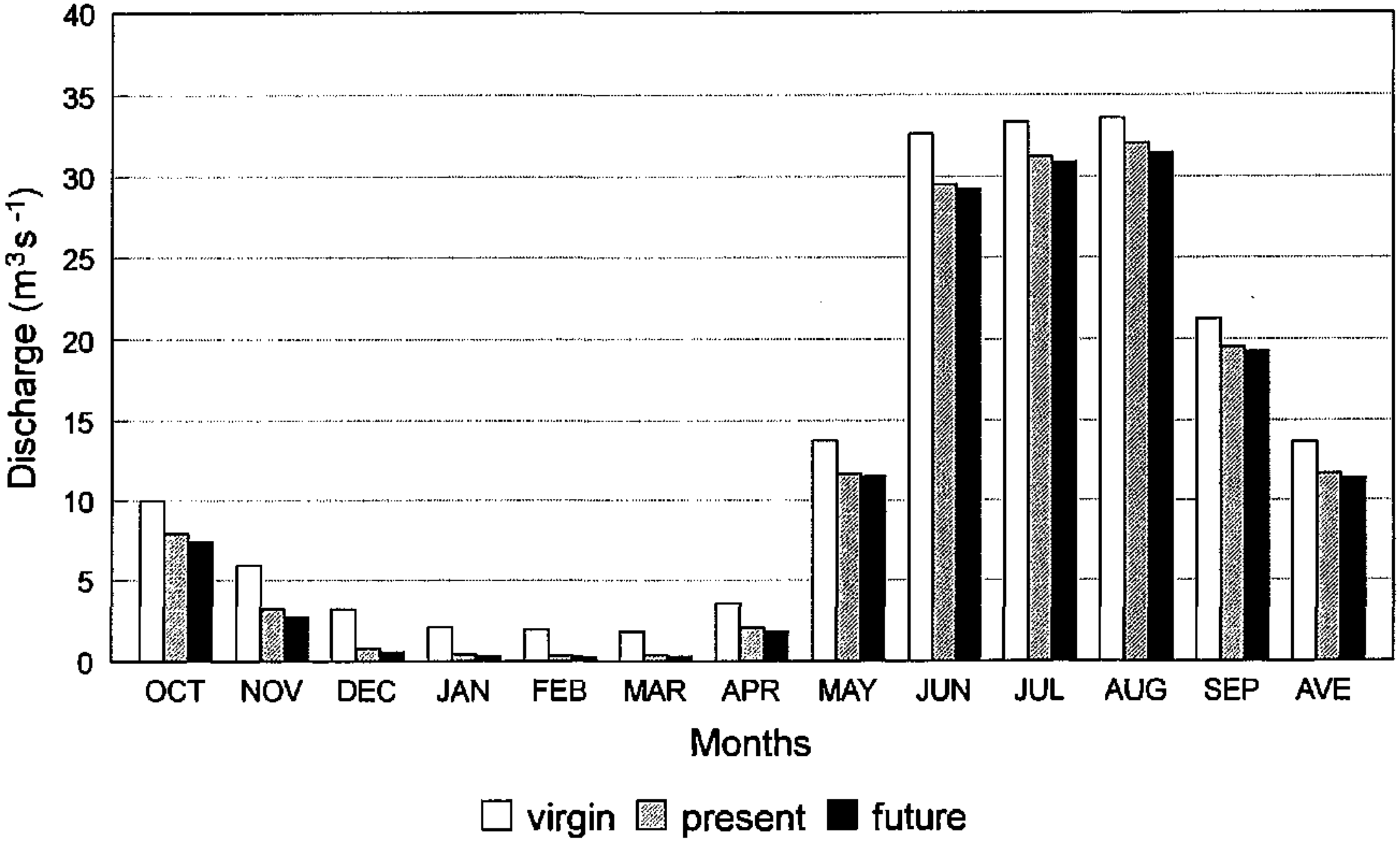


Figure 5.5 Comparative annual flow regimes based on average monthly discharge for virgin, present-day and future conditions at the inflow to Clanwilliam Dam, representing the Kriedouwkrans PHABSIM II site, with an upper reach dam at Rosendaal (NSI data). AVE represents the average annual discharge

Unfortunately, there are no comprehensive modelled hydrological data for the section of river from below Bulshoek Dam to downstream of Klawer which constitutes the lower reaches of the study area. This is due to the extremely limited information on the hydrology of this section of the river and the low reliability of the inflow data for Bulshoek Dam (McKenzie *et al.* 1990; K. de Smidt, NSI, pers. comm.). Although data are available for the Doring River, which could be used in developing an understanding of the hydrological character of the lower Olifants River, without hydrological information for the mainstream these data are of limited use.

5.3.2.3 Present hydrological zonation of the study area

The limited information on hydrology outlined above was summarised, for the purposes of macrohabitat assessment, as a series of broad scale hydrological zones (Figure 5.6). Major breaks in zonation were caused by the two dams existing on the river and by the confluence with the Doring River, this latter representing the most obvious hydrological change point in the whole mainstream. With regard to less obvious zone breaks, there was insufficient information to determine whether or not the source area of the river was hydrologically different from Visgat, so these sites were kept together. Boschkloof was separated from Visgat, due to the increase in flow associated with the tributaries within the gorge. However, this decision was based on limited qualitative information and needs to be verified. The break between Tweefontein and Kriedouwkrans represented the influence of present water abstraction in this section of the river, which has resulted in cessation of flow during some summer months. There was no quantitative information on flow between the dams or in the lower reaches which indicated a further division of these sections of river into zones. Hence, Clanwilliam, Bulshoek and Klawer each had the next downstream-most site grouped with them (Figure 5.6), as there was no specific information for each of these sites. This hydrological zonation is compared with zonation based on water quality, temperature, channel geomorphology and biology in Section 5.4.

5.3.2.4 Future hydrological zonation of the study area

The next step in the assessment of macrohabitat (Bovee 1982) is the prediction of possible future changes in flow regime as a result of the proposed water-resource development. Although identified as an important step, it was difficult to achieve in this study as information on dam design and release schedules was not available, nor had the locations and numbers of dams been decided upon. Hence, little in the way of future change to the hydrological regime could be inferred, apart from that discussed above for the scenarios with and without the proposed Rosendaal Dam. Further attempts at modelling the hydrological regime of the study area would be constrained anyway, by the limitations in terms of data particularly, but also in terms of costs, time and expertise. Certainly, hydrological field work would need to be carried out within the study area, and this would be likely to include the construction, calibration and monitoring of gauging stations, or the use of techniques for the development of stage-discharge relationships in ungauged catchments (Gordon *et al.* 1992).

Based on the discussions above for Figures 5.2 to 5.5, it is only possible to make qualitative statements on the impact of a future dam on the hydrology and, hence, on macrohabitat conditions within the study area. Probably, dam water storage would begin with the first major rains and would continue during the winter months, with releases scheduled to coincide with peak irrigation demands during the summer. This would produce a seasonally partially

<table>
<tr><th rowspan="2">MACROHABITAT VARIABLE</th><th colspan="12">ZONES BASED ON MACROHABITAT STUDY SITES</th></tr>
<tr><th>Source
A</th><th>Visgat
1</th><th>Bosch-kloof
B</th><th>Groot-fontein
2</th><th>Twee-fontein
3</th><th>Kriedouw-krans
4</th><th>Clanwilliam
5</th><th>Langkloof
6</th><th>Bulshoek
7</th><th>Zypher-fontein
8</th><th>Klawer
9</th><th>Botha's Farm
10</th></tr>
<tr><td>Hydrology</td><td colspan="2">▨
?</td><td colspan="3">▨</td><td>▨</td><td colspan="2">▨</td><td colspan="2">▨</td><td colspan="2">▨</td></tr>
</table>

Figure 5.6 **Map of the hydrological zonation of the study area. ? denotes uncertainty with regards zonation, due to lack of information**

inverted hydrograph compared to the natural pattern. At present, the river occasionally ceases to flow in the Citrusdal area during summer, due to uncontrolled abstraction of irrigation water (D. Visser, CIB, pers. comm.; Appendix 5.2), and it is envisaged that an upstream dam would restore something approaching natural summer flows, hereby preventing the flow pattern of the upper river from being changed from perennial to seasonal. However, it appears that future summer flows would be far greater than those that used to occur naturally, with unknown ecological repercussions.

From a brief review of the literature on the impacts of river regulation (Petts 1984; Ward 1982; *inter alia*), it is evident that the projected alteration of the flow regime of the study area will inevitably influence macrohabitat as represented by water quality, temperature and channel morphology. The questions that still remain unanswered, though, are to what extent this influence will be evident along the river, and whether the degree of suitability of macrohabitat for the target species would be altered as a result. It is probable that the timing of the first major winter floods of the Olifants River will change from early to late winter, with a possible flush in April instead of the first natural flush in May. There will probably also be a reduction in the frequencies and magnitudes of flushing flows, an increase in summer flow magnitudes, and decreased seasonal and daily flow variability especially in the summer (DWAF 1991). Without information on the release schedules for the proposed dams, and in the absence of adequate flow data for the study sites of concern, however, these types of change cannot be substantiated quantitatively, and the possible influences of a modified hydrological regime on the other macrohabitat variables and on macrohabitat suitability for the target species cannot be adequately addressed.

5.3.3 CHANNEL GEOMORPHOLOGY AS A MACROHABITAT VARIABLE

Longitudinal patterns in the morphology of a river channel, as represented by features such as channel shape, dimensions, and particle-size distributions of the channel bed and banks indicate the equilibrium status of the channel (Bovee 1982). This is itself an important indicator of the equilibrium status of the catchment, because it shows whether or not there are changes in sediment loadings and sources from the catchment which are inducing changes in the geomorphology of the river channel.

Changes in channel morphology are liable to affect the amount of suitable macrohabitat for the target species by changing the distance over which the PHABSIM II results can be extrapolated. However, they could also have a more direct effect on microhabitat predictions, by changing the character of the PHABSIM II site and therefore, the output from the model.

In attempting to establish longitudinal zonation using channel geomorphology as a macrohabitat variable, it was essential to first gain some insight into the processes which govern channel morphology, and the techniques available for qualitative and quantitative assessment of channel change. This was more relevant for prediction of future zonation of the channel after impoundment than present zonation, as changes in channel morphology are liable to occur in the former case (see Section 5.3.3.1). Thus, introductory comments on the theory of channel change, on the IFIM requirements for macrohabitat assessment of channel morphology and on some techniques recommended for such an assessment, precede attempts in this study to determine both the present and future geomorphological status of the river channel and then its associated longitudinal zonation.

5.3.3.1 Channel equilibrium theory

The following brief discussion of the conceptual basis of channel equilibrium and associated changes in channel morphology is intended to provide an introduction to this topic and to highlight some of the difficulties and uncertainties that are encountered within this area of macrohabitat assessment.

Channel equilibrium is complex and dynamic in that channel form changes continuously, but the changes are about some average dimensions. When the catchment is stable, a dynamic equilibrium ("quasi-equilibrium", Petts 1984) is established by alternating erosional and depositional processes, where the channel form reflects the magnitude and frequency distribution of discharges, the volume and particle-size distribution of the sediment load, and various constraints imposed by local conditions, such as channel boundary materials and valley slope (Petts 1984). Although the locations of some structural features, such as point bars, may change along the river reaches within the study area, the overall geomorphological relationships are maintained.

An impoundment alters channel morphology, not only immediately below the dam, but also throughout a significant length of the downstream river, and the channel adjusts from one state of dynamic equilibrium to another. The rate and direction of change are primarily a function of both the frequency of sediment loading to the system, which affects deposition, and of the frequency of dam releases competent to transport sediments, which influences erosion. A complete analysis of channel change requires consideration of several additional variables, including the composition of bed and bank materials and the influence of riparian vegetation. Moreover, the length of time required for complete channel response to regulation, and for the establishment of a new equilibrium state could range from tens to hundreds of years (Petts 1984).

At present, the relationships between channel form and process are imprecisely understood, but it is generally agreed that the frequency of flood discharges, and the magnitude and particle-size distribution of the sediment load are the dominant controls of channel morphology (Petts 1984). One of three potential adjustments may be induced by impoundment, depending upon the degree of flow-regulation, the resistance of the channel boundary and bed materials to erosion (alluvial as opposed to bedrock-dominated reaches, for example), and the quantity and type of sediment input. These adjustments are channel degradation, aggradation, or no overall change. Symptoms of these changes are described in Bovee (1982) and Petts (1984). In reality, combinations of these forms of channel adjustment tend to occur and responses are often river-specific, which makes generalisation difficult. Assessment of a new equilibrium can also be complicated as it is usually the result of a complex long-term series of changes, involving alternate periods of erosion and deposition, rather than of unidirectional change. It is, therefore, critical to distinguish between local and short-term changes in channel morphology, and long-term channel response to catchment dynamics. Moreover, it needs to be established that these sorts of trends are symptomatic of disequilibrium and not merely a function of the natural evolution of the river with time. Therefore, the temporal limits of equilibrium need to be defined, and some form of historical information is required to substantiate circumstantial evidence of changes in channel morphology.

5.3.3.2 Requirements for macrohabitat assessment of channel morphology

The IFIM procedure of macrohabitat analysis requires the determination of whether or not the river channel is presently in equilibrium and whether or not this equilibrium state will persist into the future. Only then can the present and future zones of channel morphology within the study area be determined with any certainty (Figure 5.1). If the current status of the channel is unknown, if channel disequilibrium is apparent, or if the impoundment is expected to induce a new state of equilibrium, the future equilibrium scenario should be predicted; channel modelling and the expertise of a fluvial geomorphologist are recommended for this purpose.

If future channel conditions cannot be predicted (by modelling or some other approach), then application of the PHABSIM II phase of IFIM either is invalid (Bovee 1982) or the terms under which it is used must be restricted. A fixed-percentage-of-flow approach such as Tennant's method (Tennant 1976), or periodic IFIM analyses to provide interim instream flow values until the channel re-equilibrates, are then recommended by Bovee (1982). However, both of these approaches may be unsuitable, due to data or other constraints, and both have numerous other problems associated with them (Tharme in prep.). Moreover, re-establishment of channel equilibrium could take several years.

Even if the channel is assumed to be currently in equilibrium and is expected to remain in this condition after a dam is in place (the latter rarely occurs), features of channel morphology need to be used to establish present and future longitudinal zonation, before proceeding with the microhabitat component of the methodology. So the assessment still has to include attempts to establish zones of channel morphology.

5.3.3.3 Approaches for assessing future changes in channel morphology and determining present and future geomorphological zones

In this section, the assessment of channel morphology as a macrohabitat variable is attempted in two complementary parts. Firstly, attempts are made to use several approaches recommended in Bovee (1982) for determining the present and future equilibrium status of the channel and then predicting future changes in channel morphology with flow regulation; future zonation cannot be established unless an estimate of the future channel form has been made. Secondly, information on channel morphology is compiled for the purposes of delineating present and future geomorphological zones along the river. Some approaches used for assessing channel change can also be used for determining zonation, although Bovee (1982) provides more information on the approaches for predicting channel change than on ways of determining zones of different channel geomorphology.

The approaches used for the first part of the assesment are a bankfull discharge approach, hydraulic geometry equations approach, the use of aerial photographs and a channel cross-section and geomorphology approach. These are briefly described below, and the relative degree of success in using each of them for predictive purposes is indicated (Table 5.2) with particular reference to the short-term nature of this study. Specific requirements for each of the approaches are summarised in Table 5.2, and the kinds of limitations encountered in the application of each approach are also listed.

In an assessment of present zonation once the present channel shape has been determined, application of some techniques used to detect and predict directions of change in channel

Table 5.2 Approaches for assessing changes in channel morphology with flow regulation, based on recommendations and data requirements described by Bovee (1982), and limitations identified for this study. Estimates of the degree of success in applying recommended approaches are recorded as partially successful (#) or unsuccessful/not attempted (X)

APPROACH	REQUIREMENTS	LIMITATIONS FOR THIS STUDY	DEGREE OF SUCCESS
1. Analysis of aerial photography	Historical sequences of high resolution photographs or orthophotographs of study reaches	Low resolution photographs from 1948 and 1960s only; Sets of photographs incomplete; No historical pre- or post-impoundment photographs of Clanwilliam Dam or Bulshoek Dam sites; High resolution 1990s photographs of only the proposed dam sites available; No recent photographs of river reaches	#
2. Calculation of bankfull and maintenance discharges	Hydrological data on flood recurrence frequencies, flood magnitudes and durations, and dam operational criteria	Extremely limited measured and synthetic hydrological data; Data require further modelling and new format for specified types of analyses; Little information on dam design, position and operational criteria; Expertise of hydrologist and fluvial geomorphologist required, but not within the scope of this study	X
3. Development of hydraulic geometry equations	Empirically derived exponents and coefficients, extensive field data on channel morphometry and some information on bankfull conditions	No empirical exponents or coefficients available for the study river; No regionalised data base for extrapolation of channel morphology relationships; Costs, data collection time and expertise not within the scope of this study	X
4. Channel profiles and in-channel sampling	Intensive data collection, including establishment and sampling of transects over extended period of time	Cross-sections of channel shapes, and bed and bank particle size distributions available for three geomorphologically distinct river reaches for single time period; Expertise and costs of adequate data collection extend beyond resources available in this shorter-term study	#
5. Modelling of sediment transport and channel change	Extensive data set and expertise of fluvial geomorphologist required	Very limited information on sediment survey transects of Clanwilliam Dam available; Resources required beyond the scope of this study	X

morphology, such as the use of information on channel pattern and sinuosity within the channel cross-section and geomorphology approach, provided the necessary information to also delimit the zones themselves, as will be illustrated later in this Section.

In the future context, zonation obviously has to be preceded by an assessment of channel change and here again, information obtained either from one of the approaches proposed by Bovee (1982) or by an independent approach(es) may be used to delineate the longitudinal zonation of channel morphology.

Discussions on the present and future zonation of the study area follow after outlines of the approaches used to determine channel change, comments on problems and limitations associated with these approaches and their applicability for also delimiting zones.

Bankfull discharge approach

Although channel morphology is related to a range of discharges, the bankfull discharge, often estimated for North American river systems as the discharge with an average recurrence interval of about 1.5 years, is generally accepted by fluvial geomorphologists as the discharge primarily responsible for maintaining both channel equilibrium and the general form of the channel (Bovee 1982; Petts 1984; K. Rowntree, Geography Department, Rhodes University, pers. comm.). This approach can, therefore, be used to identify if and how future changes in the recurrence interval of the bankfull discharge might affect channel equilibrium.

In the case of the Olifants River, which is within a semi-arid area, this approach is problematic in that peak flows with longer or more variable return periods than for North American rivers could be responsible for channel equilibrium (K. Rowntree, Geography Department, Rhodes University, pers. comm.). Moreover, none of the specific data required for this approach, which includes hydrological data on present and future flood recurrence frequencies and magnitudes, and information on dam design, operation and location, are available in a format that can be used to compare present channel morphology with the flow-related future channel shape (Table 5.2). Further hydrological modelling and synthesis of data would be required before any useful attempt at assessing channel change could be made using this approach. This would require specific hydrological and geomorphological expertise and is, therefore, not within the scope of this study. Moreover, this approach cannot be used to help determine present and future morphological zonation patterns, because it only provides information on the equilibrium state of the channel.

Hydraulic geometry equations approach

Hydraulic geometry equations, linking channel geometry with the bankfull discharge, have also been identified as predictors of changes in channel morphology with changes in discharge (Bovee 1982; Petts 1984), and thus as potentially useful for facilitating the identification of channel change with river regulation. However, these equations require empirical derivation of their exponents, and knowledge of historical and present channel geometry relationships for the purposes of comparison and prediction of future relationships (Bovee 1982). Furthermore, they cannot be used to make absolute predictions of channel morphology, but rather only to make relative judgements of changes in morphology if the hydrological regime is changed.

Such empirical data have never been produced for South African rivers, although a research programme is currently underway to develop these types of relationships (K. Rowntree, Geography Department, Rhodes University, pers. comm.), and there are no such data for the Olifants River. Therefore, it was not possible to determine present or future conditions of channel equilibrium using this approach, without the collection of extensive field data on channel morphometry and the linkage of this data with modelled information on bankfull flows (Table 5.2). A further problem with this technique is that the hydraulic geometry equations only provide information on presently existing tendencies towards dynamic equilibrium, and not on the time spans involved.

As for the previous approach, the information required would not have facilitated the delimitation of present or future zones of channel morphology.

Aerial photograph approach

The analysis of historical sequences of aerial photographs, to determine whether or not changes in channel morphology have occurred and are likely to continue occurring over time, has been suggested by Bovee (1982) as a fairly simple yet informative approach. Such an approach also provides a means of determining present geomorphological zones if recent high-resolution aerial photographs or orthophotographs of the channel are available. However, this approach alone cannot yield information on the future morphology of the channel or on the future zonation pattern.

Comparisons were made between some recent aerial photographs and orthophotographs for the study area and two extremely limited sets of poor quality aerial photographs from 1948 and the 1960s, in an attempt to detect any changes in channel morphology over time (Table 5.2). They did not reveal any obvious major changes in channel morphology, although localised shifting of the river within its channel was evident, particularly in the reaches dominated by sand and/or sand with bedrock outcrops. However, without a more complete set of aerial photographs, and additional supporting evidence from other geomorphological data, it cannot be assumed with a high degree of confidence that the channel has been and remains in equilibrium. Personal communication with a number of ecologists and fluvial geomorphologists working on regulated rivers (DWAF 1991; K. Rowntree, Department of Geography, Rhodes University, pers. comm.), highlighted the possibility that future changes in channel morphology, such as armouring, could occur with regulation of the upper Olifants River. With such a limited level of understanding it is not possible to comment on the types of changes in channel morphology that could be expected.

An attempt was also made to use historical data on transects, which were created to assess sediment levels in Clanwilliam Dam. The intention was to search for possible changes in the sediment loads or sediment transport rate of the upper river in relation to discharge. However, the data proved to be too limited and additional data would be required before meaningful results could be obtained. Pre- and post-impoundment aerial photographs of and/or transect data for the river reaches upstream and downstream Clanwilliam Dam could have proved useful in this regard, but such information was not available either.

In summary, some information on the general patterns in channel geomorphology along the river was obtained from historical aerial photographs. This helped define the present geomorphological zones of the river in conjunction with present-day information, as described below (see following subsection entitled "Channel cross-section and geomorphology approach"), but gave no information on what future zonation might be.

Channel cross-section and geomorphology approach

The establishment of cross-sections describing channel dimensions, in conjunction with in-channel sampling of bed and bank particle-size distributions and description of general geomorphological features of the channel, has been suggested by Bovee (1982) as a useful technique for determining changes in channel morphology over time. However, for the approach to be sensitive in detecting such changes, a sufficiently large number of cross-sections needs to be established in all geomorphologically distinct reaches of the study area and data collection needs to be intensive over an extended period of time. Also, mapping of such reaches would need to be carried out over time, in order to obtain information on geomorphological features such as channel gradient, sinuosity, channel pattern, biotope types and geology.

Furthermore, extrapolation of results obtained from a comparison of historical and present-day channel profiles to some future channel shape would only be feasible in conjunction with expert modelling techniques. It was, therefore, not considered possible to determine present or future channel equilibrium conditions for the Olifants River, as no historical channel cross-section or mapped geomorphological information was available, and as there was insufficient time, expertise and present-day data to enable prediction of possible future change (Table 5.2). As a result, this technique could not be used to determine a future zonation of the river in terms of channel morphology.

However, for the purposes of determining the present zonation of the channel, an attempt was made to collate quantitative data collected in this study. The data used described current channel geomorphology, and were based primarily on the survey data from transects established at the three PHABSIM II macrohabitat sites (Tables 4.1 and 4.3). The detailed level of information required in a channel cross-section approach precluded the collection of much quantitative data at all other macrohabitat sites (Table 4.1), but some largely qualitative information on channel morphology and quantitative data on bed substrate particle sizes were available from microhabitat data recorded during sampling collections of benthic macroinvertebrates. Additionally, information on the longitudinal geomorphological character of the river was obtained from 1: 50 000 topographical maps of the study area (see below for the techniques used).

This information on present channel geomorphology was summarised for each of the macrohabitat sites (Table 5.3) and the way in which it was then used to show the zonation of the river is discussed, after a brief summary of the techniques used to derive this information. Although some of these techniques were mentioned in Bovee (1982), no guidance was given on how to use them for the specific purpose of delineating channel morphology zones. Information on the use of the techniques themselves was largely obtained from Gordon *et al.* (1992).

Techniques for derivation of information on channel geomorphology

Gradient

Site gradient was calculated from 1: 50 000 topographical maps as the difference in river elevation obtained from the contours crossing the river either side of the study site, divided by the total distance along the river between these contours (Gordon *et al.* 1992). Units for gradient were expressed as m km^{-1} (Table 4.3) or were dimensionless (Table 5.3), depending on the calculation method used.

$$\frac{\text{elevation at upper contour 1 - elevation at lower contour 2}}{\text{river distance from 1 to 2}} \quad \text{(Equation 5.1)}$$

Sinuosity

Sinuosity is a measure of the degree of winding of the river and has several definitions (Gordon *et al.* 1992). For this study, the most commonly used measure, the Sinuosity Index (SI) was used, given as:

$$SI = \frac{\text{river channel thalweg distance}}{\text{downvalley distance}} \quad \text{(Equation 5.2)}$$

Channel thalweg distances between contours were obtained from a digitised GIS coverage of the river. The calculation of downvalley distance from 1:50 000 topographical maps was problematic in areas where the river was tightly confined within the gorge and in lower sections of the river where terracing of the river floodplain had occurred for agriculture. In these instances, straight-line segments which followed the broad-scale changes in channel direction were used as a measure of valley length, as recommended in Gordon *et al.* (1992).

Channel pattern

Channel pattern describes the planimetric form of a river (Gordon *et al.* 1992), and can be classified as straight, meandering. braided or anastomosing. These classes are a means of categorising a continuum of forms which can change along a river and with changes in flow level. Patterns are distinguished primarily on the basis of sinuosity and channel multiplicity. Sinuosity is discussed above, and channel multiplicity refers to the number of channels comprising the river.

The sinuosity index can be used as a criterion for classifying a section of river or an entire river as having a particular channel pattern. An SI value of 1 represents a straight river, whereas a value of 4 indicates highly intricate meandering. Meandering streams are somewhat arbitrarily designated an SI value of 1.5 or more, and the term sinuous is sometimes given to stream patterns which are intermediate between straight and meandering (Gordon *et al.* 1992).

For the classification of channel patterns for the Olifants River, SI values, channel multiplicity and width-to-depth ratios were calculated (Table 5.3) and applied to the classification system provided in Gordon *et al.* (1992); bankfull velocity and stream power, which are other criteria that can be used for classifying channel pattern, were not included as there was insufficient information available for their calculation. Sinuosity values were further arbitrarily rated as indicating low (>1.00, ≤ 1.30) or high (>1.30) sinuosity for this study, to provide a better indication of observed channel forms during field visits.

Channel dimensions

The channel dimensions of average channel width and depth, maximum and minimum depth and width-to-depth ratios (of the wetted channel) were calculated for the PHABSIM II survey site data for the November 1990, February/March 1991 and October 1991 calibration field trips. For the macrohabitat sites, channel width was estimated using information from field notes. For these sites, average channel depth and ranges in depth were calculated from microhabitat data collected with the benthic macroinvertebrate samples. Channel dimensions were only calculated for moderate flow (November) conditions (Table 5.3).

Channel materials

Channel bank materials were determined from field and survey notes, but were not available in a quantitative form (Table 5.3).

Channel bed materials were determined as percentages of substrate types based on their relative abundances within each study reach (Table 5.3). For the macrohabitat sites, quantification of substrate types was possible using the microhabitat data from all samples of benthic macroinvertebrates and from field descriptions. For the PHABSIM II sites, estimates of substrate composition were based principally on microhabitat data for standardisation, but the transect data were also referred to, to ensure that all substrate types were included.

Biotopes

Biotopes (see glossary) were classified according to the descriptions in Table 8.2 (Chapter Eight). The main biotopes for each study site could be inferred from the microhabitat descriptions for benthic macroinvertebrate samples collected, and from the survey data for the PHABSIM II sites (Table 5.3). Although it is likely that the proportions of each biotope would vary with changes in discharge, the categories themselves would remain the same. However, there might be instances where small areas of a particular biotope were present within the reach represented by a study site, but either were not sampled or were possibly under-represented during this study.

Geology

Specific information on the geology at each site was limited to information based on 1: 25 000 and 1: 250 000 geological maps of the study area.

Description of channel geomorphology information used to determine present zonation

The information derived using the above techniques and presented in Table 5.3 provided the first description of channel geomorphology of the study area. This description, given below, is far from complete, but does indicate several main features of the river and provides sufficient information to make a preliminary determination of present geomorphological zones. A more thorough geomorphological survey would help to confirm these zones.

Each of the sets of information on geomorphology was assessed separately at first, to subjectively determine obvious change points in features. The most useful variables were found to be gradient, geology, channel pattern, geomorphological units and associated gross changes in substrate. Not all variables showed obvious zone breaks, for instance average wetted channel width changed gradually from being very narrow in the upper reaches to markedly wider at Grootfontein. Examples of more obvious change points were the change in geology from Zypherfontein downstream to include Karoo Supergroup sediments, and the high proportion of alluvial sand forming the river bed at the exit of the gorge (near Tweefontein). Zonation based on obvious changes in any or every geomorphological variable would have resulted in each study site forming a separate zone. Hence, a more composite, but consequently more subjective picture of zonation was compiled by assessing all variables together.

Table 5.3 Summary information on channel geomorphology for mainstream macrohabitat study sites. Information presented is based on geomorphological features considered to be characteristic of the reach represented by each site (see text). Each feature is described, where possible, for PHABSIM II sites at low flow (L), moderate flow (M), and high flow (H) (limited information available); and at moderate flow for other macrohabitat sites. ~ represents estimated values. Substrates are coded for sizes small-S, medium-M, and large-L as follows : G-gravel; C-cobble; BR-bedrock and S-sand

SITE	GRADIENT	SINUOSITY RATIO	CHANNEL PATTERN	AVERAGE WETTED CHANNEL WIDTH (m)	AVERAGE WETTED CHANNEL DEPTH (m) (RANGE)	WETTED CHANNEL WIDTH/DEPTH RATIO
Source	0.0171	1.06	low sinuosity; single channel	~ 2 (M)	~ 0.10; (~ 0.01-0.20) (M)	—
Visgat	0.0142	1.49	high sinuosity; single channel	~ 6 (M)	0.37; (0.12-0.76) (M)	—
Boschkloof	0.0086	1.00	straight; single channel	~ 10 (M)	0.15; (0.12-0.20) (M)	—
Grootfontein (PHABSIM II site)	0.0028	1.03	low sinuosity; single/multiple channel	24.0 (L) 27.5 (M) 22.9 (H)	0.55; (1.45-0.94) (L) 0.66; (0.05-1.50) (M) 0.71; (0.12-1.40) (H)	45.6 (L) 41.7 (M) 32.3 (H)
Tweefontein	0.0024	1.00	straight; single/multiple channel	~ 27 (M)	0.13; (0.07-0.24) (M)	—
Kriedouwkrans (PHABSIM II site)	0.0023	1.04	low sinuosity; single/multiple channel	19.7 (L) 28.0 (M) 53.6 (H)	0.38; (0.01-1.02) (L) 0.71; (0.01-1.70) (M) 1.22; (0.06-2.64) (H)	51.8 (L) 39.4 (M) 43.9 (H)
Clanwilliam	0.0007	1.08	low sinuosity; single/multiple channel	~ 30 (M)	0.37; (0.17-0.56) (M)	—
Langkloof	0.0007	1.08	low sinuosity; single channel	~ 25 (M)	0.23; (0.16-0.36) (M)	—
Bulshoek	0.0079	1.06	low sinuosity; single/multiple channel	~ 30 (M)	0.19 ; (0.07-0.28) (M)	—
Zypherfontein	0.0010	1.04	low sinuosity; single/multiple channel	~ 20 (M)	0.50; (0.20-3.50) (M)	—
Klawer (PHABSIM II site)	0.0002	1.35	high sinuosity; single/multiple channel	17.8 (L) 17.1 (M) 76.5 (H)	0.25; (0.01-0.56) (L) 0.33; (0.02-0.84) (M) 0.50; (0.05-3.00) (H)	71.2 (L) 51.8 (M) 153.0 (H)
Botha's Farm	0.0002	1.35	high sinuosity; single channel	~ 15 (M)	0.32; (0.27-0.38) (M)	—

Table 5.3 continued

SITE	PRIMARY RIVER BANK MATERIALS	RIVER BED MATERIALS (%)	GEOMORPHOLOGICAL UNITS/BIOTOPES	GEOLOGY
Source	soil	~ 30% mud; ~ 14% MC; ~ 42% LC; ~ 14% BR	runs - no specific data	Cape Supergroup Table Mountain Series (TMS) shale, siltstone, graywacke, sandstone; Bokkeveld Series (BS) shale, siltstone, quartzitic sandstone, graywacke, argillaceous sandstone; some TMS quartzitic sandstone with thin shale and conglomerate lenses
Visgat	soil, bedrock	2.5% S; 2.5% MG; 0.8% LG; 4.2% SC; 20.0% MC; 70.0% BR; occasional boulders	riffles; pools; rapids; cascades (downstream); runs	TMS quartzitic sandstone with thin shale and conglomerate lenses
Boschkloof	bedrock	0.4% S; 10.6% MG; 11.8% LG; 14.1% SC; 1.4% MC; 21.9% LC; 39.8% BR; occasional boulders	riffles; cascades; runs; pools; waterfalls (upstream)	TMS quartzitic sandstone with minor shale and conglomerate lenses; some TMS shale, arenaceous shale, tillite, grit, conglomerate
Grootfontein (PHABSIM II site)	soil, sand	24.5% S; 0.8% SG; 13.0% MG; 20.2% LG; 25.7% SC; 13.7% MC; 2.1% LC; occasional boulders	riffles; pools; runs; backwaters	TMS quartzitic sandstone with thin shale and conglomerate lenses; some TMS shale, arenaceous shale, tillite, grit, conglomerate
Tweefontein	sand, cobbles	11.1% S; 22.5% MG; 28.8% LG; 34.0% SC; 3.6% MC	riffles; runs	tertiary/quaternary alluvial sands; some TMS quartzitic sandstone with thin shale and conglomerate lenses
Kriedouwkrans (PHABSIM II site)	sand, bedrock	58.2% S; 0.4% SG; 0.4% MG; 2.3% LG; 11.0% SC; 2.3% MC; 25.4% BR; occasional boulders	runs; rapids; pools; backwaters	TMS quartzitic sandstone with minor shale and conglomerate lenses; some TMS shale, arenaceous shale, tillite, grit, conglomerate
Clanwilliam	soil, sand, bedrock	6.7% MG; 7.1% LG; 7.2% SC; 4.5% MC; 4.0% LC; 70.5% BR; occasional boulders; some sand and SG	runs	tertiary/quaternary alluvial sands; TMS quartzitic sandstone with thin shale and conglomerate lenses
Langkloof	sand	100% S	runs	TMS quartzitic sandstone with minor shale and conglomerate lenses; some tertiary/quaternary alluvial sands
Bulshoek	soil, sand, bedrock	100% BR; occasional boulders; some cobbles and gravel	rapids; pools; runs; cascades (downstream)	TMS quartzitic sandstone, shale, conglomerate lenses, tillite; some schist, limestone, dolomite
Zypherfontein	soil, sand	10% mud; 90% S; bedrock upstream	pools; cascades (upstream)	TMS quartzitic sandstone, shale, conglomerate lenses, tillite; Karoo Supergroup Dwyka Series (DS) sandstone, tillite, shale; some schist, limestone, dolomite
Klawer (PHABSIM II site)	sand	100% S; some gravel and mud	runs; pools; backwaters	DS sandstone, tillite, shale; some TMS quartzitic sandstone, shale, conglomerate lenses, tillite; some schist, limestone, dolomite; tertiary/quaternary alluvial sands
Botha's Farm	sand, gravel	35.0% S; 10.8% SG; 20.8% MG; 22.0% LG; 10.2% SC; 1.2% MC; some mud	riffles; runs	DS sandstone, tillite, shale; some TMS quartzitic sandstone, shale, conglomerate lenses, tillite; some schist, limestone, dolomite; tertiary/quaternary alluvial sands

The overall picture of the study area obtained in this fashion, and the primary variables responsible for observed geomorphological changes are presented in the following description. The upper reaches of the river comprise predominantly TMS sandstone, are narrow and increasingly sinuous in the high-altitude plateau above the gorge, while the gorge itself produces a series of rapid changes in channel gradient in its upper eroding section. In the lower gorge, just above Grootfontein, the channel gradient becomes gentler and the first evidence of deposition of bed materials appears. In this lower section of the gorge and downstream, the channel is moderately narrow, with some anastomosing sections, riffle-run sequences, and a predominantly cobble/gravel bed. These characteristics are typical of a riverine foothill zone. On leaving the gorge the river enters a wider section where there is considerable deposition of alluvial sand.

The middle reaches of the river are typically of low sinuosity with some "irregular wandering" (R. Wadeson, Geography Department, Rhodes University, pers. comm.). There tend to be channel islands vegetated with palmiet (*Prionium serratum*), and sandy bed sections with bedrock outcrops. Armouring is evident below both dams, exposing large areas of predominantly bedrock. Deposits of alluvium are evident further below Clanwilliam Dam. The reach below Bulshoek Dam exhibits a steep gradient uncharacteristic of a lower reach, and this gradient, probably a function of the local geology, results in a series of cascades and rapids.

The lower reaches of the river are influenced strongly by inputs of alluvial sand from the Doring River. The channel downstream of this confluence is wider with steep sand banks in some areas and there are more reaches with slow flow through runs or pools. The river tends to meander slightly, but is constrained by agricultural terracing on the floodplain. Although the lower river reaches are predominantly sand, there are isolated areas of cobble; these may be largely artificial patches of construction rubble.

The above description obtained from the channel cross-section approach and the information on channel geomorphology, was used to produce a geomorphological zonation of the study area, as discussed further below.

5.3.3.4. Degree of success of various approaches in establishing the present geomorphological zonation of the study area

For the approaches based on the use of aerial photographs and on channel cross-section dimensions and geomorphological channel features, attempts to zone the study area were at least partially successful, although they provided information only on present zones. The bankfull discharge and hydraulic geometry equations approaches proved to be unsuccessful (Table 5.2). Predictive assessment of future channel form and, hence, future geomorphological zones was considered to be only possible using modelling techniques in conjunction with professional judgement.

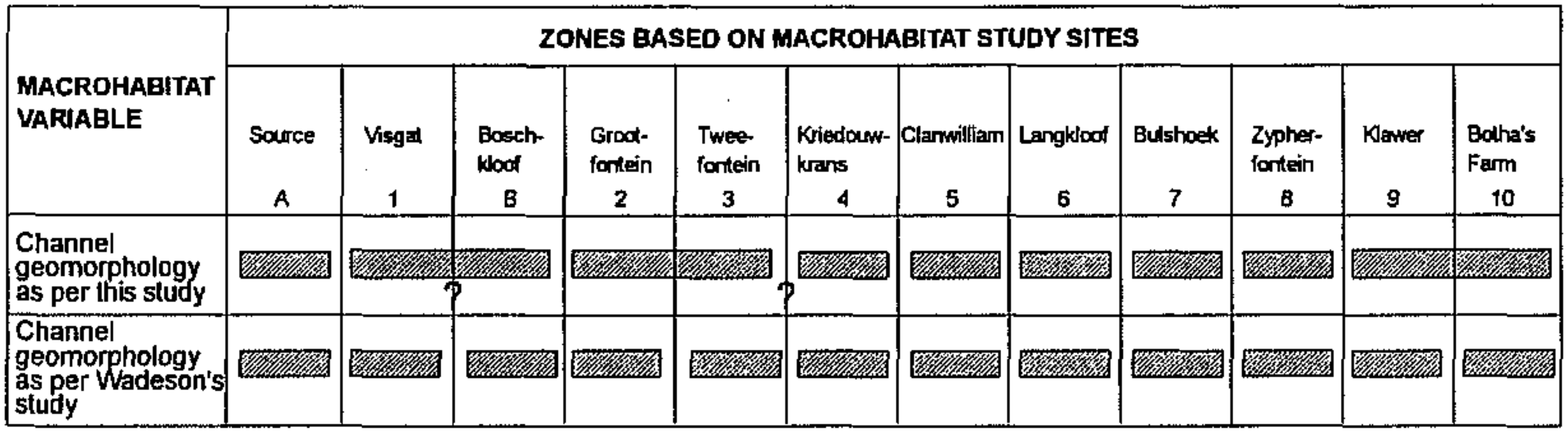
Certainly, the use of modelling techniques was recognised during this study as the only comprehensive way of collating historical and present data on channel morphology and sedimentology, for prediction of the types of change in channel form that might occur with impoundment. However, with limitations such as insufficient long-term data and resources (Table 5.2), it was not possible to achieve this objective within this study.

In summary, the study area could essentially be divided into a number of present-day macrohabitat zones based on the approaches mentioned above (Figure 5.7).

The source area was considered to be a distinct zone, primarily due to the geology of the plateau and the low gradient. However, only a short section of the river on the plateau was examined, and there could be further zones in this section. Visgat and Boschkloof were grouped as a single zone due to their steep gradient, and similar bed and bank materials. However, the area between these two sites was not examined, and would likely have yielded at least another zone due to rapid gradient changes and associated waterfalls and pools. Hence, the zonation for this section is acknowledged as conservative and probably incomplete. Grootfontein and Tweefontein exhibited typical foothill zone features, such as a predominantly cobble bed with riffle/run sequences and a fairly open riparian canopy, and were grouped in one zone. The channel pattern of the reach at Kriedouwkrans was sufficiently different from that at Tweefontein to distinguish it as being in a different zone. It is acknowledged, on the basis of the summary in Table 5.3, that there is probably at least one zone omitted between Tweefontein and Kriedouwkrans; certainly, Citrusdal bridge and Algeria causeway have each changed the nature of the downstream channel. Clanwilliam Dam forces a break in the zonation so that Kriedouwkrans is alone in a zone. Possibly, the zone would have extended quite some distance downstream, if it were not for the dam. Langkloof forms an independent zone primarily by virtue of its location between two dams, but also as a result of its predominantly sandy bed. Zypherfontein is separated from the rocky reach at Bulshoek as it represents an area of different geology, has a largely sandy bed, a dominance of pool-like reaches and a lower gradient. It is bounded at its downstream end by the confluence of the Doring River which introduces large amounts of sediment into the mainstream, hereby producing a sand-bottomed channel and fairly wide floodplain. The dominance of sand as a bed material, similar geology and extremely low gradients resulted in the reaches of the two lowest macrohabitat sites being grouped as a single zone. It is likely that this zone extends to near Lutzville causeway, as there is little evidence of changes in the river in this reach; however, this would need field verification.

Recently, a technique for determining types and numbers of different geomorphological river reaches was developed and applied to the Olifants River (R. Wadeson, Geography Department, Rhodes University, pers. comm.). Wadeson used the term "reach" in his study, which is probably equivalent to a geomorphological "zone" in this study, but might better correspond with only parts of zones (see glossary); this would need to be substantiated by further work.

The preliminary results of Wadeson's technique, which is based on an analysis of geology and degrees of change in channel gradient coupled with field ground-truthing of the reaches differentiated in this manner, suggested that the Olifants River mainstream comprises 25 to 30 reaches, some of which were similar to, but separated from, one another. The ground-truthing exercise enabled better definition of transition areas between reaches (zones, this study) that were not directly located at the contours used in the gradient analysis method. Of the macrohabitat sites selected for this study, each of the first nine either are located near one of his reaches, comprise one of them, or falls between two of them. In addition, a number of his reaches were missed during the identification of zones in this study. These were principally in the upper part of the river where Wadeson delimited a large number of reaches close together between Visgat and Boschkloof, and approximately a further four between Tweefontein and Kriedouwkrans; these reaches were not verified on the ground. This confirmed suspicions



<table>
<tr><th rowspan="2">MACROHABITAT VARIABLE</th><th colspan="12">ZONES BASED ON MACROHABITAT STUDY SITES</th></tr>
<tr><th>Source
A</th><th>Visgat
1</th><th>Bosch-kloof
B</th><th>Groot-fontein
2</th><th>Twee-fontein
3</th><th>Kriedouw-krans
4</th><th>Clanwilliam
5</th><th>Langkloof
6</th><th>Bulshoek
7</th><th>Zypher-fontein
8</th><th>Klawer
9</th><th>Botha's Farm
10</th></tr>
<tr><td>Channel geomorphology as per this study</td><td>▨</td><td colspan="2">▨
?</td><td colspan="2">▨</td><td>?
▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td colspan="2">▨</td></tr>
<tr><td>Channel geomorphology as per Wadeson's study</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td></tr>
</table>

Figure 5.7 Maps of the geomorphological zonation of the study area according to this study and Wadeson's preliminary study. ? denotes uncertainty with regards zonation or the possible omission of zones, due to lack of information

during the initial mapping phase of this study that several zones or parts of zones had been overlooked. It was acknowledged in this study that there was a zone(s) in the upper gorge (upstream of Boschkloof) that could not be sampled due to its inaccessibility. The last reach break identified from Wadeson's analysis of gradient was at the confluence of the Doring River. The macrohabitat site at Zypherfontein for this study fell midway between Wadeson's reach break below Bulshoek Dam and that of the Doring River confluence. No further reaches were identified by Wadeson downstream of this point, due to the low gradient of the lower river. However, two additional sites were selected in this lower section of the river (Klawer and Botha's Farm) for the purposes of this study.

Three provisional segments (see glossary) were also identified by Wadeson along the river, within which the above reaches were located, as representing major changes in the hydrological and sedimentological regimes. The first of these segments extended from the source to Keerom, the second from Keerom to the confluence of the Doring River with the mainstream, and the third from this point down to the estuary. None of these segments has been verified in the field. It is, however, noteworthy that each of the PHABSIM II sites chosen for this study was located in one of these segments. This could provide further support for the locations selected for these sites.

Further comments on the geomorphological zonation of the study area, in relation to the macrohabitat sites selected and other macrohabitat variables used to derive zones, are made in Section 5.4.

5.3.3.5 Integration of channel equilibrium and geomorphological zonation approaches within the assessment of macrohabitat

In summary, the above approaches to the assessment of channel equilibrium and the present and future geomorphological zonation of the river are not incorporated into the macrohabitat component of IFIM in any structured way by Bovee (1982). It is particularly unclear how the analysis of channel equilibrium should be proceeded with when historical flow records are incomplete or absent, and no sedimentological data are available. Furthermore, there are no suggestions in Bovee (1982), or any other exposition of IFIM, on how to identify and adequately assess channel equilibrium within a relatively short-term study. Determination of how channel morphology could be expected to change at the PHABSIM II and macrohabitat study sites with alteration of the flow regime, if existing and future channel morphologies cannot be assumed to be similar, is impossible without some form of long-term study or the use of modelling techniques; both were outside the scope of this study. A useful approach, were sufficient time available, could be the linking of information on: mapped changes in channel morphology and associated features such as riparian vegetation, from high quality detailed sequential aerial photographs; documented climatic and catchment land-use changes; and in-channel particle-size and channel geometry analyses.

It would be useful to develop a series of guidelines of approaches or some form of categorisation system to assist in prediction of channel adjustment in relation to changes in hydrological and sedimentological regimes, as this would facilitate the identification of channel stability thresholds below which direct application of IFIM would be inappropriate. This is vitally important, and also applies to the assessment of water quality and temperature, as an instream flow regime designed to maintain suitable microhabitat conditions could result in future instability of this microhabitat by producing unexpected modifications of channel morphology (or water quality and temperature) at the macrohabitat level.

5.3.4. WATER QUALITY AND TEMPERATURE AS MACROHABITAT VARIABLES

Water quality and temperature are identified as important variables in the assessment of macrohabitat for the target species (Bovee 1982), and need to be assessed from present and future perspectives (Figure 5.1). As with the assessment of channel morphology, the present conditions in the river would need to be determined so that a present-day zonation could be established. In some instances, historical information could be used to help identify both the kinds of changes that could be expected to occur with water-resource development (if pre- and post-dam information for a dam on a study river existed) in order that indicator variables of change might be found, and any changes that could be attributed directly to changes in catchment land-use over time. Then, future conditions would need to be predicted, before future zones of water quality and temperature could be delimited.

5.3.4.1. Approaches for assessing future changes in water quality and temperature and determining present and future zones

In theory, present and future water quality and temperature profiles should be determined as a function of discharge, and months or discharges for which these macrohabitat variables are perceived as most limiting for the target species should be identified. This information should then be linked with the tolerance ranges of the target species, to determine the length of river suitable in terms of macrohabitat, by superimposing species requirements on the appropriate water quality profile. Relevant historical information would be useful in further facilitating this link, because it would add data on what conditions are known to have been suitable in the past. However, within this study, the overall process was limited in several ways.

Modelling approaches are required in order to predict the likely water quality and temperature regimes after the establishment of a regulated flow regime, because changes in flow and hence in loading rates and concentrations of water quality variables are certain to occur. Alternatively, or in conjunction with modelling techniques, other approaches could provide further insight into the kinds of changes in water quality and temperature that could occur. These could include, for instance, comparison of historical and present-day data, studies of changes in water quality that occurred in similar river systems of the same region exposed to flow regulation, studies of general trends in water quality changes evident after damming other reaches of the study river, and comparison of changes in water quality associated with present low flow periods with the anticipated modified flow regime.

The absence of sufficiently detailed data on present water quality and temperature posed a problem in this study, as did the various requirements involved in modelling present and projected changes, such as the requisite level of detail of the data base and the lack of expertise. Modelling would be especially problematic in this study as the proposed post-impoundment flow regime is not known in sufficient detail, and the specific location and structure of the dam not finalised.

Bovee (1982) suggests the use of additional information, in the form of benthic macroinvertebrates as biotic indicators, to assess historical and present water quality conditions. In this study, the biological zonation of the study area was determined in its own right, as further support for the final macrohabitat zonation patterns to be decided upon (see Sections 5.3.5 and 5.4). From this, some indication of present water quality and temperature zones could be determined, but future zones could not be determined using this approach (see Section 5.3.5).

Modelling future thermal and water quality regimes could be achieved using recent models specifically developed to address instream flow problems associated with regulation, such as those documented in Dortch & Martin (1989). Water quality and temperature models specifically developed for IFIM appear to be largely in their developmental stages, although they have occasionally been used (R.T. Milhous pers. comm.); no assessments of their predictive accuracy appear to have been published (e.g., Grenney & Kraszewski 1981; Theurer & Voos 1984, cited in Orth 1987).

In the following sections, present water quality and temperature conditions are described and attempts are made to determine the present zonation of the study area using this information. The present data are then compared with historical data for the river, to identify any trends in variables that might assist in predicting likely future changes in water quality and temperature. No attempt is made to predict future zones.

5.3.4.2 Present water quality and temperature conditions

In order to establish the present-day water quality and temperature zones for the study area, the relevant information collected during this study first needed to be analysed and then expressed as a longitudinal profile for each variable, for each season. The methods used for the collection and analysis of water quality samples for this study are outlined in Appendix 5.3.

Seasonal water quality profiles of present conditions, at all of the mainstream macrohabitat sites (Tables 4.1 and 4.3), were determined for 22 water quality variables, in an attempt to gain an understanding of the lengths of the river with similar water quality and temperature conditions. The assessment included sites located directly downstream of Clanwilliam and Bulshoek dams, as it was hoped that these might provide some indication of how future water quality and temperature conditions could be altered by the construction of a dam within the study area.

Appendices 8.2 to 8.4 (Chapter Eight) indicate where and when water quality and temperature data were collected. Appendix 5.4 lists the raw data on water quality for all field trips for the mainstream sites, and Appendix 5.5 provides water quality (excluding Fe, Cu and turbidity) and temperature profiles for the study for all seasons and mainstream sites. Note that July water quality values were taken during a flood, and that all profiles depict real distances between sites. Appendix 5.6 summarises water quality data for all tributary sites, including those where fish data were collected (see Chapter Seven), and for sites of interest other than those specifically used for IFIM.

5.3.4.3 Using water quality and temperature profiles to delineate present zones

Although statistical analyses can be performed on water quality data to provide objectively-based zonation patterns of longitudinal change in water quality variables, replicate samples (for example, at daily intervals over a one week period) are required for all variables tested, for all sites and seasons to be analysed (L. McNeil, Statistical Sciences, University of Cape Town, pers. comm.). In terms of time and finances, it was not possible to collect information at such an intensive level in this study. Therefore, the zonation pattern for water quality and temperature had to be determined subjectively using judgement, and statistical verification of the trends and final zonation pattern was not possible.

The feasibility of using clustering and ordination techniques with the available data to assist in the delimitation of zones, was not explored in this study due to time constraints. However, at a later stage it might be useful to at least superimpose water quality data on the biological zones determined using ordination techniques in order to develop a better understanding of those water quality variables that might be partially responsible for observed species distributions (Field *et al.* 1982). Also, grouping together those water quality variables that showed similar trends would make the identification of zones easier than using techniques which assessed each water quality variable independently and only then attempted to combine zones.

In terms of the effectiveness of the water quality profiles generated in this study in illustrating longitudinal zonation, some variables, such as Chloride, showed quite obvious downstream changes in magnitude (Figure 5.8) which could be used to delineate fairly clear zones within the study area using judgement.

However, many variables, such as ammonia, showed less clear trends (Figure 5.9), at least partly because of instantaneous sampling at only a seasonal level. Also, downstream changes in water quality tend to be gradual rather than abrupt, which increases the difficulty of deciding upon longitudinal zones based on these variables.

In the compilation of the final water quality zonation pattern only the summer data were considered, for two reasons. Firstly, the summer water quality profiles generally showed the clearest longitudinal changes in magnitude of each variable; the changes were more muted in the other seasons, probably largely because of increased discharge. Secondly, the biological data used in this report were for summer samples only, and it would be necessary in the final stages of the assessment of macrohabitat to attempt to link the biological and physicochemical data.

In attempting to determine the general zonation of the study area in terms of water quality and temperature, each variable was assessed independently and obvious increases or decreases in magnitude were noted by means of subjective judgement based on a visual assessment of the data (Figure 5.10). Of the water quality variables assessed, pH, % organics in TSS, phosphate and ammonia (see asterices, Figure 5.10) showed a high degree of longitudinal variability. For many of the remaining variables, such as conductivity, large-scale trends were apparent over the whole study area, but some small-scale changes were also apparent.

Values for TDS, % organics in TSS, nitrates, reactive silicon and calcium changed significantly below Clanwilliam Dam as did conductivity, % organics in TSS and reactive silicon below Bulshoek Dam (Figure 5.10). These variables are possibly the most suitable indicators for an assessment of future changes in water quality liable to occur with impoundment as they were shown to be most influenced by existing impoundments. Obviously, they would have to be considered in relation to the location of proposed dams, because the two existing dams are in the middle reaches and may, therefore, influence water quality in quite different ways from

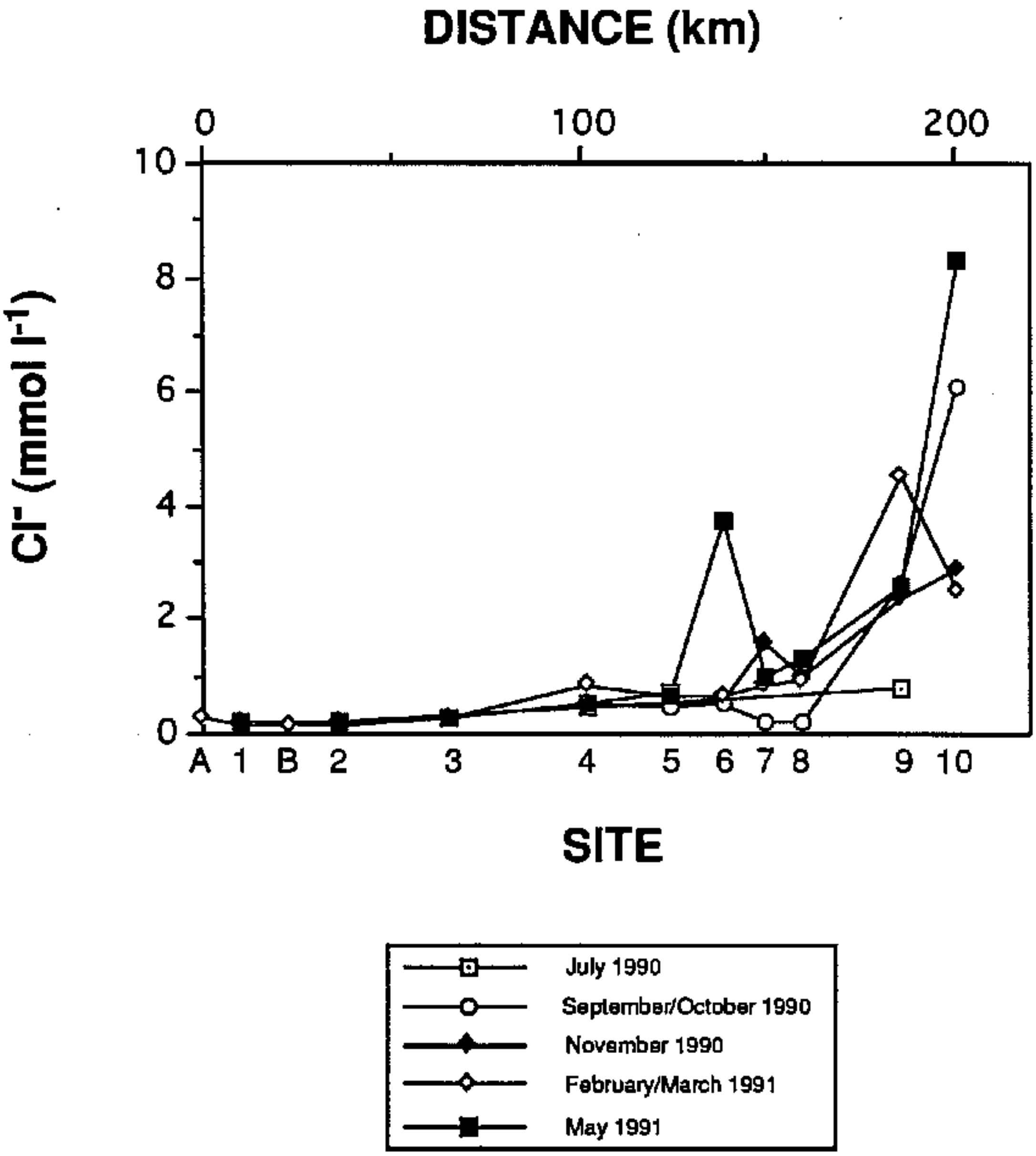


Figure 5.8 Example of a water quality profile (Chloride) that showed clear downstream trends and could, therefore, be used for delineating longitudinal zones. Sites are coded as for Table 4.1

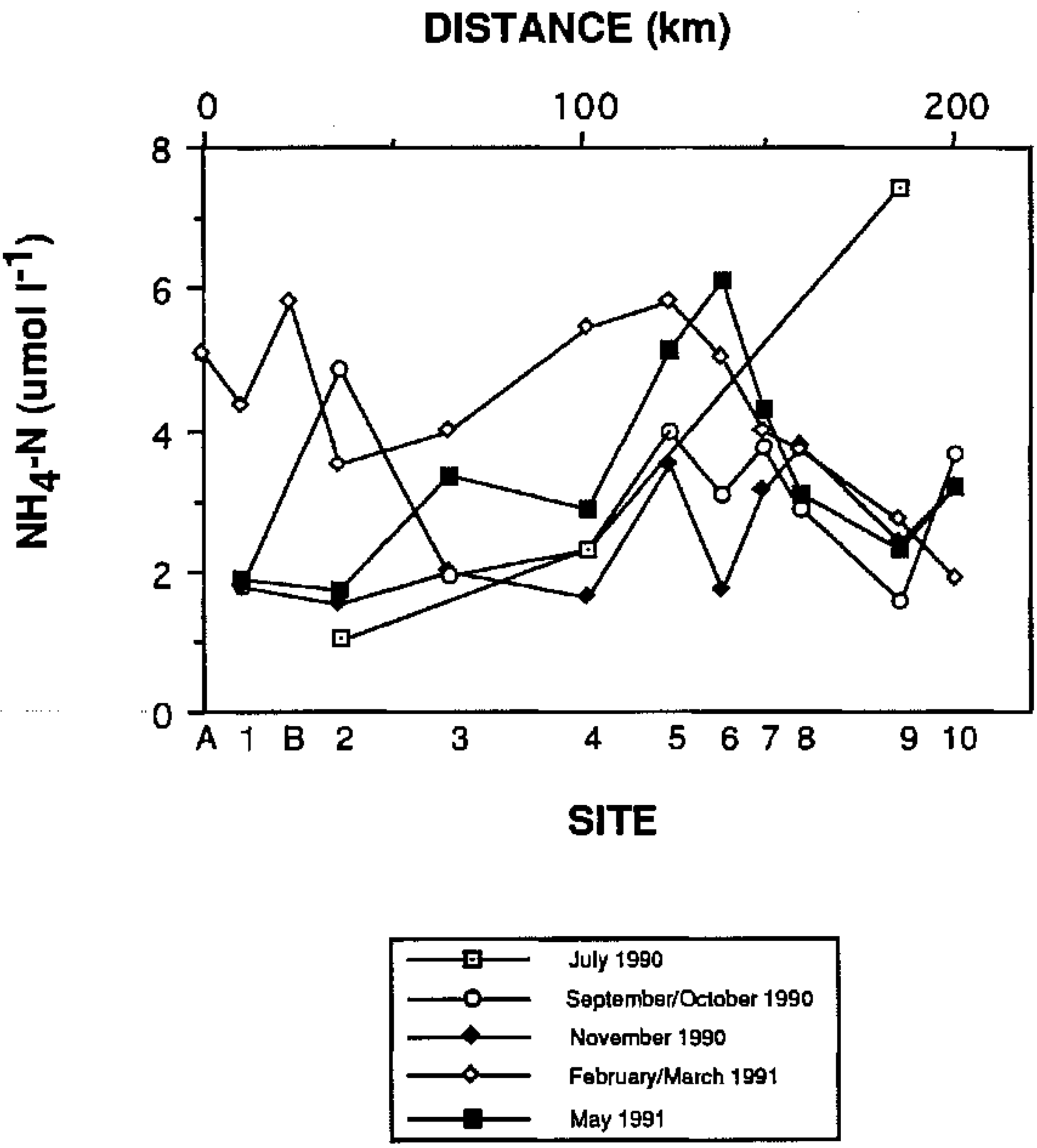


Figure 5.9 **Example of a water quality profile (Ammonia) that did not show clear downstream trends and could not easily be used for delineating longitudinal zones. Sites are coded as for Table 4.1**

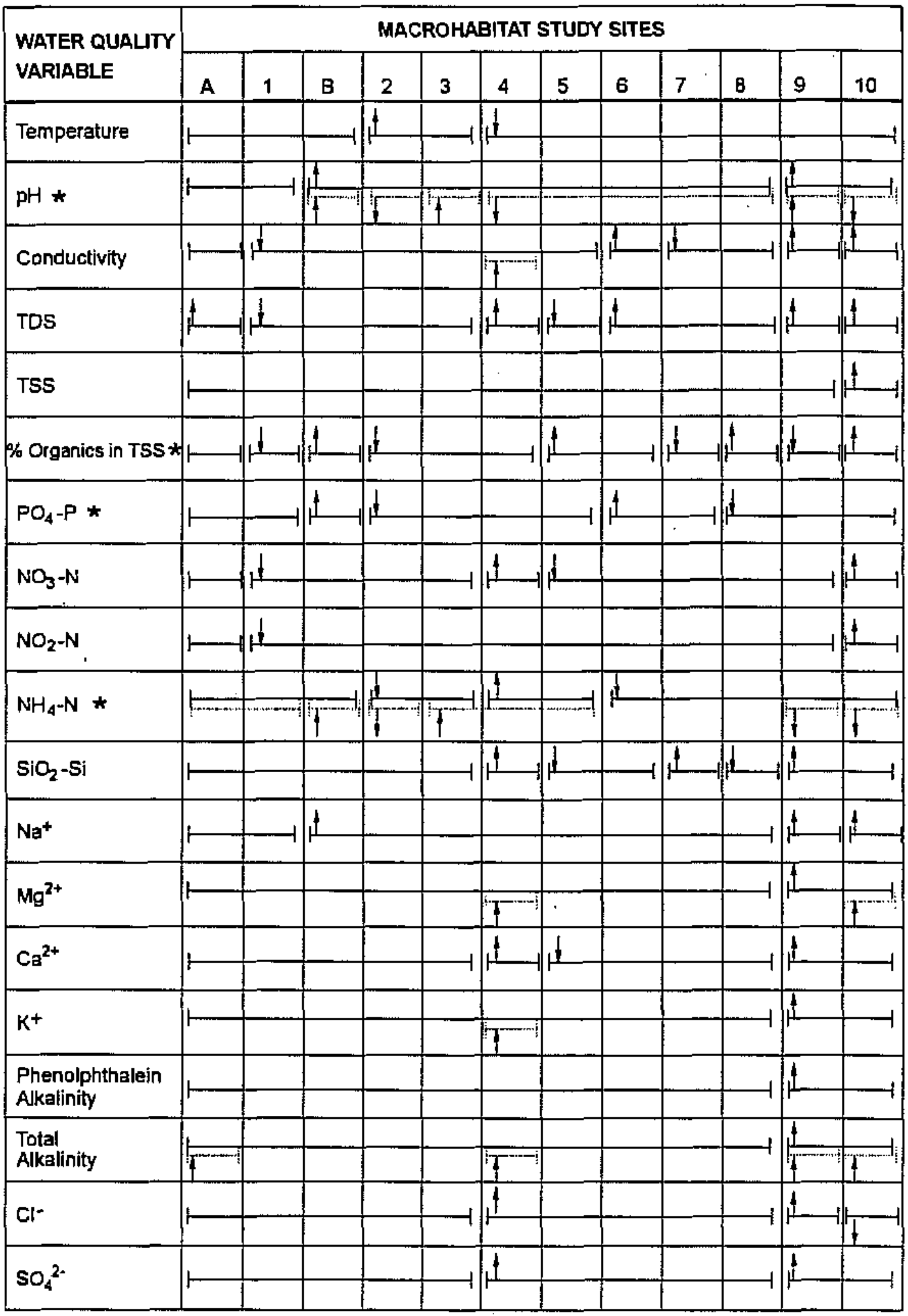


Figure 5.10 Large-scale trends (├──┤) in water quality variables for the study area based on the summer data (February/March). ↑ indicates a noticeable increase in a water quality variable at a particular site, while ↓ indicates a decrease. These trends are not necessarily statistically significant. Asterices represent those variables which exhibit highly variable longitudinal changes, and therefore, less obvious larger-scale trends. ┆┄┄┆ represents a site(s) for which smaller-scale changes are apparent

dams in upper reaches. This is important as the water of the upper reaches is presently of fairly high quality (J.A. Day, Freshwater Research Unit, University of Cape Town, pers. comm.), but is nutrient-enriched near the source. There is also the possibility of the presence of pesticides in the water, which have not been analysed for. The lower reaches are already fairly heavily impacted, due to the return-flow of irrigation water. Additional changes to this reach are brought about by the inflow of water of very different chemical composition from the Doring River, with its markedly different catchment geology and climate.

Changes in water quality for other sites along the river are not discussed here, but are illustrated in Figure 5.10 and detailed in Appendix 5.4.

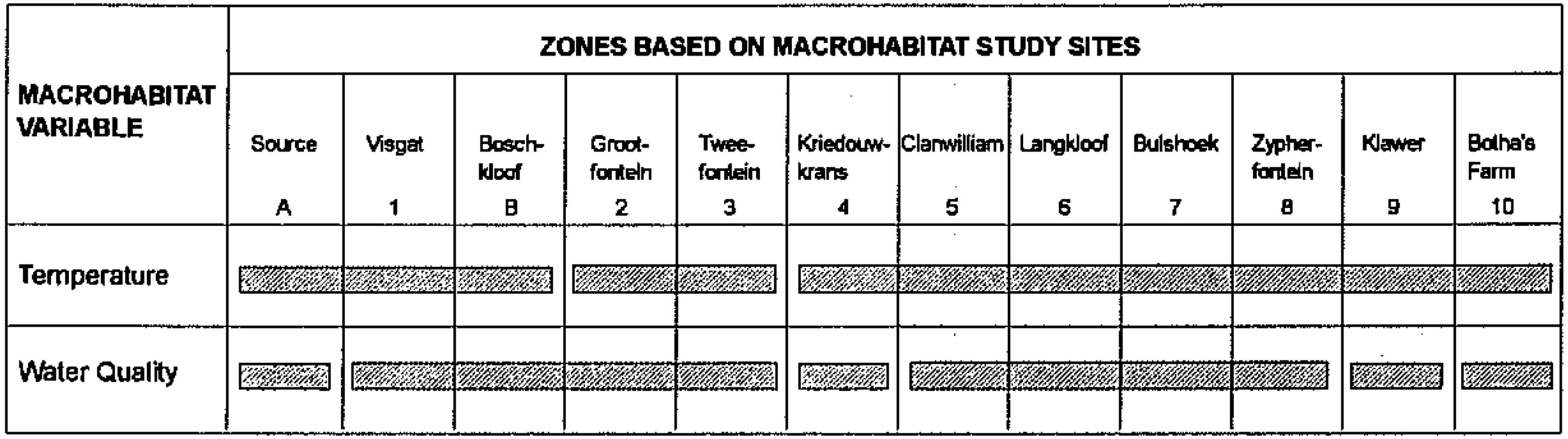
Once the trends were established for all water quality variables, all the large-scale change points were counted for each site and this information was used to decide on how many change points for individual variables constituted a sufficiently large overall change to warrant the creation of another water quality zone. This was considered a fairly objective way of deciding on the overall water quality zonation pattern. Reassessment of the zonation pattern generated in this way, by incorporating both small- and large-scale change points for each variable, did not result in a different zonation pattern from that of an assessment of only large-scale trends.

5.3.4.4 Present-day water quality and temperature zonation

The present-day zones for water quality and temperature, within the study area, are illustrated in Figure 5.11 and are discussed in relation to all other macrohabitat variables in Section 5.4.

For temperature, the study area could be divided into only three obvious zones, due to the limited information obtained from instantaneous sampling (Figure 5.11). Generally, the uppermost reaches had cool waters, while the lower section of the gorge and the shallower reaches immediately downstream of it exhibited very high diel temperatures during the summer. From Kriedouwkrans downstream, there was no obvious pattern of temperatures, but the water tended to be somewhat cooler than that of the lower gorge and foothill zone, possibly as a result of the releases of water from both upstream dams, increased inflow from tributaries, deeper channel sections, and subsurface seepage (Coetzer 1982 suggested the latter).

Generalised zones representing the summation of the effects of the water quality variables were difficult to determine. A conservative pattern, based on the method outlined in the previous Section, was adopted (Figure 5.11). The source area of the river had a distinctly different water quality from the other upper reaches, possibly because of the combined influence of agriculture and the alternating shales and siltstone strata of the Table Mountain and Bokkeveld Series. Visgat to Tweefontein formed a single zone, with Grootfontein and Tweefontein exhibiting most similar water quality. Kriedouwkrans was proposed as a single zone, bounded at one end by Clanwilliam Dam, and separated from Tweefontein, probably as a result of the effects of intensive agriculture in this section of the river concomitant with severe reductions in flow during all summer months. Moreover, the possibility that a zone was omitted between sites 3 and 4 could mean an exaggeration of the changes between sites. Sites 5 to 8 formed a single zone; interestingly, Bulshoek Dam did not seem to markedly alter water quality conditions downstream. The confluence of the Doring River with the mainstream caused a division between sites 8 and 9, with large increases in the values of many of the variables



MACROHABITAT VARIABLE	ZONES BASED ON MACROHABITAT STUDY SITES											
	Source A	Visgat 1	Boschkloof B	Grootfontein 2	Tweefontein 3	Kriedouwkrans 4	Clanwilliam 5	Langkloof 6	Bulshoek 7	Zypherfontein 8	Klawer 9	Botha's Farm 10
Temperature	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Water Quality	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

Figure 5.11 Maps of the water quality and temperature zonation of the study area

occurring downstream of the confluence. Further increases between Klawer and Botha's Farm were large enough to warrant separating these two downstream-most sites from each other.

5.3.4.5 Comparing past and present trends in water quality and temperature

Historical data are reviewed in this Section to provide some indication of whether or not water quality and temperature conditions have remained fairly stable over time, despite land-use changes in the catchment, and would remain so in the future. Such data could assist in identifying those variables that are changing most over time, and which are likely to continue changing in the future. This could assist with the establishment of both present-day and future zones of water quality and temperature.

Historical water quality data for the Olifants River study area are limited to work by Coetzer (1982), and to a lesser extent by Van Rensburg (1966), both of whom took instantaneous measurements for several sites throughout the river system, only some of which corresponded directly to the mainstream sites selected for this study.

Coetzer's (1982) data provided some useful information on the trends in several water quality variables for ten sites on the mainstream. However, the nature of the sampling equipment used and the degree of accuracy of specific values for each variable (A. Coetzer, CNC, pers. comm.) precluded a more detailed comparison of his data with data collected during this study. Some of the more obvious points of comparison are discussed below.

Nine of Coetzer's sites (Coetzer 1982) are at fairly similar locations to the sites in this study (Table 4.1), but not always in the same reaches. His site 1 corresponded roughly with site A of this study, his site 2 with site 2 to 3 of this study, site 3 with a reach some distance downstream of site 3 of this study, and site 4 with the middle reaches upstream of Clanwilliam Dam (upstream of site 4 of this study). Coetzer's site 7 was near site 8 for this study, and his site 8 was upstream of site 9 (this study). Furthermore, Coetzer had an additional site upstream of Vredendal and one at Lutzville causeway, and did not have any sites within the Olifants gorge as were used in this study. One of Coetzer's sites was located directly below Bulshoek Dam as was site 7 for this study. Another of Coetzer's sites was situated downstream of Clanwilliam, and hereby provided some indication of water quality conditions below Clanwilliam Dam. For the purposes of comparison with the trends for other macrohabitat variables examined in this study, only the summer data sets on water quality were compared.

Generally there was very close agreement with the longitudinal patterns observed by Coetzer and those of this study for the eight variables that could be compared. Values for total alkalinity were in fairly close agreement, except that Coetzer did not observe phenolphthalein alkalinity in any of the reaches of the river while it was evident in the lower reaches for this study. Chloride exhibited similar trends, including a decrease below both dams and an increase below site 8 (Zypherfontein). Sulphate trends were also similar, but the marked decrease observed below the two dams in the 1982 study was not as apparent in this study. Information on nutrients was limited to combined nitrogen for Coetzer's study, but the same decrease from high values at the source and subsequent increase at site 4 (Kriedouwkrans) were evident. A similar decrease in combined nitrogen was observed below Clanwilliam Dam for both studies, but the decrease below Bulshoek Dam for this study was not observed by Coetzer. Phosphate values varied more and exhibited clearer trends in the 1982 study than in the present one, and included an increase below Clanwilliam Dam and a decrease below Bulshoek Dam which were not found in this study. Temperature patterns were very similar for both studies for the upper and middle reaches, largely it would appear due to cool water tributary inflows from the mountains. Slightly cooler waters were also encountered in both studies in the lower reaches, below Bulshoek Dam. None of the changes in trends noted over time from Coetzer's study to the present, are sufficient to warrant the creation of different historical and present zonation patterns from one based on water quality and temperature data from this study. However, this is to be expected, as Coetzer's study took place fairly recently and does not provide a picture of true historical conditions.

Van Rensburg's (1966) data, although from 1963-64 and for several different times of the year including summer, were limited to the variables pH, total alkalinity, total chloride and water temperature. These data were collected for four sites on the mainstream which were close to sites 2 to 3, 4, 6 to 7 and 7 for this study (Table 4.1). The information was inadequate to determine historical trends for the study area for comparison with the data from this study. However, such as it was, it did not show marked differences between the water quality and temperature regimes in the 1960s and 1990s.

Although historical DWAF data on water quality were available for the Olifants River, they were not representative of conditions in the natural river channel, but rather of conditions in the irrigation canals and dam outlets (DWA 1990b).

In summary, it is impossible to assess whether or not the degrees of change apparent in certain variables between the 1963/64, 1982 and 1990/91 are significant, without a better understanding of the biological significance of small-scale fluctuations in variables and without specific knowledge of the tolerance ranges of all of the target communities and species used in this study.

5.3.4.6 Comparing present and future trends

Future changes in water quality and temperature conditions could have more of an impact on the river than the changes recorded up to the present. For instance, water quality changes are liable to occur downstream of the proposed dam due to the nature of the impounded water, the influence of the agriculturally-developed upper catchment, dam release schedules and outlet locations. Also, the thermal regime could change downstream of the dam, even to the extent of seasonal temperature reversals (A. Bath, NSI, pers. comm.).

It is acknowledged that water quality and temperature modelling should be performed in an attempt to predict future changes with flow regulation, and hence, the future zonation pattern. These have not been done here, due to the obvious constraints of time, money and data associated with a short-term study. However, even if such analyses were done, the entire approach is liable to remain futile, because adequate assessment of the suitability of projected conditions for the target species cannot be made, due to lack of knowledge of their requirements and tolerance ranges (Section 5.3.1). The implications of this are discussed in Section 5.5.

5.3.5 USE OF BIOLOGICAL INFORMATION TO DETERMINE MACROHABITAT ZONES

Although not explicit in Bovee (1982), biological zonation patterns are an extremely useful means of determining the longitudinal zonation of the river and of determining "suitable" macrohabitat zones or conditions. Biological zones reflect the sum response of the biota to the macrohabitat variables discussed above (and others), and thereby enable the avoidance of many of the problems encountered in zoning macrohabitat (see Chapter Three, Section 3.6 for an explanation of the relevance of hydrobiological zones). Indeed, this type of data might reflect present macrohabitat zones more faithfully than the zonation patterns obtained by piecing together fragments of physical and chemical information, as was necessary for the establishment of hydrological, geomorphological and water quality zones. Furthermore, as the biological zones identified for the study area were based on the distribution patterns of the benthic macroinvertebrate fauna, they were expected to assist in determining the tolerances ranges of this target component of the biota. Such information could be used later, if modelling of future conditions became possible, to reassess macrohabitat available to the target species after water-resource development.

5.3.5.1 Methods for determining biological zonation

Benthic macroinvertebrates were collected at all macrohabitat sites along the river. Information on the methods and associated software used, and on the results obtained, are presented in Chapter Eight. A series of classification and ordination techniques (Field *et al.* 1982) were used to assess the species distribution patterns of the macroinvertebrates and the results from these analyses (Figures 8.3 to 8.8) were used to delimit possible biological zones for the study area.

As indicated by the results presented in Chapter Eight, both family-level and species-level analyses (using rock and sand samples combined) produced a similar longitudinal pattern of zones at a moderate level of resolution (Figure 5.12). As no benthic macroinvertebrate samples were collected for the source site (A), this site could not be zoned in any definite way. However, the physical habitat conditions at this site (Tables 4.3 and 5.3) suggest that the biological community associated with this area may be different from that at Visgat and in the downstream gorge.

The biological zonation pattern that is obtained using the above techniques is dependent to a considerable extent on fairly arbitrary cut-off points of degrees of similarity, and to a lesser extent on the degree of taxonomic resolution. The resultant possible differences in zonation are illustrated in Figure 5.12.

Using a combination of the biological zones derived from the moderate and fine levels of resolution of the species-level data, supported by the species-level ordination (see Chapter Eight, Figure 8.6), eight zones were identified within the study area (as summarised in Figure 5.13). The upper reaches from Visgat to Boschkloof grouped separately from Grootfontein to Kriedouwkrans upstream of Clanwilliam Dam (Figure 5.12). The dams appeared to influence the biological communities downstream of each of them, possibly partly as a result of bed armouring which resulted in a predominance of bedrock as available substrate. The increase in the proportion of sand in the lower reaches, and the high proportions of sand at Grootfontein and Kriedouwkrans also influenced the zonation pattern, as rocky and sandy areas had quite different biota associated with them (Figures 8.7 and 8.8). These results are dealt with in greater detail in Chapter Eight. Here, the biological zones are discussed relative to zonation maps for the other macrohabitat variables below (Section 5.4; Figure 5.13).

5.4 COMPILING MACROHABITAT ZONES BASED ON SEVERAL VARIABLES

The final macrohabitat zonation pattern decided upon for each type of macrohabitat variable is dependent on the level at which change in a particular macrohabitat variable is considered to be significant for the target species, while acknowledging that each and every target species may perceive "significant change" differently. For several of the techniques recommended for macrohabitat assessment from the literature on IFIM, there are no objective means of deciding whether perceived boundaries between macrohabitat zones are real, imaginary or transitional in nature. Also, as there is no knowledge in this study of species biological tolerance ranges, the delimitation of boundaries is even more difficult (see Section 5.3.1). In fact, there are more likely to be areas of transition linking zones than clearly defined boundaries, and these would supply areas of marginal habitat for target species, rather than areas that are totally suitable or unsuitable.

For this study, the simplified zone maps created for each macrohabitat variable under present river conditions are presented below one another for comparison in Figure 5.13. The amount of information compiled on potential future macrohabitat conditions was insufficient for the production of similar maps of future zones.

At this stage of the assessment, no guidance is given in Bovee (1982) on methods of compiling and analysing the macrohabitat zonation patterns for the study area, or on deciding which of the predicted changes in macrohabitat (if this aspect can be adequately investigated) are likely to exert the most important or detrimental influence on available habitat for the target species. These problems are exacerbated in the context of this study by limitations discussed in this Chapter, and particularly by the lack of knowledge of the tolerance ranges of the target species and their relative sensitivity to each of the macrohabitat variables. These latter limitations are of crucial significance when attempting to consolidate the final stages of the assessment of macrohabitat (Section 5.3.1).

The majority of study sites stand alone for one or more macrohabitat variables (Figure 5.13). However, for the upper river, Visgat and Boschkloof tend to group either together or with the sites upstream or downstream of them, rather than each standing alone. Similarly, Grootfontein and Tweefontein tend to group either together or as part of a larger zone. Kriedouwkrans and the source area of the river were found to stand alone most often (three times each). In the case of the source, this could simply be the result of insufficient information. It should be noted here, that the zone breaks could fall somewhere either side of the site where the data were actually collected. Hence, although the zones are depicted here as breaking at the macrohabitat sites themselves, this is merely for the purposes of ease of representation. Areas of transition between sites really should be determined, and this information used to better reflect real change points in the macrohabitat variables.

If all variables are considered, the study area appears to be completely fragmented, with each macrohabitat zone having to be considered independently from the ones on either side. The number of zones for a particular macrohabitat variable could have been reduced only if very large changes in the variable were used to delimit zones.

The result of a highly fragmented zonation pattern was expected in this study, as there are presently three major breaks in zonation along the river irrespective of other changes; these are the two artificial breaks imposed by the dams, and the confluence of the Doring River with the mainstream. Probably, a more useful result would have been obtained if a greater number of sites had been used in the assessment. However, the increases in cost, data analyses and time would have been prohibitive for this study. If it had been possible to identify a single critical macrohabitat variable as being of greatest importance to the target species, an increase in the number of sites where that variable was measured could have been an option. However, as the number of sites is increased, the changes observed will become increasingly less obvious and a pattern of zones will blend into a continuum. Hence, the overall zonation pattern obtained for any variable is highly dependent on the initial number of sites selected in order to assess it. Also, as the target species were not chosen at the time the sites were established, it was not possible to identify critical macrohabitat variables anyway.

The production of a composite zonation map, taking into consideration all macrohabitat zones for all variables would, in theory, summarise the zonation of the river and enable some form of extrapolation of microhabitat results. However, this would not be of any use for two main reasons. Firstly, there would be zone breaks at virtually every macrohabitat site. Secondly, the zones themselves seem to be meaningless unless they are species- or community-specific and based on the known ranges of tolerance of that species to the macrohabitat variables. A further problem to consider with any form of zonation map, is that the zone may extend certain distances upstream and downstream to the next macrohabitat site. There is no guidance within the methodology on how to determine how far to extend each zone between sites. The fewer the sites that are used in the assessment, the greater this problem becomes. Biological zones may be the best to use in these circumstances as they provide a summation of all influences. However, without some kind of link to physical and chemical conditions, there is no possibility of ever predicting future conditions and biological reactions to them. So, all of these kinds of data are useful, but not enough is known yet to make adequate links and predictions.

For the purpose of this study, it was decided to recognise three major zones which corresponded with Wadeson's segments (see Section 5.3.3.4). Each of the three PHABSIM II sites was located in one of these major zones along the Olifants River, and represented a reach of limited distance (representative reach) upstream and downstream of itself. However, it was not known to what extent these reaches represented conditions throughout their respective zones.

5.5 SUMMARY OF THE APPLICABILITY OF THIS COMPONENT OF IFIM

Although the macrohabitat component of IFIM is identified as a vitally important part of the methodology, it is not adequately explained and approaches for its implementation are mostly theoretical, with few practical guidelines. Many of the requirements within these documented

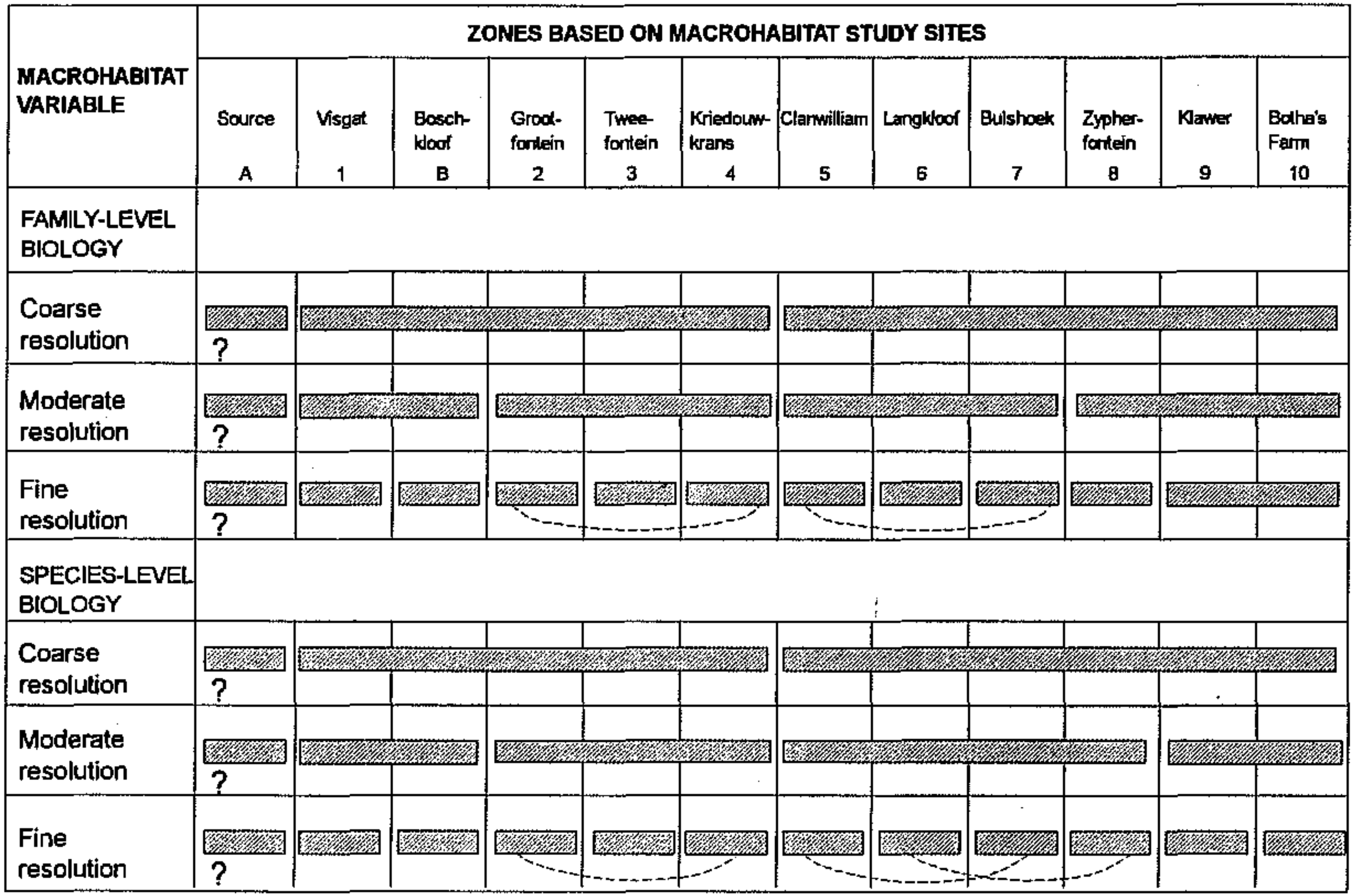


Figure 5.12 Maps of the biological zonation of the study area at both the family- and species-level for three degrees of resolution. ? denotes uncertainty with regards zonation, due to lack of information. --------- represents non-contiguous sites that grouped together in the classification and ordination analyses

approaches are also not pragmatic. For example, inadequate consideration is given in the methodology to implications of the study in terms of time, cost and expertise, or of the limitations imposed by restrictive data bases both on macrohabitat variables and on the tolerance ranges of target species. In actuality, much of Bovee (1982) appears to represent untested concepts regarding how a true IFIM study should be done.

This is probably the main reason why this component of the methodology is not regularly applied in IFIM studies conducted elsewhere in the world. It is certainly not routine procedure in North America to assess, in any structured way, the equilibrium status of the catchment and how it may affect channel equilibrium and associated macrohabitat conditions, or to report on such an assessment. Also, the combining of the microhabitat result (the habitat-discharge relationship) with macrohabitat variables to give total habitat is not performed, and much of the time the results from the PHABSIM II programs are used alone or only in conjunction with time series analysis (R.T. Milhous pers. comm.). In completed instream flow analyses in North America using IFIM, there are no comprehensive assessments of macrohabitat or examples of studies where total habitat was determined for a reach of river (K.D. Bovee, U.S. Fish and Wildlife Service, pers. comm.).

In terms of addressing specific macrohabitat variables, temperature information has been used in a few of the IFIM studies to date. For instance, physical habitat was conditioned by temperature criteria in a study of the American River in central California (T. Payne, North American consultant, pers. comm.). Water chemistry is very rarely assessed as a macrohabitat variable, and composite zones based on combinations of all macrohabitat variables never appear within such studies (R.T. Milhous pers. comm.). Although it is likely that hydrology and channel geomorphology are considered in instream flow studies, there is little information in the scientific literature to show this or to indicate the kinds of approaches that are used.

The following serves as an example of this neglect of macrohabitat variables within studies using IFIM. As PHABSIM II produces a habitat-discharge relationship on the basis of the channel morphology and hydraulics of the river, the fact that the same morphology may occur in both a warm and a cold water section of the river does not alter this specific relationship, although the macrohabitat zones representing these two sections would be different, and support quite different aquatic communities. In most studies, the PHABSIM II results would merely be extrapolated to other zones with similar channel form even if water chemistry and temperature were known to be radically different (R.T. Milhous pers. comm.). This would perhaps be acceptable if the purpose of the study was just to quantify changes in physical microhabitat, but the results are intended to go beyond this and predict the total habitat available to a particular species. Therefore, unless the researcher has the prior knowledge that the species can tolerate the entire range of conditions represented by all the zones with similar channel morphology, such extrapolation of PHABSIM II results would be incorrect.

In this study, the assessment of catchment equilibrium which precedes an assessment of each variable comprising macrohabitat was not attempted in any detail, due to the complexities of this kind of assessment and the theoretical nature of many of the proposed techniques. However, although catchment equilibrium was not wholly addressed, it was considered likely that the catchment was sufficiently stable to enable the study to proceed further. In most studies, it is unlikely that an instream flow study would be postponed on the basis of possible catchment disequilibrium anyway. Hence, although a review of the status of the catchment is essential in a study using IFIM, it is acknowledged that the results of such a review are liable

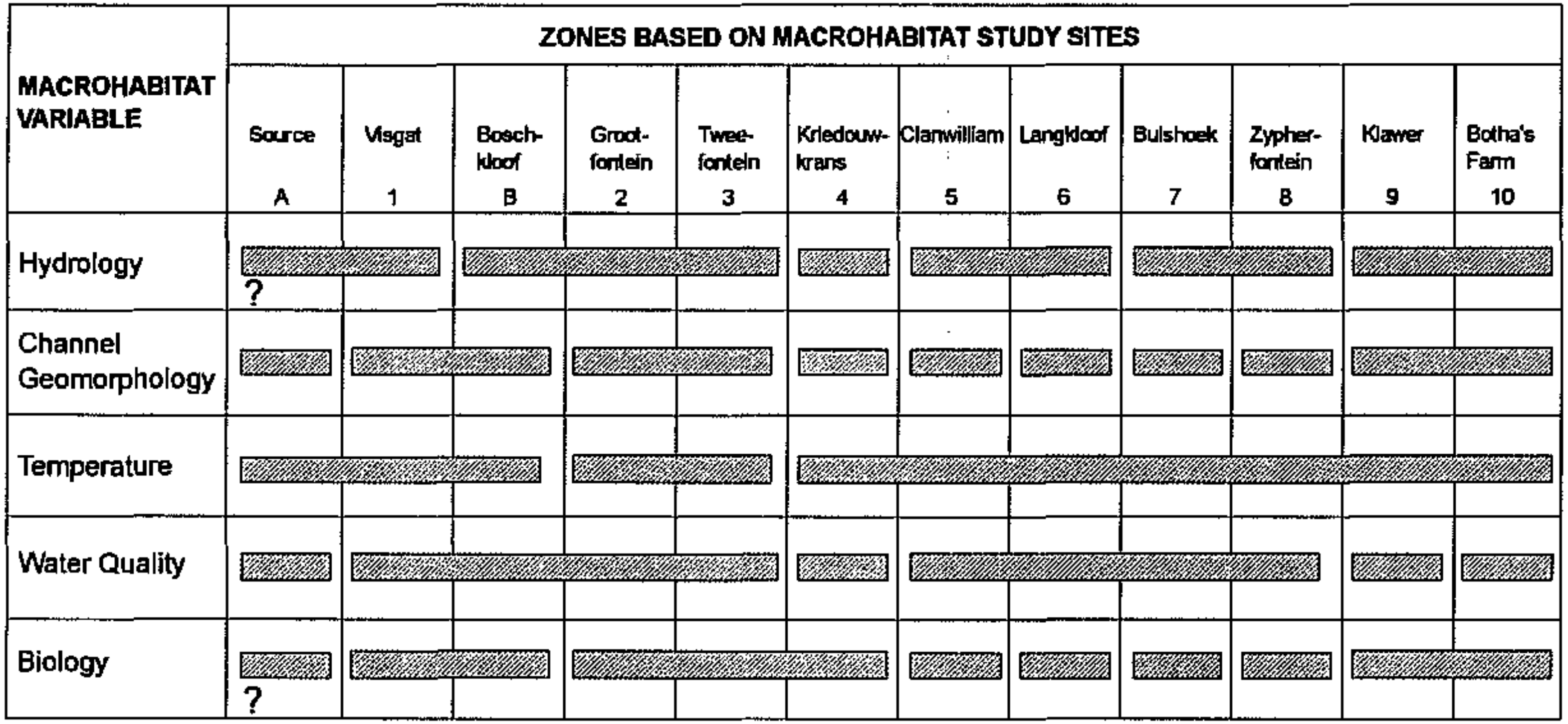


Figure 5.13 Generalised summary maps of the zonation of the study area for each of the macrohabitat variables assessed. ? denotes uncertainty with regards zonation, due to lack of information

to be inconclusive in the short- to medium-term, and that the approach is more theoretical than pragmatic. It would, therefore, seem most likely that this component of the methodology was introduced by Bovee (1982) principally to safeguard the validity of the assessments of macrohabitat and microhabitat, as these are dependent on an assumed persistence in channel morphology which is associated with a state of equilibrium.

The macrohabitat zones generated in this study were based on a limited amount of information and it is acknowledged that they tended to be fairly simplistic. In retrospect, they were well chosen, though, in that they enabled major break points in zonation of all macrohabitat variables to be identified. However, it is likely that a number of change points between the selected sites were missed. Moreover, the entire assessment of macrohabitat conditions was found to be unsatisfactory and of limited use for two main reasons. Firstly, without information on the tolerance ranges of the target species and communities, it was not possible to say what were meaningful zones for species presently eradicated from the river (fish) or, if presently there (benthic macroinvertebrates), what was restricting them and would thus affect future distributions. Therefore, it also would not be possible to extrapolate the PHABSIM II results on microhabitat to total habitat for present or future conditions. Further, because modelling was not possible, the information made available during this study did not enable any adequate quantitative assessment of the changes in macrohabitat that could occur in future with a dam. Hence, future macrohabitat zones could not be determined. Even if such zones had been produced, the absence of information on tolerance ranges of the target biota would have rendered them futile.

This aside, several of the approaches used to determine changes in macrohabitat conditions and hence, zonation, were found to be too complex and data intensive, or to require long-term studies, while others appeared to have some potential for futher use. For instance, the use of hydraulic geometry equations for determining channel change requires the establishment of large empirical data bases. However, where present information on channel geomorphology is lacking, the use of fairly simple techniques such as Wadeson's gradient analysis technique, with ground-truthing of the results could provide adequate information on zonation. Certainly, more attention should be placed in future on studies of methods for determining channel change and zonation, as the results of PHABSIM II are based largely on variables associated with channel morphology. It thus became obvious during this study that the modelling of future channel morphology should be an essential aspect of macrohabitat assessment.

For assessments of water quality and temperature, there are less likely to be simple approaches available, and modelling would have to play a key role in determining future conditions. Biological information, such as that obtained in this study on longitudinal changes in the community composition of benthic macroinvertebrates was found to be extremely useful in providing a form of composite zonation of present macrohabitat conditions in the river. Nevertheless, it did require the collection of large amounts of field data on the present biota. If the biota used for the assessment represented all or some of the target species themselves, as for this study, then some information would also be provided on species tolerance ranges. However, the biological zonation approach cannot be used to predict future conditions, and is therefore limited unless linked with physical and chemical data and modelling of predicted changes in these conditions. Also, as water-resource developments such as dams are likely to influence channel morphology and water quality, these variables need to be assessed in their own right anyway.

In conclusion, the macrohabitat component of the methodology could be vastly improved if the focus was on pragmatic methods of assessment which could be used at a series of levels, depending on study-specific limitations. This should include better definition of the degree of resolution necessary, for example, in terms of the data required and the procedures to be followed for each component of the overall assessment. Macrohabitat is undoubtedly a useful concept, and it is really necessary to perform an assessment of macrohabitat if an IFIM study is to be completely representative and accurate in its predictions and address issues beyond the present-day situation at the study site. The goals of a study may well be achievable to some extent without attempting a full assessment of this component of the methodology, but the limitations associated with the results would then require full acknowledgement.

From the above discussions, the main problem with the use of macrohabitat zones appears to be that these zones were originally sought to produce limits on channel morphology within which the results from PHABSIM II could be extrapolated. Secondly, they were devised to circumvent the problem that a zone that may be suitable for extrapolation from a geomorphological standpoint, may not, however, be suitable in terms of temperature or water quality. Hence, this component of the methodology was expanded to encompass all of these issues, so that the extrapolation of the PHABSIM II output could be justified. It is clear from the above attempts to apply an assessment of macrohabitat, however, that the only macrohabitat zones that are meaningful are those that are based on variables that the target species is responding to. This response will almost always be a composite one to many variables and be different for each species (although there may be individual variables which are particularly limiting for any one species). The response and, thus the tolerances, of any one species, cannot be determined without the collection of large amounts of information. Even then, the assessment is questionable as future macrohabitat zones will be difficult to predict at a satisfactory level of resolution.

These difficulties bring into focus the question of whether or not the PHABSIM II output of present-day microhabitat availability should ever be linked to a prediction of future total habitat availability. At present, the justification and methodology for such a link seem inadequate.

6. ASSESSING IFIM (STEPS 5-8): ESTABLISHMENT OF PHABSIM II MICROHABITAT STUDY SITES AND COLLECTION OF CALIBRATION DATA

6.1 APPROACH

Within each of the recognised major zones of the study area, a representative reach was chosen and within it, a study site was established (Chapter Five, Section 5.4). Each of these study sites represented an unknown length of river upstream and downstream of itself, but probably did not encompass the whole zone (Section 5.4). Transects were established to describe the channel morphology, substrate and cover characteristics and hydraulics of each study site. Data on velocity, discharge and water surface elevations (WSLs), for calibration of the hydraulic simulation programs in PHABSIM II, were collected for each transect at one or more discharges, as was information on channel index (CI) on the main survey trip.

6.1.1 SITE VISITS

The three selected PHABSIM II study sites, at Grootfontein, Kriedouwkrans and Klawer (Tables 4.1 and 4.3) were surveyed between 13 and 21 November 1990 and hydraulic data were collected (DWA 1990c). Following this, two more sets of hydraulic data were collected, in February 1991 and October 1991. These provided calibration data for moderate flows, low flows and high flows respectively.

First attempts to collect high-flow calibration data, in July 1990 and again in May 1991 failed because, respectively, the flows were too high for work in the river or too low. One benchmark per study site was established in July 1990, however, and later linked with the permanent headstakes established during the main survey trip in November 1990. The benchmarks were used in July 1990 to survey in flood WSLs at the three sites, each WSL being linked to a single location in the river which later became one of the established transects. These flood WSLs had to be linked with discharge values, which could only be measured at the high-level bridge at Citrusdal, the causeway leading from the N7 freeway to Algeria Forestry Station, Cedarberg, and the high-level bridge at Klawer. The latter two locations are very close to the study sites Kriedouwkrans and Klawer, respectively, and discharges measured there were considered to be acceptable as calibration data for those study sites. Citrusdal bridge, however, is about 40 km downstream of Grootfontein, and several tributaries enter the Olifants in between, so the discharge measured at this location is of questionable value as calibration data for Grootfontein.

The various attempts to collect accurate high-flow data reveal the difficulties faced during the wet season. The river has no gauging weirs near the study sites and so it was necessary to measure discharges in the river. As flow is too strong for this for most of the winter (May to August), the high-flow data of October 1991 were a compromise, collected when flows were falling at the end of the wet season.

6.1.2 TRANSECTS

DWAF kindly gave permission for two surveyors, Messrs. D. van der Boon and F. J. Bruwer, to provide expert assistance for the initial surveying exercise. The success of this exercise, and the high quality of the complete set of calibration data (R.T. Milhous pers. comm.), were due in large part to the excellent professional input of these two specialists.

Seven transects were surveyed at Grootfontein, five at Kriedouwkrans and five at Klawer (DWA 1990c). A greater number of transects was established at Grootfontein than at the other two sites because of its complex mosaic of channel features, and thus of aquatic biotopes. As far as could be determined in the rugged terrain, transects were placed at all hydraulic controls, and at additional points to describe important biotopes. Permanent beacons were created at both headstakes of each transect and labelled with site and transect number and bank (right or left) location.

Details of the transects are given in DWA (1990c). The report provides information on:

- The marker numbers of beacons created on the left and right banks, and of any intermediate beacons, for each transect
- WSLs for each transect in November 1990
- X and Y co-ordinates for each transect, representing land elevations and horizontal distance, with elevations expressed as real heights above sea level
- Plots of the cross-sectional profile of each transect
- Left and right bank, and thalweg, distances between transects
- Survey details of the location of each transect, linked to the nearest trigonometric survey beacon
- A DWA survey map of each PHABSIM II site (scale 1":500'), showing the location of each transect
- A description of substrate and cover conditions linked to each dry vertical of each transect
- A marker number linked to each wet vertical of each transect for which was recorded, in another document, the water depth, mean column velocity and substrate and cover conditions

The study site at Grootfontein was 840 m long, that at Kriedouwkrans was 497 m long and that at Klawer 1400 m long (Table 6.1). In general, in a downstream direction, the width of the total channel increased, and the nature of the river bed changed from cobble, to bedrock and sand, and then to sand only. The three PHABSIM II study sites reflected these changes in substrate, Grootfontein having a cobble-boulder bed with clear riffle-run sequences, Kriedouwkrans having a sandy bed with substantial bedrock outcrops and islands of palmiet *Prionium serratum*, and Klawer having a simple sandy bed, mainly with very high sand banks. Further descriptions of these sites are given in Table 4.3.

It should be noted that the numerical sequence of the transects in the DWA report (1990c) is the opposite to that finally used. Thus, the first transect at Grootfontein (GR000 - Table 6.1) is shown as DWA cross-section number 7, and so on, for all three sites.

6.1.3 VELOCITIES, DEPTHS, WATER SURFACE ELEVATIONS AND DISCHARGES

Mean column velocity and water depth were recorded at every wet vertical on the moderate-flow and low-flow visits. WSLs were also surveyed in for each transect on each of these two visits. The depth and velocity data, combined with the X and Y co-ordinates of each vertical, allowed a discharge value to be calculated for each transect for each of these visits. These data provided the basic information for calibrating the hydraulic models in PHABSIM II.

Table 6.1 Identity codes and descriptions of the transects used for PHABSIM II input

SITE	TRANSECT NUMBER	IDENTITY NUMBER	NUMBER OF POINTS SURVEYED	DISTANCE SURVEYED (m)	CHANNEL FORM/HABITAT
Grootfontein	1	GR000	45	157	turbulent run over cobbles; backwater over sand
	2	GR276	45	129	riffle over cobbles
	3	GR302	49	122	smooth run over cobbles
	4	GR517	45	104	smooth run, half over cobbles, half over sand
	5	GR628	42	107	two channels: deep run over cobble; deep, still backwater over cobbles
	6	GR695	34	107	smooth run over cobbles
	7	GR840	42	111	riffle over cobbles
Kriedouwkrans	1	KR000	48	153	one or more channels: smooth flow over sand
	2	KR119	63	227	one or more channels: smooth flow over sand
	3	KR166	58	221	bedrock rapid in main channel; multiple small flood channels under palmiet and over cobbles
	4	KR352	55	233	smooth flow over bedrock and sand; small palmiet islands
	5	KR497	44	279	smooth flow over sand; small palmiet islands
Klawer	1	KL000	42	288	smooth flow over sand; flood channels in riparian trees
	2	KL130	51	349	as for KL000
	3	KL256	56	340	as for KL000
	4	KL1048	39	193	as for KL000
	5	KL1400	45	199	as for KL000

High flows in October 1991 prevented the measurement of velocity and depth at every transect, although WSLs were always recorded. At Grootfontein, WSLs, velocities and discharge were measured for GR000, but overnight rains meant that the discharge figure was only applicable to that transect. At the subsequent higher flows, WSLs were measured at the remaining six transects (the theodolite broke before a second WSL reading was attempted at GR000). To link with the six WSLs, velocities and thus discharge could only be measured at the shallow riffle GR840, and so the discharge figure for GR840 was used for transects GR276 to GR840, while the WSL taken previously for GR000 was linked with its own discharge figure. At Kriedouwkrans, discharge was measured at transect KR000 but, because of difficulties with high-flows, velocity measurements were not taken at the recognised cell points and so could not be used as PHABSIM II input. At Klawer, flows were too high to enter the river anywhere, and discharge was estimated from depth and velocity readings taken at Klawer bridge, on either bank and as far into the stream as possible.

In terms of calibration data for the hydraulic programs in PHABSIM II, the final data set thus consisted of three complete sets of WSL and discharge data, and two complete sets and one partially complete set of data on velocity distributions.

6.1.4 CHANNEL INDICES

Information for the CIs was recorded at every dry and wet vertical on the main survey trip in November 1990. At that stage it was not understood that the CI information collected on the survey trip had to be at the same resolution as that collected on the biological trips for creation of the microhabitat suitability index (SI) curves of channel index. Thus, substrate and cover conditions were recorded in a far simpler form when surveying in transects (e.g. sand, mixed cobble) than when later collecting fish and invertebrate microhabitat data (e.g. 50% large cobble, 40% medium cobble, 10% sand, 40% epilithon on large and medium cobble). It is necessary to conform when recording the two kinds of data because the same CI code is used both for describing the substrate and cover conditions in the surveyed cells (in PHABSIM II) and for creating the SI curve relating to substrate and cover for the target species. It is pointless recording in great detail the substrate and cover conditions occupied or preferred by the target species, if this information has to be linked to cells which are described in a much simpler way in the model.

Confusions such as this are all too possible because of the number of manuals and chapters within any one manual that deal with specific topics in IFIM but do not clearly link them to other topics, and because of the absence of a flow chart comprehensively illustrating the whole IFIM procedure.

The specific CI codes used in this project for the fish and invertebrate investigations are described in Chapters Seven and Eight respectively. The particle sizes of named substrates are given in Table 6.2, and their derivations explained in Appendix 6.1.

6.2 DATA MANIPULATION AND PRESENTATION

Site maps for the three study sites are given in Figures 6.1 to 6.3. For each site, the transects are given by the identity numbers listed in Table 6.1, and their position is shown. Other

Table 6.2 Wentworth grade scale for substrates with modifications for the PHABSIM component of this study (see Appendix 6.1)

WENTWORTH GRADE SCALE				MODIFIED SCALE FOR THIS STUDY		
SUBSTRATE (GRADE)	DESCRIPTION (A)	GRADE LIMITS (mm)	PHI RANGE FOR GRADE	SUBSTRATE DESCRIPTION (B)	SPECIFIC MODIFICATIONS (C)	MODIFIED GRADE LIMITS (mm) FOR (C)
BEDROCK	Bedrock	Not specified	Not specified	Bedrock	Particle size class grouped as ***bedrock/boulder***	$512 < X \leq$ unlimited
GRAVEL	Very large boulder	$2048 < X \leq 4096$	$-11 < X \leq -12$	Large boulder		
	Large boulder	$1024 < X \leq 2048$	$-10 < X \leq -11$	Medium boulder		
	Medium boulder	$512 < X \leq 1024$	$-9 < X \leq -10$	Small boulder		
	Small boulder	$256 < X \leq 512$	$-8 < X \leq -9$	Large cobble	Particle size class grouped as ***cobble***	$32 < X \leq 512$
	Large cobble	$128 < X \leq 256$	$-7 < X \leq -8$	Medium cobble		
	Small cobble	$64 < X \leq 128$	$-6 < X \leq -7$	Small cobble		
	Very coarse pebble	$32 < X \leq 64$	$-5 < X \leq -6$	Large gravel		
	Coarse pebble	$16 < X \leq 32$	$-4 < X \leq -5$	Medium gravel	Particle size class grouped as ***gravel***	$2 < X \leq 32$
	Medium pebble	$8 < X \leq 16$	$-3 < X \leq -4$	Medium gravel		
	Fine pebble	$4 < X \leq 8$	$-2 < X \leq -3$	Small gravel		
	Very fine pebble	$2 < X \leq 4$	$-1 < X \leq -2$	Small gravel		
SAND	Very coarse sand	$1 < X \leq 2$	$0 < X \leq -1$	Very coarse sand	Particle size class grouped as ***sand***	$1/16 < X \leq 2$
	Coarse sand	$1/2 < X \leq 1$	$+1 < X \leq 0$	Coarse sand		
	Medium sand	$1/4 < X \leq 1/2$	$+2 < X \leq +1$	Medium sand		
	Fine sand	$1/8 < X \leq 1/4$	$+3 < X \leq +2$	Fine sand		
	Very fine sand	$1/16 < X \leq 1/8$	$+4 < X \leq +3$	Very fine sand		
MUD	Coarse silt	$1/32 < X \leq 1/16$	$+5 < X \leq +4$	silt	All silt, clay and associated organic detritus grouped as ***mud***	$X \leq 1/16$
	Medium silt	$1/64 < X \leq 1/32$	$+6 < X \leq +5$	silt		
	Fine silt	$1/128 < X \leq 1/64$	$+7 < X \leq +6$	silt		
	Very fine silt	$1/256 < X \leq 1/128$	$+8 < X \leq +7$	silt		
	Coarse clay	$1/512 < X \leq 1/256$	$+9 < X \leq +8$	clay		
	Medium clay	$1/1024 < X \leq 1/512$	$+10 < X \leq +9$	clay		
	Fine clay	$1/2048 < X \leq 1/1024$	$+11 < X \leq +10$	clay		
	Very fine clay	$1/4096 < X \leq 1/2048$	$+12 < X \leq +11$	clay		

features illustrated are the distance between transects, and prominent features of the channel. The proportion of the inter-transect distance represented by each transect is shown as a linear distance, percentage or proportion of 1.00. The latter is the form of the input required by PHABSIM II and is commonly, though misleadingly, called the reach-length weight (elsewhere in IFIM, as explained in Chapter Three, the reach represents all or much of a macrohabitat zone and is not linked in any way with distances between transects).

From these data the lengths of the cells associated with each transect were calculated. Thus, for transect GR302 at Grootfontein (Figure 6.1), the cells associated with each of its verticals stretched 92% of the distance downstream (24m) towards transect GR276 and 91% of the distance upstream (195m) towards transect GR517.

Other values necessary as input for PHABSIM II are the slope and stage of zero flow (SZF) of each transect. Milhous *et al.* (1990) suggested that slope be simplistically calculated as the change in WSL between transects, which does not describe the slope actually pertaining at the transect; Gan & McMahon (1990) stated that "it could not be determined from the scanty documentation as to how the program makes use of the information". It is **thought** that the value entered for slope is not critical, as coefficients introduced later when running the hydraulic model adjust for slope.

Determination of SZF is not well explained in the manuals and in the past has often - possibly wrongly - been assumed to be the lowest point of the transect and thus the point at which surface water disappears and the main channel becomes dry. Care must be taken to ensure that the lowest point of the transect is in the main channel, however, for some channels have secondary channels which are deeper than the main one but may be dry. Even if the lowest point on each transect is in the main channel, this still may not represent the SZF. The value has to be determined for each transect by considering both the lowest main-channel point on that transect and the equivalent point on successive downstream transects. This is because, for instance, a shallow riffle downstream of a deeper run will, on a decreasing discharge, dry out and stop flow in the run long before the run dries out. Thus the lowest main-channel point on the riffle will be the SZF not only for the riffle, but also for all successive upstream transects with a lowest main-channel point that is lower than that of the riffle.

Data for the total of 17 transects were arranged by cell, in the format required as input for the hydraulic models in PHABSIM II (Appendices 6.2 to 6.4). Transect profiles, WSLs at the three calibration discharges, and velocity distributions at the two lowest discharges (and also at the highest discharge for those transects where this was measured) are given for one transect at each PHABSIM II site (Figures 6.4 to 6.6). The rest of the cross-section profiles for all three sites are given in Appendix 6.5. Zero velocities, or those that were too low to be measured, are shown as lines just above the horizontal axes.

6.3 PROBLEMS AND ANOMALIES WITH THE DATA SETS

6.3.1 TRANSECT CHARACTERISTICS

A notable feature of the transects was the large width of the total channel compared with that carrying water. Many transects had a number of secondary flood channels which were within,

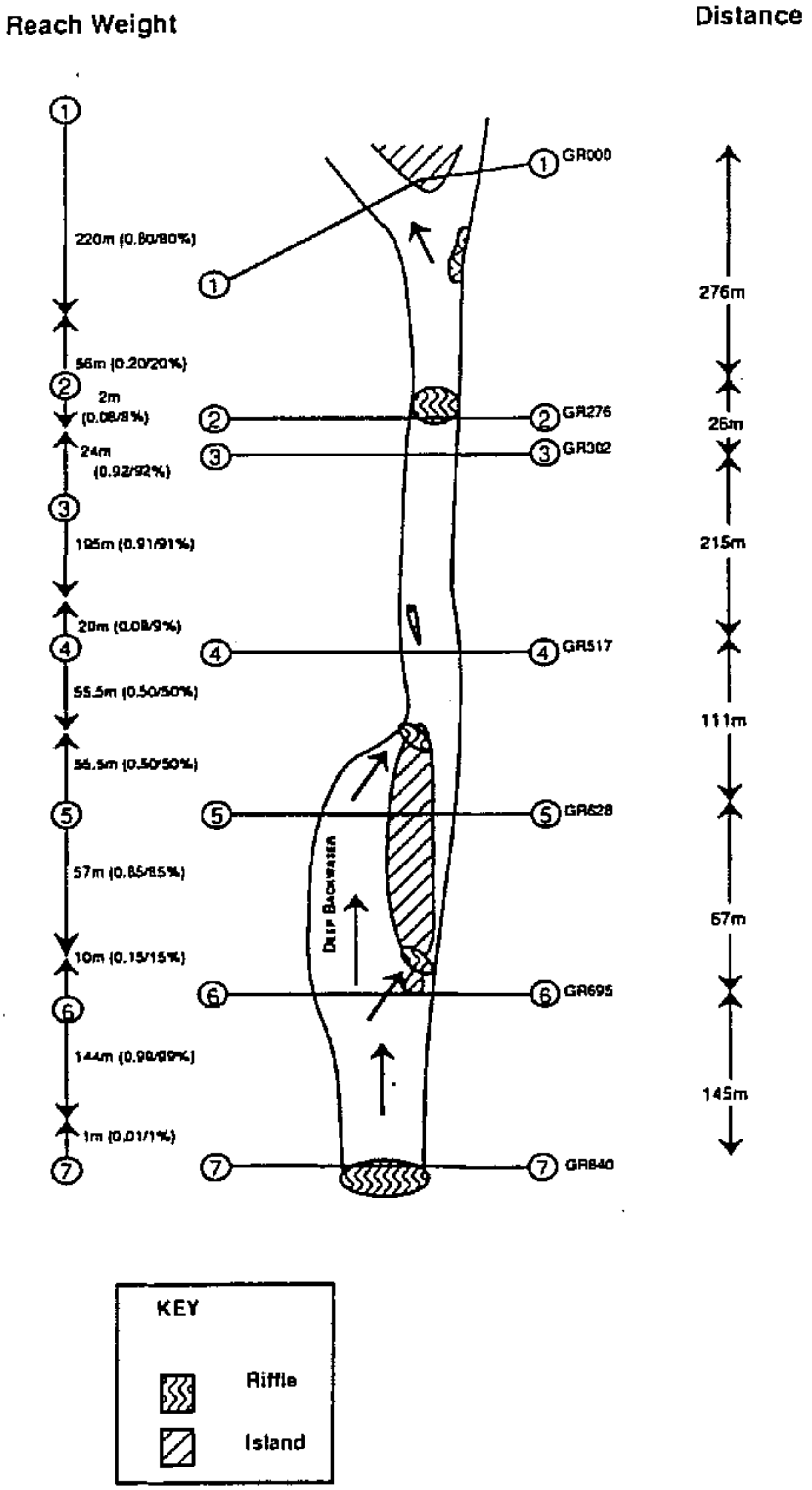


Figure 6.1 Site map of the PHABSIM II study site at Grootfontein, showing channel shape, position of transects and inter-transect distances. Transects are described in Table 6.1 and inter-transect distances are explained in Section 6.2

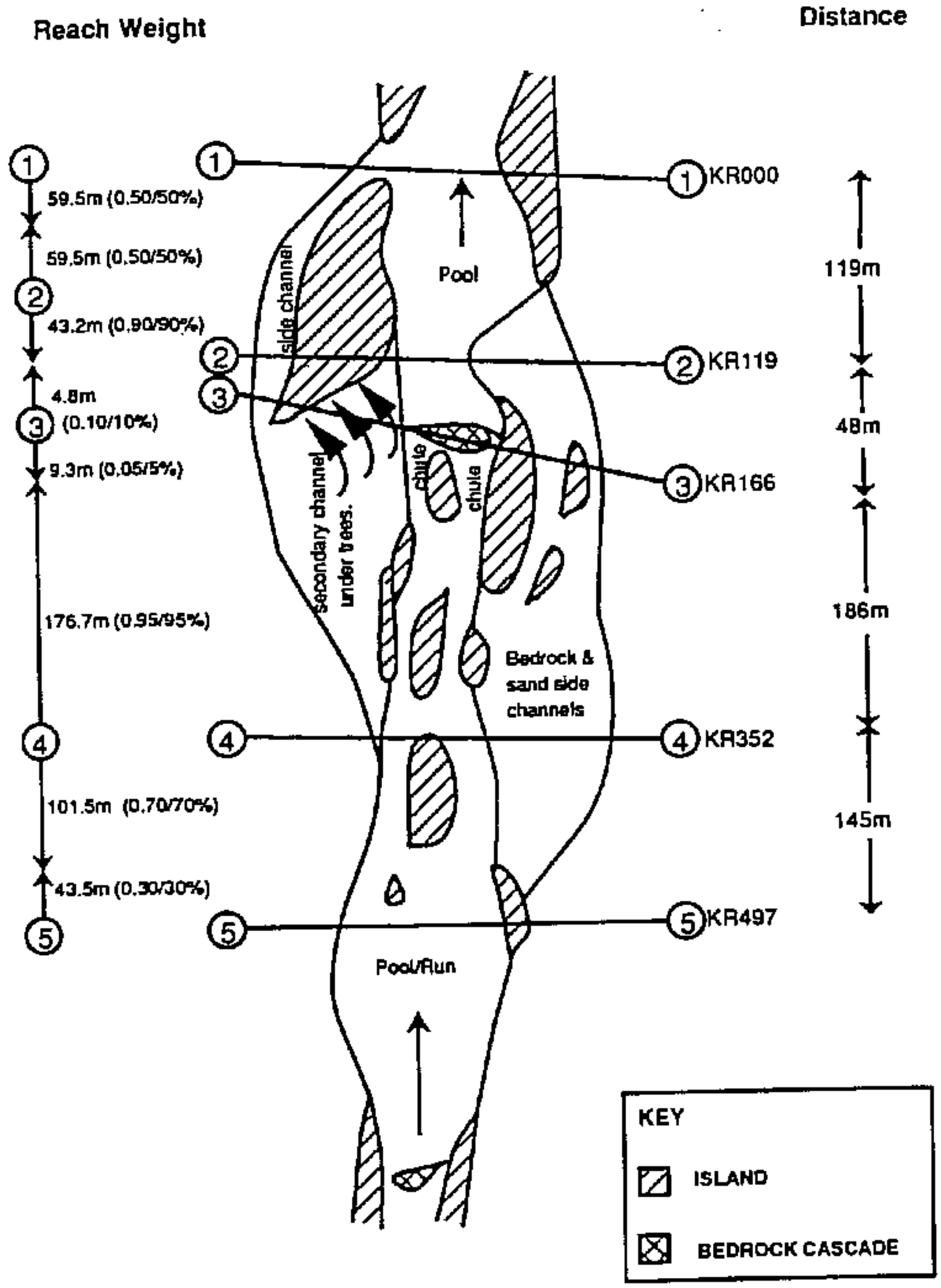


Figure 6.2 Site map of the PHABSIM II study site at Kriedouwkrans

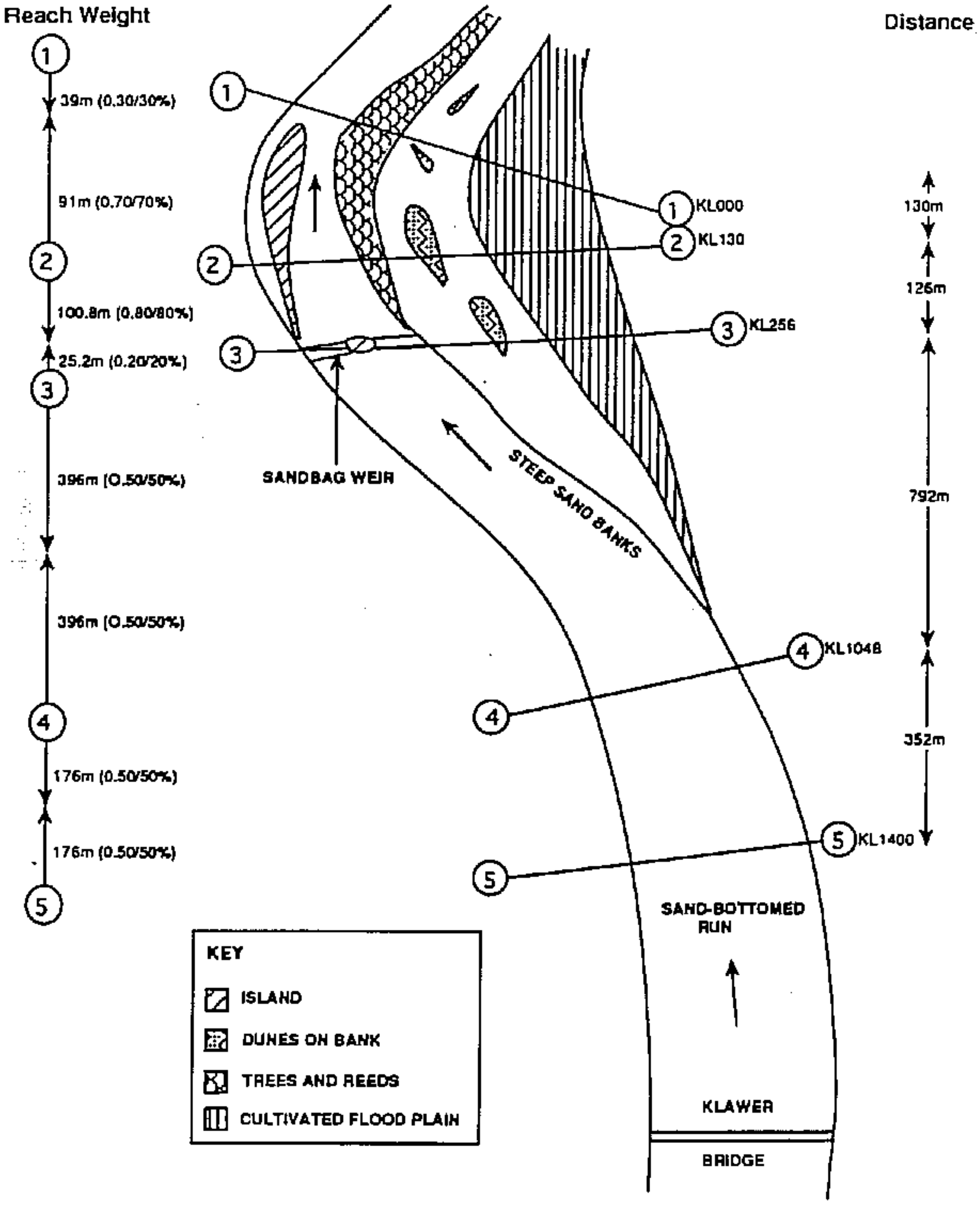


Figure 6.3 Site map of the PHABSIM II study site at Klawer

but hydraulically isolated from, the main channel at low flows (e.g. GR302, Figure 6.4; GR695, Appendix 6.5). In one or two cases these were almost as deep as the main channel, but all only carried flow during high floods. This can cause problems when running the hydraulic programs in PHABSIM II as, at any specific WSL, all parts of the channel below that level are simulated as containing water. Two possible ways suggested by Dr R.T. Milhous for coping with the problem involve subjectively altering the data sets before running the hydraulic simulations. The first is to artificially manipulate the ground elevations in such secondary channels to bring them above the WSL, and the second is to increase the roughness (Manning's n) values along the edges of the main channel, in order to "make it more difficult" for water to fill the secondary channels at any flow. It is not known what consequences these actions will have on the accuracy of the resulting hydraulic and habitat simulations.

One of the major problems encountered with the collected data was that transect GR628 at Grootfontein included an island, on one side of which was a large, still pool-like stretch of water with a high WSL, and on the other side a small turbulently flowing channel with a much lower WSL. A small riffle at the head of the island, which was completely hidden by tree roots, fed the fast-flowing channel, while another equally well-hidden riffle at the downstream end of the island allowed minor spillage of the deep pool back into the fast channel (Figure 6.1). Because it was not initially realised that the channels had different WSLs, and also because of surveying difficulties at high flows, WSLs were only measured for the pool-like stretch. WSLs of the fast channel during low-flow and moderate flow conditions could be calculated from depth readings taken at those times, but no depth readings, and therefore WSLs, were possible for the fast channel during high flow. These extra WSLs would have been of little use in standard PHABSIM II runs anyway, as the model cannot cope with more than one WSL per transect. The option for entering multiple WSLs per transect exists in the hydraulic programs of PHABSIM II, but has not yet been implemented in the habitat simulation programs (Milhous *et al.* 1989).

Problems associated with hydraulic simulations and transect GR628 are discussed again in Chapter Nine, but it is worth noting here that the authors, as ecologists, had not initially realised the significance of the two hidden riffles and so had not included them when selecting locations for transects. As the two riffles were important hydraulic controls, they should have been described by transects. The omission was recoverable, in that additional transects could have been added to describe the riffles, at the cost of more field trips, or an experienced hydraulic modeller could have built in dummy transects to account for them. Without these additional data, however, the hydraulic program within PHABSIM II which performs standard step backwater calculations (see Chapter Three) could not be used. There are other hydraulic programs which could be used, but the options for aiding production of a satisfactory simulation were reduced.

6.3.2 WATER SURFACE ELEVATIONS

In general at each site, values for WSLs increased in an upstream direction, as they should do in terms of the natural hydraulics of a river (GR000, KR000 and KL000 were the most downstream transects) (Table 6.3). However, the trend was not consistent at Grootfontein, where a riffle (GR276) had a backwater effect on both a nearby upstream run (GR302) and the run's upstream extremity in the vicinity of transect GR517; all three transects had very similar WSLs at low and moderate flows. At higher flows, the expected trend of increasing WSLs with increased upstream locations of transects was re-instated because the smaller hydraulic

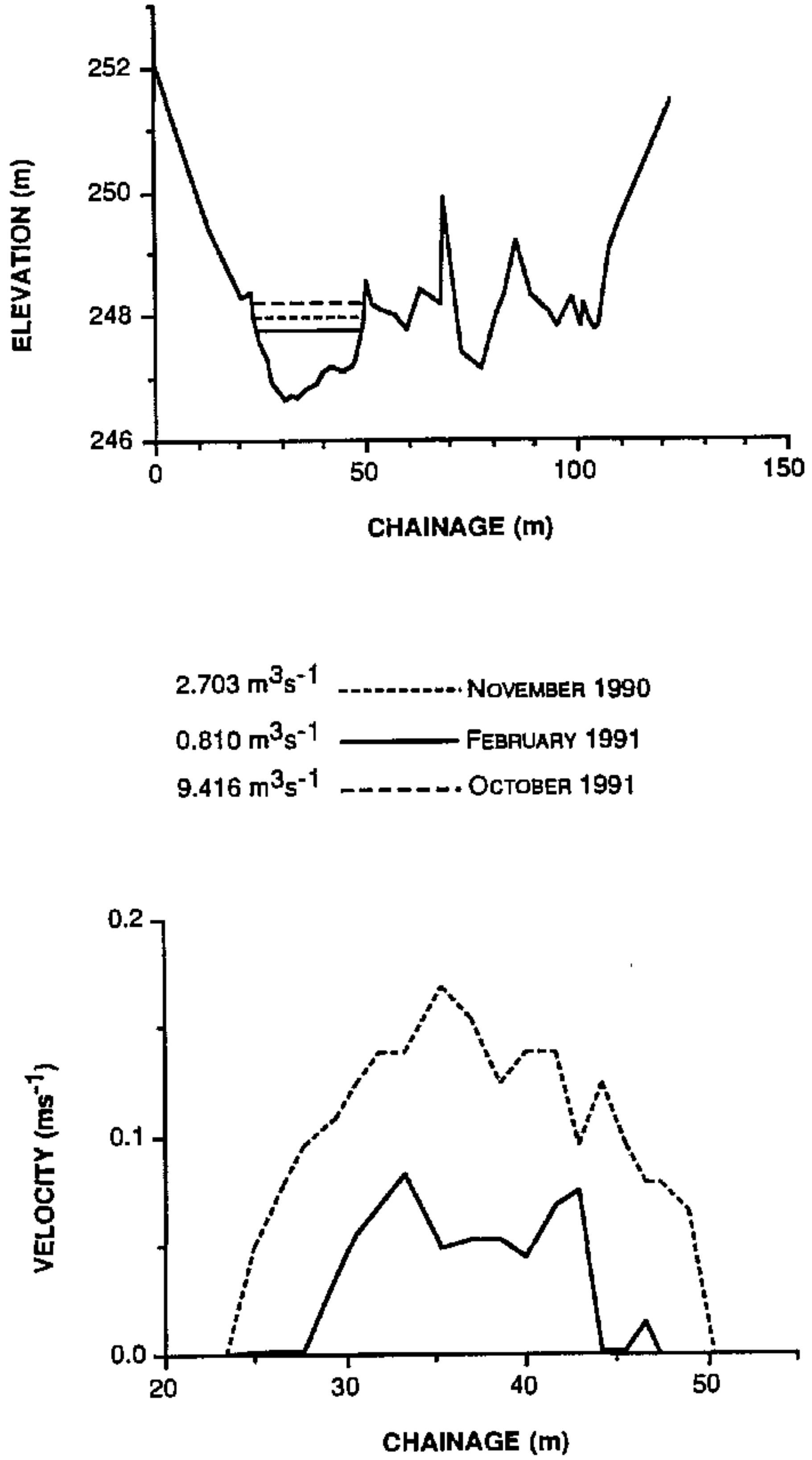


Figure 6.4 Cross-sectional profile of transect GR302 at Grootfontein showing WSLs at the three calibration discharges and velocity distributions at the two lowest of these discharges. Secondary channels, as discussed in the text, are shown

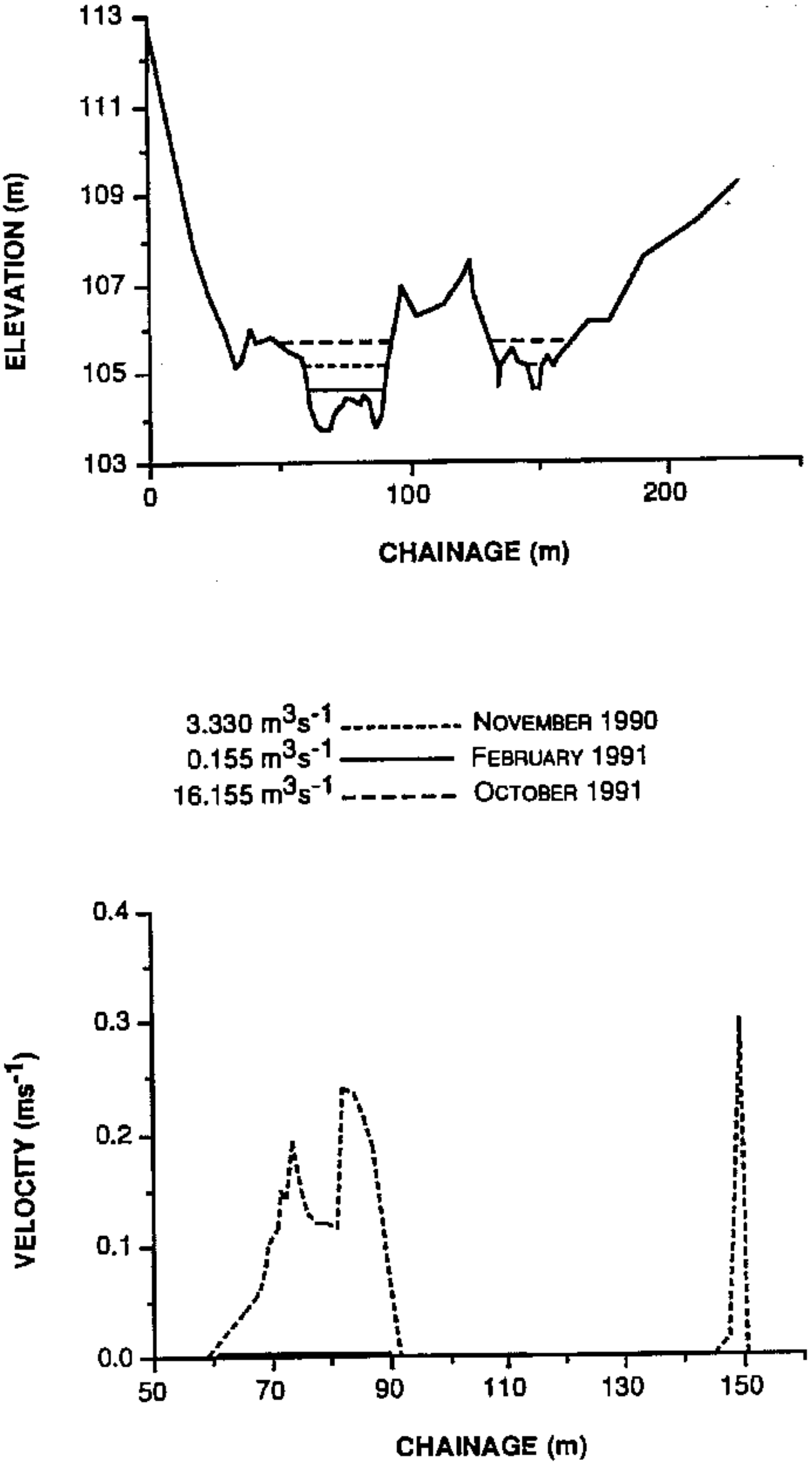


Figure 6.5 Cross-sectional profile of transect KR119 at Kriedouwkrans showing WSLs at the three calibration discharges and velocity distributions at the two lowest of these discharges

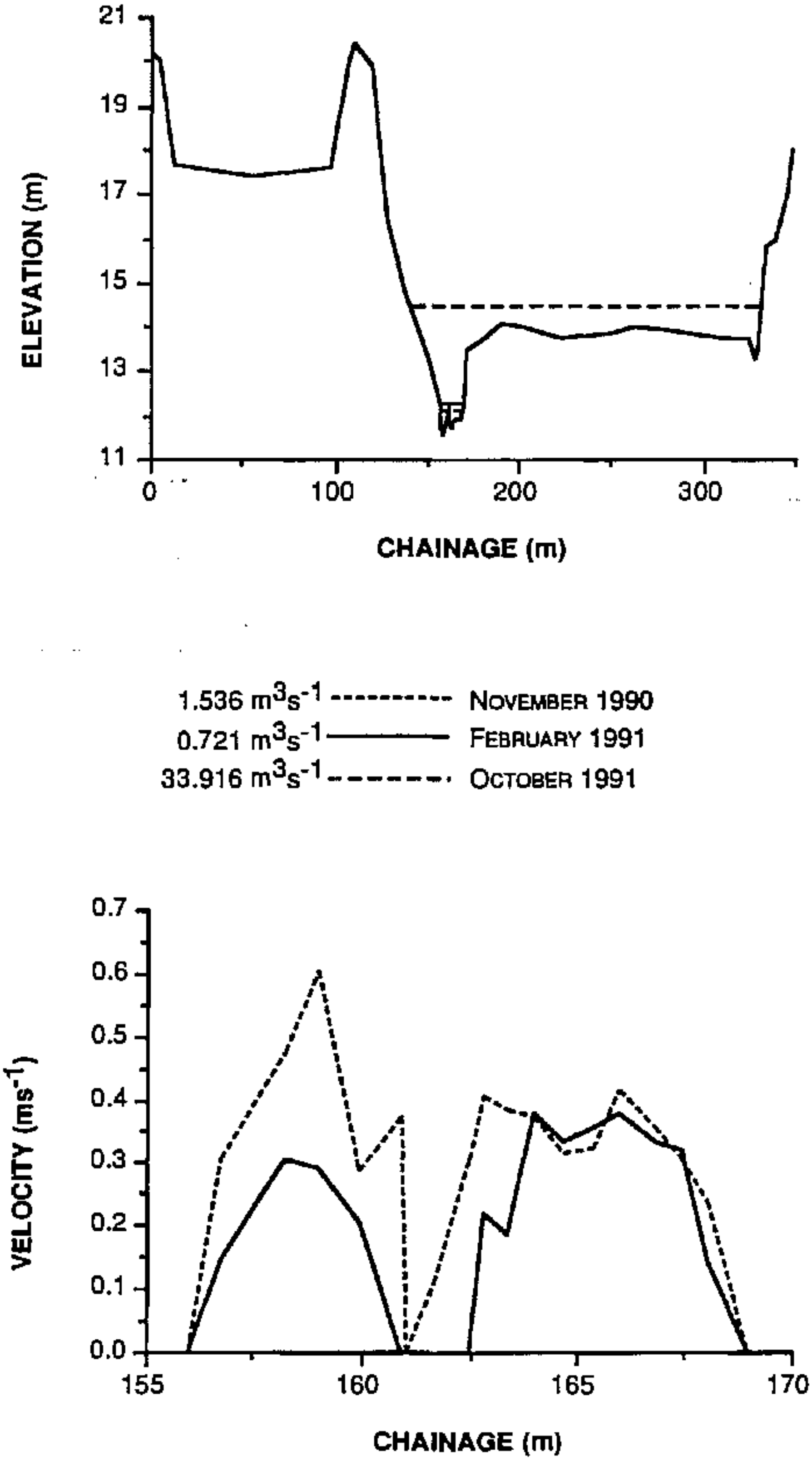


Figure 6.6 Cross-sectional profile of transect KL130 at Klawer showing WSLs at the three calibration discharges and velocity distributions at the two lowest of these discharges

controls exerted less influence on local WSLs. Transect GR628 similarly did not adhere to the trend because of its two channels with different WSLs, but for this transect WSLs for the two higher flows were reversed (Table 6.3). As these WSLs refer only to the deep pool-like channel, the values suggest that water backed-up in this channel during moderate flows, due to the constricted exit into the main channel at the downstream end of the island (Figure 6.1), but scoured out a more substantial exit route during high flows.

For Kriedouwkrans and Klawer, the expected gradual upstream increase in WSLs at low flows was partially obscured by WSLs fluctuating independently at each transect over the time of measurement. The causes of these fluctuations appeared to be upstream water abstraction and, possibly, dam releases. Under such conditions, it is probably necessary to allocate each transect with its own discharge value in the hydraulic simulations rather than a mean discharge that has been calculated for the site. Discharge readings were always taken within an hour or two of WSLs being surveyed, but time intervals between the two sets of measurements probably needed to be even shorter in irrigated reaches.

A final observation on upstream trends in WSLs is that, on the high-flow trip, the two lowest transects at Kriedouwkrans, KR000 and KR119, may have been showing some backing-up effect from stored water in Clanwilliam Dam, although there is no clarity on this.

Another pattern in WSLs that deviated from the expected concerned the WSL reading taken for each transect at the three calibration discharges. Normally, WSLs should increase with increasing discharge, but the collected data revealed that occasionally they did not. All but one of the anomalous results were for Klawer, where four of the five transects showed higher WSLs for low flows than for moderate flows, with the low-flow WSLs being higher by 0.02 to 0.39 m. There is no certainty why this happened, but two possible explanations are firstly, that the active water abstraction taking place on the low-flow trip caused discharges to fluctuate rapidly throughout the day and secondly, that as these transects were on sand the headstakes may have sunk slightly. The fifth anomalous data set was for the bedrock cascade at Kriedouwkrans (KR166), where the WSL at moderate flow appeared to be higher than that at high flow. However, the difference of 0.04 m in the two readings could easily have been a result of difficulties in accurately reading WSLs in the turbulent flow.

6.3.3 VELOCITY DISTRIBUTIONS

Velocity distributions for each transect showed that at any one vertical the velocity generally increased with discharge, as is required by most hydraulic models. However, occasionally this did not hold true (e.g. GR517, KL000; Appendix 6.5). This does not appear to be a problem with PHABSIM II as the hydraulic programs within the model seem to only use one velocity set at a time as calibration data. Despite this, additional sets are useful because they can be used to check calibration of the hydraulic program, or to calibrate for different parts of the discharge range being studied if the initial calibration velocity set gives poor results over parts of the range.

6.3.4 DISCHARGE CALCULATIONS

The erratic velocity distribution patterns for the shallow riffle GR840 indicate why riffles are not ideal for calculating discharge. Discharges are best measured at a regular-shaped cross-section with smooth-flowing water of moderate depth. As the water becomes shallower,

Table 6.3 **Summary of hydraulic data from calibration trips: date of visits, WSLs (m) and measured discharges (Q_{cal} in $m^3 s^{-1}$) for the surveyed transects. * - transect used for high discharge reading in October 1991**

		LOW DISCHARGE			MODERATE DISCHARGE			HIGH DISCHARGE		
SITE	TRANSECT	DATE	WSL	QCAL	DATE	WSL	QCAL	DATE	WSL	QCAL
Grootfontein	GR000*	28.02.91	246.46	1.214	13.11.90	246.72	3.163	14.10.91	246.95	4.942
	GR276	28.02.91	247.82	1.397	13.11.90	247.93	3.352	15.10.91	248.10	9.416
	GR302	28.02.91	247.80	0.810	13.11.90	247.96	2.703	15.10.91	248.22	9.416
	GR517	27.02.91	247.82	1.127	15.11.90	247.99	2.480	15.10.91	248.35	9.416
	GR628	26.02.91	248.94	1.039	15.11.90	249.05	2.939	15.10.91	249.34	9.416
	GR695	28.02.91	248.97	1.197	15.11.90	248.97	2.717	15.10.91	249.30	9.416
	GR840*	26.02.91	249.00	1.749	15.11.90	249.08	3.340	15.10.91	249.37	9.416
Kriedouwkrans	KR000	01.03.91	104.74	0.148	17.11.90	105.09	1.901	09.10.91	105.69	16.155
	KR119*	01.03.91	104.66	0.155	17.11.90	105.11	3.330	09.10.91	105.69	16.155
	KR166	01.03.91	105.17	0.286	17.11.90	105.63	5.845	09.10.91	105.59	16.155
	KR352	01.03.91	106.27	0.078	18.11.90	106.67	3.201	09.10.91	107.76	16.155
	KR497*	01.03.91	106.13	0.083	18.11.90	106.73	2.629	08.10.91	107.89	16.155
Klawer	KL000	05.03.91	12.06	0.677	20.11.90	12.04	1.061	11.10.91	14.38	33.916
	KL130	05.03.91	12.31	0.721	20.11.90	12.14	1.536	11.10.91	14.47	33.916
	KL256	03.03.91	12.18	0.468	21.11.90	12.36	1.194	10.10.91	14.50	33.916
	KL1048	05.03.91	12.48	0.506	21.11.90	12.38	0.750	10.10.91	14.62	33.916
	KL1400	05.03.91	13.10	0.335	19.11.90	12.49	0.840	10.10.91	14.80	33.916

large-particle bed elements such as cobble exert an increasing influence on velocity distributions, and in very deep waters velocities are so low that they may be difficult to measure and the thalweg may be missed.

Differences in calculated discharges for the transects at any one site on any one visit (Table 6.3) were largely a reflection of these difficulties of accurately measuring relatively low flows in rough channels. In addition, the differences in calculated discharge between transects at Kriedouwkrans at both low and medium flows may have been reflecting upstream abstractions as well as, perhaps, inaccurate measurements in such conditions as isolated seeps of very shallow flow over fractured bedrock.

Although PHABSIM II will accept a different discharge value for every transect on every visit, it often seems clear that water is not being lost or gained between transects and that one value should be used for the whole study site. Judgement then has to be used as to whether to average all the values for a site, choose the value for the most simple transect, drop the extreme values and average the rest, or use individual values for each transect. When such discrepancies between transects exist, Dr R.T. Milhous (pers. comm.) recommended using the calculated discharge for each transect as input to PHABSIM II, rather than an averaged value. This is presumably useful in that the most successful calibration can probably be achieved for each transect by using its own data, but ignores the problem that the differences in discharge may not be real. The details of which discharge value was used for each transect are addressed in Chapter Nine.

6.4 DISCUSSIONS WITH DR MILHOUS REGARDING TRANSECT DATA

During Dr R.T. Milhous' visit in 1992, the PHABSIM II sites on the Olifants River were visited, and transect placement, and the data for use in the hydraulic programs, were assessed. Relevant points from the discussions with Dr R.T. Milhous are presented here.

6.4.1 SELECTING TRANSECTS

It is time well spent to map out the study site before choosing transects, ensuring that all hydraulic controls and small secondary channels are recorded, and the points of potential flow into and out of secondary channels mapped. In order to produce good hydraulic information from the transects, it seems essential to discuss their final placement with an experienced hydraulic engineer. Transects are always placed perpendicular to the direction of flow, and may have to dog-leg where some flow is forced sideways into secondary channels. It is best to initially choose transect locations at moderate or slightly lower flows, when details of the substrate and most hydraulic controls are apparent; however, the transects should extend beyond the highest observed flood level on both banks.

Dr R.T. Milhous felt that an appropriate number of transects had been established per site, and most were well situated. Important hydraulic controls that were missed, such as those at either end of the island at Grootfontein (Figure 6.1), could be described by dummy transects or surveyed-in later, but this would require the assistance of an experienced hydraulics engineer.

6.4.2 SECONDARY CHANNELS

Secondary channels of the nature and extent of those on the Olifants River were seen as very unusual (Dr R.T. Milhous pers. comm.). Such channels are unknown in the North American region for which PHABSIM II was designed, and it was suggested that they may be a feature of rivers in semi-arid climates, of rivers with marked seasonal changes in flow, or of rivers with "flashy" flow patterns of sporadic high floods in an otherwise low baseflow regime.

6.4.3 FILLING AND SPILLING OF SECONDARY CHANNELS AND BACKWATERS

Secondary channels and backwaters will fill and spill at rising discharges, invalidating the stage-discharge (S-Q) relationship determined for the main channel at lower flows. Thus, additional S-Q relationship(s) will have to be determined for each part of the discharge range that relates to a different-shaped part of the channel. It is necessary to know the discharges at which these fill and spill events are likely to occur, so that each S-Q relationship is only used for simulations within a valid range of discharges.

To do this, secondary channels should be investigated during the field trip to assess when and from where they are likely to fill; if the height of the land restraining overspill is surveyed, the discharge at which this occurs (and thus the upper limit of the range of discharges for which the original S-Q relationship holds good) can be estimated. Similarly, with rising discharges backwaters may eventually start to flow, creating new downstream flood channels and requiring a new S-Q relationship to be determined.

6.4.4 WATER SURFACE ELEVATIONS IN MULTIPLE CHANNELS

The hydraulic programs within PHABSIM II do not cope easily with transects describing multiple channels with different WSLs, but Dr R.T. Milhous felt that flow in such channels could be simulated by an experienced hydraulic modeller. This exercise would be beyond the capability of most ecologists. In the field, the WSL of every channel on every transect should be measured, preferably on every calibration visit.

6.4.5 CHANNEL SLOPE

In the PHABSIM II tutorial, Milhous *et al.* (1990) suggest that the slope for any one transect be calculated as the average slope between adjacent upstream and downstream transects, or variations on that theme. This may be fairly inaccurate for stretches of river such as riffles where sharp changes in slope can occur. As explained in Section 6.2, the value given to transect slope may not be critical in PHABSIM II runs, but a more accurate value may be needed for other reasons. Spot readings of bed elevation should then be taken a few metres upstream and downstream of the transect, and transect slope calculated from this. The average slope of a riffle, for instance, could be calculated from spot readings of elevation at the head and foot of the riffle.

6.4.6 BACKWATER EFFECTS

The most downstream transect at a site should have a unique stage-discharge relationship. In other words, flow through the transect should not be influenced by flow impediments further downstream. Thus, when establishing the lowest transect, the reaches downstream of it should be checked for possible backwater effects. If these are likely to occur, the transect should be positioned elsewhere, as two of the three hydraulic programs in PHABSIM II cannot be used under such conditions.

6.4.7 CHANGES IN CHANNEL MORPHOLOGY

Sediment sources for the studied reach should be identified. A dam created in a reach that is generating or carrying sediment loads will restrict downstream movement of sediments, changing the sizes and proportions of substrate particles downstream. If the nature of these changes cannot be accurately predicted, application of PHABSIM II may be invalid.

Additionally, wherever the channel is sandy, the changes in channel morphology likely to be produced by scouring floods should be predicted, in order to verify the validity of subsequently using PHABSIM II. Dr R.T. Milhous said that it might not be necessary to model such channel changes, but instead a construction of the future channel shape using best available information could be produced and used to create a new suite of transects and thus, relevant input data for the hydraulic models. In practice, any of the objectives stated in this Section are very difficult to achieve, and are rarely done with any degree of accuracy, if attempted at all.

6.4.8 AQUATIC VEGETATION

Seasonal changes in the distribution and abundance of aquatic vegetation can affect flow patterns. Such changes should be recorded on each site visit, so that the seasonal data sets can be treated differently in the model, if necessary.

6.4.9 FIXED-POINT PHOTOGRAPHY

A comprehensive library of fixed-point photographs should be created for each transect. At each transect, photographs should be taken of all obvious changes in channel features and bed and bank materials across it. Details of the vegetation and substrate along the terrestrial parts of the transects should be included. These photographs will aid in the determination of realistic roughness values for each part of each transect. In the absence of such data, PHABSIM II adopts values for each dry cell that are the same as those calculated internally for the nearest wetted cell. These might be quite inappropriate if, for instance, the wetted cell had a substratum of sand and no vegetation, while the dry cells on the bank contained dense vegetation and rocks.

Photographs should also be taken of different known flows at each transect, so that the general appearance of the flow and the channel can be referred to when running hydraulic simulations.

6.5 SUMMARY OF THE APPLICABILITY OF THIS COMPONENT OF IFIM

The activities described in this Chapter are some of the more straightforward and intuitively understandable within IFIM. Even so, ecologists approaching this work without previous relevant experience would find it difficult initially, would be likely to miss some hydraulically important features in the channels and would probably do some tasks, such as placement of transects, inadequately. On the other hand, hydraulics engineers or hydrologists familiar with transect analysis might have little understanding of aquatic biotopes and communities, and of the tolerance ranges of aquatic organisms. Clearly, the best information would be obtained from transects if they were placed and initially established by a team consisting of a river ecologist, a fluvial geomorphologist, an hydraulic engineer/modeller and a surveyor, all of whom should be experienced. If, as in IFIM, much subsequent work is to be based on the data collected at these transects, it is a wise investment to bring these four experts together in the early stages of the project.

The hydraulic modelling emanating from the transect data clearly requires the services of an experienced hydraulic modeller. This was not at all obvious at the beginning of this project and it is not clearly stated as a prerequisite for using IFIM. Yet PHABSIM II is so complicated, and some of the options within it are so poorly explained, that only an experienced hydraulician, or someone able to spend considerable time studying the model, could be expected to understand it sufficiently to obtain respectable hydraulic simulations from it.

After some considerable time (months rather than weeks) spent collecting field data for PHABSIM II and learning the rudimentary workings of the model, the authors of this report feel competent to collect good transect and calibration data, but would not be comfortable running the hydraulic programs without expert help (see Chapter Nine).

In conclusion, the methods used in IFIM to describe channel morphology and flow patterns are felt to be as good a means as any presently available to acquire these data at the fine level of resolution needed in ecological studies. Whether or not these data are subsequently used in a model such as PHABSIM II, the structured way in which channel shape, microhabitats and flow patterns are studied in IFIM would be of immeasurable value to any river ecologists seeking to study flow-related phenomena.

7. ASSESSING IFIM (STEPS 9-11): COLLECTION AND ANALYSIS OF FISH DATA

7.1 INTRODUCTION

Two target components of the biota, namely the fish and the benthic macroinvertebrates, were chosen for the purpose of providing input data to PHABSIM II (Chapter Four, Section 4.4); outputs of the model would be used to assess the instream flow requirements of the Olifants River. Collection and analysis of the fish data, and the creation of suitability index (SI) curves for the fish, are reported on in this Chapter. The invertebrate data are dealt with in a similar way in Chapter Eight, and the use of all these biological data in PHABSIM II is described in Chapter Nine.

The concept of using the fish as target species was complicated by the fact that an instream flow assessment needed to be done for the main Olifants River, which is likely to be dammed, but most of the system's endemic fish are now confined to its tributaries, having been eradicated from the mainstream by introduced smallmouth bass *Micropterus dolomieui* (Skelton 1987). The reasoning adopted for using the fish was that abiotic conditions in those tributaries that still support the endemic species must be similar to the conditions that they had experienced when inhabiting the mainstream, and so their microhabitat requirements in the tributaries could be measured and used as a guide to the kind of conditions it would be desirable to maintain in the dammed mainstream. A desirable modified flow regime for the mainstream was seen as one that was a muted version of the natural one and could be hoped to maintain the river in some semblance of its natural condition, whether or not this included an option to re-instate the locally extinct fish species.

To provide the necessary information to guide the instream flow assessment, the following tasks needed to be done:

- choose target fish species (this Chapter)
- record details of their preferred microhabitats in the tributaries (this Chapter)
- arrange this information as input to PHABSIM II (this Chapter), together with channel information from the mainstream sites (Chapter Six)
- simulate the amount of the preferred microhabitats available at the PHABSIM II sites over a range of discharges (Chapter Nine)
- determine macrohabitat zones in the mainstream and match each of the fish sites on the tributaries with a zone on the mainstream (Chapter Five and Section 7.7)
- calculate the amount of total habitat available to each species in the whole of the mainstream over a range of discharges by multiplying available microhabitat at the PHABSIM II site (PHABSIM II output) by available macrohabitat (see Section 7.7)
- use this to determine, for the regulated mainstream, a desirable modified flow regime (Chapter Nine)

As mentioned in Section 4.4.1, virtually nothing was known of the distribution, population numbers, life cycle, limits of tolerance to any environmental variable, or microhabitat requirements of any of the fish species in the river. Thus, target species could not be chosen at the outset and instead a general sampling programme had to be adopted. This involved collecting a wide range of microhabitat data for all fish species found in the river system during the fieldwork (Table 7.1), and then using these data to choose target species and create appropriate SI curves.

Within IFIM, biological data can be collected in three ways: as category I, II or III criteria (Chapter Three, Section 3.11.1). Category I criteria are derived from the literature, professional judgement, or other non-field data, while categories II and III criteria require field measurements. Category I and II criteria illustrate the microhabitat conditions **utilised** by the target species, while category III criteria take into account not only the microhabitat conditions utilised but also the range of conditions **available**. They thus give a better indication of suitable microhabitat, and are thought to be more universally applicable than the utilisation

Table 7.1 **Fish species occurring in the Olifants River system, their conservation status and the rivers in which they were studied. Endemic species are confined to the Olifants River system, indigenous species are native to southern Africa, and alien species are introduced. Information from Skelton (1987) and de Moor & Bruton (1988)**

SPECIES	STATUS	RIVERS STUDIED
FAMILY Bagridae		
Austroglanis barnardi	endemic	1
Austroglanis gilli	endemic	1, 2, 3, 4
FAMILY Cyprinidae		
Barbus capensis	endemic	1, 3, 4, 5, 6, 7
Barbus serra	endemic	5, 9
Barbus calidus	endemic	1, 2, 3, 4, 5
Barbus erubescens	endemic	8
Barbus anoplus	indigenous	NI
Pseudobarbus phlegethon	endemic	1, 2, 3, 4, 9
Labeo seeberi	endemic	NI
FAMILY Galaxiidae		
Galaxias zebratus	indigenous	1, 2, 8, 9
FAMILY Anabantidae		
Sandelia capensis	indigenous	8
FAMILY Centrarchidae		
Lepomis macrochirus	alien	6
Micropterus dolomieui	alien	6
Micropterus salmoides	alien	6, 9

KEY TO RIVERS

Noordhoek — 1
Thee — 2
Boskloof — 3
Rondegat — 4
Ratel — 5
Olifants (Grootfontein) — 6
Olifants (Clanwilliam) — 7
Middeldeur — 8
Driehoeks — 9
NI — not included in study

criteria, which might be more river-specific. However, there is much disagreement between researchers on the transferability of criteria (Thomas & Bovee unpub.; Bovee & Zuboy 1988). In this project, SI curves were created from category III criteria for both the fish and the invertebrates, so that the PHABSIM II outputs, and thus the flow requirements, of the two target components could be compared.

7.2 AVAILABLE BACKGROUND INFORMATION

In 1989, as a first assessment of the applicability of PHABSIM II in South Africa, a preliminary investigation was done of the microhabitat requirements of seven of the indigenous fish species occurring in the Olifants River system (Gore *et al.* 1991). In that preliminary study only those species found in the mainstream and two tributaries were studied, and a coarse size split between juveniles and adults was adopted (Gore *et al.* 1991). The split was set at 25-35 mm for the small redfin minnow and rock catfish species and 100 mm for *Barbus capensis* and *B. serra* (K.C.D. Hamman, Cape Nature Conservation (CNC), pers. comm.). The data collected in that study were used as input for PHABSIM II in order to make a first assessment of the minimum flow requirements of the Olifants River in the low-flow summer months. It was recognised that further research would be required on, *inter alia*, the microhabitat requirements of all life-history stages of the fish species studied in order to refine this flow recommendation. The findings of that study are compared with those of the present study in Section 7.6.4.

A limited amount of information was available on the breeding times and sites of the river's larger indigenous fish species. Data from the Clanwilliam Yellowfish Station, run by CNC, indicated that Clanwilliam yellowfish *Barbus capensis* spawn from late spring to summer (November to February). Van Rensburg (1966) noted, based on gonad activity, that the main spawning season of *B. capensis* and the sawfin *B. serra* in the river was between October and December, with limited spawning continuing through January. He also reported small individuals (< 20 mm) of *B. capensis* and the Clanwilliam sandfish *Labeo seeberi* in the middle reaches of the mainstream between early November and mid-December. There are no similar data for the smaller endemic species in the system, but at the beginning of this study the general opinion among scientists from CNC was that these breed at about the same time as the larger species.

Griffiths (1990) summarised other relevant literature on the distributions and breeding cycles of the fish species. She cited older texts that agreed with the current general impressions on breeding times, and illustrated sites where the various species presently occur. She noted that most of the species probably once occurred in the mainstream but that the smaller species are now confined to tributary reaches that are inaccessible to *M. dolomieui*. She described characteristic habitats in very general terms and it seemed that, at the beginning of this study, the data collected by Gore *et al.* (1991) were the only specific information available on the microhabitat requirements of any of the species.

7.3 FIELD SAMPLING METHODS

7.3.1 TEAM MEMBERS AND DATE OF FIELD VISIT

The authors of this report were joined for the field work by Dr J. Cambray of the Albany Museum, who is the country's leading specialist in the early life-history stages of South African freshwater fish, and Mr S. Thorne of CNC, who is an experienced fish biologist with specialist knowledge of the fish of the Olifants River.

Due to other commitments the visit to the Olifants River system could not take place until mid-January 1992. It was recognised that spawning may have ended, but that it should be possible to locate, and measure the physical attributes of, microhabitats supporting eggs/free embryos, or larval or juvenile fish, as well as those used for spawning, if found. It was intended that most attention would be paid to the indigenous species, but that similar data would be recorded for any alien fish species encountered (Table 7.1).

7.3.2 STUDY SITES

Gore *et al.* (1991) used a study site about 10 km upstream of site 4 on the main Olifants River, and a site on each of two tributaries, the Noordhoek and Thee Rivers. The same sites on the same two tributaries were used in this study, and in addition two new sites were selected on reaches of the mainstream Olifants, as well as sites on the Ratel, Middeldeur, Boskloof, Driehoeks, and Rondegat tributaries (Figure 7.1 and Table 7.2). Sites included in this investigation were those known to have supported endemic fish species in the past (CNC distribution records), and at each of them the range of microhabitats available was sampled. All of the sites were in mountainous areas of near-pristine fynbos, but all except one were subject to disturbance (Table 7.3).

Table 7.2 Location of sites used for fish studies

RIVER	MAP 1: 50 000	LATITUDE	LONGITUDE
Olifants (Grootfontein)	3219 CC	33°09'33"	19°14'08"
Olifants (Clanwilliam)	3218 BB	32°10'05"	18°52'25"
Ratel	3219 CC	32°52'25"	19°05'00"
Middeldeur	3219 CA	32°40'31"	19°12'36"
Boskloof	3219 CA	32°33'33"	19°03'38"
Driehoeks	3219 AC	32°26'05"	19°10'55"
Rondegat	3219 AC	32°21'25"	19°02'30"
Noordhoek	3219 CA	32°43'18"	19°04'21"
Thee	3219 CC	32°47'44"	19°05'36"

Table 7.3 Description of sites for fish studies

RIVER	UPSTREAM CATCHMENT LAND-USE	CATCHMENT FORM	HYDROLOGY	CHANNEL GEOMORPHOLOGY	WATER QUALITY (see Appendix 5.5)	CATCHMENT VEGETATION	RIVERINE VEGETATION
BOSKLOOF	undisturbed	mountainous	perennial stream	gradient 15 m km^{-1}; cobble bed	high quality	mountain fynbos	no instream vegetation; wooded banks
RATEL (5 reaches)	fruit farming area	mountainous	perennial stream	gradient 32 m km^{-1}; bedrock pools and runs, waterfalls	some enrichment from farming areas	mountain fynbos and orchards	no instream vegetation; scattered, low fringing vegetation
DRIEHOEKS	low-intensity farming area; water abstraction for irrigation	high altitude plateau with mountainous rim	semi-perennial; flow may cease in summer due to irrigation abstraction	gradient 8 m km^{-1}; cobble bed embedded in silt	high quality	high altitude wetland	no instream vegetation; low fringing vegetation
RONDEGAT (2 reaches)	some pine plantations; small rural village; upstream camping area	mountainous	perennial stream	gradient 15 m km^{-1}; cobble bed	high quality	mountain fynbos	no instream vegetation; low fringing vegetation
THEE	largely undisturbed; channel bulldozed in lower reaches	mountainous	perennial stream	gradient 20 m km^{-1}; cobble bed	high quality	mountain fynbos	no instream vegetation; low fringing vegetation alternating with wooded banks and closed canopy
NOORDHOEK	largely undisturbed; channel bulldozed in lower reaches; some flood damage	mountainous	perennial stream	gradient 17 m km^{-1}; cobble bed	high quality	mountain fynbos	no instream vegetation; low fringing vegetation
MIDDELDEUR (2 reaches)	farming area; water abstraction for irrigation	open valley downstream of mountains; downstream reach in more pronounced valley	semi-perennial; flow may cease in summer due to irrigation abstraction	gradient 11 m km^{-1} (upstream reach); bedrock and boulder bed	some enrichment from farming areas	mountain fynbos and farmland	palmiet stands forming islands and along banks; low fringing vegetation
OLIFANTS GROOTFONTEIN see Table 4.3							
OLIFANTS CLANWILLIAM see Table 4.3							

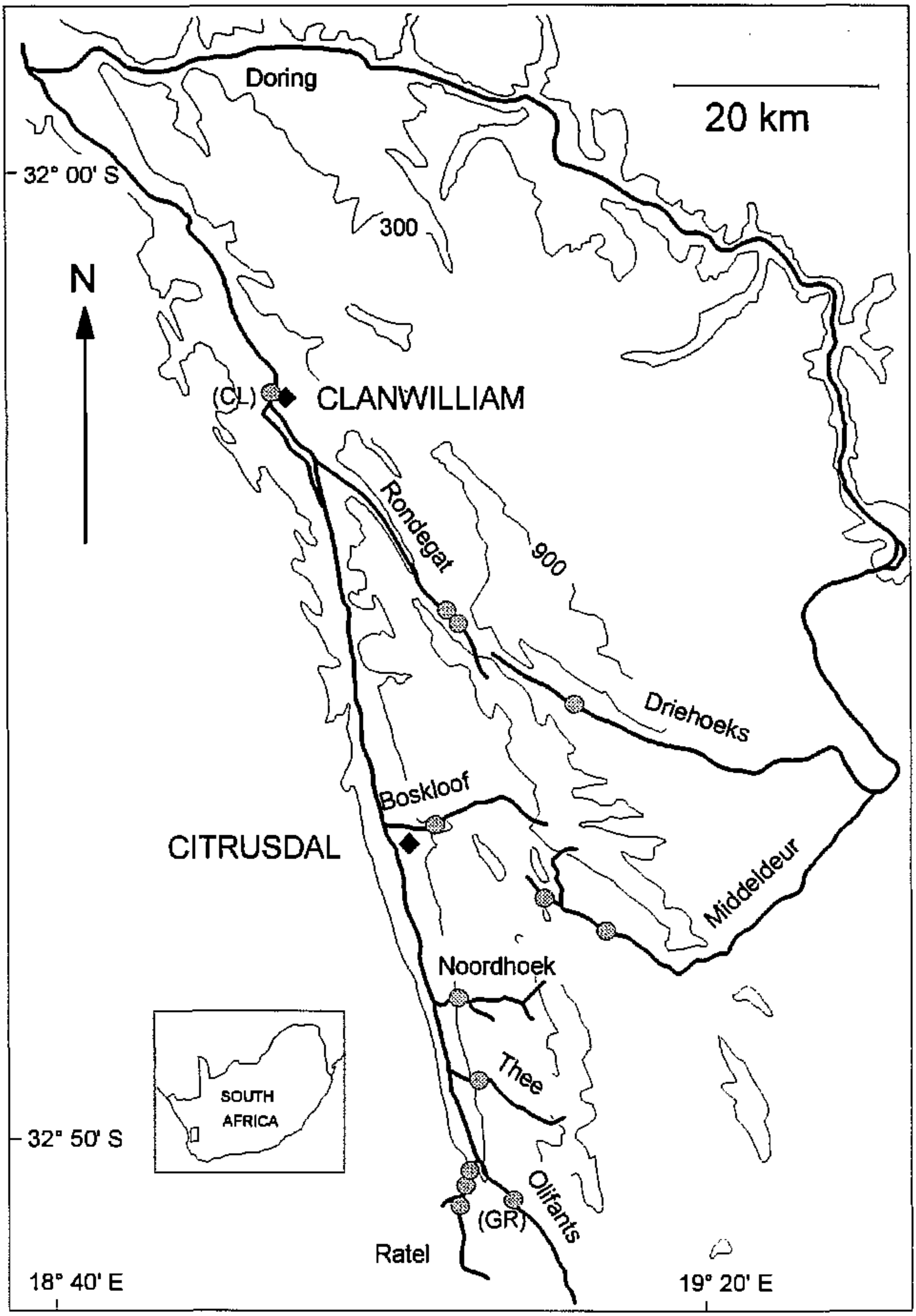


Figure 7.1 **Study sites (circles) used during the fish studies. GR and CL are the Grootfontein and Clanwilliam sites on the mainstream. Contours are in metres**

Data on water chemistry for each fish site (Appendices 5.5 and 5.6) show that their waters were clear and relatively pure. These and the catchment data were collected in order to match tributary sites with macrohabitat zones on the main Olifants River. This is discussed in Section 7.7.

7.3.3 DATA COLLECTION

All fieldwork was done in mid-summer, between 20 and 31 January 1992, thus providing data that complemented those for the invertebrates (Chapter Eight) and allowing direct comparison of PHABSIM II outputs for the two target components of the fauna. Standard input data for PHABSIM II (water depth and velocity, channel index) (Bovee 1986) were collected wherever fish were found. Other relevant data, as described below, were collected at the same time.

On visiting reaches pre-chosen on the basis of known fish distributions, it was found that fish were generally rare but some species were locally abundant in particular sections of one or two rivers. Some rivers supported far larger populations than others, and several species were found in only one river (Table 7.1). Some species, such as the small rock catfish *Austroglanis* spp., occurred only in riffles, while the small minnows *Barbus* spp. inhabited quieter waters. In order to create as many records as possible, each chosen reach was searched for as long, and over as long a distance, as time allowed; that is, the sites were of unspecified lengths, but usually between 0.5 km and 1 km long, and were searched for unspecified lengths of time. In all cases, the site lengths used and time spent were recorded. One or more reaches were visited on each river (Figure 7.1). Locations for the main site on each river (Table 7.2) indicate the downstream points where sampling started.

The clarity of the waters made preliminary observations of fish distributions, numbers and behaviour possible from the bank. Always moving upstream, sampling then commenced by wading or snorkelling in still waters and electro-shocking in riffles; data were recorded for most fish seen (some disturbed groups or individuals were ignored), but there was particular focus on the early life-history stages. Usually, only one sampling method, that is either snorkelling or electro-shocking, was necessary for any one species, as their separation into specific microhabitats was quite marked; occasional individuals of one or two species were collected in an atypical area but were too few in number to warrant separate processing of their records (Section 7.5.2). In one deep pool in the Ratel River, a school of *Barbus serra* was trek-netted for body measurements, and at most sites underwater photographs of the fish were taken. A numbered marker was placed at each point where one or more fish were recorded, so that measurements of the microhabitat could be made later. Further details of sampling equipment and methods are given in Cambray *et al.* (in prep.).

The species data that were collected at each observation point included numbers of individuals, size and life-stage, and behaviour. The schooling endemic species in the pools did not react negatively to human presence and so, once initial observation of the undisturbed fish had been made and the location marked, closer underwater observations were made of identity and body length. If the species identity or life-stage was still uncertain at this stage, one or two individuals were collected for later study. The endemic species in the riffles, which tended to occur singly, were collected in a net after electro-shocking and identified and measured before release.

The microhabitat data recorded at each marker included details of substrate particle size, instream and overhead cover, water temperature and depth, depth of the fish from the bottom (nose depth), and mean velocity and velocity at the position of the fish (nose velocity). Substrates were recorded as the percentages of bedrock, three sizes each of boulder, cobble and gravel, and sand and mud (Table 6.2). Particular attention was given to the availability of hydraulic cover from vegetation or large-particle substrates and to shade cover from such features as overhanging vegetation and banks. Instream and overhead cover provided by vegetation or rock were recorded as percentages available over the general area of the observation, as were the extent of epilithon and organic detritus covering the substratum and the degree of embeddedness of the rocks in finer sediments. Substrate and cover conditions were recorded in this degree of detail so that a suitable CI (channel index) code could be created later (Section 7.5.2) when more was known of the distributions and behaviour of the fish.

Water temperatures were measured vertically through the water column using a digital thermometer with extendable probe. Velocities were measured with a Scientific Instruments AA or "mini" current meter at a depth of six-tenths of the total depth from the water surface, and at nose depth of the fish. Other details recorded included whether the fish were in riffle, pool or other similar biotope, the proximity of this to any other biotope, and distance of the fish from the bank.

A total of 296 observations was made, involving 11 species and just over 3000 individuals. A computerised data base of all the information detailed above was created and is available from the authors of this report.

7.4 LABORATORY IDENTIFICATIONS

Eggs, free embryos and larval and juvenile fish collected in the field for later identification and measurement, were studied live under a stereo-microscope. All standard body features were measured, to determine the range of sizes and other characteristics of each life-stage, and the fish then photographed before fixing in 5% phosphate-buffered formalin; further details are available in Cambray *et al.* (in prep.). All the specimens have been lodged at the Albany Museum.

Size divisions between larvae, juveniles and adults for each species were based on body-length measurements and stage of development of the fish collected during the field work, in conjunction with the study of specimens previously lodged at the Albany Museum (Table 7.4).

7.5 DATA ANALYSIS AND CREATION OF MICROHABITAT SUITABILITY INDEX (SI) CURVES

7.5.1 GENERAL CONCEPTS BEHIND THE CREATION OF SI CURVES

SI curves describe, in terms of three hydraulically-related variables, the preference of target species for certain physical microhabitat conditions (see Sections 3.11 to 3.13). The three

Table 7.4 Size limits (mm) of fish species life-stages

SPECIES	ADULT	JUVENILE	LARVA
FAMILY Bagridae			
Austroglanis barnardi	≥ 50	< 50	-
Austroglanis gilli	≥ 80	< 80	-
FAMILY Cyprinidae			
Barbus capensis	≥ 300	20-299	11-19
Barbus serra	≥ 250*	20-249	≤ 19
Barbus calidus	≥ 50	15-49	< 15
Barbus erubescens	≥ 40	20-39	< 20
Pseudobarbus phlegethon	≥ 40	17-39	11-16
FAMILY Galaxiidae			
Galaxias zebratus	≥ 40	< 40	-
FAMILY Anabantidae			
Sandelia capensis	-	> 16	≤ 16
FAMILY Centrarchidae			
Micropterus dolomieui	≥ 150	< 150	-

* occasional males as small as 165 mm and females of 200 mm recorded as mature

variables - velocity, depth and channel index - are seen as especially important microhabitat features of running waters with respect to instream flow studies (Slauson 1988). The response of a target species to any one of these variables can be represented by an SI curve with class intervals or categories of the variable on the horizontal axis and measured or observed values for the species on the vertical axis. Values for the species can be expressed in several ways, including number of organisms per sample, population density, productivity or biomass (Slauson 1988). Species values for both utilisation (category II criteria) or preference (category III criteria) curves are scaled or normalised (see glossary) between 0.0 (not utilised or preferred) to 1.0 (most utilised or preferred), with the line of the curve describing the utilisation or preference of the microhabitat variable by the target species (Figure 7.2). For any one chosen target species, the co-ordinates of its three SI curves are the biological input to PHABSIM II.

Typically, the field data for any one target species and variable may show a less than smooth distribution, because of gaps in the data due to insufficient sampling, or other inadequacies of the sampling programme. The SI curve derived from these data as input to PHABSIM II will thus need to be smoothed (Bovee 1986; see glossary), in order to better reflect the overall trend in the response of the species to the variable concerned. Additionally, field data obtained from a variety of sites, over different days and discharges, may need to be pooled, because rarely will the data requirements for an SI curve be satisfied in one visit to one site.

Such manipulation of the field data on fish collected in this study, to achieve smooth, composite curves, is described in Section 7.5.2. The validity of dealing separately with three variables which are largely interactive, is commented upon in Chapters Eight and Nine.

7.5.2 MANIPULATION OF THE DATA

Bovee & Zuboy (1988) give an up-to-date account of techniques for the development and evaluation of SI curves. This information was not available to the authors of this report until the end of this project, and much good advice given therein could not be acted upon. It is, however, an exceedingly useful document for anyone contemplating research on the links between species and microhabitat, and it is strongly recommended that it be referred to at the initial planning stage of such work.

With respect to the fish data reported upon here, the over-riding constraint on data analysis was the small amount of data available even when those from different rivers were pooled. Locke (1988) recommends that, to avoid bias when pooling data, only one method of collecting data be employed for any one species; that the method should be employed for a standard length of time at each study site on each day; that each site should be visited the same number of times; and that all sites should be the same size.

In reality, it was unrealistic to attempt to achieve this; times and study areas could not be standardised due to the need to search for the patchily-distributed fish. Some rivers were visited more often or for longer than others simply because they contained more fish and so provided more data points, an important consideration when data points are scarce. However, more animals did not necessarily mean a more favoured microhabitat (/biotope), for their distributions seemed to reflect a combination of influences. One or two species were possibly truly endemic to one or two tributaries; other species were naturally more generally distributed but were under pressure from agricultural developments and introduced predatory fish species

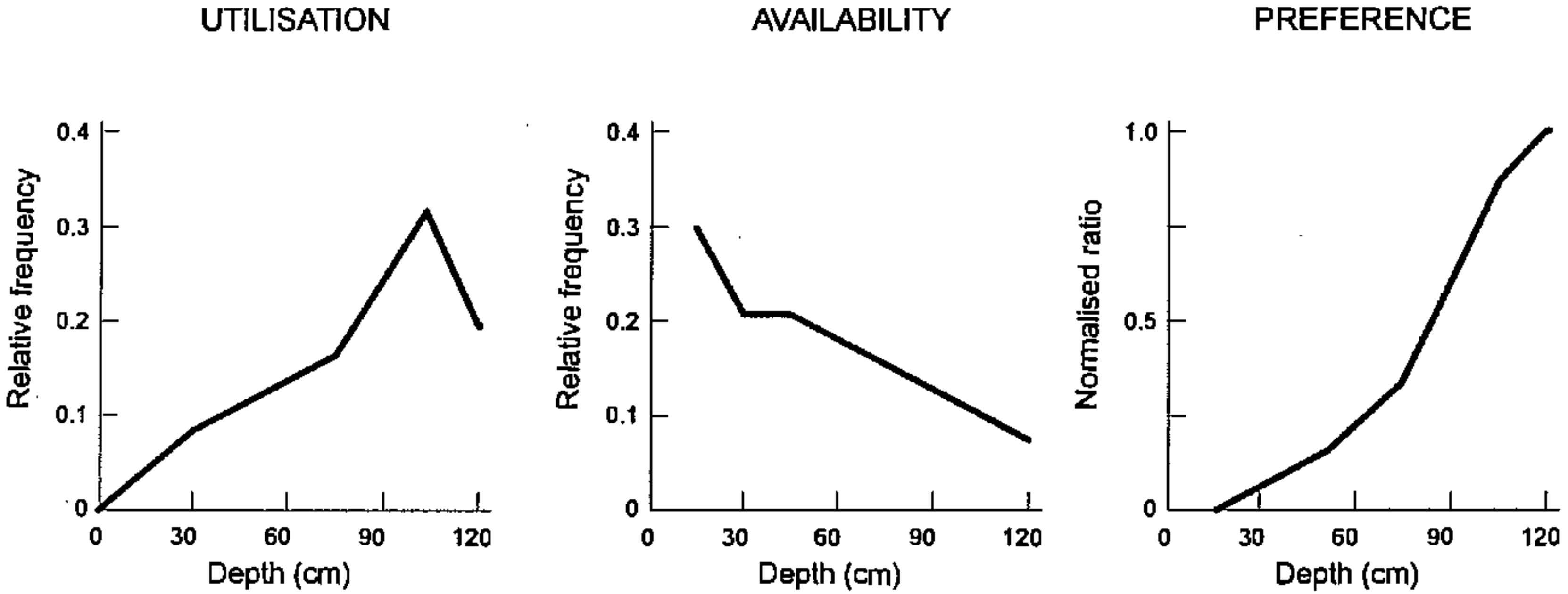


Figure 7.2 An example of utilisation, availability and preference curves derived from histogram analysis (modified from Bovee 1986). Normalised ratio=suitability index

and possibly locally extinct; and some species seemed mostly to be represented by relict populations in streams which still enjoyed a measure of protection by concerned landowners. It seemed clear that microhabitat alone was not dictating distribution patterns between rivers, even if it possibly was within any one site of one rivers.

When the field observations from this study (numbering 296) were separated by river, species and life stage, few values were available in any one set of observations for allocation to the class intervals of any one microhabitat variable. A "good" data set consisted of about 30 observations, while for many lifestages of many species the number of observations was closer to ten; any one of these observations could represent from one to 200 individuals, depending on whether or not the species exhibited schooling behaviour. Clearly, far more data than these are required to create reliable SI curves (estimates range from tens to hundreds of observations; Bovee & Zuboy 1988), but the probable accuracy of any created curve can be calculated using specialised statistical techniques (Jakle & Barrett 1988). Accepting this, and that there is little other information on the microhabitat requirements of the very rare fish species dealt with here, the data collected in this project and the study of Gore *et al.* (1991) represent a first tentative description of these requirements, and are available for later refinement by others.

In arranging the fish data to create SI curves, six main concerns had to be addressed: choosing an appropriate approach to data analysis; choosing size classes for each microhabitat variable; coding abundances to cater for schooling fish; describing microhabitat availability (necessary for category III curves) when the specified procedures for measuring this (Bovee 1986) were not followed; pooling data from different rivers; and the procedures for actually creating the SI curves.

7.5.2.1 Choosing an appropriate approach to data analysis

The three techniques for data analysis suggested by Bovee (1986) are histogram analysis, nonparametric tolerance limits and nonlinear regression; to this Slauson (1988) adds a fourth technique, running filters.

Histogram, or frequency, analysis seems to be most often used, being an easily-understood graphical approach to the various stages of the analysis. It has two main disadvantages; firstly, the researcher has to make decisions about, for instance, the class intervals, which may affect the shape of the histogram; and secondly, a smooth histogram can often only be achieved by grouping adjacent classes, which is done at the expense of accuracy (Slauson 1988). When samples sizes are small, however, fitting curves to the histogram by eye, and using expert judgement, is probably the best technique (R.T. Milhous pers. comm.).

Regression analysis usually involves the use of polynomial regression to express species response as a polynomial function of a single microhabitat variable. There are several disadvantages to this approach (Slauson 1988), most centering around the fact that assumptions of regression (e.g. that the x- and y-axes are unbounded) are likely to be violated. Advantages of the approach are that it employs standard techniques that are widely available as computer packages but, as with histogram analysis, decisions still have to be made by the researcher. These include such issues as which degree polynomial to fit and whether or not to transform the raw data.

The method of **nonparametric tolerance intervals** avoids many of the assumptions about distribution of the data that are implicit when employing regression analysis. In the method, a suitability index of at least 0.1 is assigned to the central 95% of the population, of at least 0.2 to the central 90%, of at least 0.5 to the central 75% and of 1.0% to the central 50% (Slauson 1988). Tables of nonparametric tolerance limits show the number of observations to exclude from the tails of the curve formed, for these and other proportions of the population and for chosen confidence levels. The published tables of nonparametric tolerance limits referred to do not provide values for sample sizes of less than 50, but values for smaller sample sizes now produced by Slauson (1988) make this an attractive option to use in future. Disadvantages of this approach mostly centre around its possible misuse because of, for instance, the inherent problem that a curve will be produced even if the response of the species was exactly the same across the measured range of the variable.

Just as frequency analysis can be used to average out "high frequency jitter" (Slauson 1988) by grouping adjacent classes, **running filters** use running means in a variety of forms to separate the data signal from the noise. Disadvantages of the approach are that a wide variety of running filters exist, with different ones possibly producing different results, and that a reasonable amount of data is required. Advantages include its relative simplicity and freedom from statistical assumptions.

In summary, Cheslak & Garcia (1988) found that the technique that produced the least error was construction of frequency histograms with carefully chosen class intervals. They give guidelines for choosing optimal size classes and comment that the most accurate curve may result merely from connecting the midpoints of histograms created using these guidelines. Additional smoothing of the histogram can be achieved by using, for example, a three-point running mean.

As a result of the limited data sets for fish in this study, all of the following discussions on analysis of the fish data refer to histogram analysis, with histograms fitted by eye and with expert judgement.

7.5.2.2 Choosing class intervals

Data sets for each life stage of each species in each river should initially be analysed separately, and then pooled (Locke 1988) (Section 7.5.2.5 deals with pooling bias). With so little information available in each of the small unpooled data sets, class intervals for the three variables had to be chosen with care. Too many classes would result in little or no information in most of them, while too few classes would cause valuable detail to be lost. The small data sets also made adherence to Cheslak & Garcia's (1988) guidelines on optimal class sizes of questionable value, because they rely on past knowledge of the microhabitat preferences and tolerance limits of the target species.

Thus, in this project and with trial and error, five size classes for depth and velocity were chosen with, in both cases, the last class being an all-encompassing one for the few higher recorded values.

The channel index code was restricted to two digits, each with five values (Table 7.5); this created 25 possible combinations of substrate and cover, although only 16 were actually available in the field (that is, nine combinations did not occur in the project records). The features encoded in each of the two digits were those deemed most suitable not only for describing the complex array of microhabitats seen, but also because they are commonly recognised as important to fish species (Pienaar 1978; Skelton 1987). An explanation of why a more complicated code was not used is given in Section 3.9.7 of Chapter Three.

Table 7.5 Channel index code for all target fish species, for use in PHABSIM II

TENS	REFUGE VALUE (OVERHEAD/INSTREAM COVER)	
1	No cover	
2	Overhead cover only (includes riparian vegetation and trees, overhanging banks)	
3	Hydraulic cover only (cobbles, boulders, roots)	
4	Hydraulic and overhead cover (includes any combination of above, and combination cover such as deep crevices in bedrock)	
5	Aquatic vegetation (can act as hydraulic or overhead cover; if either 2 or 3 is present with this category, the combined code of 4 is used)	
UNITS	**DESCRIPTION OF DOMINANT PARTICLE BY PERCENTAGE AREA, OR BY SIZE WHERE AREAS ARE EQUAL**	**MODIFIED WENTWORTH GRADE LIMITS (mm)**
1	Sand and fines	$x \leq 2$
2	Gravel	$2 < x \leq 32$
3	Cobble	$32 < x \leq 512$
4	Boulder	$x > 512$
5	Bedrock	Slabs

7.5.2.3 Coding abundances

Irregular-shaped histograms occur for several different reasons, some of which are not related to animal behaviour (Bovee 1986). For instance, grouping measurements into classes can cause such irregularities, and can perhaps be solved by regrouping the data into classes with different intervals or by joining adjacent classes. Among the reasons for histogram irregularity that are related to animal behaviour the most important is probably schooling behaviour, for one or 100 fish might be involved in a single observation. Ways to avoid the irregularity in histogram shape that this can cause include obtaining a larger data base, expressing frequency as catch per unit effort (CPUE), or assigning each observation a value of one regardless of the number of individuals concerned (Bovee 1986).

The size of the data base could not be increased for this report, because of time constraints and the limited total size of the fish populations. Nor could CPUE be measured when snorkelling, as definition of a unit of effort for observational techniques is virtually impossible. With regard to allocating all observations a value of one, it is arguable whether a single observation of many fish in one microhabitat should be treated as more or less important than a few observations of a few fish in another microhabitat. High numbers in a single observation may indicate a preferred area, or simply a school moving through a non-preferred area. More observations in a single microhabitat, but each involving a lower number of fish, may indicate either a more or a less attractive microhabitat than in the first example. It seems likely that higher numbers of both individuals and observations are indicative of preference to some degree, and both should be given emphasis.

It was therefore decided to code abundance in a semi-quantitative manner on an arbitrary scale (Field *et al.* 1982). Widely different fish frequencies had been recorded: riffle-dwelling catfish (*Austroglanis* spp.) had occurred singly, as had some individuals of the schooling *Barbus* spp. that inhabited quieter waters. Some pool dwellers, however, especially *B. calidus* and *B. serra*, had occurred in schools of up to 200 individuals, though most were in smaller groups of about 3-30 individuals. The coding system adopted was:

- for all **singly-occurring** species:

each individual coded as 1

- for **schooling** species:

one individual coded as 1
2-10 individuals coded as 2
more than ten individuals coded as 3

The codes were applied to all counts of abundance, to provide the basic data on utilisation.

7.5.2.4 Describing microhabitat availability

To create SI curves showing microhabitat preference (category III curves) the range of microhabitat conditions (in terms of depth, velocity and CI) that were available in the study area at the time that utilisation data were collected must be known. For any one target species, Bovee (1986) outlines the procedure for combining these two sets of data as follows:

$$P_r = \frac{P\left(\frac{E}{F}\right)}{P\,(E)} \quad \text{(Equation 7.1)}$$

Where P_r = the relative preference index of a target species for a specific set of environmental conditions; P(E/F) = the probability of occurrence of a specific set of environmental conditions, given the presence of one or more individuals (i.e. utilisation); and P(E) = the probability of occurrence of that set of environmental conditions in the stream at the time the organism was sampled (i.e. availability)

"Environmental conditions" refers to the three variables depth, velocity and CI, with P(E) and P (E/F) being computed from the raw data as relative frequencies per size class of whichever variable is being considered (Figure 7.2). Bovee (1986) uses the terms relative frequency and probability of occurrence synonymously.

Availability data must be collected at the same time as the utilisation data, because available microhabitat changes with changes in discharge and may thus result in different utilisation patterns. Usually, availability data are collected in one of two ways (Bovee 1986). One approach is to randomly record microhabitat conditions in areas where utilisation records for the target species are also being collected. These records will describe microhabitats both used and unused by the target species, and give an availability data set several times larger than the utilisation data set. However, the technique can increase the field time by up to 100%. The second method involves using the available-microhabitat data automatically created by PHABSIM II. This technique is restricted in that it can only be applied when working at a PHABSIM II study site.

Having to travel long distances to create a reasonable number of utilisation records, and facing time constraints, there was no possibility in this study of a structured programme for collecting availability data. As most of the endemic fish species to be studied no longer occur in the PHABSIM II study sites on the main Olifants River, the second method of collecting availability data also could not be used.

It was therefore decided to use a measure of pseudo-availability in order to be able to create category III curves. Microhabitat records had been created for any place where a fish of any species had been found; such records described the full range of microhabitats deemed to exist in the rivers at that time except waterfalls, and included information on riffles, rapids, runs, pools and backwaters (see Wadeson 1993, and Chapter Eight, Table 8.2 for descriptions of these biotopes). Thus, for any one species, all records of microhabitat where it occurred at a site were used to create utilisation curves, and all records of microhabitat for any species that occurred at that site were used to create availability curves.

It was recognised that this measure of pseudo-availability described where fish occurred rather than providing an unbiased description of microhabitat availability. However, it was felt that the combined data set for any one site provided a fair measure of the range of conditions that existed there and, when combined with utilisation data, provided preference curves that were more useful and realistic than the category II utilisation curves. For simplicity, the term availability and not pseudo-availability will be used in this report, while acknowledging its limitations.

7.5.2.5 Pooling data

Data that have been collected from different sites or streams, under different conditions of flow, using different techniques can, and usually do, create data-pooling problems when creating SI curves. Locke (1988) described these problems and some ways of dealing with them. Essentially, the given guidelines for pooling data without bias are: (1) use the same data-collection technique at each site each time; (2) use study sites of equal area; (3) sample each site the same number of times. This procedure guarantees that the data are not influenced by unequal sampling effort. As observational efforts such as snorkelling cannot easily be defined in terms of unit of effort, bias can be avoided by spending an equal amount of time observing each unit area.

The problem faced in this study of searching for rare species with patchy distributions precluded adherence to either equal areas or equal times. As a result the data collected had to be weighted in some fashion before being pooled. As the same method of data collection was used throughout for any one species, as discharges were at stable low-flow levels throughout the field trip so that data for any one site but from different days could be added directly, and as multiple sites on any one river (except the Olifants River) were close and deemed to be sufficiently similar to allow their being treated as one, weighting was only needed when combining data from different rivers.

Weighting per river should take into consideration size of the area(s) studied and the time spent at each, but both criteria were somewhat meaningless in this investigation, because such large areas were covered and could not be delineated. Nevertheless, if data from different rivers were simply combined data bias could have occurred, because those rivers with more fish were sampled for longer times, and over longer distances, than those with few fish. As more fish did not necessarily mean more of a favoured microhabitat or a microhabitat that was more favoured than others, unweighted data from such rivers would have assumed undue importance in the creation of SI curves. At the same time, data from rivers with a higher number of records were probably statistically more reliable than from those with few records, implying that they should be given greater importance. Under these conditions weighting can itself potentially bias the data, and applying the correct weighting factors becomes principally a matter of judgement.

It was decided to use a composite weighting factor per river, based primarily on the time in days spent at a river (which increased a river's weighting), but also on the number of records collected there (which could increase or decrease its weighting) and on the dissimilarity of the river to the others sampled (which reduced its weighting). The number of days spent at a river ranged between a half and three. Under this system, data for the Ratel River, for instance, received a positive weighting of three, because three days were spent studying its exceptionally abundant fish populations, but this was reduced to a final weighting of two because it was the only river with a largely bedrock channel (Table 7.6). As there was ample reason to believe that the fish populations of the Ratel River were abundant due to protective practices of the land-owner and not only because of the bedrock substrate, it would have been unwise to over-emphasise the requirements for bedrock microhabitat in a pooled (i.e. composite) preference SI curve for channel index.

7.5.2.6 Creating the SI curves

For each species and life stage in each river, separate data sets were created of the velocity, depth and CI conditions utilised. CI conditions were given in terms of the chosen code (Table 7.5). An example of manipulations of the relevant data sets of velocity utilisation and availability, to produce a composite SI curve for velocity for one fish species, is given in Table 7.7.

The raw values for the relevant variable (i.e. the field readings) in each data set were ranked and then allocated among the chosen size (depth/velocity) or substrate classes (see Table 7.7: (a)). Within each class, the number of observations was converted into an abundance-related utilisation index by replacing the number of individuals associated with each observation with a number determined by the abundance code described earlier, and then adding these numbers (Table 7.7: (b)). Relative frequencies of these class values for the utilisation index were calculated (Table 7.7: (c)) to provide the final values used to create the utilisation curve (Figure 7.3).

Table 7.6 Composite weighting values for rivers, used when pooling fish data

RIVER	WEIGHTING VALUE
BOSKLOOF	1.00
DRIEHOEKS	0.50
MIDDELDEUR	0.25
NOORDHOEK	1.50
OLIFANTS (CLANWILLIAM)	0.25
OLIFANTS (GROOTFONTEIN)	1.00
RATEL	2.00
RONDEGAT	1.00
THEE	1.00

Availability curves were created in a similar way, using, for any one target species, all the data collected for all species and life stages at the relevant river (Table 7.7: (d) and (e)). Preference curves were created by dividing the relative frequency value of each class for the utilisation index by the equivalent value for availability (Table 7.7: (f)) and then normalising the resulting numbers by allocating a value of 1.0 to the highest and ranking the rest accordingly (Table 7.7: (g)).

After this had been done for each river, the class values for the normalised preference curve for each river were weighted (using Table 7.6) and the final values, which were used to create the composite preference curve, normalised again (Table 7.7). For depth and velocity curves the values used represented class midpoints, and so the endpoints of the curve then had to be added. The lower endpoint must have an X value of 0 (Milhous *et al.* (1990), and an estimated Y value. The estimated Y value will always be 0 for depth, because there will be no preference for microhabitat with zero water depth, and for velocity it was determined as the proportion of entries in the lowest velocity class that had zero, or near zero, velocities. The higher endpoint cannot be extended beyond the highest depth and velocity values recorded as available microhabitat (Baldridge & Amos 1981), because there is no knowledge of how the species would react in greater depths or velocities.

The same procedure was completed for the utilisation data, so that the composite preference and utilisation curves could be compared.

Table 7.7 **Calculations for creation of composite SI curves from pooled data for velocity for *Austroglanis gilli* adults. Note that for species such as *A. gilli* that do not school, rows (a) and (b) are identical because each individual was counted separately when coding for abundance. Calculations are shown in full for Boskloof only. U - utilisation; A - availability**

		VELOCITY CLASSES (m s^{-1})				
RIVER	**PROCEDURE**	**0-0.200**	**0.201-0.400**	**0.401-0.600**	**0.601-0.800**	**> 0.800**
BOSKLOOF	(a) number of observations	1	5	1	1	1
	(b) observations coded for abundance: utilisation index	1	5	1	1	1
	(c) relative frequency (U)	0.10	0.60	0.10	0.10	0.10
	(d) pseudoavailability	24	6	2	1	1
	(e) relative frequency (A)	0.70	0.18	0.06	0.03	0.03
	(f) preference (c ÷ e)	0.14	3.33	1.67	3.33	3.33
	(g) normalised preference	0.04	1.00	0.50	1.00	1.00
THEE	utilisation index	6	1	0	0	0
	relative frequency (U)	0.86	0.14	0	0	0
	pseudoavailability	25	3	2	0	0
	relative frequency (A)	0.83	0.10	0.07	0	0
	preference	1.04	1.40	0	0	0
	normalised preference	0.74	1.00	0	0	0
NOORDHOEK	utilisation index	2	1	1	0	0
	relative frequency (U)	0.50	0.25	0.25	0	0
	pseudoavailability	37	8	5	3	2
	relative frequency (A)	0.67	0.15	0.09	0.05	0.04
	preference	0.75	1.67	2.78	0	0
	normalised preference	0.27	0.60	1.00	0	0
RONDEGAT	utilisation index	4	4	1	0	0
	relative frequency (U)	0.44	0.44	0.12	0	0
	pseudoavailability	28	4	1	0	0
	relative frequency (A)	0.85	0.12	0.03	0	0
	preference	0.52	3.67	4.00	0	0
	normalised preference	0.13	0.92	1.00	0	0

Table 7.7 continued

	VELOCITY CLASSES (m s^{-1})				
PROCEDURE	**0-0.200**	**0.201-0.400**	**0.401-0.600**	**0.601-0.800**	**> 0.800**
COMBINED PREFERENCE CURVE					
Boskloof x 1	0.04	1.00	0.50	1.00	1.00
Thee x 1	0.74	1.00	0	0	0
Noordhoek x 1.5	0.41	0.90	1.50	0	0
Rondegat x 1	0.13	0.92	1.00	0	0
total	1.32	3.82	3.00	1.00	1.00
divide by total weighting (4.5)	0.29	0.85	0.67	0.22	0.22
normalised combined preference	0.34	1.00	0.79	0.26	0.26
COMBINED UTILISATION CURVE					
Boskloof x 1	0.17	1.00	0.17	0.17	0.17
Thee x 1	1.00	0.16	0	0	0
Noordhoek x 1.5	1.50	0.75	0.75	0	0
Rondegat x 1	1.00	1.00	0.27	0	0
total	3.67	2.91	1.19	0.17	0.17
divide by total weighting (4.5)	0.82	0.65	0.26	0.04	0.04
normalised combined utilisation	1.00	0.79	0.31	0.05	0.05

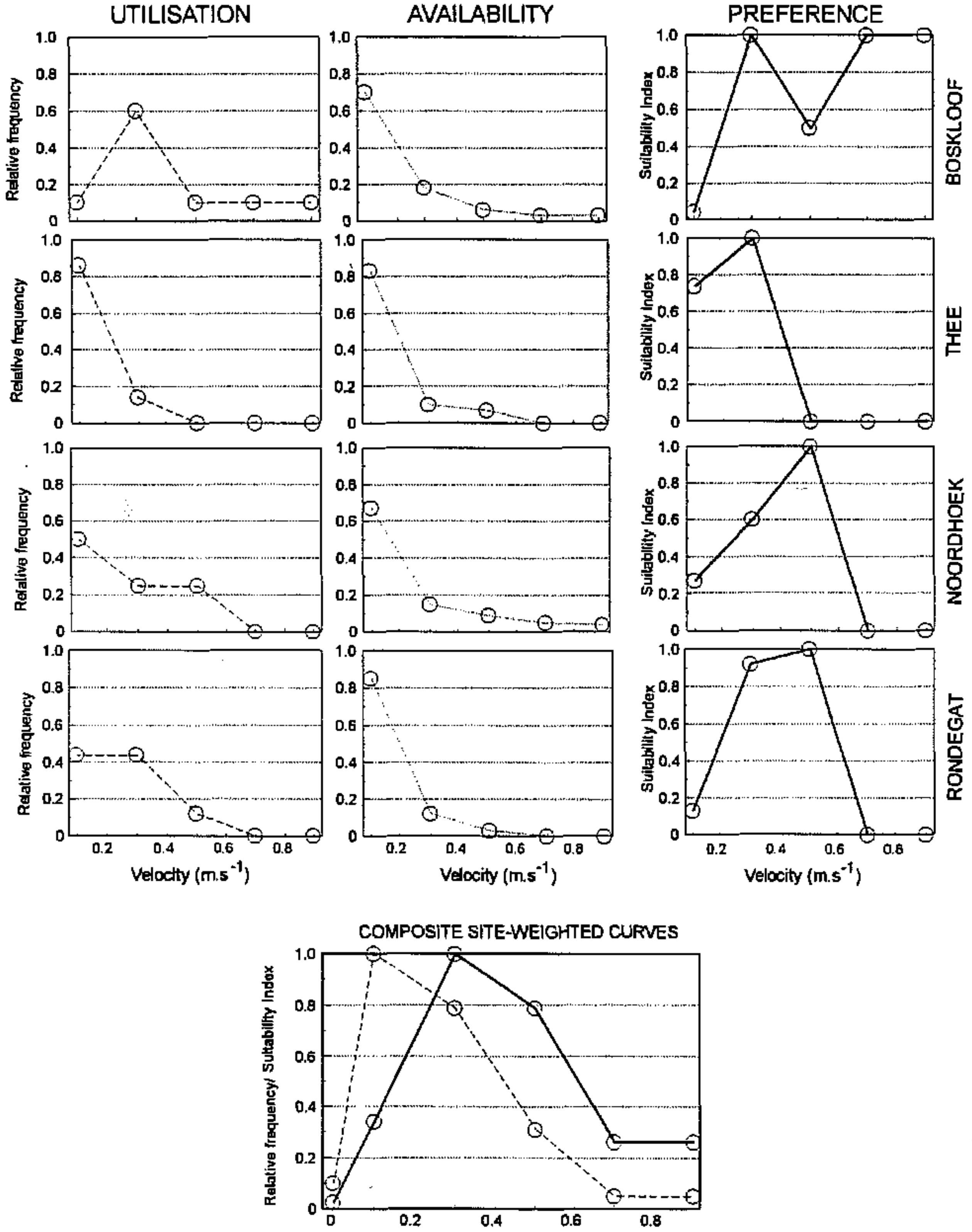


Figure 7.3 **Utilisation, availability and preference curves for velocity for *Austroglanis gilli* adults in four rivers, and composite utilisation and preference curves from the pooled data**

7.6. SELECTION OF TARGET SPECIES AND INTERPRETATION OF THE SI CURVES

7.6.1 SELECTION OF TARGET SPECIES

The target species chosen from among all the fish species and life stages sampled needed to satisfy two criteria. These were that the target species should, between them, be characteristic of different microhabitats, and represent both schooling and solitary species. Additionally, there needed to be a reasonable data set for each target species which, in this case, meant more than 20 data points for any one microhabitat variable. These criteria were chosen to allow the maximum representation of different microhabitats and to provide different kinds of data sets to aid learning.

The selected target species were the riffle-dwelling catfish *Austroglanis gilli*, the pool-dwelling cyprinids *Barbus calidus* and *Barbus serra*, and the introduced smallmouth bass *Micropterus dolomieui*. *B. serra* tended to occupy deeper waters and to occur in schools more often than did *B. calidus*; *M. dolomieui* was chosen in order to assess if any differences in microhabitat requirements could be detected between it and the indigenous fish, which could then be used for control purposes.

All three indigenous species used to occur in the mainstream Olifants River but are now confined to certain tributaries; *B. serra* possibly still occurs in parts of the main Olifants River (Skelton 1987). *M. dolomieui* is now widespread in the system except for headwater reaches believed to be inaccessible to it, threatens the remaining indigenous species in those reaches, and is rapidly increasing in numbers despite some attempts at control such as fishing competitions.

The physical microhabitats used by the target species are described in the following Sections. Data on the microhabitats used by the other fish species included in this study are given in Cambray *et al.* (in prep.).

7.6.2 UTILISATION VERSUS PREFERENCE (SUITABILITY) CURVES

Field data were collected only in summer, and there is little knowledge of how the fishes' use of microhabitats might change through the year. All of the SI curves in this report therefore refer to microhabitat use in summer conditions, and all of the following comments refer only to summer. Additionally, the range for each microhabitat variable in each preference curve is defined by the range of microhabitats that was available. For instance, species may have been inhabiting quiet waters simply because nothing else was available. Therefore, where the highest class interval of a variable on a preference curve has an SI value >0, the highest value encompassed in that class and variable is shown in the appropriate figure; interpretations should not be extended beyond that value.

The velocity utilisation, availability and preference curves for *A. gilli* adults (Figure 7.3) illustrate the difference in interpretation of microhabitat requirements brought about by taking microhabitat availability into account: in each of the four rivers in which this species occurred, preferred velocities were between 0.3 and 0.5 m s^{-1} (Figure 7.3; preference curve) but, due to the limited availability of such velocities, many used quieter areas with velocities of 0.1-0.3 m s^{-1} (Figure 7.3; utilisation curve).

However, although the combined, site-weighted curves for utilisation and preference suggest a shift from utilisation of quiet waters to a preference for faster waters, there is another possible explanation. This is that the species needed to use both kinds of microhabitats for such activities as feeding and resting, with the apparently preferred area being the one in which most time was spent and so it contained most individuals. Whatever the reason for the distribution pattern, *A. gilli* occupied faster-flowing areas to a greater extent than might be expected from a species with no specific microhabitat requirements. For simplicity, and as the wider ecological implications of possible conflicting interpretations of SI curves are recognised but beyond the brief of this project, the microhabitats described by the peaks of the preference curves will hereafter be referred to as the preferred microhabitat.

7.6.3 READING THE SI CURVES

Figures 7.4 to 7.6 illustrate the SI curves for the chosen target species; these are discussed for each species in the following section. Utilisation and preference curves for velocity and depth are given for each target life-stage or target species, with SI values of 1.0 indicating the most used or most preferred condition, and SI values of 0.0 showing the least used or least preferred condition.

SI curves for substrate and cover look somewhat different, because they are based on discrete CI codes rather than continuous data (Table 7.5). Vertical dashed lines in Figures 7.4 to 7.6 indicate breaks in the sequence of substrate codes along the X-axis. Most of these breaks are due to the CI code having only two digits, each with five values (Table 7.5). Thus, for instance, codes 31 to 35 exist, but 36 to 40 do not exist and so constitute a break in the sequence. Additional breaks occur, however, because the X-axes show only the CI codes that were available to the species. Thus, a break between, for instance, 11 and 15 indicates that although the intervening code numbers exist (as shown in Table 7.5) they represent conditions not available to the species.

Preference envelopes (solid lines) encompass a sequence of preferred substrates, sometimes enclosing poorly represented codes that sense dictates should be included (e.g. Figure 7.4; code 42 for *A. gilli* juveniles is not represented, but is enclosed by the envelope described by codes 41 and 43, as there is no reason to believe that the species would be found on sand and cobble, but not on gravel). In such cases, under-representation of codes was deemed to be a result of too few data. Asterices occur at break points where it is necessary to "anchor" an envelope, but where no CI code is present. To avoid confusion on the figures, utilisation envelopes were not created.

Co-ordinates of the preference envelopes, including the anchor points, become the input data on substrate and cover for PHABSIM II.

Final preparation of the data represented in the SI curves (Figures 7.4 to 7.6) for input to PHABSIM II included converting depth and velocity values from metric to imperial feet and creating an appropriate set of X and Y co-ordinates for each curve. The co-ordinates must include an X value of 0 for the first point on the curve and an X value of 100 for the last point.

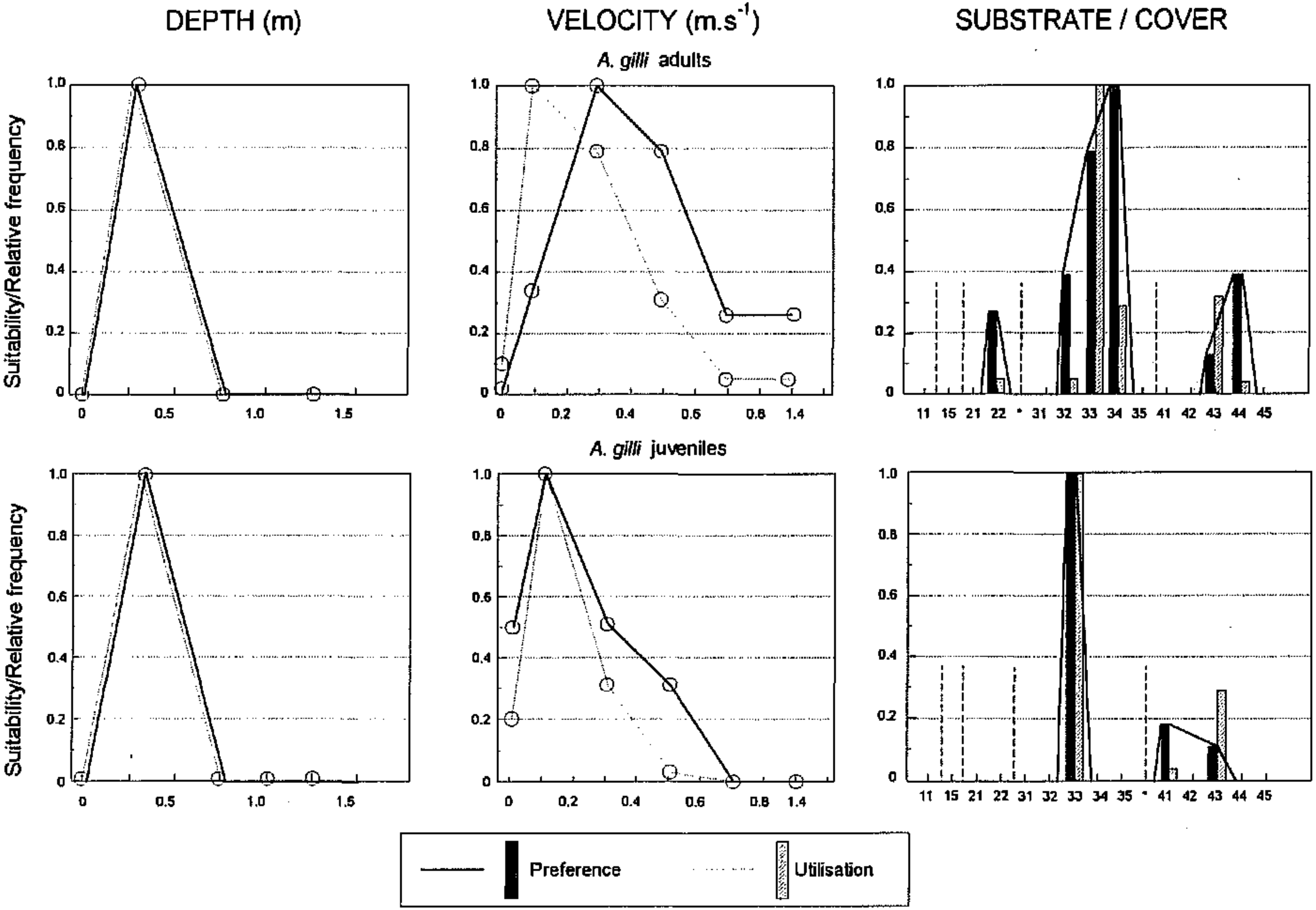


Figure 7.4 **Composite weighted utilisation and preference curves for depth; velocity and substrate/cover: *Austroglanis gilli* adults and juveniles. For explanation see text**

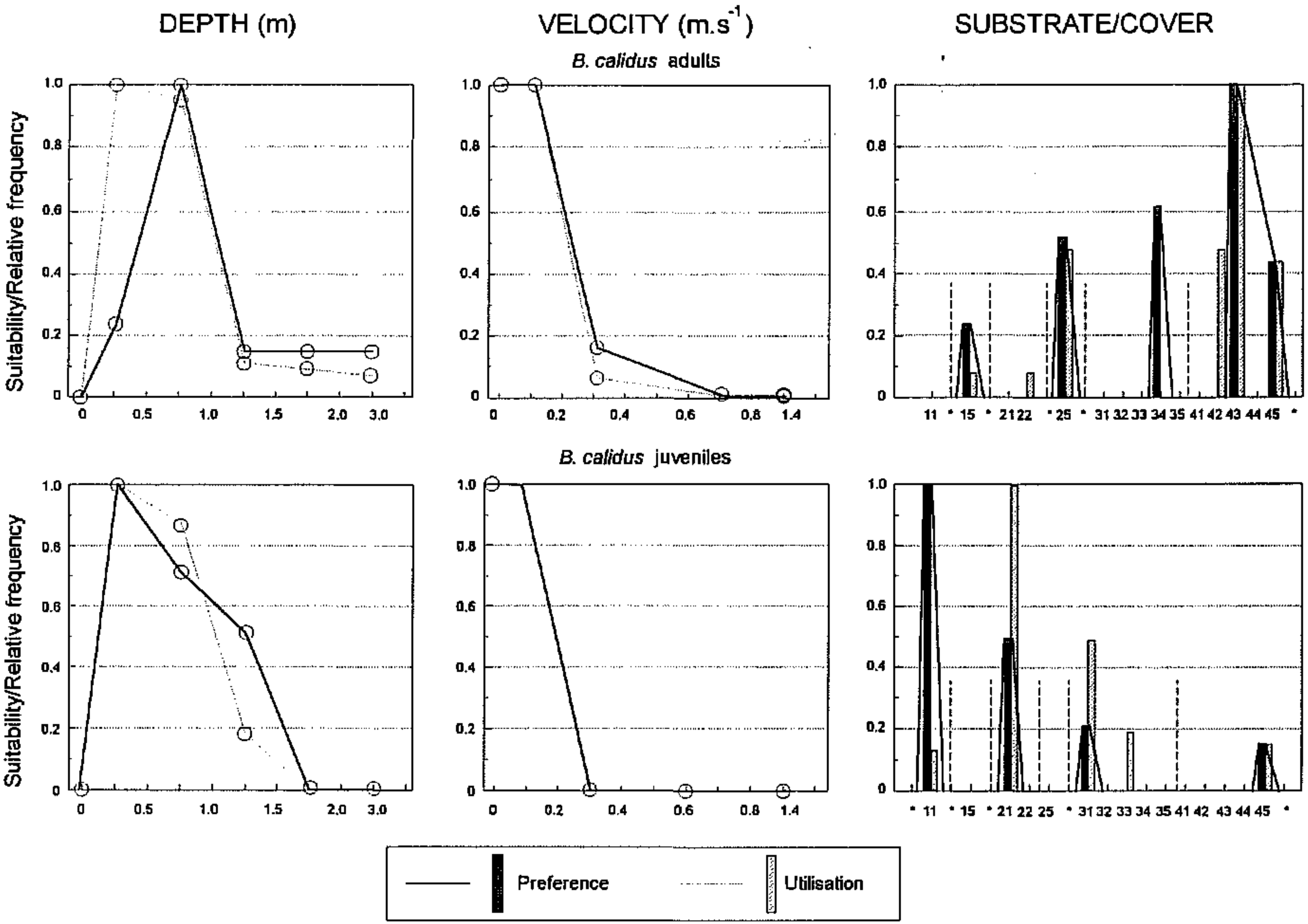


Figure 7.5 Composite weighted utilisation and preference curves for depth, velocity and substrate/cover: *Barbus calidus* adults and juveniles. For explanation see text

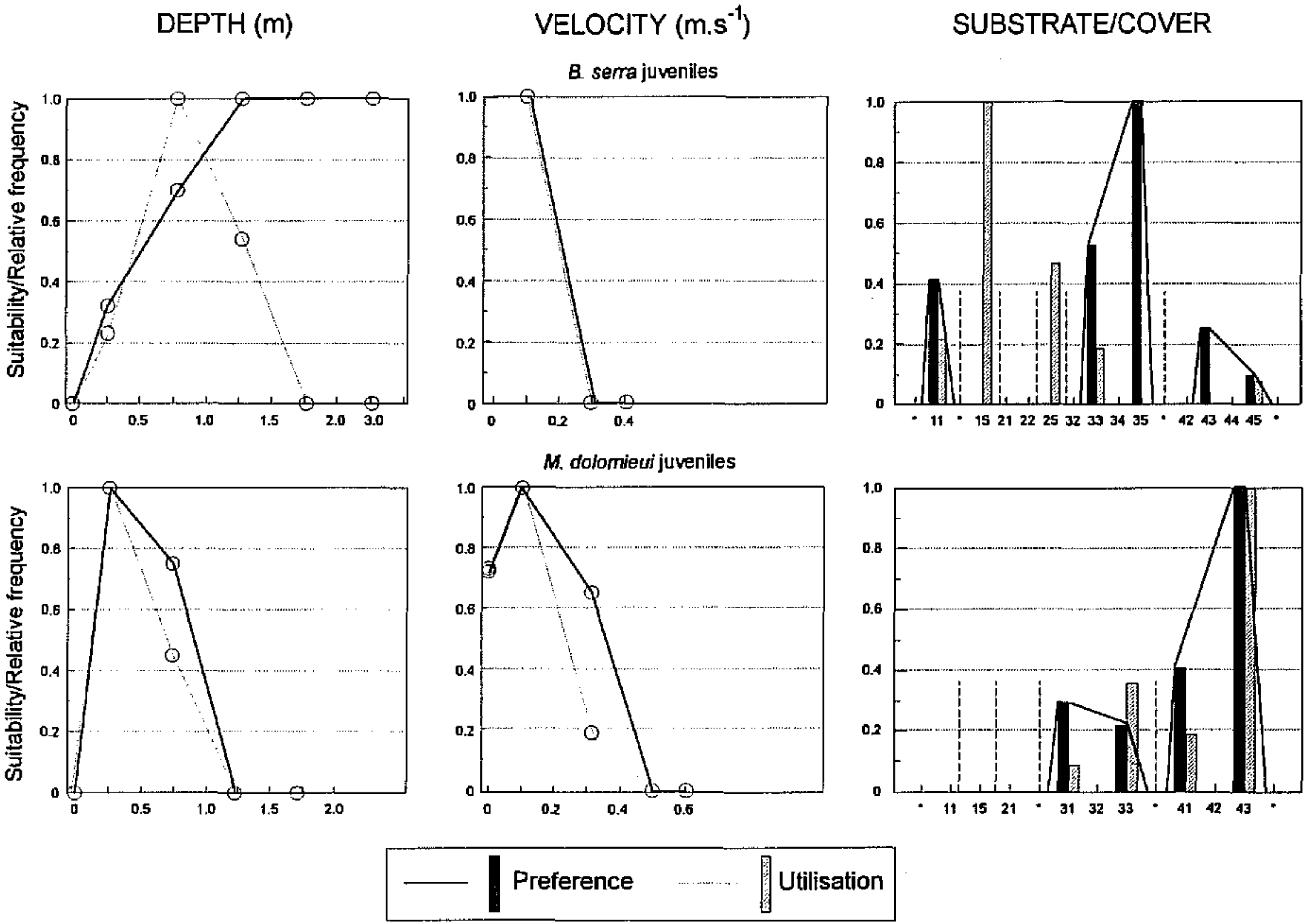


Figure 7.6 Composite weighted utilisation and preference curves for depth, velocity and substrate/cover: ***Barbus serra*** juveniles and ***Micropterus dolomieui*** juveniles. For explanation see text

Milhous *et al.* (1990), in the PHABSIM II tutorial manual, state that the Y value at an X value of 100 may have to be estimated, but will almost always be 0.0 or 1.0.

7.6.4 DESCRIPTIONS OF MICROHABITATS PREFERRED BY THE TARGET SPECIES, USING THE SI CURVES

The values mentioned for each variable are illustrated in Figures 7.4 to 7.6, and are those corresponding to the peaks of the preference curves. It should be noted that the clarity of the SI curves may in part be due to the low number of observations. More observations might have introduced more variability in the results and hence more erratic curve shapes which would have required the application of smoothing techniques.

7.6.4.1 *Austroglanis gilli*

Number of records: adults 29; juveniles 18
Number of individuals: adults 31; juveniles 19

The adults preferred faster waters (0.3 m s^{-1}) than did the juveniles (0.1 m s^{-1}), but most individuals of both life stages were in shallow riffle areas (0.25 m depth) with open canopies and cobble or boulder beds (Figure 7.4). A few adults were in more gravelly areas with overhead vegetal cover, while some juveniles were on sandy substrates under overhanging vegetation. These conditions agree closely with those described by Gore *et al.* (1991) for the same time of year.

7.6.4.2 *Barbus calidus*

Number of records: adults 38; juveniles 28; larvae 8
Number of individuals: adults 729; juveniles 305; larvae 75

The curves indicate that waters of velocity <0.2 m s^{-1} were preferred by both adults and juveniles (Figure 7.5), while the larvae (too few data points to create curves) inhabited totally still water. The similarity of the utilisation and preference curves for both adults and juveniles suggest that their distributions were not restricted by availability of waters of suitable velocity. Adults showed a trend toward inhabiting deeper waters (0.75 m) than did juveniles and larvae (0.25 m), but many juveniles and larvae cruised in small groups very close to the water surface irrespective of water depth. Most adults occurred in waters with overhead vegetal cover and instream hydraulic cover provided by cobble or boulder beds. The juveniles and larvae tended to be in more open-canopied areas with sandy or bedrock substrates.

The preferred depth and substrate conditions described here agree closely with those given by Gore *et al.* (1991), as do the preferred velocity conditions except at the higher end of the range. Gore *et al.* (1991) show velocities >0.3 m s^{-1} being as suitable as those of 0.3 m s^{-1}, whereas in this study suitability of flows >0.3 m s^{-1} decreases with increasing velocities. Perhaps the difference arises because Gore *et al.* took samples in two different seasons and may have recorded a wider range of conditions than in this study. Whether or not information from different seasons should be combined remains open to study.

7.6.4.3 *Barbus serra*

Number of records: juveniles 32
Number of individuals: juveniles 964

All *B. serra* found were between 20-249 mm length and will be referred to as juveniles, although one or two were small adults (Table 7.4). Most occurred in still waters (0-0.10 m s^{-1}) and showed a marked preference for deeper areas (>1.25 m deep) (Figure 7.6). These preferences seemed to outweigh any preference for substrate and overhead or hydraulic cover, as they were found in open or shady areas, over sand, cobble, boulder or bedrock. These findings are in general agreement with those of Gore *et al.* (1991), although they described *B. serra* as having a preference for somewhat shallower waters of about 0.8 m. They did not, however, work in the Ratel River, which provided most of the deep areas recorded in this study, nor did they record the range of depths measured at all their study sites. As they also did not clearly distinguish between utilisation and availability of microhabitats, their final SI curves may not have been preference curves adjusted to account for a possible unavailability of deeper areas.

7.6.4.4 *Micropterus dolomieui*

Number of records: juveniles 11
Number of individuals: juveniles 18

M. dolomieui juveniles (Figure 7.6) tended to prefer fairly shallow (0.25 m) slow to faster waters (0.1-0.3 m s^{-1}). They occurred over a range of substrate and cover conditions, with most preferring overhead vegetal cover. The most common substrate used was cobbles, but some fish were found over sand.

Within these small data sets there were no obvious differences between the preferred microhabitat of *M. dolomieui* and the range of preferred microhabitats of the indigenous species, which could be used to control the alien species.

7.6.5 ADDITIONAL OBSERVATIONS ON THE SI CURVES AND THEIR USE AS INPUT FOR PHABSIM II

Additional data collected during the field work, such as temperatures through the water column and fish behaviour, could not be used in the creation of SI curves for the purposes of input to PHABSIM II, as the model only accepts the three physical variables dealt with here. However, there is no reason why they cannot be created for other purposes. Such additional information from this study is provided in Cambray *et al.* (in prep.).

It seemed possible that the distribution patterns recorded in this study were not always directly dictated by the three microhabitat variables represented in the SI curves, although there might have been an indirect influence. Juvenile and larval *Barbus calidus*, for instance, were often found in any depth water over any substrate, but were clearly holding to a warmer layer of water within 10 cm of the water surface. Their tendency to be in waters of low to zero velocity might have been because such a thermocline could only develop in such areas, but this equally well might not have been so because many other individuals of the same species and life-stages were below an established thermocline.

Several assumptions in the use of preference curves have been criticised by, *inter alia*, Shirvell (1986). Originally wrongly interpreted as the mathematical probability of fish occurrence and now referred to as SI curves, most users of IFIM still interpret the curves as if they were probabilities instead of merely preference functions (itself a controversial issue - see Section 7.6.2). Secondly, concern has been expressed over the assumption of independence in the influence of the three microhabitat variables on habitat selection by target species. Options within PHABSIM II to combine the values for the three variables in three different ways allow some flexibility in this regard (see Chapter Three, Section 3.14), but the implication of independence remains. Multivariate response surfaces (see Section 3.11.2) are being developed to meet this criticism, but are not yet available for use (Gan & McMahon 1990). The third and fourth problems listed by Shirvell (1986) have both been mentioned briefly in this report; the question of transferability of the curves between streams is still a subject of study (Bovee & Zuboy 1988), as is the confusion between real and apparent differences in preference brought about by sampling techniques. All of these issues have been receiving attention for much of the last decade from researchers in North America, and attempts to resolve them here are far beyond the scope of this report.

7.7 THE LINK BETWEEN MICROHABITAT AND MACROHABITAT

An important component of IFIM is linkage of the PHABSIM II output on available microhabitat with data on available macrohabitat zones, in order to assess the total present and future physical habitat available to the target species. This link cannot be made until the model has been run (Chapter Nine), but is mentioned here because it was clear that for the target fish species used in this project it could not be made anyway.

The problem arises because the natural fish fauna has been largely eradicated from the mainstream, and most species now occur only in some tributaries. One of the stated objectives for the study (Section 7.1) was to identify a desirable modified flow regime for the dammed mainstream as defined by the requirements of these fish species. As there are no comprehensive records of the fishes' historical distributions in the mainstream or of the physical and chemical conditions that would have related to those historical distributions, there is little on which to base an assessment of suitable macrohabitat conditions or tolerance ranges for any of the species. It was therefore hoped to record macrohabitat conditions while working in the tributaries, and link these fragmentary data with similar data from previously-recognised and described macrohabitat zones in the mainstream. This would have allowed some assessment to be made of the extent of potentially suitable macrohabitat zones in the mainstream for the fish species, despite the lack of comprehensive data on their environmental requirements.

However, in the assessment of macrohabitat (Chapter Five) it became clear that the recognition and description of macrohabitat zones is not a simple exercise of linking "similar" stretches of river, because small changes in a single variable might be important for one species but not for another. "Similar" stretches, or macrohabitat zones, thus can only be defined in terms of a species' perception of important changes in its environment, and different zones might thus result for each species. If a species is already in the river much can be inferred about its requirements simply by recording the range of conditions in which it exists, but if it is not in the river, or if future macrohabitat zones are being predicted, the exercise is particularly difficult because it requires extensive knowledge of what the species' requirements and reactions might be. Such knowledge would not be achieved with the brief sampling programme conducted in the tributaries in this project (Appendix 5.6), which was designed merely to produce sufficient data to link in to established and described macrohabitat zones in the mainstream.

In summary, then, macrohabitat zones are not simply-identified physical and chemical zones that will be the same for each species (Chapter Five). For this and other reasons, all-encompassing macrohabitat zones that would have been relevant to any species could not be successfully delineated and described for the mainstream. Consequently, the data from the tributaries could not be linked with those for previously-recognised macrohabitat zones, and so no inference could be made of the extent of macrohabitat presently available for the target fish species should they be able to return to the river; equally impossible was any prediction of the extent of future available macrohabitat for them. Thus, the link between microhabitat and macrohabitat could not be made for the fish species. This would affect interpretation of the PHABSIM II output for these species, as discussed in Chapter Nine.

7.8 SUMMARY OF THE APPLICABILITY OF THIS COMPONENT OF IFIM

The fish microhabitat data collected in this study represent a bare minimum of information. SI curves were created using very small data sets, and represent the best present knowledge of the microhabitat conditions in which the various fish species occur during the daylight hours in mid-summer. Outside of these conditions there is still nothing known of their microhabitat requirements. It is not known if they move between different microhabitats during a day-night cycle, if microhabitat preference changes between seasons, what to do if at any one time they require two distinctly different microhabitats for different activities, what conditions they seek in times of flood, if they have a requirement for floods and whether or not they need smaller flow fluctuations. Even less attainable from these data sets is any indication of the indirect requirement for different flow conditions to aid, for instance, maintenance of their food supply and microhabitats.

These are entirely relevant questions, however, when attempting to rebuild a modified flow regime to attain specific ecological objectives for a river. Four conclusions can be drawn. Firstly, far more data-gathering efforts than were done here are required, in order to compile and amend velocity, depth and substrate/cover curves until they satisfactorily reflect a species' requirements in respect of these variables at all times of the year; indeed, one might envisage the effort as an ongoing exercise, contributed to by many. Secondly, the influence of other variables on species distribution and abundance requires investigation, because there is no consensus that the three variables depth, velocity and CI are the main ones involved; such knowledge is needed in order to explore the potential for developing PHABSIM II-type models into true ecological models. Thirdly, even if comprehensive data are collected through all seasons, the methods described here will probably not allow an assessment of the requirement for floods, because the immediate reactions of the fish to floods (even if these could be measured) could well be avoidance of high flows, irrespective of the fact that in the longer term such flows might maintain their microhabitats and stimulate some essential life-cycle response from them. Fourthly, IFIM and PHABSIM II are not, and perhaps were never intended to be, an approach to aid compilation of a comprehensive modified flow regime that would ensure long-term maintenance of a species in a river or, even less, ensure maintenance of the riverine ecosystem itself. This is discussed further in Chapter Ten. A final finding was that the link-up between microhabitat and macrohabitat was not possible.

Such comments should not detract from the fact that data on flow-related microhabitat preferences are valuable in their own right, whether or not they are linked to a model such as PHABSIM II. Few such data have been collected in South Africa, but those now becoming available are valuable for two reasons: they provide insights into the different flow requirements of the riverine species, which can be used in many ways and, perhaps more importantly, their collection causes attention to focus on the flow-related environment of rivers. The understanding of the importance of different flows that emerges from such focussed studies will be far greater than that which is summarised in three SI curves per species.

8. ASSESSING IFIM (STEPS 9-11): COLLECTION AND ANALYSIS OF BENTHIC MACROINVERTEBRATE DATA

8.1 INTRODUCTION

Benthic macroinvertebrate data were collected for two main purposes within this study. The first of these was to produce an ecological analysis of the longitudinal zonation of the Olifants River, by determining the species composition and distribution of benthic macroinvertebrate communities. This would then be used to verify and possibly refine those longitudinal or macrohabitat zones already selected using physical, geomorphological and chemical characteristics (Chapter Five). The methods of analysis of the data used to create biological zones are presented in this Chapter, while the biological zones themselves are described in Chapter Five.

Secondly, benthic macroinvertebrates were selected both as a target community and as individual target species for assessing the PHABSIM II component of IFIM. The development and use of the data for this second purpose are described in this Chapter.

The data are also important from a purely ecological standpoint, as they provide the first comprehensive description of the benthic macroinvertebrate communities of the Olifants River, and some of the first qualitative and quantitative information on their physical microhabitat requirements or of these requirements for any aquatic invertebrates anywhere in South Africa.

In attempting to achieve both of the above objectives, the main aim was to follow the specified requirements of IFIM as closely as possible, but to particularly note those recommended procedures that were impractical or difficult to apply. This lead to several instances where the requirements of the methodology were beyond the scope of this study, primarily in terms of available time. In many cases, this problem was the result of IFIM being initially designed for use with fish studies, which tend to be less labour intensive in their sampling requirements and initial stages of processing of samples. Hence, the procedures for data collection and subsequent analyses had to be streamlined in several ways, as described where relevant.

8.2 AVAILABLE BACKGROUND INFORMATION ON BENTHIC MACROINVERTEBRATES

The availability of background information on the benthic macroinvertebrates was limited to only two studies, one of which focused on a general assessment of the communities present within the river system (Coetzer 1982). The other was in an IFIM study (Fouts 1990), which used benthic macroinvertebrate data to make a limited assessment of the instream flow requirements of the Olifants River. Both studies are briefly summarised below in terms of their relevance to this study. The information on the flow-related requirements of the benthic macroinvertebrates presented by Fouts is compared in later Sections (Sections 8.10.3, 8.11.3 and 8.11.4) to the results obtained for this study.

8.2.1 HISTORICAL SURVEYS

The only historical data that could be located on the benthic macroinvertebrates of the Olifants River system are in an unpublished survey report by Coetzer (1982) for Cape Nature Conservation (CNC).

The period of Coetzer's study was April 1978 to March 1979. He divided the year seasonally into categories: early wet winter, wet winter, early dry summer and dry summer. A network of sites was established in the catchment including on the Doring River and some of its tributaries. Eight of ten sites on the mainstream Olifants River were sampled for benthic macroinvertebrates. Of these, seven corresponded with sites used in this study. Coetzer only took benthic macroinvertebrates from the stones-in-current biotope. He did not collect faunal samples from marginal or instream vegetation, sandy beds or the water column. Samples were only semi-quantitative and identifications were at several taxonomic levels, with most information at the level of family. His species-level data were based on the taxonomic literature available at the time, which has since undergone considerable modification. Coetzer did collect some data on physical microhabitat conditions such as substrate, velocity ranges, and channel form, and on water quality (see Chapter Five), and also provided general descriptions of each of the sites. However, none of the microhabitat data were in a form that was usable for this study.

Abundances of individuals of the major orders of benthic macroinvertebrates are presented in Coetzer's report, as are lists of the taxa collected for each season at each site. He also presented information on the distributions and abundances of taxa, with particular reference to stream order and theories on community zonation, and calculated biotic indices from the data to provide an indication of biological water quality conditions. Furthermore, he delimited zones along the river; these are discussed in Chapter Five in relation to the zones chosen in this study.

A sufficiently accurate comparison of historical data from Coetzer (1982) with present data would only be possible at the family level. Moreover, the original data from Coetzer's survey only became available in the later stages of this study. As the primary focus of this study was an assessment of the instream flow requirements of the benthic macroinvertebrates, and as the community zonation of the river was adequately addressed by the data collected during this study, it was, therefore, not considered necessary to re-analyse the historical data here.

However, these data did provide a useful baseline of comparison for the results obtained in this study.

8.2.2 INSTREAM FLOW REQUIREMENTS

A single study has been conducted on the instream flow requirements of the benthic macroinvertebrates of the Olifants River (Fouts 1990). However, this study was restricted to a single study site at Arbeidsgenot, some 23 km downstream of Citrusdal and upstream of site 4 (Kriedouwkrans) of this study. The reach surveyed by Fouts was only 200 m long, and was considered representative of that section of the river. It comprised one example of each of the three biotopes characteristic of the reach, namely a gravel/cobble/boulder riffle, a sand bed run and a sand bed pool. No assessment of macrohabitat was made, so there is no information on how far upstream and downstream along the river this study site might represent suitable conditions for the benthic macroinvertebrate community, or specific target invertebrate species.

Fouts surveyed and sampled benthic macroinvertebrates in the reach at five transects in March 1989 (summer; discharge 0.9 $m^3 s^{-1}$) and sampled again in May 1989 (autumn, discharge 7.5 $m^3 s^{-1}$). She collected microhabitat data for a total of 35 benthic samples, 25 of which were taken in summer and ten in autumn. A stratified sampling approach was adopted for proportional sampling of the various biotopes. Benthic macroinvertebrates that were collected with a net of mesh size 80 µm, by Fouts, were identified to species level (or lowest possible taxon), as in the present study. Hence, better comparisons of her data and data from the present study were possible than for Coetzer's data. However, the taxonomy employed by Fouts differed from the revised taxonomic literature used in the present study, which made comparisons of the flow-related requirements of individual species difficult. In some cases, however, genus- and species-level comparisons were possible.

Fouts first focused on the microhabitat requirements of the benthic macroinvertebrate community of the reach, using the Shannon-Weiner diversity index (see Section 8.10). Her objective was to develop suitability index (SI) curves for depth, velocity and channel index in relation to community diversity, and to use these to recommend flows that should maintain a high community diversity. Secondly, Fouts developed species-specific SI curves for depth and velocity for seven species that were common in the samples. Substrate and cover data were presented as a series of channel index codes of varying suitability, but were not depicted in the form of SI curves (Fouts 1990).

Suitability curves for depth and velocity were developed by Fouts using the fourth order polynomial regression method of Gore & Judy (1981) which is commonly used for developing such curves for benthic macroinvertebrates, but is subject to much debate (Slauson 1988, *inter alia*; see Section 8.7.2 for further discussion of this method).

The SI velocity curve for the benthic macroinvertebrate community showed that a high community diversity was associated with a wide range of suitable velocities, with those of about 30 cm s^{-1} being optimal. The depth preference range was narrow and centered around 20 cm, and the most preferred substrate and cover combination was medium cobble with less than 25% overhead cover. A minimum discharge of 1 $m^3 s^{-1}$ was calculated from the WUA-Q curve, generated from these SI curves (see Chapter Nine), as necessary to maintain highest community diversity. WUA-Q curves for all the target species were created and compared with the instream flow requirements for community diversity, in order to identify potential indicator species. Two such species were identified by Fouts, namely *Rheotanytarsus* sp. and *Austrocaenis capensis*. Fouts emphasised, though, that further information on the life histories of the two species was needed before either was established as an indicator organism.

Further discussion of the results obtained by Fouts (1990), in comparison with the data for this study, is presented in Sections 8.10.3 and 8.11.3 where the SI curves produced for this study are presented, and in Chapter Nine, where the WUA-Q relationships generated using these SI curves are discussed.

8.3 SOURCES AND TYPES OF DATA COLLECTED

In accordance with the intensive data requirements of IFIM, as many benthic macroinvertebrate samples were collected as possible for as many seasons and sites as possible, to provide sufficient data points for use in PHABSIM II and the best possible representation of species tolerance ranges for different environmental conditions. Thus, for all samples, physical microhabitat, and physical and chemical macrohabitat data were also collected. Although there were two different objectives for the collection of the benthic macroinvertebrate data in this study (Section 8.1), the sampling procedure used was the same for both the three PHABSIM II study sites (described in Chapters Five and Six), and the macrohabitat study sites (described in Chapters Four and Five).

The benthic macroinvertebrate data collected at both PHABSIM II and the macrohabitat sites between them were used as input to the model, especially as large numbers of observations would be required for construction of the SI curves. However, collections at the PHABSIM II sites were more intensive, as described below, as it was not clear at the outset to what extent the model results for each PHABSIM II site could be extrapolated upstream and downstream between them, and therefore to what extent physical microhabitat data from other sites could be pooled with that from PHABSIM II sites.

Benthic macroinvertebrate samples at all study sites were collected on a seasonal basis. Other kinds of data were collected at the same times (see Appendices 8.1 to 8.4), but are not dealt with further in this report.

The collection of seasonal data was done for two main reasons. Firstly, baseline information on the benthic macroinvertebrates of the river was extremely limited (Coetzer 1982; Fouts 1990), and the collection of seasonal data would enable a preliminary understanding of community dynamics over time. Secondly, it was planned to ultimately incorporate the data sets from all seasons into an annual time series of the habitat available to the benthic macroinvertebrates with changes in discharge. This was felt to be an important longer-term goal, as the ecological flow requirements eventually determined for the river would need to reflect the natural flow pattern to which the biota was adapted and hence, to correspond to the changing flow requirements over a year of the benthic macroinvertebrates themselves. Furthermore, the ecological requirements only reflect the needs of the biota. Modifications to the flow regime at different times of the year by other users is a further problem, and predictions of changes in habitat with discharge could be useful in this regard. It was understood that this second aim would not be fulfilled during this study, but might be feasible at some later stage.

Data were collected in autumn (including a very brief preliminary field trip), winter (a curtailed field trip due to floods), early spring (to compensate for the shortened winter field trip), spring and summer (Appendices 8.1 to 8.4; Chapter Six). Summer data were collected for 12 mainstream study sites (the biota were sampled at 11 of these), while only ten mainstream study sites were sampled for all other field trips. Appendices 8.1 to 8.4 summarise the numbers and types of samples collected during each field trip, and Table 4.1 lists all relevant study sites. The general characteristics of each study site are described in Table 4.3.

Three tributary sites were also sampled on all field trips (Tables 4.1 and 4.3). Samples were collected in the Doring River as it is the main tributary of the Olifants River, is seasonal in nature, and represents an entirely different suite of physicochemical and habitat conditions from those of the mainstream. Its dramatic influence on the hydrology and water chemistry of the mainstream (Appendices 5.5 and 5.6) identified it as an important river for consideration in the overall instream flow assessment. It was hoped that benthic macroinvertebrate samples from this tributary would indicate whether the physical microhabitat requirements of its benthic macroinvertebrate community were comparable with those of benthic macroinvertebrates in the lower reaches of the Olifants River. Also, it was hoped that some of the same invertebrate species would be found to be present in both rivers, as this would increase information on tolerance ranges. Furthermore, there is no ecological information on the benthic macroinvertebrate fauna of this river and several of the Red Data fish species (the other target component of this study) utilise it as habitat, probably relying on benthic macroinvertebrates as a major food source (Van Rensburg 1966).

The other two tributaries chosen for invertebrate studies, the Noordhoek and Ratel Rivers, were included for several reasons. Perhaps most importantly, as most of the rare fish species occur there, it was intended that the benthic macroinvertebrate community data of these rivers could be matched with the most similar communities of the mainstream so that the tributary reaches where the fish occur could then be matched with the best-fitting mainstream macrohabitat sites (Chapter Five). Thereafter, it could be possible to extrapolate the PHABSIM II output on usable habitat for the fish (see Chapter Seven) to the most suitable mainstream macrohabitat zones. In other words, the invertebrates would be used as a guide to where fish could live in the mainstream.

Moreover, the data from these two tributaries could be used to extend the known distribution ranges of the benthic macroinvertebrate communities of fairly pristine mountain stream environments, and to provide additional information on the ranges of macrohabitat and microhabitat conditions tolerated by species that are or would be likely to occur in the upper reaches of the Olifants River. Some species that would be likely to occur in the upper Olifants River, based on species distributions in the southwestern Cape, could be absent due to anthropogenic disturbance.

The data collected were also felt to be of ecological value outside the terms of this study, as there is little ecological information on the tributaries of the Olifants River system, and the Ratel and Noordhoek Rivers have been identified as possibly the two most important refuge tributaries for several of the Red Data fish species (K.D. Hamman, CNC, pers. comm.). The benthic macroinvertebrates of these rivers provide a vital link in the ecological functioning of these rivers and an important food source for their fish. Hence, the habitat requirements of the fish should not be considered in isolation, but should ideally be linked with the requirements of the benthic macroinvertebrate communities. Although this final link-up between the benthic macroinvertebrates and the fish was identified as a very important one from the outset, it was not immediately clear whether or not there would be time or the resources to make this link. So, the initial collections of samples were undertaken in the hope of achieving this secondary objective at some later stage.

Although all the above samples were deemed necessary for a full instream flow study using IFIM, processing of them could not be completed for this report. Instead, the data for this report were restricted to the February/March 1991 field trip for the mainstream only (Appendix 8.4). These samples were selected as they reflected low flow summer conditions in the river, corresponded to one of the calibration survey trips (Chapter Six), and represented the same time of year as the fish data, hereby enabling comparisons of these two data sets. Samples not reported on here, however, are a valuable collection which will provide data for later research projects.

Of a total of 462 samples collected, 93 were analysed for this report (Table 8.1). Sample BKR4 had to be discarded due to poor preservation of the animals.

Descriptions of the biotopes (see glossary) referred to in this study, and from which samples were collected, are provided in Table 8.2.

8.4 FIELD SAMPLING METHODS

As mentioned above, the main objective of collecting the benthic macroinvertebrate samples was to obtain information on species composition, species numbers and associated physical microhabitat data which would be used to create the SI curves as input to the habitat suite of programs within PHABSIM II (Bovee 1982). Such information on this target component of the biota would ultimately be used to produce an output of changes in available physical habitat with changes in discharge. The other objective was both to determine the biological longitudinal zonation of the study river and thus to obtain macrohabitat data on invertebrate tolerances ranges.

As a result of the highly specific input requirements of PHABSIM II, attempts were made to follow the suggested sampling approches documented in Bovee (1982) as closely as possible.

For each of the study sites (Table 4.1), a stratified random sampling procedure was employed. Stratification was based firstly on the recognition of two dominant channel bed materials along the river, namely sand and rock. The second basis for stratification was the identification of different biotopes associated with specific geomorphological units (Wadeson 1993), such as cobble riffles, bedrock rapids and runs over sand (Tables 8.1 and 8.2).

In order to construct SI curves, Bovee (1986) recommended approximately 150 to 200 observations per target species per microhabitat variable, and more recently Jakle & Barrett (1988) provided a range of case-specific formulae to calculate the numbers of observations needed for any particular study. However, the sorting and identification of such large numbers of benthic macroinvertebrate samples to species level is time consuming and requires considerable expertise. This necessitated restriction of the number of samples collected to

Table 8.1 Synopsis of benthic macroinvertebrate sample numbers, types and biotopes comprising the IFIM summer (February/March) data set for all mainstream sites

SITE	NUMBER OF SAMPLES	SAMPLE TYPE	BIOTOPE (NUMBER OF SAMPLES)
Visgat	5	rock	• cobble/bedrock riffle (2) • bedrock rapid (1) • bedrock run (2)
Boschkloof	4	rock	• cobble riffle (3) • bedrock run (1)
Grootfontein	18	rock	• cobble run (10) • cobble riffle (5) • gravel/cobble backwater (3)
	7	sand	• sand run (7)
Tweefontein	5	rock	• cobble riffle (3) • cobble run (2)
Kriedouwkrans	15	rock	• bedrock pool (4) • bedrock/cobble pool (1) • cobble/bedrock rapid (2) • bedrock rapid (3) • boulder/bedrock run (1) • bedrock run (4)
	10	sand	• sand run (3) • sand backwater (5) • sand pool (2)
Clanwilliam	5	rock	• bedrock run (3) • cobble/bedrock run (1) • cobble run (1)
Langkloof	5	sand	• sand run (5)
Bulshoek	5	rock	• bedrock pool (2) • bedrock rapid (3)
Zypherfontein	3	sand	• sand/silt pool (3)
Klawer	5	sand	• sand run (5)
Botha's Farm	3	rock	• cobble riffle (3)
	3	sand	• sand/gravel run (3)

Table 8.2 Generalised descriptions of riverine biotopes for this study

BIOTOPE	DESCRIPTION	COMMENTS	REFERENCES
Riffle	Typically shallow depth relative to bed particle sizes. High velocity area with turbulent flow, indicated by broken water surface. Substrate predominantly cobbles and boulders, with limited deposition of fines. Generally noticeable change in slope from head to foot of riffle. Spatially and temporally variable in that the riffle can migrate upstream or downstream with changes in flow and transform into a run at high flows.	Limited consensus as to limiting depth and velocity values (see Wadeson 1993). Can effectively become a run at high flows. Often acts as hydraulic control point affecting upstream and downstream flow conditions. Objective techniques exist for discriminating between riffles and pools (O'Neill & Abrahams 1984).	Allen (1951) Harrison & Elsworth (1959) Grossman & Freeman (1987) Bisson *et al.* (1986) Boulton *et al.* (1988) King *et al.* (pers. comm., 1992) (cited in Wadeson 1993)
Rapid	Variable water depth. Velocity generally high to very high, interacting with bed to produce marked turbulence and white/broken water. Substrate principally bedrock, can include small areas of boulders, cobble or other bed particles.	Can be viewed as a "turbulent run over bedrock" or as a "chute" where flow is constricted by the channel sides and there is evidence of turbulence.	King *et al.* (pers. comm., 1992) (cited in Wadeson 1993)
Pool	Feature with slow through-flow of water. Deep relative to river size. Low to zero velocity. Substrate ranges through all types from bedrock to sand. Flow smooth apart from small area of turbulence at head of some pools. The combination of deep water and low velocity often promotes deposition of fine particulate matter on pool bottom, such as sand, silt and organic detritus. Scouring action and eddy effects can occur at very high flows. Forms body of standing water at very low to zero flows.	Lack of consistency with regard ranges of depth or velocity (see Wadeson 1993). Can effectively become run at very high flows. Objective techniques exist for discriminating between riffles and pools (O'Neill & Abrahams 1984).	Allen (1951) Harrison & Elsworth (1959) Bisson *et al.* (1988) King *et al.* (pers. comm., 1992) (cited in Wadeson 1993)

Table 8.2 continued

BIOTOPE	DESCRIPTION	COMMENTS	REFERENCES
Run	Feature representing an area of transition between a pool/rapid and riffle. Depth variable from fairly shallow to deep. Velocity generally moderate, but can be low or high depending on flow conditions. Substrate conditions variable. Characterised by tranquil smooth flow with no broken surface water. No obvious change in stream bed gradient. Higher ratio of depth to stream bed roughness elements than for riffle.	Two different classifications of this biotope within the literature based on water surface disruption versus no disruption (see Wadeson 1993).	Allen (1951) Harrison & Elsworth (1959) Bisson *et al.* (1988) Chutter (1970) Pridmore & Roper (1985) Grossman & Freeman (1987) King *et al.* (pers. comm., 1992) (cited in Wadeson 1993)
Backwater	Hydraulically "detached" alcove where there is no through-flow of water, and water tends to enter and leave using same route. Depth is variable. Velocity tends to be very low and often zero. Substrate is variable. Often area of deposition of fine material such as sand, silt and organic detritus. Can become a run at high flows when area is flushed of accumulated fines. Tends to occur along the margin of the main channel, and often results from isolation of small side flood channels, when flow decreases.	General agreement of recognition of a backwater as a biotope, and considered by many to be a type of pool.	Bisson *et al.* (1988) King *et al.* (pers. comm., 1992) (cited in Wadeson 1993)
Cascade	Feature characterised by free-falling water over slabs of bedrock in step-like arrangements. Water depth and velocity are not distinguishing features. Rather, the feature is a series of low "waterfalls" and pools. Average gradient is steep, and elevation of the substrate is a distinguishing criterion where step height is ± 3m maximum.	Commonly used biotope term with two broad definitions in the literature (see Wadeson 1993).	Allen (1951) Harrison & Elsworth (1959) Chutter (1970) Bisson *et al.* (1988) King *et al.* (pers. comm., 1992) (cited in Wadeson 1993)

enable the identified study objectives to be achieved within the constraints of this study. Although sample numbers were reduced, caution had to be exercised to prevent a reduction in numbers below a figure necessary for producing acceptable results. Hence, considerably more manageable figures of 25 samples for each PHABSIM II site and generally five or six samples for each macrohabitat site per field trip were decided upon. As mentioned above, even with this reduction in the number of samples collected, it was impossible to process all of them in this study and only the summer ones were completed.

For each macrohabitat site, three replicate samples were taken to represent each of the two main substrate (see glossary) types or, where only one substrate type (sand or rock) occurred, in different biotopes where these were apparent. For the PHABSIM II sites, a more detailed level of stratification of biotopes was possible, due to the greater total number of samples taken.

Sampling procedures for collecting benthic macroinvertebrates in rocky and sandy bed areas were different due to the nature of the substrate, and the approaches used for both are described in Sections 8.4.1 and 8.4.2 respectively.

8.4.1 SAMPLING OF ROCKY AREAS

Benthic macroinvertebrates were sampled using a standard short 0.34 m x 0.34 m (0.1 m^2) box sampler (King 1981), or a modified taller version for deeper water (developed by R.E. Tharme and H.F. Dallas, Freshwater Research Unit, University of Cape Town, unpublished), with an 80 μm-mesh collecting bottle. The substrate was sampled to a depth of approximately 10 cm, standardised by visual estimation. The macroinvertebrates were preserved in 8% buffered formalin diluted down to 4% using river water (Figure 8.1 A).

8.4.2 SAMPLING OF SANDY AREAS

A coring device (developed by R.E. Tharme, unpublished) was used for sampling sand bed areas. The corer is cylindrical with an open mouth at one end and a bottom which can be sealed with a sliding plate at the other. It has a diameter of 15.06 cm, a surface area of 178.1 cm^2 (0.0178 m^2) and an absolute volume of 2000 ml. A fixed-depth gauge ensured that samples were taken to a standard depth of 10 cm. As the corer could not seal-in the sand sample completely in coarser sands and was less efficient in areas of deep water, the actual volume of each sand sample was generally less than potentially possible and was, therefore, measured in the field immediately after collection using a volumetric beaker. Actual volumes generally ranged between 1250 and 2000 ml, but surface areas remained constant. The assumption was thus made that the corer surface area multiplied up to 1 m^2 would enable direct and fairly quantitative comparisons of species composition and abundance between rock and sand samples, particularly as animals from both types of sample tended to be concentrated most densely in the top 10 cm of substrate (R.E. Tharme, pers. obs.). Hence, a multiplication factor of 56 was employed to convert to numbers of animals per m^2 for sand samples from all sites (Figure 8.1 B) except Zypherfontein (see below).

At the Zypherfontein site, bottom sediments along the river edges tended to be very shallow (partially as a result of rooted vegetation and underlying bedrock) and very fine, necessitating the use of a mini-corer as opposed to the standard sand corer used at all other sites. The mini-corer had a diameter of only 6.0 cm, an absolute volume of 143 ml and a surface area of 28.3

cm^2 (0.0028 m^2). A multiplication factor of 357 to convert to numbers of animals per m^2 was employed in this instance. The middle areas of the river bed were not sampled, due to the depth of water (2-4 m). The same procedure for separating the macroinvertebrates from the sediment was followed as for other sand bed areas (Figure 8.1 B).

As the sand samples collected in the above manner were too bulky to be preserved *in toto*, a series of procedures was performed to remove the macroinvertebrates by floatation and most of the sand was then discarded. Some sand was kept for substrate particle size analyses and to check whether the field procedures for separation of the macroinvertebrates from the sand were sufficiently efficient. A measured subsample, of approximately 350 ml, of the cored sample was preserved in the same manner as for rock samples; this would constitute a test of the efficiency of the floatation procedure. The remainder of the sample was placed in a sorting tray with a little water, gently swirled around, and the macroinvertebrates floated off and collected in an 80 µm-mesh sieve. This procedure was repeated at least eight times, or until no further macroinvertebrates were collected in the sieve following floatation. The floatant containing all the macroinvertebrates recovered from the sample was then preserved in 8% buffered formalin diluted down to 4% formalin, and the remaining sand was discarded.

Laboratory methods for the samples collected in the field are discussed in Section 8.5.

8.4.3 COLLECTION OF PHYSICAL MICROHABITAT DATA

At each site, for each location where a benthic macroinvertebrate sample was taken, physical microhabitat data were also recorded. The microhabitat information was recorded as representative of approximately 1 m^2 of surface area of the river bed, corresponding to the final multiplied-up surface area of each benthic macroinvertebrate sample. These microhabitat data included water depth, mean water column velocity (0.6 x depth), and instream and overhead cover. Water velocity was measured using a Price AA or mini current meter, and depth using the current meter wading rod. Instream and overhead cover were estimated as percentages by eye. Bed substrate particle sizes, substrate proportions, degree of embeddedness of substrate particles in finer sediments, substrate surface heterogeneity (using a sampler modified by the authors from that of Gore 1978), estimates of the percentage of organic material on and within the substrata and any other information of potential ecological significance were also recorded for each sample.

Not all of this information is generally used in the creation of the habitat suitability index curves as input to PHABSIM II. Usually, only depth, velocity and substrate/cover (channel index) variables are used to describe physical microhabitat in the model (Bovee 1982). However, it was considered that the additional information collected in the field might assist in better understanding the composition and distribution of the benthic macroinvertebrate communities. Furthermore, some of this information could be found, in this study, to be important enough that methods for incorporating it into PHABSIM II should be considered at some later date. It could also possibly be used as a test of the validity of only using velocity, depth and channel index criteria to describe physical microhabitat for benthic macroinvertebrates in PHABSIM II. As such, the additional data are not discussed further in this report, but are included in Appendices 8.5 to 8.8, and will be dealt with in future scientific papers on the subject.

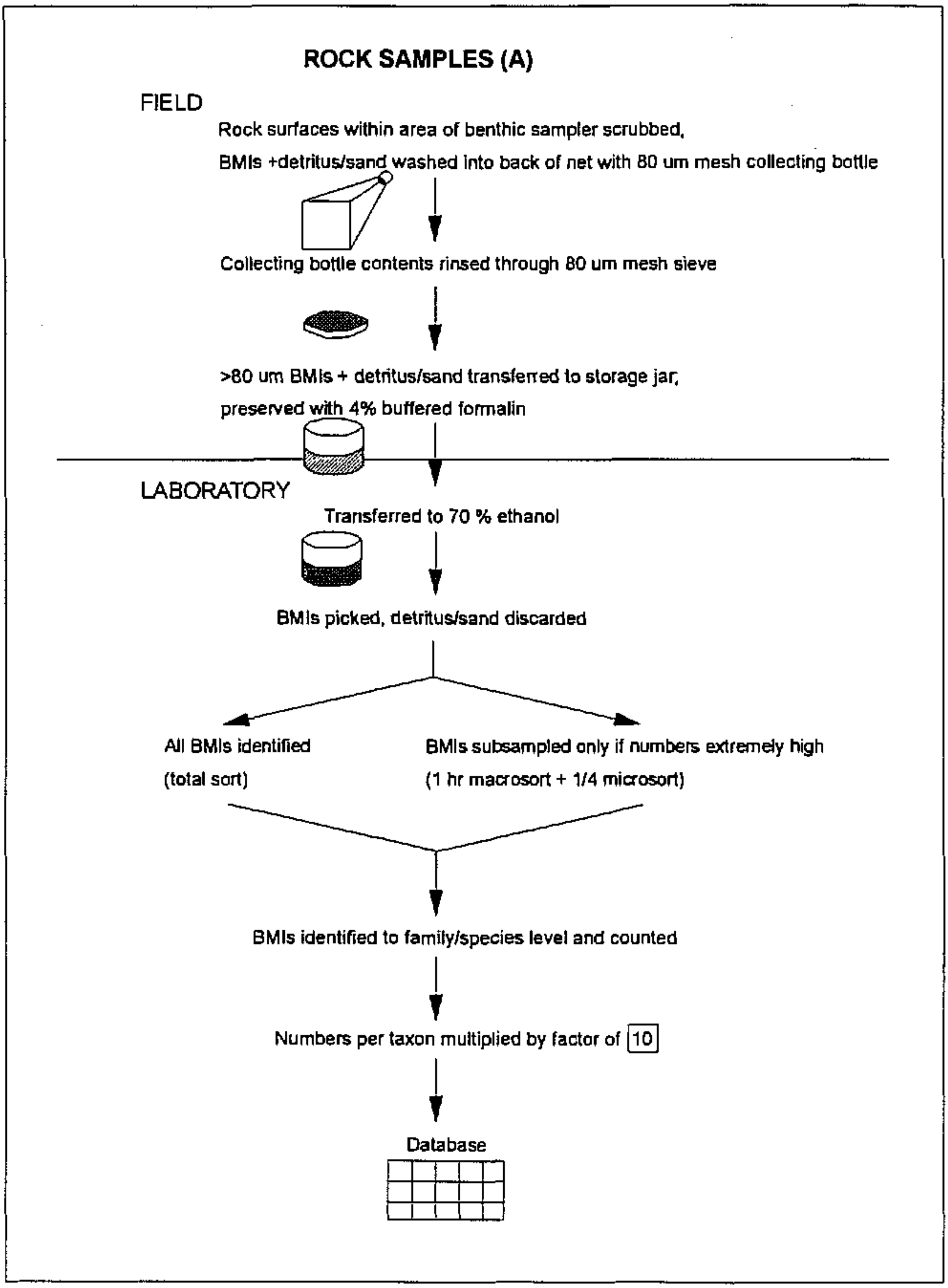
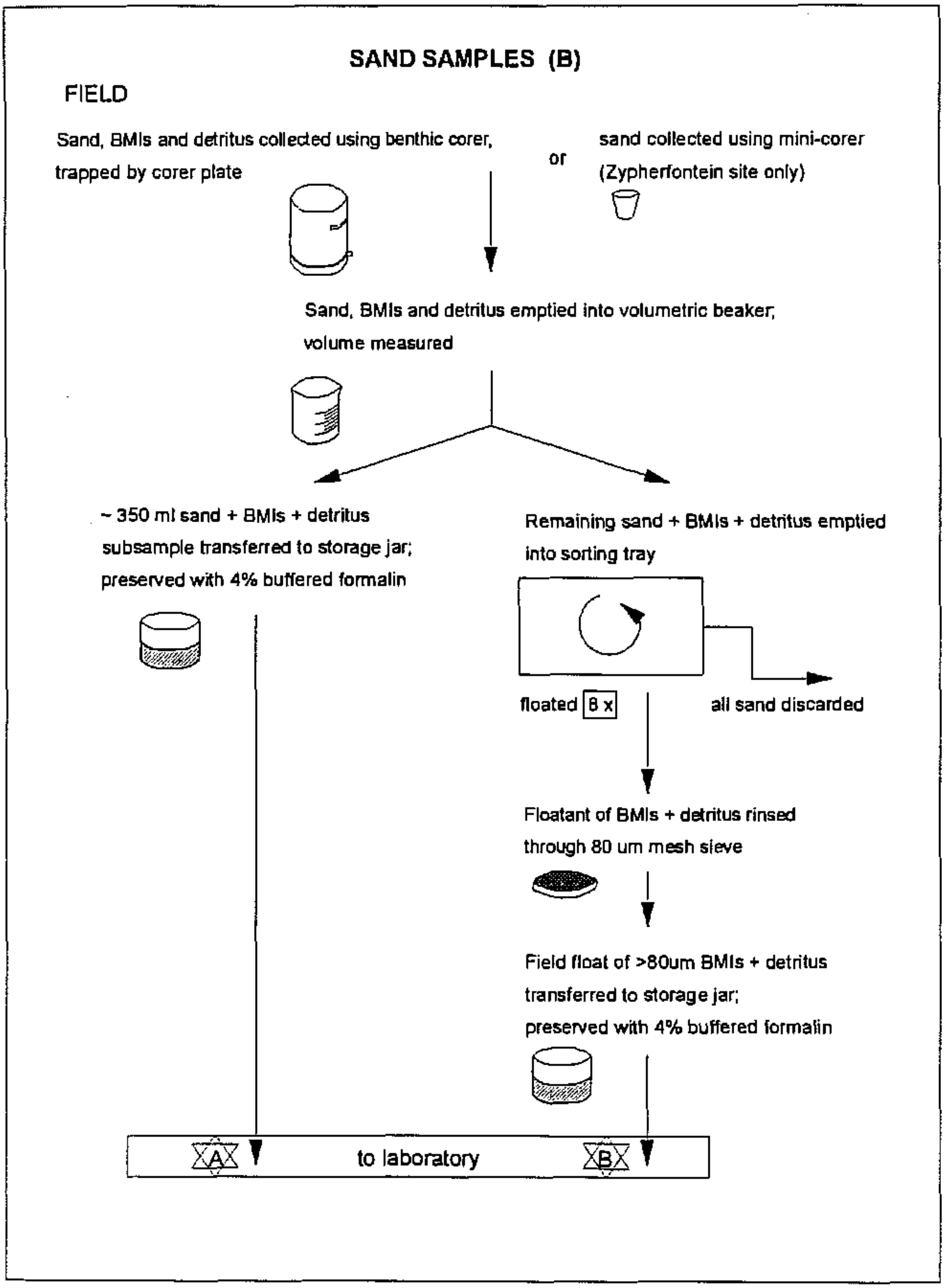


Figure 8.1 Schematic flow chart illustrating field collection and laboratory procedures for rock (A) and sand (B) samples. BMIs - benthic macroinvertebrates



SAND SAMPLES (B)

FIELD

Sand, BMIs and detritus collected using benthic corer, trapped by corer plate

or

sand collected using mini-corer (Zypherfontein site only)

Sand, BMIs and detritus emptied into volumetric beaker; volume measured

~ 350 ml sand + BMIs + detritus subsample transferred to storage jar; preserved with 4% buffered formalin

Remaining sand + BMIs + detritus emptied into sorting tray

Floatant of BMIs + detritus rinsed through 80 um mesh sieve

Field float of >80um BMIs + detritus transferred to storage jar; preserved with 4% buffered formalin

Figure 8.1 continued

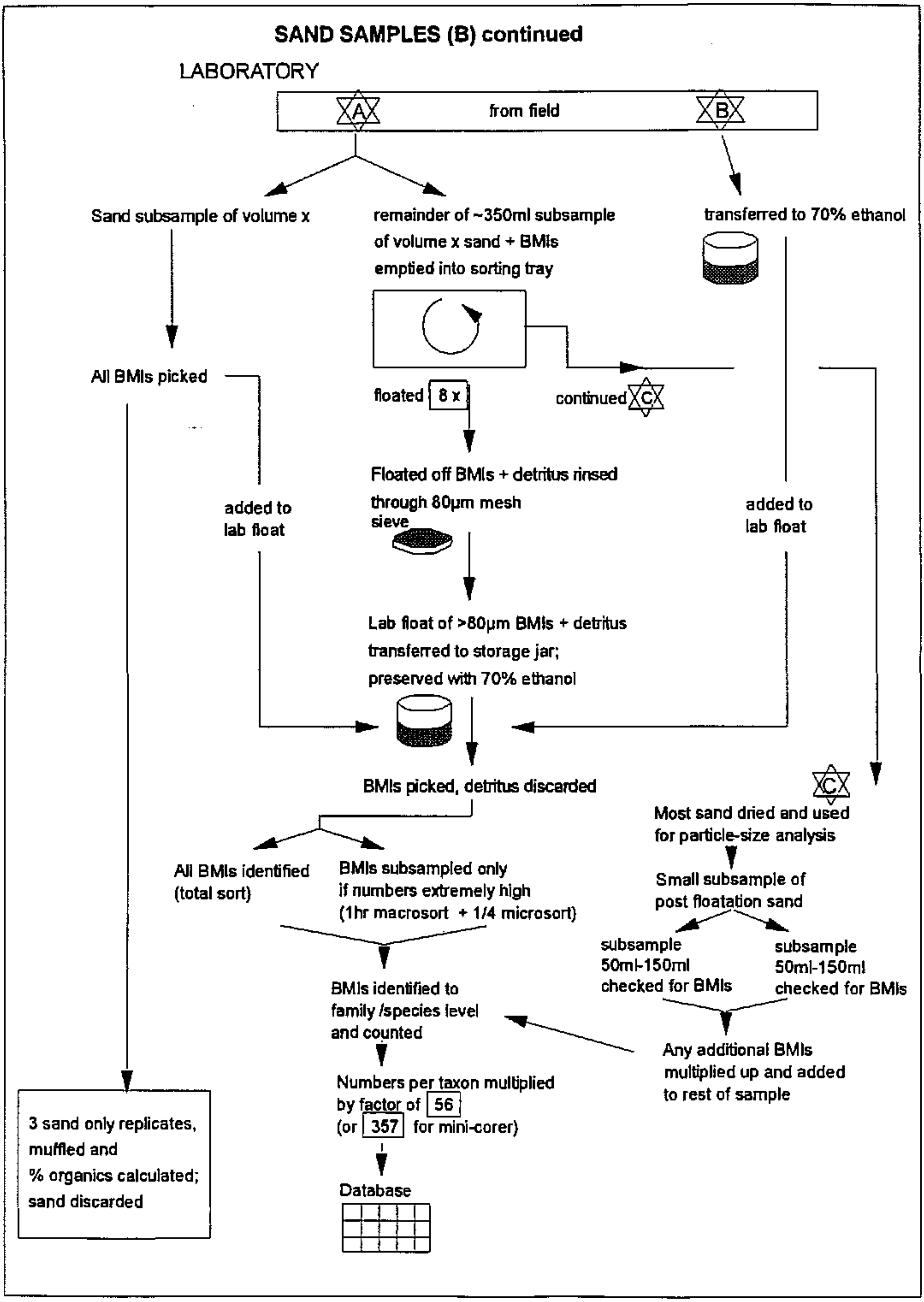


Figure 8.1 continued

Physical microhabitat data linked to each of the summer invertebrate samples listed in Table 8.1, are detailed in Appendix 8.8.

8.5 LABORATORY METHODS

On return to the laboratory, all fixed benthic macroinvertebrate samples collected in the field were transferred from 4% formalin to 70% ethanol for their long-term preservation (Figure 8.1).

For all sand samples, an assessment of the percentage of organic material in the sand was made. The 350 ml subsample (Figure 8.1) was used for this pupose. A small portion of this subsample was sorted to remove all macroinvertebrates; these were stored with the macroinvertebrates sorted by floatation in the field, for later identification. Three replicates taken from the remainder of this subsample were dried in an oven at 60 °C to constant mass. They were then pre-weighed, combusted in a muffle furnace at 450 °C for 5 hours to burn off all organic material and re-weighed to calculate the percentage of organic material in the sand. The remainder of the 350 ml subsample was subjected to the same floatation procedure used in the field, and the macroinvertebrates collected were also stored in ethanol ready for identification. Two 50-150 ml subsamples of measured volume were then taken from the rinsed sand, before it was discarded. These were examined for any macroinvertebrates that may not have been removed during the floatation process. This constituted a measure of the degree of efficiency of the field floatation procedure in removing all animals, and particularly heavier-bodied animals such as molluscs, from the sand. It was found that the floatation procedure was more than 99% effective in recovering macroinvertebrates, and as a result, future post-floatation subsampling is not considered essential.

An analysis of sand particle-size distributions was made, from all sand remaining after flotation of the samples, using the settling column at the Geology Department, University of Cape Town (equipment designed and constructed in-house). Hand-sieving using a 2 mm phi sieve was first done to remove the > 2 mm gravel fraction. All fine sediments less than 80 µm were lost from the samples during the flotation process. It is envisaged that these data will prove useful in future studies of changes in the sediment transport and channel geomorphology of the Olifants River (K. Rowntree, Geography Department, Rhodes University, pers. comm.)

The interim products of the above sets of procedures for sandy bed samples were: field and laboratory floats comprising only animals in alcohol, and the sand used for the determination of particle size distributions and percentage organics.

The benthic macroinvertebrates from both rock and sand samples were identified to family level and then to genus or species level where possible, and counted. The taxonomy of freshwater benthic macroinvertebrates in South Africa is extremely poorly documented for many of the taxonomic groups, and is under continual revision (F.C. de Moor, Curator of Freshwater Invertebrates, Albany Museum, Grahamstown, pers. comm.). Consequently, for several taxa it was not possible to identify below the level of genus or family. Additionally, some identifications to species level required time and taxonomic expertise beyond the scope of this project. Several taxonomic keys were used to aid identifications (Appendix 8.9), and sets of type specimens were compiled for the taxa Trichoptera, Chironomidae and

Ephemeroptera. These type specimens were sent to local specialists in southern Africa for confirmation of identifications. In some instances, species-level identifications could not be adequately confirmed, even by experts, and these species are designated by question marks in the data bases. For the other taxonomic groups, identifications were based solely on available keys as experts were not available for comment.

Data bases were created at both the family and the species level. In cases where the numbers of individuals in a benthic sample were particularly high, subsamples were used as follows. A one hour macrosort was done to remove all large individuals clearly visible with the naked eye. The rest of the sample was then placed in a sorting tray divided into 12 sections and 1/4 of the sample was removed, based on random selection of three subsections, and sorted as a 1/4 microsort. Numbers of individuals for each taxon were then multiplied-up to represent a full sample. However, subsampling was kept to a minimum in this study as it may exaggerate the numbers of individuals of some species, particularly when their original numbers are low and large multiplication factors are used to standardise to unit area. To standardise to unit area, all species numbers for rock samples were multiplied by 10, and sand samples were multiplied by 56 or in the case of Zypherfontein, by 357 (Section 8.4.2). The use of such multiplication factors introduced several problems with analysis of the data; these are discussed where encountered.

8.6 ANALYSIS OF LONGITUDINAL ZONATION USING BENTHIC MACROINVERTEBRATE COMMUNITY DATA

In order to fulfil the first objective identified for this component of the study, namely the identification of biological zones for macrohabitat assessment based on longitudinal changes in the distributions and abundances of the benthic macroinvertebrates communities, multivariate analyses of the community data were performed. The following Sections introduce the methods used for this analysis, and discuss the zonation patterns obtained. The macrohabitat zones produced from this analysis are discussed in Chapter Five, and comments on the macrohabitat tolerance ranges of the benthic macroinvertebrates and on the link between macrohabitat and microhabitat requirements are made in Section 8.13.

8.6.1 THEORY OF METHODS OF ANALYSIS

A group of computer-based programs specifically developed for multivariate and statistical analyses of multi-species data and associated environmental variables was used. These programs collectively form the software package PRIMER Version 3.1a, which was developed by members of Plymouth Marine Laboratory, England (User Guide to PRIMER 1993). The theory and principles on which all of these programs are based are discussed in Field *et al.* (1982) and Clarke & Warwick (1993) *inter alia*, and are outlined below. Specific requirements and functions of each of the Primer programs are outlined in User Guide to PRIMER (1993).

The benthic macroinvertebrate family and species data used in the analyses are summarised in Appendices 8.10 and 8.11 respectively, and a complete summer species list is provided in Appendix 8.12.

8.6.1.1 First stages of analysis

Normal or q-type analysis was used for the classification and ordination of the macroinvertebrate data (Field *et al.* 1982), whereby the samples were ultimately arranged into groups which each had a similar biotic composition, for the purpose of producing longitudinal zones. The stages of q-type analysis are summarised in Figure 8.2.

The biotic data consisted of a matrix of *n* sites by *s* species (or families), where the number of individuals of each taxon was the average per site. This average per taxon was calculated using all the samples for each site, and the sites were then treated as samples within the programs. This was done to better reflect the nature of the site by making some allowance for patchy distribution patterns of the species.

The data were initially analysed by family. However, for certain taxonomic groups the information was not at the taxonomic level of family, but at another level such as Order or Subfamily. These have been termed "equivalent taxa" for this report, for example, Acarina or Mollusca as opposed to Leptoceridae or Elmidae. The family Chironomidae was grouped at the subfamily level, due to the very high numbers of individuals involved and to obvious differences in the proportions of each subfamily at each site. In a second analysis, the macroinvertebrates were separated into species where possible, or into other suitable equivalent taxa. As a result of using "equivalent taxa", the results of the classifications and ordinations (and the measures of diversity, Section 8.10.1) are relative rather than absolute in nature.

The data on family and species abundances were first transformed, because the densities obtained produced very skewed data (J.G. Field, Marine Biology Research Institute, University of Cape Town, pers. comm.). The data were root-root transformed (Equation 8.1, Appendix 8.13) in order to downweight the importance of the very abundant species so that the less dominant, and even the rare species, played some role in determining similarity levels between samples (Clarke & Warwick 1993). This form of transformation also has an advantage over other forms of transformation such as log-transformation, when similarity is assessed by the Bray-Curtis measure, because the similarity coefficient is invariant to a scale change (Field *et al.* 1982). This fairly severe type of transformation was especially useful with the benthic macroinvertebrate data from this study, as it reduced the influence of exaggerated abundances introduced by the multiplication of numbers of individuals to unit area.

As the next step in the analysis, the overall similarity between every pair of sites was summarized for all sites, taking all families or species into consideration. The measurement of similarity selected for this analysis, and used by the PRIMER programs, is the Bray-Curtis measure of similarity (Equation 8.2, Appendix 8.13) (Bray & Curtis 1957, cited in Field *et al.* 1982).

Application of the Bray-Curtis similarity measure in CLUSTER, the classification and ordination program (User Guide to PRIMER 1993), produced a similarity (or dissimilarity, depending on the option selected) matrix, which then formed the input to the classification and ordination stages of analysis. Dendrograms, produced by classification, and ordinations, are convenient ways of summarizing the matrix and were used in this study to explore community relationships.

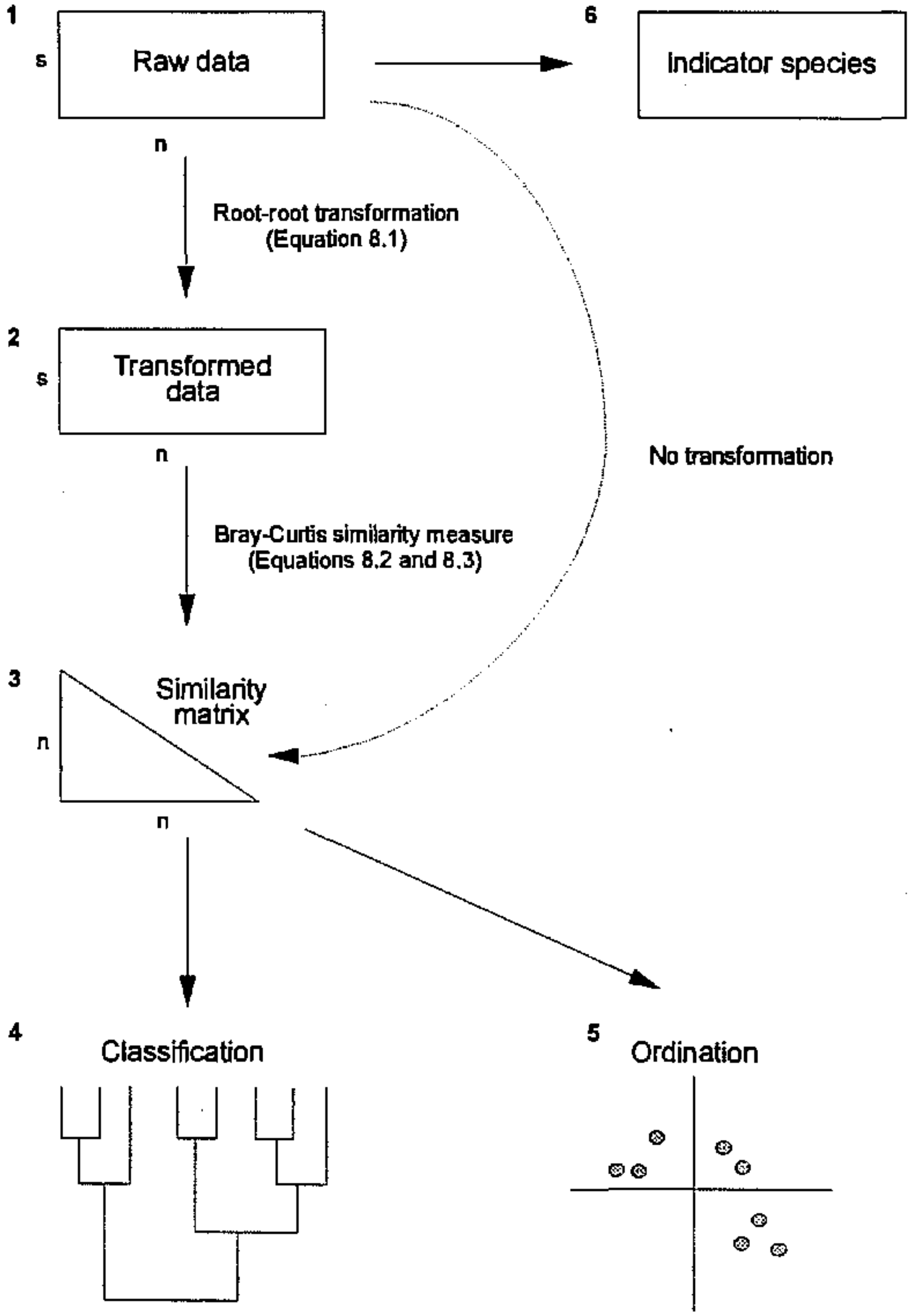


Figure 8.2 Diagrammatic summary of the stages of q-type analysis leading to classification and ordination of samples, and determination of indicator species (modified from Field *et al.* 1982). Raw data are represented in a matrix of n samples by s species (1). It may be necessary to transform the data (2). Comparison of each sample with every other sample using a measure of similarity produces a similarity matrix (3). Classification (4) and ordination (5) are complementary summaries of the relationships between eight samples in this diagram. Indicator species are obtained directly from the raw data (6)

8.6.1.2 Classification

Classification (Figure 8.2), to produce an hierarchical agglomerative clustering of the species/samples was performed using the Bray-Curtis similarity matrix generated by CLUSTER. The results of the classification procedure were represented as a dendrogram created using DENPLOT, with group-average linking of the Bray-Curtis similarities (Clarke & Warwick 1993). Of the various hierarchical sorting strategies available, group-average sorting was used, because it joins two groups of samples together at the average level of similarity between all members of one group and all members of the other and so considers natural variability between samples.

Although dendrograms have the advantage of clustering samples into distinct groups, the cut-off levels for the groupings are arbitrary. There are also several disadvantages to this approach which make it advisable to employ an additional method of presentation of the group relationships (Field *et al.* 1982). Firstly, once a sample has been placed in a group its identity is lost. Dendrograms show only inter-group relationships and the sequence of samples in a dendrogram is arbitrary, with two adjacent samples in a group not necessarily being the most similar. Moreover, dendrograms tend to over-emphasize discontinuities and may, therefore, force a continuum or graded series into discrete classes.

8.6.1.3 Ordination

As recommended in Field *et al.* (1982) and Clarke & Warwick (1993), clustering analysis was used in conjunction with ordination analysis, as superimposition of the clusters obtained from dendrograms at various levels of similarity on corresponding ordination plots enabled relationships between groups to be re-assessed. Furthermore, agreement between the two forms of representation of the data lent support to the mutual consistency and adequacy of both in describing the community relationships. This is particularly important, as cluster analysis attempts to group samples into discrete clusters while ordination displays group inter-relationships on a continuous scale (Clarke & Warwick 1993).

The non-metric multidimensional scaling method of ordination (non-metric MDS) was performed, using the programs MDS and CONPLOT (User Guide to PRIMER 1993). The principles of non-metric MDS are described in Shepard (1962, cited in Clarke & Warwick 1993) and Kruskal (1964, cited in Clarke & Warwick 1993).

Briefly, in the context of sample analysis, the purpose of non-metric MDS is to construct an ordination of the n sites, in a specified number of dimensions, by interpreting some function of the dissimilarity measure between each pair of sites as Euclidean distance. It is an iterative procedure where a starting map of the n sites is constructed (in an arbitrary fashion or by an ordination technique) in the required number of dimensions, and the configuration is perturbed in a direction which decreases the stress (Equation 8.4, Appendix 8.13) to an acceptable minimum (see below). The interpoint distances of the configuration are then regressed on the corresponding dissimilarities using a general monotonic transformation to distance. The MDS is non-metric in that the regression is non-parametric, hereby making allowance for the typically non-linear relation of dissimilarities to distance for biological q-type analysis (Field *et al.* 1982).

A scatter plot or Shepard diagram is constructed by the program of distance against dissimilarity for all pairs of values in the plot. The goodness-of-fit of the regression is then indicated by the stress value, which totals the scatter around the regression in the Shepard diagram (Equation 8.4, Appendix 8.13). Further use of the Shepard diagram is described in Clarke & Warwick (1993). Stress provides an indication of the distortion involved in compressing the data to a small number of dimensions (usually 2-d for ease of interpretation); low stress indicates that the sample relationships are well represented by a plot of the sites in the specified dimensionality (Field *et al.* 1982). As a general rule-of-thumb, Field *et al.* (1982) state that a stress value < 0.05 provides an excellent representation of the data, and < 0.1 gives a good ordination with misleading interpretation being highly unlikely. At higher stress values, increasingly less reliance should be placed on the plot, and it may be necessary to use higher-dimensional ordinations to improve the representation.

For all ordinations produced in this study, the number of iterations carried out to ascertain with reasonable certainty that a global minimum had been obtained (see Field *et al.* 1982 for an explanation) was determined by checking the stress values associated with different numbers of iterations. It was found that at about 15 iterations, the configuration map converged at a consistently low stress value which was very similar to that associated with 30 or more iterations. Furthermore, each ordination was first performed in three-dimensions, and the configuration obtained was used as the starting map for the two-dimensional ordination. 2-d stress values were compared with 3-d values and with the recommended values in Field *et al.* (1982), and it was found that all ordinations had a sufficiently low stress value to enable good representation in 2-d.

8.6.2 RESULTS AND DISCUSSION

The biological zonation patterns resulting from the classifications and ordinations performed at the family and species level with site averages are presented in this section. Although analyses of individual samples rather than site averages were also performed using the data, the patterns that emerged were at too detailed a level of resolution for the purposes of this study and these analyses were not pursued any further.

8.6.2.1 Family-level classification and ordination

The family-level classification (Figure 8.3) and ordination (Figure 8.4), were used to create a simplified description of longitudinal patterns in community structure along the study river. These were then used, in conjunction with the species-level results (see below), to decide on the most suitable division of the river longitudinally into biological zones, as outlined in Chapter Five. The abbreviations of site names used in this Section are listed in Figure 4.4.

The five upper-reach sites of Visgat, Boschkloof, Grootfontein, Tweefontein and Kriedouwkrans diverged from sites of the middle and lower reaches at a similarity level of 46.5% (Figure 8.3). All these upper sites exhibited levels of similarity above 60%, with Kriedouwkrans and Grootfontein being most similar, probably as a result of their both comprising sandy and rocky areas. Tweefontein was shown to be very similar to these two sites, but possibly split off from them due to its predominantly cobble bed and associated fauna. The second main group of sites split into a middle reach group, which included the sites below both dams, and a lower reach group from Zypherfontein downstream. Klawer and Botha's Farm exhibited the highest similarity of any sites (69.4%).

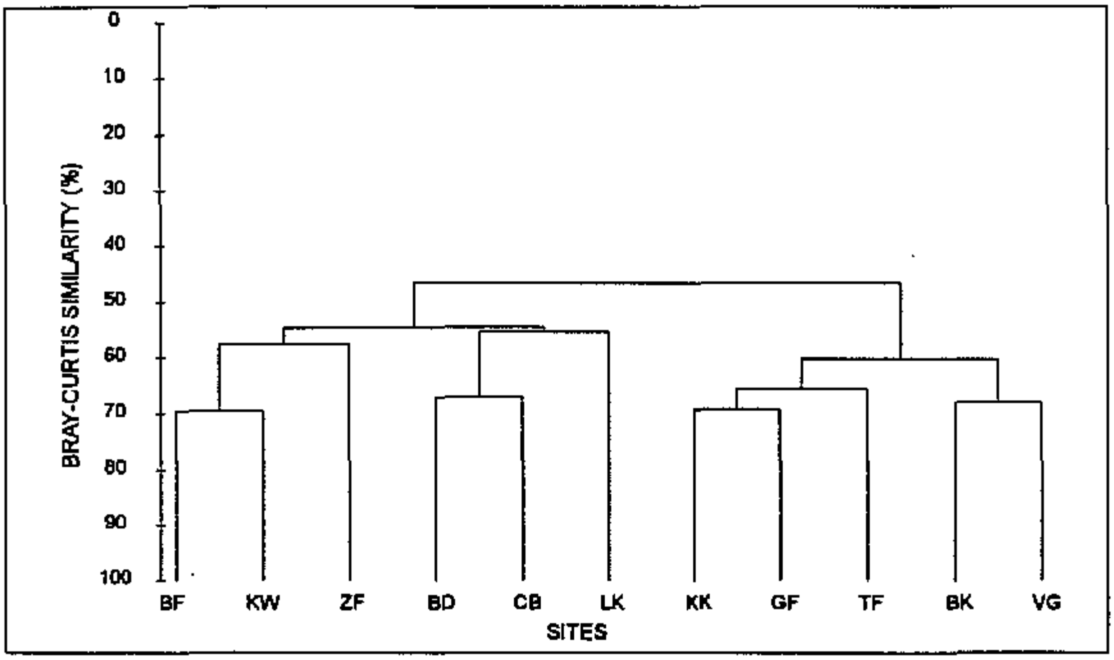


Figure 8.3 Dendrogram showing classification of the 11 macrohabitat sites of the study area based on mean sample abundances per family of benthic macroinvertebrates (summer data); samples from rock and sand bed areas were combined for sites with both types of substrate. Two main clusters of sites were distinguished at an arbitrary similarity level of 50% and six groups at 65%

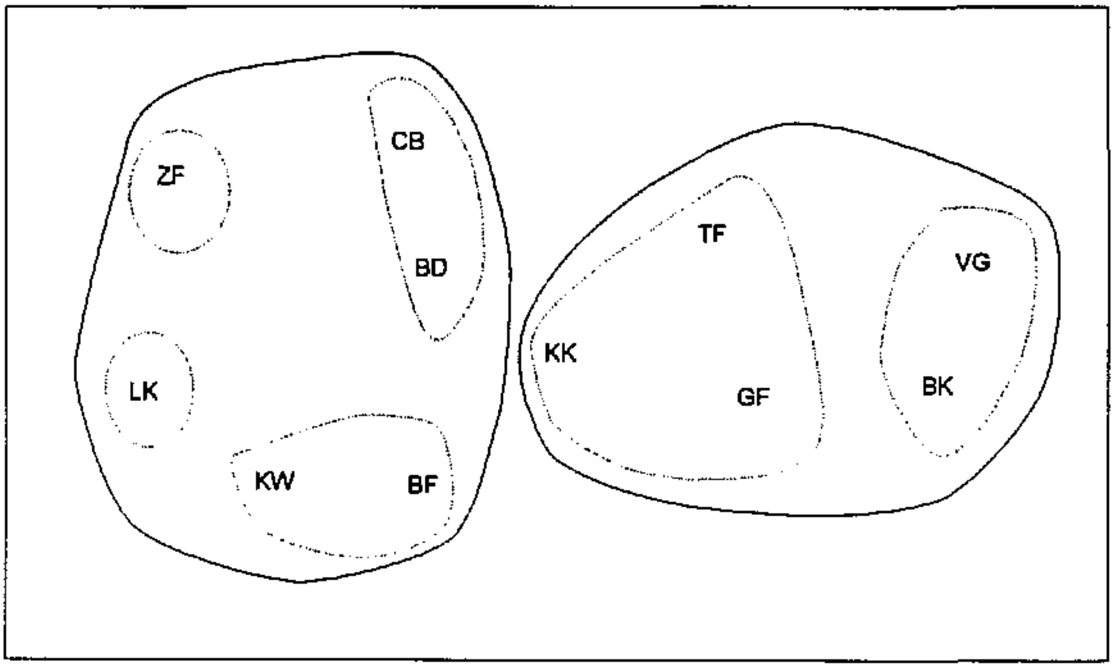


Figure 8.4 Ordination of the 11 macrohabitat sites using non-metric MDS on the same similarity matrix as Figure 8.3, based on mean sample abundances per family of benthic macroinvertebrates (summer data). Clusters at the 50% similarity level (solid line) and subclusters at the 65% level (dashed line), distinguished in the dendrogram, were superimposed. Stress = 0.096

The two-dimensional ordination (Figure 8.4) conformed with the clusters defined from the dendrogram. It was produced using 15 iterations of the starting configuration, and the stress value of 0.096 indicates that the 2-d plot produced a good representation of the data (Field *et al.* 1982). Superposition of the dendrogram-defined clusters at arbitrarily designated 50% and 65% similarity levels indicated the main groupings obtained. Again, Visgat and Boschkloof grouped together, and the three other upper reach sites of Grootfontein, Tweefontein and Kriedouwkrans formed a separate cluster. The sites below both dams grouped as having similar invertebrate communities, as did the Klawer and Botha's Farm sites.

8.6.2.2 Species-level classification and ordination

The species-level classification and ordination were performed in two complementary ways. Firstly, all samples from each site were combined (Figures 8.5 and 8.6). In a second set of analyses, rocky bed and sandy bed samples were kept separate for those sites where both these substrate types occurred (Figures 8.7 and 8.8).

For the classification exercise with all samples for each site combined, the clusters were fairly similar to those for the family-level analysis, but at lower levels of similarity between clusters (Figure 8.5). Groupings for the upper-reach sites from Visgat to Kriedouwkrans were the same as for the family data. Botha's Farm and Klawer split off first for the sites in the middle and lower reaches, at a similarity level of 39.0% where the overall similarity calculated for all study sites was 31.7%. In the middle reaches, the sites below Clanwilliam and Bulshoek Dams grouped together, while Langkloof grouped with Zypherfontein as opposed to standing alone at the family level. The Clanwilliam and Bulshoek sites probably grouped as they are both located directly below dams and have bedrock-dominated channels, possibly as a result of bed armouring.

The species data ordination (Figure 8.6) indicated the same trends as the classification, and the low stress value (0.066) based on 15 iterations showed that the results could be considered highly reliable. An increase to 30 iterations produced a similar configuration of sites, with a stress value only slightly lower at 0.061. Clusters based on similarity levels of 35% and 50% were superimposed on the plot. Interestingly, this showed a very high degree of similarity between Visgat and Boschkloof, while Klawer and Botha's Farm appeared less similar than at the family level.

The same data were then analysed at the species level using presence or absence of species rather than measured abundances and also using raw untransformed data, to check whether or not the general trends obtained for the data still applied. Both sets of analyses supported the overall patterns of site groupings; thus, the results of these analyses are not presented here.

Classification of the study sites considering mean sample abundances of species for rock and sand separately (Figure 8.7) clearly indicated the influence that substrate type has on community composition. Once again, the upper reach sites from Visgat to Kriedouwkrans split from the rest at a similarity of 30.4%. However, the sandy bed component of both the Grootfontein and Kriedouwkrans sites did not group with their rocky counterparts forming the upper-reach group. Instead, they grouped, within an overall middle-reach to lower-reach group, with all other sandy sites along the river, at a similarity of 47.6%. Bulshoek and Clanwilliam again grouped together as sites below dams, and split off from the sites

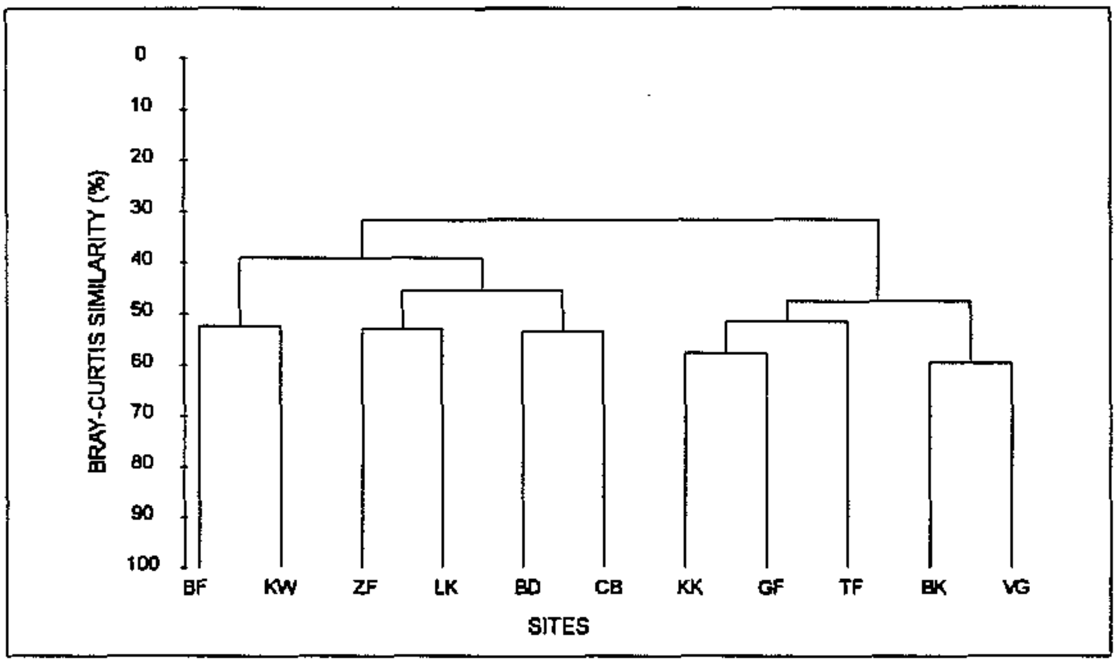


Figure 8.5 Dendrogram showing classification of the 11 macrohabitat sites of the study area based on mean sample abundances per species of benthic macroinvertebrates (summer data). Samples from rock and sand bed areas were combined for sites with both types of substrate. Two main clusters of sites were distinguished at an arbitrary similarity level of 35% and five groups at 50%

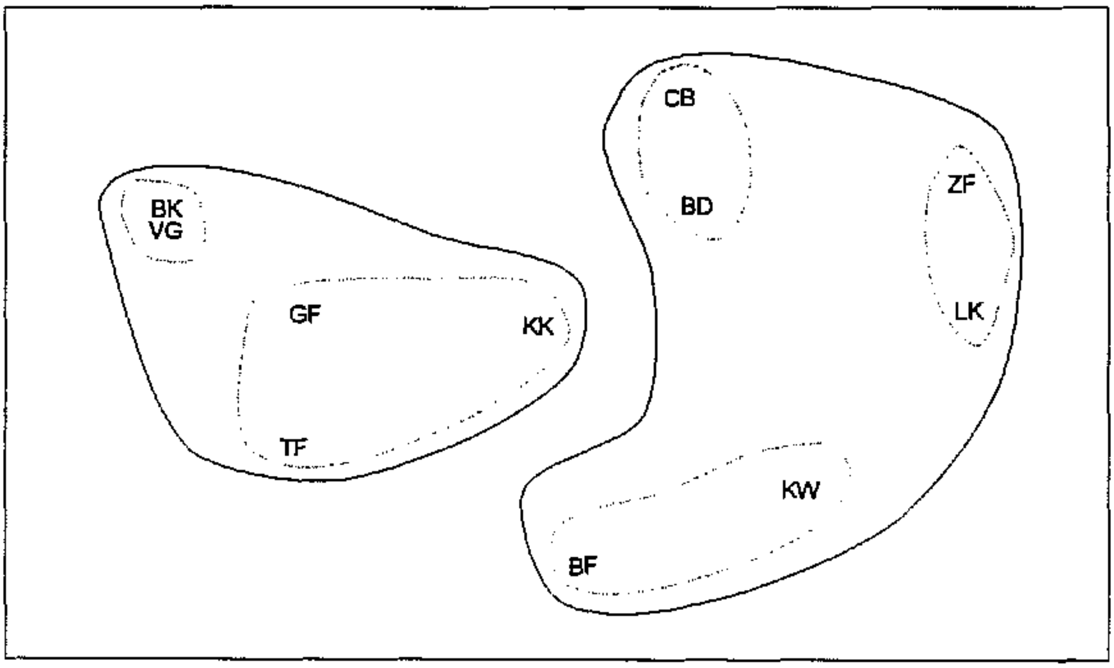


Figure 8.6 Ordination of the 11 macrohabitat sites using non-metric MDS on the same similarity matrix as Figure 8.5 based on mean sample abundances per species of benthic macroinvertebrates (summer data). Clusters at the 35% similarity level (solid line) and subclusters at the 50% level (dashed line), distinguished in the dendrogram, were superimposed. Stress = 0.066

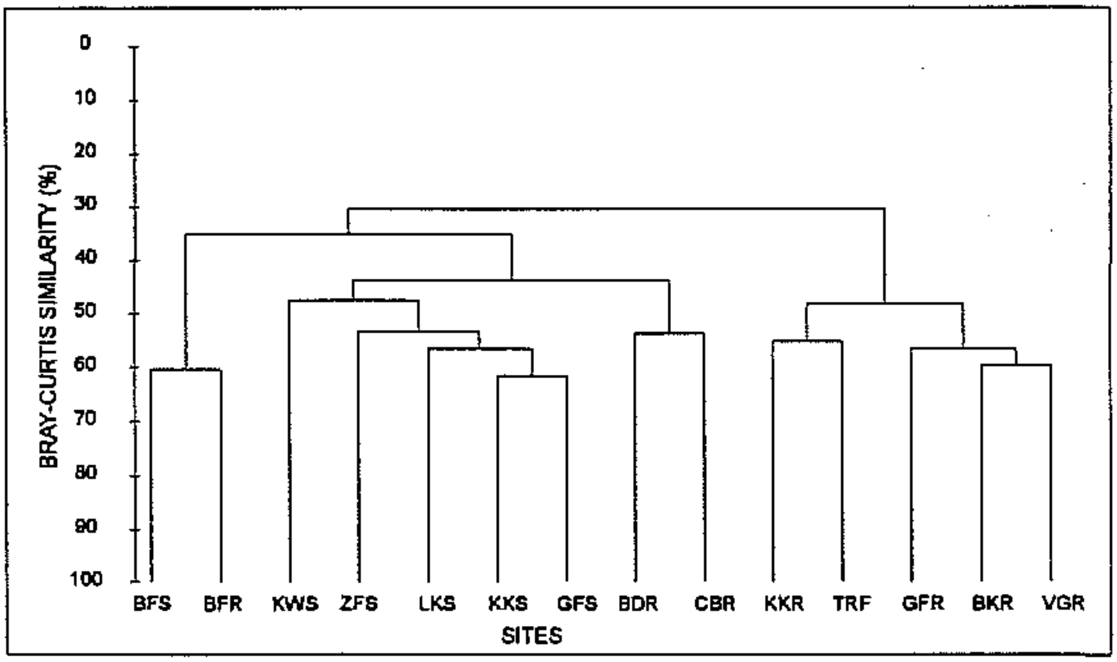


Figure 8.7 Dendrogram showing classification of the 11 macrohabitat sites of the study area based on mean sample abundances per species of benthic macroinvertebrates (summer data); samples from rock (R) and sand (S) bed areas were considered separately for sites with both types of substrate. Two main clusters of sites were distinguished at an arbitrary similarity level of 30% and six groups at 50%

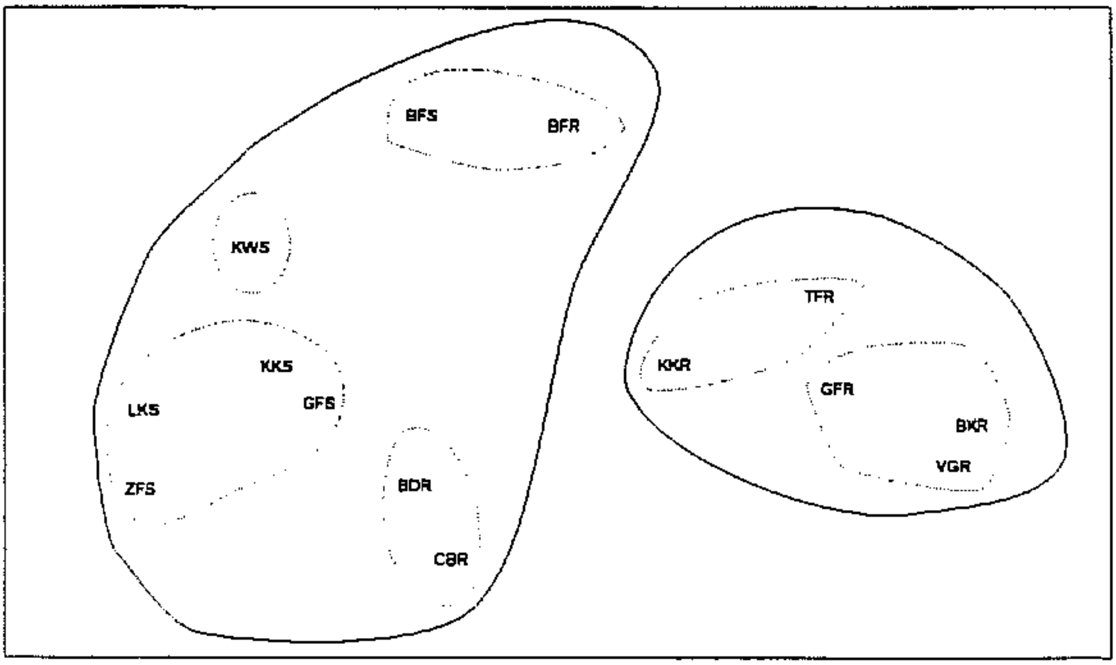


Figure 8.8 Ordination of the 11 macrohabitat sites using non-metric MDS on the same similarity matrix as Figure 8.7, based on mean sample abundances per species of benthic macroinvertebrates (summer data). Clusters at the 30% similarity level (solid line) and subclusters at the 50% level (dashed line), distinguished in the dendrogram, were superimposed. Stress = 0.086

representing sandy areas at 43.7% similarity. Klawer grouped with the other sandy sites rather than with Botha's Farm, but split off on its own at a level of similarity not much higher than that for the group as a whole. This is probably as a result of the influence of the Doring River which has its confluence with the mainstream just upstream of Klawer. Botha's Farm rock and gravel/sand sample groups separated as a cluster at a low level of similarity with all the other middle-lower reach sites, which indicated the distinctive nature of the benthic macroinvertebrate communities in this the most downstream section of the river studied. The Grootfontein and Kriedouwkrans sandy bed areas of the sites exhibited the highest degree of similarity at 61.5%. The grouping of these two upper-reach, partly sandy sites with the sandy middle and lower reach sites suggested that the sandy areas of the river are characterised by a community that is more tolerant of longitudinal changes in environmental conditions than the rocky bed fauna.

Ordination supported the classification results, and highlighted the differences between treating rock and sand areas together (combined) or independently. Particularly, it showed that the Grootfontein rocky bed component grouped with Visgat and Boschkloof, rather than with Tweefontein and Kriedouwkrans which suggested that it is the sandy bed component of the fauna at Grootfontein that resulted in this site previously grouping with Kriedouwkrans. Furthermore, Botha's Farm was shown as being quite different from Klawer due to its differences in substrate composition, especially the dominance of cobbles and gravel. The stress value of the plot was 0.086, indicating an adequate representation of the data in 2-d.

8.7 STUDY OBJECTIVES AND CONCEPTUAL BACKGROUND TO MICROHABITAT SUITABILITY INDEX CURVES FOR BENTHIC MACROINVERTEBRATES

8.7.1 STUDY OBJECTIVES

The second purpose for the collection of benthic macroinvertebrate data was to determine the instream flow requirements of this component of the biota both at the community level and for individual species, using the methods described in IFIM. The instream flow requirements for this component of the biota would then be compared with those of the fish, in an attempt to detemine the most suitable instream flow regime for two important components of the riverine ecosystem (Chapter Nine). Also, the development of physical microhabitat suitability index (SI) curves from benthic macroinvertebrate data needed to be assessed as part of the overall assessment of IFIM. In particular, the use of indices of community diversity for the development of SI curves, as opposed to standard kinds of curves for individual target species, required assessment. Furthermore, a secondary aim was to develop systematic and objective ways of constructing invertebrate SI curves, while testing some of the options available for their construction. The collection of more data for the invertebrates than for the fish allowed a more in-depth assessment of curve construction in this Chapter. Chapter Seven will be referred to for descriptions of construction methods, where possible, but additional information will be given here on aspects such as curve smoothing and the determination of curve end points.

8.7.2 HISTORICAL DEVELOPMENT OF METHODS

The majority of past research on using IFIM has focused on developing SI curves for target fish species, as input to PHABSIM II. Only recently, have benthic macroinvertebrate data been used for a similar purpose.

The determination of instream flows for benthic macroinvertebrates has generally been neglected in the past, because it has been assumed that this component of the biota would either respond to changes in flow in a similar way to fish or that the food they provide does not normally limit fish production. However, there is insufficient evidence to support either of these assumptions. Moreover, benthic macroinvertebrates have many crucial roles to play in the functioning of riverine ecosystems and are an important component of the riverine biota in their own right. Therefore, their instream flow requirements should be addressed independently of those of fish. The lower degree of mobility of invertebrates than fish, and existing evidence that many invertebrate species have narrower tolerances to changes in flow than fish (Bovee *et al.* 1978) support this argument, and indicate that invertebrates may well be equally, or even more useful in some instances, for determining the instream flow requirements of rivers. This may be especially true in cases where there is no pre-determined target fish species of economic or conservation importance in a study, but rather, a general instream flow requirement needs to be determined for the riverine ecosystem as a whole.

Several methods, models and methodologies have been developed over about the past fifteen years for predicting the distribution of benthic macroinvertebrates in relation to variables controlled by flow (see Tharme in prep., for a review). The first effort to predict the instream flow requirements of benthic macroinvertebrates was made by Gore (1978), and involved the use of three-dimensional response surfaces of pairs of selected instream physical variables, such as depth and turbulence, which were plotted against species or community diversity (or other measures of organism response such as biomass or abundance). The centroids of highest diversity of each response surface were used as a representation of optimum conditions for the species or community for the particular set of microhabitat variables being addressed. Once the response surfaces were developed, the combined preference surface for highest community diversity and its centroid representing the condition for optimum diversity, could be compared with the preference surfaces and associated centroids of individual species in order to identify potential indicator species. These would have requirements that most closely matched those of the entire community.

The theory of this method of response surfaces was later adapted by Gore & Judy (1981) for use specifically within IFIM. Gore & Judy used the basic concepts underlying standard SI curves (see Chapter Three, Sections 3.10 to 3.13) to derive mathematical techniques for constructing SI curves for benthic macroinvertebrates. Basically, the first of these techniques produced curves by what is termed the incremental method, where the best fits to the data of plots of the cumulative mean numbers of individuals of species per sample are determined as a function of arbitrary increments in velocity, depth and channel index. The region of the curve exhibiting the greatest incremental increase in cumulative mean values then represents the most suitable range of the particular microhabitat variable being assessed. Generally, third or fourth order polynomials were found to be most appropriate for representing the shape of the curve, with the first derivative of the polynomial representing the optimum value of a particular microhabitat variable for the species. More recently, though, fifth-order polynomials have been applied to benthic macroinvertebrate data (Gore 1983) in an attempt to incorporate size-related changes in the flow preferences of some species during different stages of their life cycles. The curves produced using these forms of polynomial are then normalised between zero (zero suitability) and one (maximum suitability) as for fish SI curves (see Chapter Seven), and can then be interpreted in a similar fashion.

Further development, application and testing of this basic method of SI curve construction were undertaken by Gore (1987) and Morin *et al.* (1986). Several similar methods were produced as a result of this, such as the exponential polynomial approach which was found to more adequately express the interdependence of depth and velocity than the standard incremental polynomial method. A model of polynomial regression on a single factor was also produced (Orth & Maughan 1983), where the end products of independent regression models of each microhabitat variable were then converted to suitability functions to produce SI curves. Furthermore, a multiple regression procedure has been employed to produce SI curves, as outlined in Gore & Judy (1981). Within this procedure, the SI curve for a particular microhabitat variable is calculated by dividing the partial regression equation by the maximum log-transformed abundance of the benthic macroinvertebrate species, over the range of sampled values.

Essentially, all of these methods define ways of constructing SI curves which describe the physical microhabitat requirements of benthic macroinvertebrates, using the standard variables depth, velocity, and substrate and cover (as for fish SI curves). However, more recently, work has been done on the use of models, based on the concept of hydraulic stress, which incorporate several key hydraulic variables such as shear stress and the Reynolds boundary layer number (Statzner 1981; Statzner *et al.* 1988). Protocols and models for the incorporation of these kinds of factors into PHABSIM II are currently being developed (Gore & Nestler 1988; J.A. Gore, Center for Environmental Research and Service, Troy State University, pers. comm.). The first evidence of this is provided in the latest PHABSIM II manual (Milhous *et al.* 1989) where alternative equations and associated routings through the model are provided to enable the incorporation of nose velocities and shear stress velocities into the model.

Many of these latest models using key hydraulic factors have not been verified or tested in the field. However, Statzner *et al.* (1988) and Gore & Nestler (1988) mention that this is in progress in the U.S.A. for various key hydraulic characters used for detemining habitat suitability. As a result of their limited state of development and lack of adequate verification, the use of these hydraulic variables was not considered for this study, and the shear stress and other equations provided in the most recent version of PHABSIM II were not used. Additionally, for the purposes of simplicity and direct comparison with the results obtained for fish (Chapter Nine), mean column velocity was used for construction of invertebrate SI curves for velocity.

All of the mathematically- and statistically-based approaches described above have been used for constructing SI curves with varying degrees of success, as they each have a number of fundamental assumptions and associated problems (Statzner *et al.* 1988). Some of these assumptions and problems will be dealt with in Section 8.8, where the most frequently used approaches are discussed.

8.8 GENERAL METHODS FOR DATA MANIPULATION AND CONSTRUCTION OF SI CURVES

Bovee (1986), Morhardt (1986, cited in Cheslak & Garcia 1988) and Slauson (1988) introduce and discuss some of the main techniques used to manipulate data for the construction of SI curves. A brief summary of several of these is provided in Section 7.5.2.1, and only additional information needed for the construction of SI curves with high numbers of data points is provided in this Chapter.

Of the available methods, the use of polynomials (Section 8.8.1) has been favoured historically for constructing invertebrate SI curves. However, it was not used in this study, for the reasons outlined in Section 8.8.1. Frequency analysis (Section 8.8.2) has, however, often been used with fish data and is also the method favoured for invertebrates in this study for the reasons outlined in Sections 7.5.2.1 and 8.9, and below. A further technique, that of running filters, is also discussed (Section 8.8.3), because it provides a useful way of constructing SI curves and, additionally, can be used to smooth curves created using other techniques. This technique is discussed in detail here because it could be used to some extent with the invertebrate data, but not with the lesser amount of data available for the fish.

8.8.1 REGRESSION ANALYSIS

Polynomial regression using a cubic, fourth- or higher-order polynomial (Gore 1987) is an obvious method to apply to the problem of deriving smooth SI curves from raw data (Slauson 1988). However, there are several basic assumptions and problems with this technique which render it less suitable than might be expected judging by the number of studies in which it has been used. These are discussed briefly in this Section and constitute the main reasons why this approach was not adopted here for constructing invertebrate curves.

Firstly, since species response to any microhabitat variable is generally expected to be either monotonic or unimodal rather than multimodal (Slauson 1988), the use of higher order polynomials might not be appropriate, except in specific cases (Gore 1983; Section 8.7.2). Secondly with polynomials, the data are forced to follow a specific distribution, but without biological evidence to support this distribution it would seem more acceptable to use a non-parametric technique. The fourth-order polynomials fitted by Gore & Judy (1981) and Orth & Maughan (1982), were fitted to cumulative frequencies. Tests of this procedure by Slauson (1988) produced questionably high regression statistics pertaining to the significance and strength of the regression. Moreover, there does not appear to be any obvious reason for the use of cumulative frequencies over straight frequencies. With the application of higher order polynomials, there may be instances where biologically meaningless negative frequencies, rising tails or secondary modes arise as a result of the distribution represented by the equation. In such cases, professional judgement would have to be used to modify such features before calculating the final SI curve. The assumption that variances associated with invertebrate data are similar for all values of the independent variable is also unlikely with the type of data represented by SI curves, in that high species abundances typically have high variances and the converse. Transformation of the abundance data, however, could act to overcome this problem. Unequal variances and the susceptibility of least squares regression to outliers often appear to result in poor visual fits of the data, as illustrated in Slauson (1988). Furthermore, the higher the order polynomial used in the regression, the more likely it is that the curve example, would have produced a distinct bimodality in the data with a wide range of suitable low velocities and a narrow band of suitable very high velocities. There was no reason to suppose that such bimodality would be biologically meaningful.

The end point of the upper tail was based on the same rationale as that used for the depth curve (Sections 8.9.4 and 8.10.3.1). As the highest velocity sampled at Grootfontein was within the 1.301-1.400 m^3 s^{-1} class, the tail was taken to zero at 1.500 m^3 s^{-1}. At the lower range of velocities, the tail of the curve was taken straight across to zero, so that both zero and the 0-0.100 m^3 s^{-1} class has a suitability of 0.82 (Section 8.9.4).

Based on the final preference curve for velocity (Figure 8.9), the preferred velocities for highest benthic macroinvertebrate community diversity encompassed a wider tolerance range than for depth, with the optimum velocity being within the range 0.401-0.500 m^3 s^{-1}. However, two factors should be considered. Firstly, the number of samples defining the optimum velocity class was low and the presence of a few samples of high diversity could have over-emphasised the suitability of this class. Also, the depth curve was not smoothed and as the velocity data were far more variable in terms of their relative suitability than the depth data, smoothing would have tended to have a moderating effect on curve shape.

Preference for velocity was in general agreement with that from Fouts' study (1990; Section 8.2.2), but somewhat higher velocities were found to be associated with high species diversity in the present study.

8.10.3.3 Substrate curve

The substrate preference curve comprised five envelopes representing the ten substrate combinations that were both available and utilised by the benthic macroinvertebrates (Figure 8.9). The general form of this type of microhabitat SI curve is explained in Section 8.9.3.

The total number of samples used to produce the curve was 93, with counts of samples within any one substrate code ranging from 25 to one. Substrate code 52 had the most counts, followed by code 15, then 24 and 14 respectively. All other categories exhibited five counts or less. Consequently, there was the possibility, as for the depth and velocity preference curves, that certain substrate combinations appeared more suitable than others due to an exaggerated influence of outliers. It should be noted that the preference was not necessarily highest for a particular substrate envelope, but could be similarly high for categories in different envelopes. This is a result of the curve being separated into envelopes on the basis of the proportion of sand, while the substrate types represented by the code digits were repeated in each envelope.

The most preferred substrate was 26-50% sand with cobble (Figure 8.9). Generally, high species diversity was associated with about 0-50% sand with cobble, with higher percentages of sand being increasingly less preferred than low percentages. The envelope of 76-100% sand showed the lowest associated preference, with a combination of predominantly sand and some mud (see Table 8.3) being least preferred. Sand alone, was the second lowest preferred substrate type overall. Within each envelope, where by definition the percentage of sand remains the same, bedrock or small to large boulder bed materials (defined in Table 8.3) were consistently less preferred than cobble (where cobble included large gravel). Similarly, small to medium gravel (see Table 8.3) was less preferred than cobble.

These findings agree with those of Fouts (1990), that cobble was the substrate most often associated with high species diversity. In this study, samples were generally taken from areas of low overhead cover, so the results conform with Fout's statement that areas of less than 25% cover are most suitable. Suitability for sandy areas was lower in Fout's study than in this one.

8.11 DEVELOPMENT OF SI CURVES FOR SPECIES OF BENTHIC MACROINVERTEBRATES

8.11.1 THEORY

Past work using IFIM to determine the flow requirements of invertebrates (Section 8.7.2) has been based on both community requirements and the requirements of target invertebrate species, the latter being principally used as indicators of community requirements. In this study, SI curves were developed for benthic macroinvertebrate target species for three main reasons. Firstly, they would enable comparison of the instream flow requirements of the fish (Chapter Seven) with those of the invertebrates. Secondly, the method of curve construction for target species requires independent consideration of both utilisation and availability data for the construction of the preference curves, whereas curves based on community requirements are preference curves by virtue of their method of construction (Section 8.10.2). Hence, to assess this component of the methodology, it was necessary to construct curves for individual species. Furthermore, species SI curves could enable the identification of potential indicator species for the overall community. Such indicator species could be those with flow requirements that closely matched those for highest community diversity, or those that exhibited extremely narrow physical microhabitat suitability ranges and were, therefore, highly sensitive to changes in flow.

An additional reason for developing species curves, was to compare the results with those of a previous study (Fouts 1990) where attempts were made to identify indicator species in relation to the requirements for highest community diversity. Furthermore it was hoped that the SI curves would provide the first indications of species that are characteristic of different biotopes. These biotopes, in turn, could be described by typical physical microhabitat conditions. This was considered an important longer-term aim as there were likely to be different hydraulic conditions, and hence critical flow thresholds, associated with various biotopes, such as pools and riffles. From an ecological standpoint, too, it was expected that there could be different patterns of microhabitat suitability that were characterisic of certain biotopes.

8.11.2 METHODS

Specific target species were selected mainly on the criterion of the amount of data available. An arbitrary number of not less than 35 individual records of utilisation was used for each species as it was felt that at least this number of data points would enable a fair representation of microhabitat suitability (specifically preference). This number represented the number of samples in which the species was present anywhere in the river, and did not include abundances per sample. As a result of the limited overall number of samples for which species data were available, microhabitat data were used for each target species at all sites along the river at which the species was known to occur, and not only at the PHABSIM II sites, for the purposes of constructing species SI curves. Information on species distribution ranges along the river was available from the analysis of longitudinal zonation (Section 8.6).

There were very few species with more than 35 observations of utilisation over their entire distribution range (Appendix 8.11). Furthermore, only those species with a distribution range that included the Grootfontein, Kriedouwkrans or Klawer reaches could be chosen as possible candidates, as these were the PHABSIM II sites used for the hydraulic simulations (see Chapter Nine). As a result of limited time in this study, the known acceptable quality of the hydraulic data collected at Grootfontein and the location of this site downstream of the proposed dam at Rosendaal, emphasis was placed on it for the PHABSIM II modelling. Hence, SI curves were constructed for target species with a distribution range that included the section of river represented by this site. Although the data for each species included sites on either side of the PHABSIM II sites within their distribution range, it was understood that it would probably not be possible to extrapolate the final WUA outputs beyond the PHABSIM II reaches (see Section 8.13 and Chapter Nine).

The requirement for a large data set for the SI curves, meant that curves could not be constructed for rarer and possibly flow-sensitive species, and commoner species tended to be the only suitable candidates. In future studies, where prior knowledge is available of the species composition of the study area, it would perhaps be useful to concentrate on those biotopes known to contain species with highly specific or generalised flow requirements (the latter possibly better representing community requirements).

Three target species were finally selected for the species SI curves: *Pelориolus granulosus* (Elmidae), and two chironomids; *Rheotanytarsus* sp A (Tanytarsini) and *Polypedilum ?articola* (Chironomini). All of these species fulfilled the criterion of more than 35 data points, and they were thought to be the same species as those taxa identified by Fouts (1990) as indicator species in her study at Kriedouwkrans. Furthermore, the elmid larva typically occurs in riffle and run biotopes, and *Rheotanytarsus* sp A is common in fast-flowing waters and was thus a possible flow-sensitive species. *Polypedilum ?articola* is widely distributed along the river, and was therefore chosen as a potential generalist species.

SI utilisation and preference curves for the chosen target species were created using the methods described in Section 8.9, and the results are presented in the following Section (8.11.3). Several of the required data manipulation practices for these curves, and specifically the differences in method for each of the microhabitat variables, are outlined in the following Section (see Tables 8.5 and 8.6), in addition to the information already provided in Table 8.4.

8.11.3 RESULTS

8.11.3.1 *Peloriolus granulosus* (Family Elmidae)

The data for this species were used to test whether or not it was necessary to pool data by first creating SI curves on a site-specific basis and then adding them together according to a weighting system to produce a final set of curves, or whether all data from all sites could simply be combined. The former method of pooling (Section 8.9.5) results in what are termed **composite** SI curves in this study, whereas curves resulting from pooling all data from all sites, but not in a structured way, are referred to as **combined** curves. The results from this comparison were intended to show whether or not more accurate curves would be produced by independently assessing and then pooling data from different sites, or by simply combining all the data. For the other target species discussed below, only combined curves were produced.

In order to produce composite SI curves for the elmid larva, utilisation and preference curves were constructed for each site where it occurred, and these curves were then added together to produce composite curves. All sites were allocated a weighting of one (Section 8.9.5). The site-specific utilisation and preference curves were both fitted using standard techniques for species utilisation curves (Section 8.9.4), with interpolation where necessary. No smoothing of the preference curves was attempted, due to the very low numbers of observations used to create them.

Comparisons of the SI curves for *Pelorioltus granulosus* with Fouts' (1990) results for elmid larva A (most likely the same species/species complex; A. Harrison, University of Waterloo, Canada, pers. comm.), were made for the site-specific curves for Kriedouwkrans, as this represented the most similar reach to the one used in her study.

Combined SI curves for *P. granulosus*

P. granulosus occurred between site 1 (Visgat) and site 4 (Kriedouwkrans) of the mainstream (Appendix 8.11). Sixty-four samples were used to determine microhabitat availability, using all samples collected at these five sites. Fifty-three benthic macroinvertebrate samples were found to contain this elmid and represented the utilisation data. Actual counts of the species for each sample were used, rather than presence/absence data, but all abundances were double-root transformed (Section 8.9.6).

Depth curve

The depth utilisation curve initially showed a high suitability at 0.21-0.30 m, followed by a decrease in suitability in the range 0.31-0.40 m and a subsequent increase at higher depths. The assumption was made for this curve that the bimodal peak in suitability was unlikely to be biologically realistic, and so the general decreasing trend of the curve was followed instead by interpolation, as shown in the final depth curve (Figure 8.10). The upper tail of the curve was curtailed at the midpoint of the last depth class for which utilisation data were collected (Section 8.9.4).

The preference data (Figure 8.10) required two passes of a three-point weighted mean to smooth the curve. After this smoothing process, a decision still had to be made to interpolate between the suitability values for the 0.00-0.10 m and 0.21-0.30 m classes, as the suitability for the former class was 0.88 while that of the 0.11-0.20 m class was negligibly less at 0.87. The degree of interpolation was considered minor as the difference in the suitabilities was very small at 0.01. The upper tail of the curve was extrapolated in the standard way to zero at 0.75, and its end point was determined using Method 1 (Section 8.9.4). The shape of the lower tail was determined using end point Method 2 (Section 8.9.4) Interestingly, the use of Method 1 would have reduced the high suitability allocated to the 0.00-0.10 class, which would have resulted in the preference curve more closely approaching the utilisation curve.

The raw preference curve did not show any clear trend in suitability with depth, but a general trend became evident after smoothing. The final preference curve exhibited a broader range of suitable depths than the utilisation curve (Figure 8.10), with the most suitable depth range as 0.31-0.40 m, and high suitabilities for the adjacent depth classes 0.21-0.30 m and 0.41-0.50 m.

Velocity curve

The utilisation curve for velocity (Figure 8.10) required minor interpolation between the classes 0.201-0.300 and 0.401-0.500, and between 0.401-0.500 and 0.801-0.900 m^3 s^{-1}. Comparison of the relative suitabilities for zero velocity and velocities greater than zero but less than or equal to 0.100, indicated that zero velocity was less than 10% more preferred than higher velocities in this class, so the suitability at zero was allocated the same value as the suitability for the entire 0.00-0.100 m^3 s^{-1} class.

Low velocities were most utilised, with a marked decrease in suitability after 0.100 m^3 s^{-1} which was maintained until the end class at 0.900 m^3 s^{-1}.

The raw preference curve required two passes of a three-point running mean, followed by minor interpolation to produce the final preference curve (Figure 8.10). The upper tail of the curve was taken to zero at 1.250 m^3 s^{-1}, rather than at 0.850 m^3 s^{-1}, due to the evidence of class 1.201-1.300 m^3 s^{-1} being available but not utilised, and only one observation in the highest velocity class (Section 8.9.4). There was no futher information to assist in assigning suitabilities to the 0.801-1.200 m^3 s^{-1} velocity range. The upper end point was determined using Method 1 (Section 8.9.4), followed by smoothing. The shape of the lower tail was determined using end point Method 2 (Section 8.9.4)

Generally, there was a broad range of preference for velocity (Figure 8.10), although there was a tendency for velocities between zero and 0.500 m^3 s^{-1} to be most preferred. Suitability decreased fairly rapidly after 0.600 m^3 s^{-1}.

Substrate curve

In Table 8.5, the substrate data for *P. granulosus* are used to provide an example of the manipulation procedures used with this kind of curve data, some of which also apply to depth and velocity data.

Of the eight substrate categories available over the range of sites inhabited by the elmid larva, only six were utilised (Figure 8.10); categories 51 and 25 were not utilised. Possibly, this is an accurate representation, but the absence of utilisation data could also be a function of the low number of times (twice) that these two categories were sampled. Utilisation was highest for 1-25% sand with cobble, second highest for 100% sand, and lowest for 26-50% sand with cobble.

The preference curve (Figure 8.10) indicated several shifts in suitability from those indicated by the utilisation curve. The most pronounced shift was for the code of highest suitability for each curve. In the second utilisation envelope, code 24 representing mostly cobble with a little sand (Table 8.3) was most utilised, while a substrate of mostly sand with a little cobble (code 44 of the fourth envelope; Table 8.3) was used far less. Once availability data were incorporated into the curve to generate preference envelopes, the substrate comprising mostly cobble exhibited a marked reduction in suitability and the substrate with proportionately more sand became most preferred. The secondmost preferred code was 34, again a marked shift from the utilisation curve. It should be noted that both of these substrates had only one

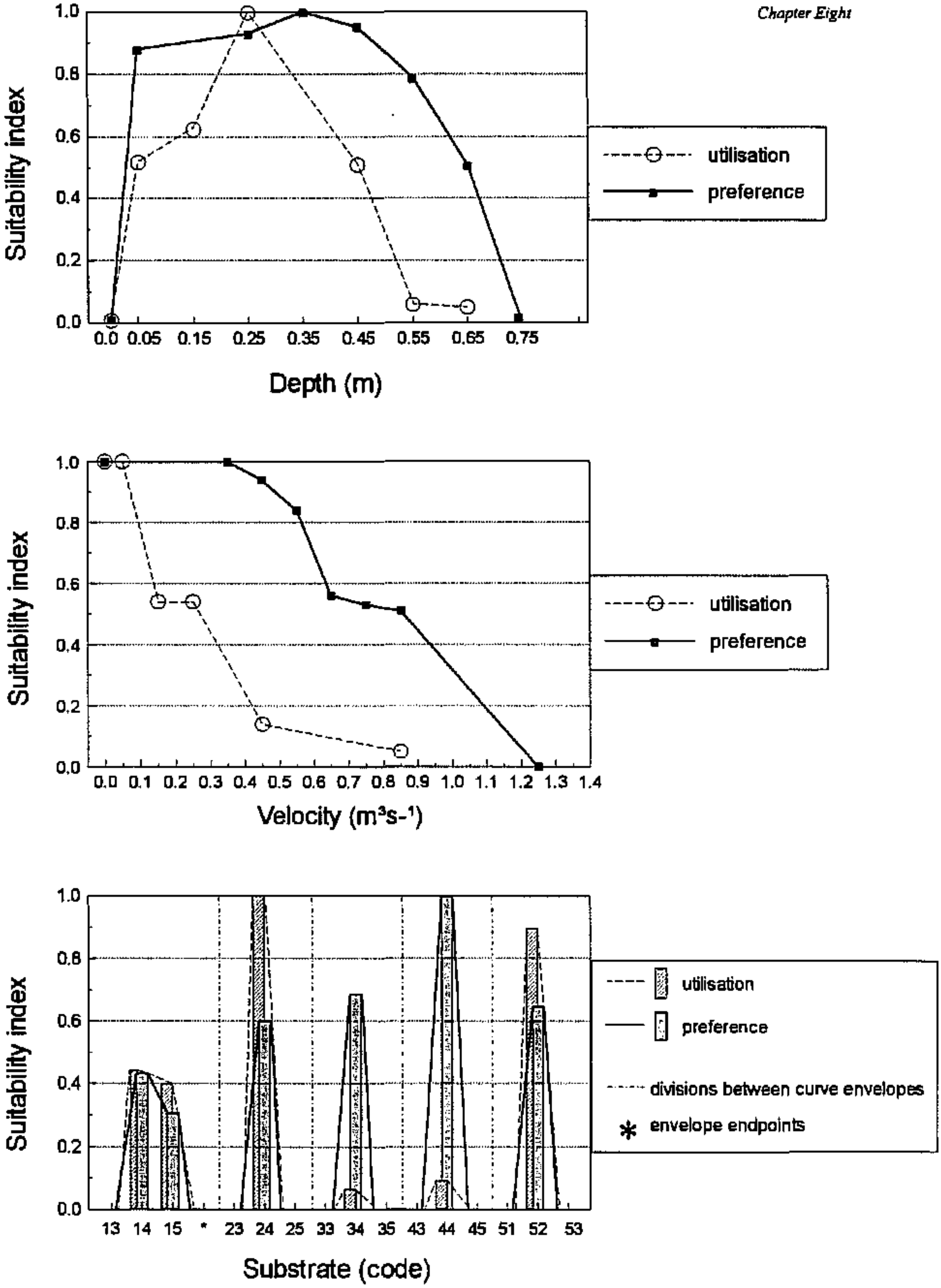


Figure 8.10 Utilisation and preference curves for depth, velocity and substrate for the elmid larva, *Peloriolus granulosis* (combined data)

observation each which could be partially responsible for their high suitability. A bedrock/boulder substrate with no sand was found to be the least suitable substrate combination overall. Within this first envelope of 0% sand, cobble substrate was more suitable than bedrock or boulders.

Composite SI curves for *P. granulosus*

Composite utilisation and preference curves for all three microhabitat variables were produced for each site at which the species occurred, for comparison with the combined curves presented above, as previously discussed. The results for all site-specific curves for all microhabitat variables are briefly described, but not all the curves are presented graphically. However, those for depth are presented to illustrate the pooling procedure (Figure 8.11). Site-specific curves for velocity and substrate were produced in a similar manner. The depth data are also used to explain the general manipulation steps undertaken when pooling microhabitat data (Table 8.6).

Many of the utilisation and preference curves for each site were very similar to each other in shape, as might be expected with low numbers of observations and the utilisation of almost all conditions that were available. Where there were more observations, namely at Grootfontein and Kriedouwkrans, the curves diverged more from each other.

Depth curves

Site-specific curves

The site-specific utilisation and preference curves for depth are depicted in Figure 8.11.

At Visgat, *P. granulosus* did not utilise waters shallower than 0.20 m, and the most utilised depths were between 0.41 and 0.50 m. The preference curve showed a reduced suitability of waters between 0.21 and 0.30 m depth.

The species utilised and preferred waters of about 0.15 m depth at Boschkloof, but this assessment was based on only two observations.

The most utilised depths at Grootfontein were from 0.21 to 0.50 m, with a maximum in the 0.21-0.30 m depth class. However, the preference curve showed a shift towards preferring deeper waters from about 0.41 to 0.60 m.

Depth utilisation and preference were similar at Tweefontein, with the deeper waters that were available, 0.21-0.30 m, being most preferred.

Very shallow waters were used at Kriedouwkrans, with gradually decreasing utilisation with increasing depth. However, when availability was considered, the actual preference of the species tended to be for deeper water from 0.21-0.30 m. Depths of >0-0.10 m and 0.31-0.40 m were also highly suitable. Comparison with the preference curve constructed by Fouts (1990) showed that slightly deeper waters were preferred based on this study.

Composite curves

The composite utilisation curve for depth required minor interpolation (Figure 8.12), while the preference curve needed only one smooth. The tails of both curves were constructed based on the methods of Section 8.9.4.

Table 8.5 Data manipulation procedures for the construction of substrate utilisation and preference curves for the elmid larva, *Peloriolus granulosus*

		SUBSTRATE CODE (see Table 8.3)							
PROCEDURE	**RESULTANT DATA FORMAT PER SUBSTRATE CODE**	**14**	**15**	**24**	**25**	**34**	**44**	**51**	**52**
Utilisation curve									
1. Sum root-root transformed abundances for the species for all samples in which it occurs, for each substrate code; over all sites representing species distribution range	total transformed count	28.07	25.41	63.81	0	4.05	5.89	0	57.25
2. Divide total transformed count per substrate code (1.) by total transformed count summed over all substrate codes (= 184.48)	relative frequency	0.15	0.14	0.35	0	0.02	0.03	0	0.31
3. Divide relative frequency per substrate code (2.) by highest relative frequency. Plot as utilisation curve	normalised utilisation	0.44	0.40	1.00	0	0.06	0.09	0	0.90
Preference curve									
4. Calculate availability of substrate codes by summing number of samples of each code. Include samples without species and with it; over all sites representing species distribution range	total number samples available	11	14	18	2	1	1	2	15
5. Divide *total transformed count* per substrate code (1.) by availability of each substrate code (4.)	*relative frequency*	2.55	1.81	3.55	0	4.05	5.89	0	3.82
6. Divide relative frequency per substrate code (5.) by highest relative frequency. Plot as preference curve	normalised preference	0.43	0.31	0.60	0	0.69	1.00	0	0.65

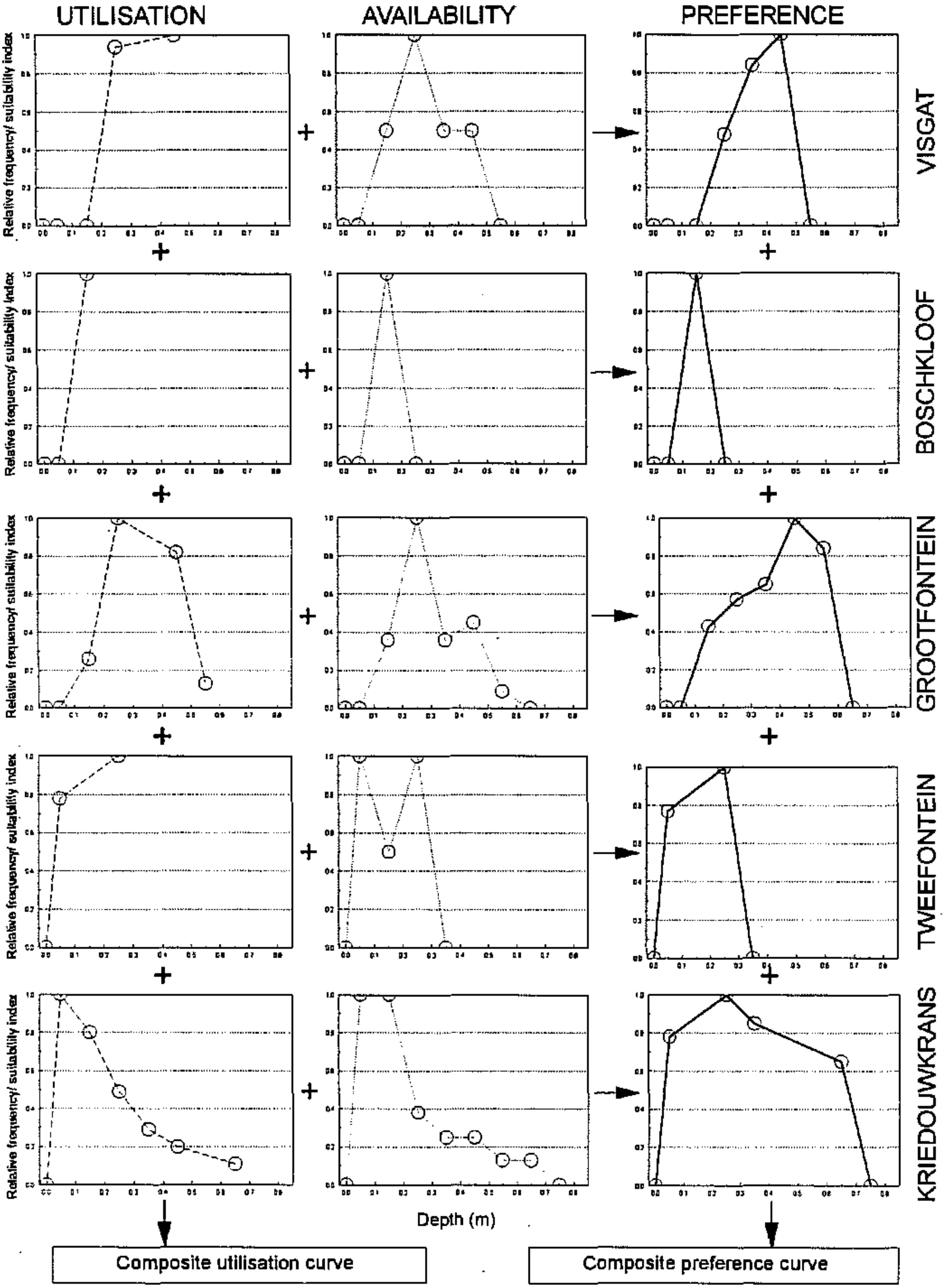


Figure 8.11 Utilisation, availability and preference curves for depth for the elmid larva *Peloriolus granulosis*, for five adjacent sites along the river. These curves are pooled to produce composite utilisation and preference curves for this species (see Figure 8.12)

Table 8.6 **Data manipulation procedures for producing composite depth utilisation and preference curves from pooled site-specific curves, for the elmid larva, *Peloriolus granulosus***

			DEPTH CLASS (m)						
SITE	**PROCEDURE**	**RESULTANT DATA FORMAT PER DEPTH CLASS**	**0.00-0.10**	**0.11-0.20**	**0.21-0.30**	**0.31-0.40**	**0.41-0.50**	**0.51-0.60**	**0.61-0.70**
VISGAT	**Utilisation curve**								
	1. Sum root-root transformed abundances for the species for all samples in which it occurs, for each class interval	total transformed count	0	0	4.2	3.7	4.4	0	0
	2. Divide total transformed count per class interval (1.) by total transformed count summed over all class intervals (= 12.3 for Visgat)	relative frequency	0	0	0.34	0.30	0.36	0	0
	3. Divide relative frequency per class interval (2.) by highest relative frequency	normalised utilisation	0	0	0.94	0.83	1.00	0	0
	Preference curve								
	4. Calculate availability of depths by summing number of samples in each class interval. Use all samples, without and with species	total number samples available	0	1	2	1	1	0	0
	5. Divide total transformed count per class interval (1.) by depth availability (4.)	relative frequency	0	0	2.1	3.7	4.4	0	0
	6. Divide relative frequency per class interval (5.) by highest relative frequency. Determine values of end points (see text for explanation)	normalised preference	0	0	0.48	0.84	1.00	0	0
BOSCHKLOOF	1. - 6. using only samples collected at this site	normalised utilisation	0	1.00	0	0	0	0	0
		normalised preference	0	1.00	0	0	0	0	0
GROOTFONTEIN	1. - 6. using only samples collected at this site	normalised utilisation	0	0.26	1.00	0.42	0.82	0.13	0
		normalised preference	0	0.43	0.57	0.65	1.00	0.84	0
TWEEFONTEIN	1. - 6. using only samples collected at this site	normalised utilisation	0.78	0.27	1.00	0	0	0	0
		normalised preference	0.77	0.51	1.00	0	0	0	0
KRIEDOUWKRANS	1. - 6. using only samples collected at this site	normalised utilisation	1.00	0.80	0.49	0.29	0.20	0	0.11
		normalised preference	0.76	0.83	1.00	0.85	0.59	0	0.65

Table 8.6 continued

PROCEDURE	RESULTANT DATA FORMAT PER DEPTH CLASS	DEPTH CLASS (m)						
		0.00-0.10	0.11-0.20	0.21-0.30	0.31-0.40	0.41-0.50	0.51-0.60	0.61-0.70
Combined utilisation curve								
7. Allocate a weighting to each site: all 5 sites given equal weighting = 1	site-specific weighting factor							
8. Sum normalised utilisation values for all sites (3.) and divide by total weighting = 5								
• Total ÷ 5	relative frequency	0.356	0.466	0.686	0.308	0.404	0.026	0.022
9. Divide relative frequency per class interval (8.) by highest relative frequency. Determine curve end points (see text for explanation)	normalised combined utilisation	0.52	0.68	1.00	0.45	0.59	0.04	0.03
Combined preference curve								
10. Sum normalised preference values for all sites (6.) and divide by total weighting (= 5, as for utilisation)								
• Total ÷ 5	relative frequency	0.310	0.514	0.610	0.468	0.518	0.168	0.130
11. Divide relative frequency per class interval (10.) by highest relative frequency. Determine curve end points (see text for explanation)	normalised combined preference	0.51	0.84	1.00	0.77	0.85	0.28	0.21

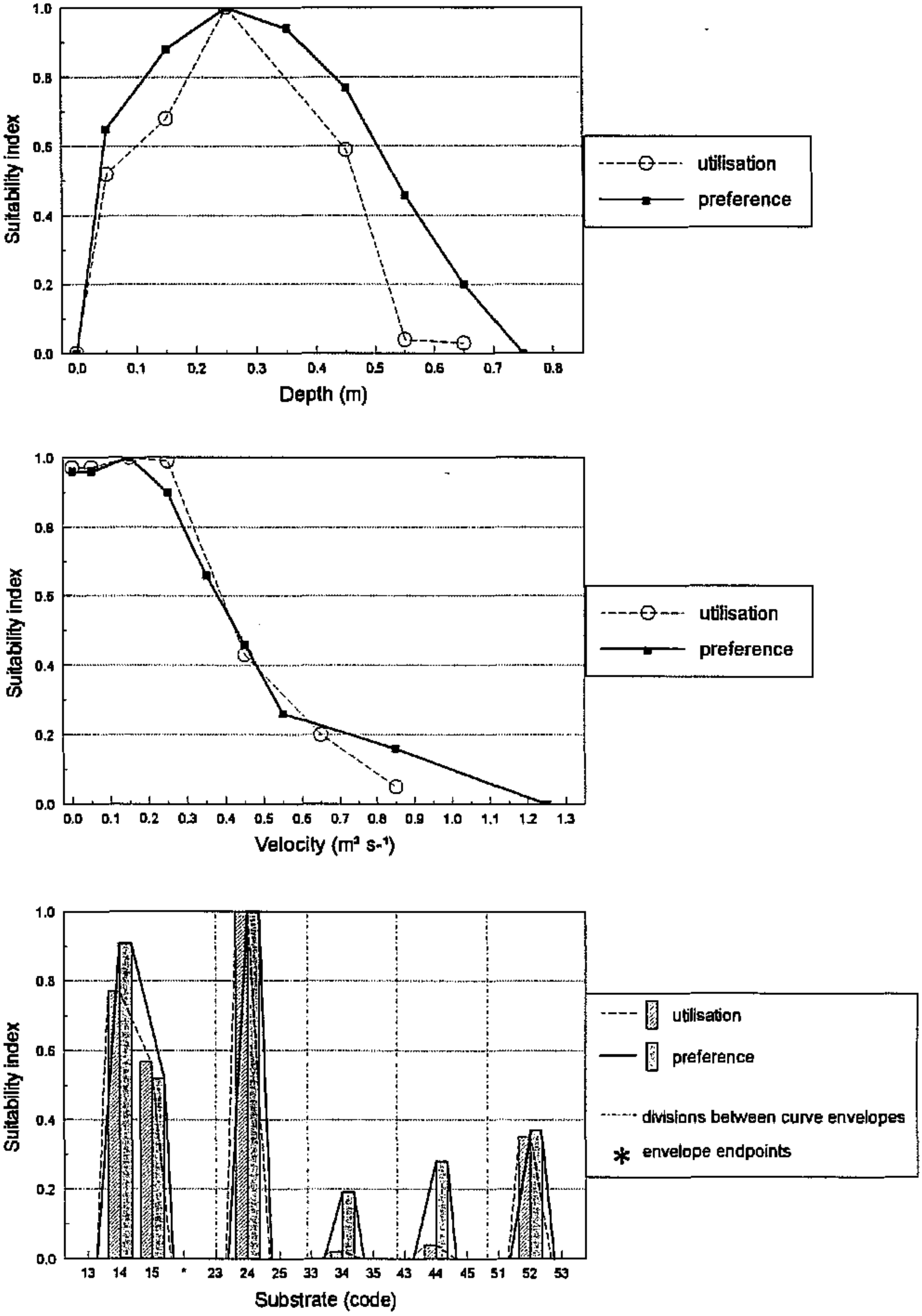


Figure 8.12 **Composite utilisation and preference curves for depth, velocity and substrate for the elmid larva *Peloriolus granulosis*, from the pooled data from five sites**

Both curves exhibited very similar trends, with depths of 0.21-0.30 m being most utilised and most preferred by the elmid larva.

Comparison of composite and combined curves
The composite and combined utilisation curves (Figures 8.12 and 8.10, respectively) showed extremely similar suitabilities for utilisation, with maximum utilisation in the range 0.21-0.30 m.

However, the combined depth preference curve (Figure 8.10) indicated a higher preference for deeper waters, for the elmid, than did the composite curve (Figure 8.12). The former showed maximum preference was attained in the 0.31-0.40 m class as opposed to the 0.21-0.30 m class for the pooled data.

Velocity curves

Site-specific curves
At Visgat, the utilisation and preference curves both showed a low suitability for near-zero velocities, and a narrow peak of maximum suitability between 0.101 and 0.200 $m^3 s^{-1}$.

A broader range of velocities was utilised at Boschkloof than at Visgat, with a gradual increase in utilisation from velocities just above zero to a maximum for the 0.401-0.500 $m^3 s^{-1}$ class interval. The preference curve showed the same peak in suitability, and extended the broadness of the curve to include higher velocities from 0.501 $m^3 s^{-1}$. As for Visgat, there was a zero suitability for zero velocity.

The elmid larva showed a low utilisation of zero velocity areas, at Grootfontein. The utilisation peak was fairly narrow and decreased sharply at velocities exceeding 0.300 $m^3 s^{-1}$. The preference curve differed markedly, displaying a broad range of velocities that were more than 0.80 suitable, from 0.101 $m^3 s^{-1}$ to a maximum for the 0.801-0.900 $m^3 s^{-1}$ class interval.

Velocity utilisation and preference curves were highly similar in shape for Tweefontein, both with no suitability for zero velocity areas. Velocities over the range > 0 to 0.350 $m^3 s^{-1}$ were most suitable, but velocities of about 0.601-0.700 $m^3 s^{-1}$ were still moderately suitable.

Low and zero velocities were found to be most utilised and preferred at Kriedouwkrans, in contrast with the other sites. There was a sharp decrease in utilisation after 0.100 $m^3 s^{-1}$, but this was absent for the preference curve where there was a gradual decrease in preference with increasing velocity. Velocities only became highly unsuitable once they exceeded about 0.650 $m^3 s^{-1}$. The results from Fouts (1990) showed a greater preference for higher velocities than represented by the most preferred class in this study, although such velocities were also highly suitable on the basis of this study.

Composite curves
The pooled velocity utilisation and smoothed preference curves (Figure 8.12) were very similar. They showed high suitabilites for zero and low velocities, and a decrease in suitability after about 0.300 $m^3 s^{-1}$. The most preferred velocity class matched the most utilised one, namely 0.101-0.200 $m^3 s^{-1}$. The preference curve required smoothing and minor interpolation in the upper tail. This was extended to zero at 1.250 $m^3 s^{-1}$ as the highest class used by the species contained only one observation, and there was evidence to suggest that higher

velocities were not used when available (Section 8.9.4). Possibly, the high preference for zero was over-emphasised by continuing the curve straight across from the 0-0.100 $m^3 s^{-1}$ class, but there does not appear to be any standard way of pooling data for the tails of curves.

Comparison of composite and combined curves
Comparison of the composite utilisation curve (Figure 8.12) with the combined one (Figure 8.10), showed that the latter curve exhibited a more rapid decrease in suitability with increasing velocity, and the highest utilisation occurred at very low velocities. In contrast, the composite curve showed a gradual decrease in suitability, and a shift towards greater use of faster waters.

The composite preference curve (Figure 8.12) showed a far narrower range of preferred velocities than the non-pooled curve (Figure 8.10). Both curves indicated that slow-flowing waters were highly suitable.

Substrate curves

Site-specific curves
The utilisation curve for Visgat indicated that the elmid was utilising three of the four available substrate categories; sandy areas (1-25%) with bedrock and boulders were not used. The most utilised substrate was cobble with a small percentage of sand, while bedrock or cobble areas with no sand were also highly utilised. The preference curve was extremely similar, and indicated that cobble with a small percentage of sand was the most preferred substrate overall.

The substrate preference and utilisation curves for Boschkloof were extremely similar to each other and to the preference curve for Visgat. Both sites had the same dominant substrate categories, but the suitability for cobble with a small amount of sand was far higher than for the other two categories.

At Grootfontein, five of six substrates were utilised; a combination of a high percentage of sand with mud was not used. Cobble with a small percentage of sand was most utilised, while all other substrates had suitabilities lower than 0.2. The preference curve indicated a shift to a highest preference for cobble areas with no sand, while various other proportions of sand with cobble exhibited suitabilities higher than 50%. No bedrock areas were available to the species at this site, but areas of only sand were used.

At Tweefontein, cobble was the only dominant substrate, with either no or a little sand. Cobble with no sand was most utilised, but cobble with a little sand was more preferred; this shift could have been due to the single data point for the latter substrate combination being linked to a high abundance of *P. granulosus*.

All of the three combinations of substrate available at Kriedouwkrans were utilised by the elmid: cobble and bedrock, both without sand; and sand only. Sandy areas were most preferred, and there was a slightly higher preference for cobble than for bedrock, although the latter predominated in terms of its availability. *P. granulosus* exhibited a preference for small gravel in the earlier study by Fouts (1990) at a site near Kriedouwkrans. Some small gravel would likely be included in the sand found to be most suitable in this study. Comparison was limited due to the differences in the substrates sampled and available in each reach.

Composite curves
Of the six substrate combinations utilised, cobble with a small proportion of sand (1-25%) had the highest suitability although other proportions of these two substrates and particularly cobble with no sand were also suitable (Figure 8.12). Bedrock was less utilised than cobble, and sand had a low degree of utilisation.

The composite preference and utilisation curves were extremely similar (Figure 8.12), both showing that cobble with little sand was most suitable.

Comparison of composite and combined curves
Comparison of the composite (Figure 8.12) and combined (Figure 8.10) utilisation curves, indicated that both methods produced a similar final curve with cobble and a small percentage of sand being most utilised. However, sand showed a higher suitability in the combined curve than in the composite one, and was more suitable in the former case than either bedrock or cobble with no sand.

The composite and combined preference curves (Figures 8.12 and 8.10, respectively), were somewhat different from each other. The composite pooled data reflected a more pronounced preference for cobble with low proportions of sand, while sand and cobble with high proportions of sand were more suitable based on the combined curve.

8.11.3.2 *Rheotanytarsus* sp A (Family Chironomidae)

The second species for which SI curves were produced, *Rheotanytarsus* sp A, had a fairly widespread distribution in the upper and middle river reaches, from Visgat to Bulshoek. Seventy-nine samples were taken in these reaches (constituting the availability data), and *Rheotanytarsus* sp A occurred in 36 of these. For this species, only combined SI curves were constructed, but two methods of determining end points were used to develop the preference curve (Section 8.9.4).

Depth curve

The most utilised depths (Figure 8.13) were in the range >0-0.10 m, but all depths from this class to 0.50 m had suitabilities above 80%. However, the entire curve had to be interpolated between the first and last classes utilised.

To explore the two methods of determining curve end points described earlier (Section 8.9.4), the depth preference curve was first constructed with a single smooth, followed by calculation of end points using Method 3 (Figure 8.13). This curve showed a preference of greater than 80% for all observed depth classes, with maximum preference being attained for the 0.41-0.50 m class. Again, considerable interpolation was required between the first and last depth classes. The slope of the SI curve shifted from a positive slope for utilisation to a negative slope for this preference curve. Next, the preference curve was constructed using the Method 2 for the lower tail and Method 1 for the upper tail (Figure 8.13). This curve showed a very similar trend in suitability and slope to that of the utilisation curve, and interpolation was also required for this curve. Maximum preference was for depths at the lower end of the range, but all classes again showed suitabilities exceeding 0.80.

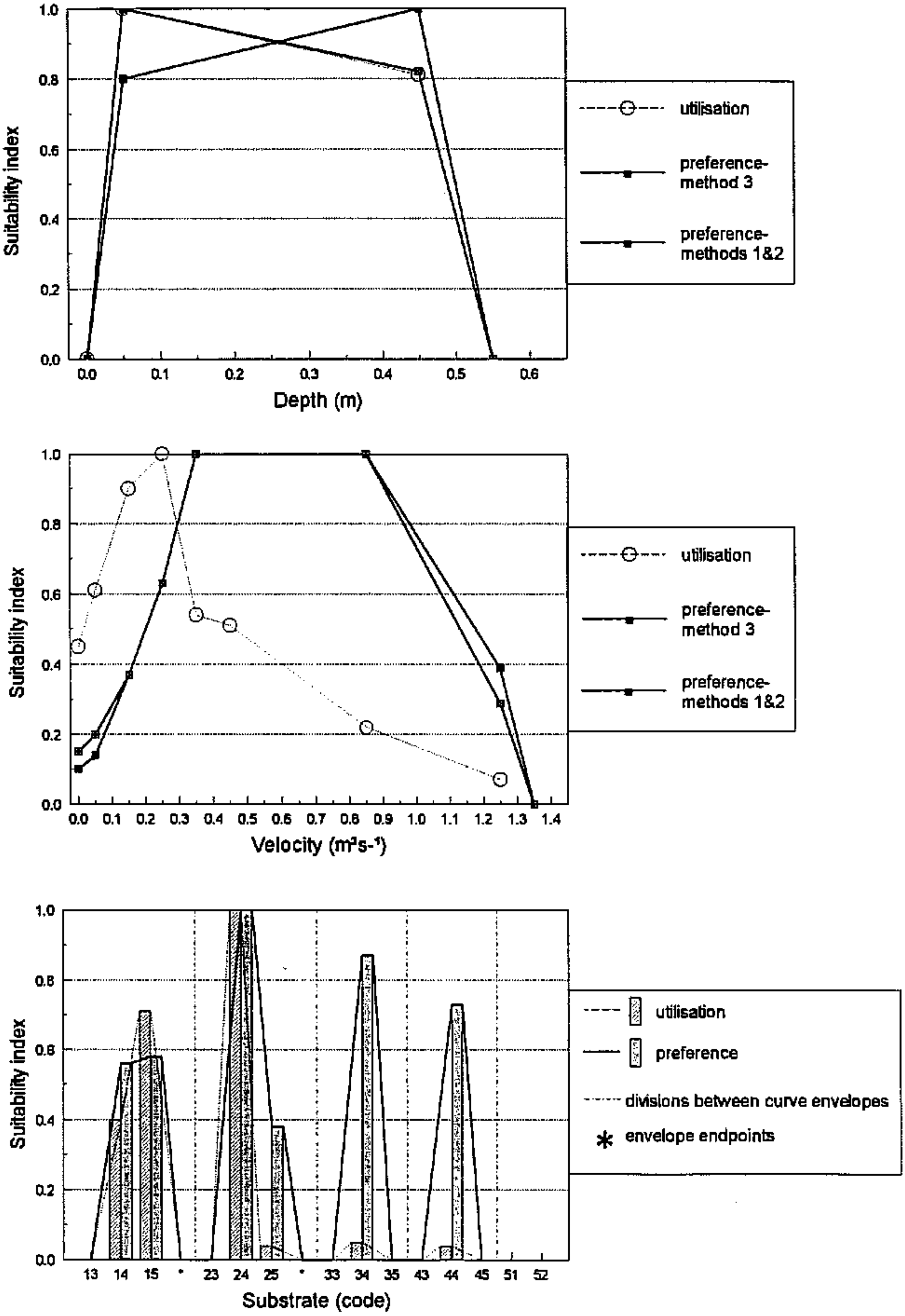


Figure 8.13 **Utilisation and preference curves for depth, velocity and substrate for the chironomid larva, *Rheotanytarsus* sp A. Two forms of the depth and velocity preference curves are presented based on different construction methods**

Comparison of the end point created using Methods 1 to 3 indicated that: for the lower tail, Methods 3 and 2 produced similar non-normalised values of 0.67 and 0.72 respectively, and Method 1 a lower value of 0.49; for the upper tail, Methods 3 and 2 produced the same result of 0.84, and Method 1 a reduced end point value of 0.59.

The two preference curves indicate that the use of different construction methods, end point methods in this instance, can influence the shape of an SI curve. Here, for example, the depths exhibiting maximum suitablity were at opposite ends of the preference curves created using the two methods, although the effect was not great overall as suitabilites were very high over the rest of the range for both curves. If the middle depth range had been better represented in terms of the number of observations in each class, it would have been possible to determine a more correct (i.e. more realistically reflecting the natural situation) curve shape.

The depth preference obtained by Fouts (1990) for this species fell within the middle of the range of depths that were found to be more than 80% suitable in this study; this was probably the result of the data for the earlier study being for only one site, while data from eight sites were used here.

Velocity curve

The utilisation curve showed a marked peak in utilisation (above about 0.60 suitability) over a narrow velocity range from 0.101-0.300 $m^3 s^{-1}$, with the higher of the two classes comprising this range being most utilised (Figure 8.13). Some interpolation was necessary in the upper tail (above 0.500 $m^3 s^{-1}$) of the curve where there were several classes without any observations.

The preference curves constructed using, firstly, only Method 3 and, secondly, Methods 1 and 2 (Figure 8.13), were similar except at the very ends of the curves. Preference was highest for both curves over a broad range of high velocities from 0.301-0.900 $m^3 s^{-1}$. A high degree of interpolation was necessary both in the middle of the range of velocities and for the upper tail for these curves.

Comparison of the non-normalised end points calculated from each of the three methods showed that: for the lower tail, Methods 3 and 2 produced similar non-normalised values of 0.08 and 0.12 respectively; for the upper tail, Method 3 produced a value of 0.23 which was similar to the end point value of 0.17 for Method 1.

The velocity preference curve developed by Fouts (1990) showed a similar trend to that of this study, with least tolerance for low velocities and preference for high velocities at the lower end of the broad range of preferred velocities shown in Figure 8.13.

Substrate curve

Substrate utilisation (Figure 8.13) was greatest for cobble bed areas with very low proportions of sand. Both sand-free cobble and bedrock areas were utilised, with no obvious difference in suitability between the two. There was zero utilisation of sandy areas.

The clearest result from the substrate preference curve (Figure 8.13) was the complete lack of suitability of sand areas, although such areas were available to this species in a high proportion (n = 20 samples). This would suggest that the marked elevation in suitability from utilisation to preference envelopes for combinations of proportions of sand greater than 26-75% with the remainder cobble, would probably be more an indication of a requirement for cobble than of a preference for large amounts of sand. If all substrate codes containing cobble as the units category, i.e. 14, 24, 34, and 44 are compared, there is an obvious gradual decrease in suitability as the proportion of sand increases, with 1-25% sand and cobble being most preferred. Although there is a decrease in preference from cobble areas with some sand, to areas with similar proportions but of bedrock and sand, the trend is less clear from the envelope encompassing the zero sand with cobble or bedrock codes. Thus, no firm statement would seem possible regarding the relative preference of this species for these rock substrates; possibly this a function of an approximately equal preference for either substrate.

Fouts' results (1990) supported the unsuitability of sandy or muddy substrates, and the wide range of suitable cobble sizes for this species. No information was available from this earlier study on the degree of suitability of bedrock areas for comparison.

8.11.3.3 *Polypedilum ?articola* (Family Chironomidae)

As for *Rheotanytarsus* sp. A, only combined SI curves were constructed for *Polypedilum ?articola*, but two methods of determining end points were used to develop the preference curve (Section 8.9.4). *P. ?articola* exhibited an extremely wide distribution, and was found at all 11 study sites from Visgat in the upper river to the most downstream site sampled, Botha's Farm, in the lower river. It was found in 88 of the 93 benthic macroinvertebrate samples collected and was therefore the commonest species sampled. The number of observations of utilisation was thus 88, and of availability was 93.

On the basis of the common occurrence of this species, the SI curves were expected to be fairly generalised without many obvious preferences for certain microhabitat conditions. Also, although there was a high number of observations for this species, these observations were shared among a high number of class intervals and substrate codes. Thus, there was a high potential for bias of the preference curves, associated with the possibility of low numbers of observations in some classes or codes.

Depth curve

Depths of 0.11-0.20 m were most utilised by this species (Figure 8.14), while preference for depth was found to be over a far wider range (Figure 8.14). No interpolation was required for either curve type, although the preference curve was smoothed once.

Using Method 3 for the upper preference tail and Method 2 for the lower tail, 0-0.10 m was the most preferred depth class, but depths from 0.11-0.50 m also had high suitabilities (greater than or equal to 85%) (Figure 8.14). Using Method 1, a similar trend was produced, but with reduced suitability for depths greater than 0.40 m (Figure 8.14).

Comparison of the lower tail for Methods 1, 2 and 3 indicated that Method 3 gave an intermediate non-normalised end point value (0.86), closest to that of Method 2 (0.93; Method 1 = 0.68). Comparison of the upper tail values indicated a similar pattern, although all three results were very similar (Method 1 = 0.44; Method 2 = 0.58; Method 3 = 0.55).

Depth preference for *Polypedilum* larvae, in the study by Fouts (1990), was within the lower intervals of the fairly wide range of highly suitable depths for the present study. The additional data collected in this study showed a shift within this range to preferring even shallower water (< 0.10 m).

Velocity curve

The velocity utilisation curve showed that very slow velocities were most utilised (Figure 8.14), and that the degree of suitability decreased sharply after about 0.150 m^3 s^{-1} and remained low from then onwards. A small degree of interpolation was required for this curve (velocity classes 0.101-0.200 and 0.501-0.600 m^3 s^{-1}).

The smoothed velocity preference curve determined using Method 3 and one pass of the three-point filter (Figure 8.14) indicated a marked shift towards higher velocities, with the most preferred being from 0.601-0.700 m^3 s^{-1} and a wide range of highly suitable velocities extending from 0.101-0.901 m^3 s^{-1}. Methods 1 and 2 produced a similar trend, but with a sharper decrease in preference after 0.800 m^3 s^{-1}. The velocity preference curves constructed using both methods required interpolation for classes 0.401-0.500 and 0.501-0.600 m^3 s^{-1} after the smooth.

Comparison of the lower velocity tail for Methods 1, 2 and 3 indicated that Method 3 gave an intermediate non-normalised end point value (0.68) extremely similar to the 0.70 value of Method 2. For the upper tail, Method 1 resulted in the lowest value of 0.53, while Methods 2 and 3 gave end points of 0.70 and 0.74 respectively.

Although both Fouts (1990) and this study indicated that *Polypedilum* (assumed to be the same species in both studies) had a wide preference for velocity, this study showed a greatest preference for velocities that were considerably higher.

Substrate curve

P. ?articola utilised all ten substrate categories that were recorded as available to it. Of these, 100% sand was the most utilised, followed by bedrock with no sand (Figure 8.14).

The substrate preference curve (Figure 8.14) indicated that this species found most types of substrate combinations moderately suitable. Although sand was still highly suitable, there was a shift to highest preference for 51-75% sand with some small to medium gravel (Table 8.3). Although there were low numbers of observations associated with codes 33 and 43, which might suggest that part of the shift was due to the effects of random sampling, there were high numbers of observations of the species using sandy areas. This would indicate that there is a definite preference for smaller bed materials such as sand and gravel. Within any one rock type, such as cobble, there was little evidence of a trend of increasing or decreasing suitability as the proportion of sand increased.

The study by Fouts (1990) indicated a preference by this species for small boulders, in strong contrast to that for small substrate sizes found in this study. This is probably the result of her study being at only one site, while the species was sampled at 11 sites in this study.

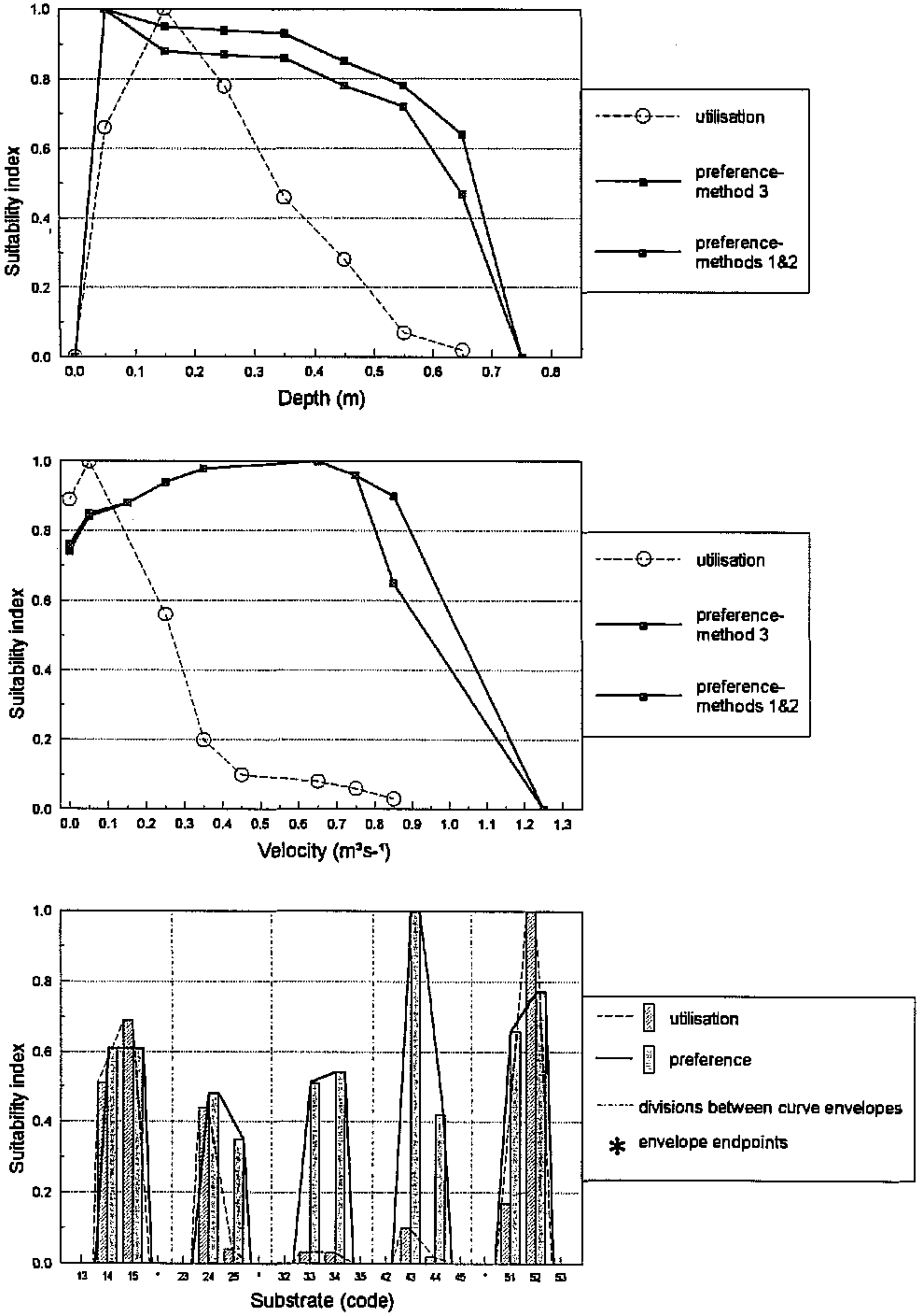


Figure 8.14 Utilisation and preference curves for depth, velocity and substrate for the chironomid larva, *Polypedilum ?articola*. Two forms of the depth and velocity preference curves are presented based on different construction methods

8.11.4 IDENTIFICATION OF INDICATOR SPECIES

Comparisons were made between the highest preferences of the most diverse macroinvertebrate community and the target species, in an attempt to identify indicator species (Table 8.7). Fouts (1990) had selected potential indicator species as being those with microhabitat tolerances in the range of those of the entire community, but of narrower range.

Table 8.7 Summary of the most preferred physical microhabitat requirements for highest benthic macroinvertebrate community diversity, and of selected target species. Values marked with asterices denote the maximum requirement for each microhabitat variable. The species in bold is a potential indicator species

COMMUNITY/ TARGET SPECIES	DEPTH (m)	VELOCITY $(m^3 s^{-1})$	SUBSTRATE
community diversity	0.41-0.50*	0.401-0.500	26-50% sand with cobble
Peloriolus granulosus (composite curves)	0.21-0.30	0.101-0.200	1-25% sand with cobble
Peloriolus granulosus (combined curves)	0.31-0.40	0-0.500	51-75% sand with cobble
Rheotanytarsus **sp. A**	0.41-0.50*	0.301-0.900*	1-25% sand with cobble
Polypedilum ?articola	> 0-0.10	0.601-0.700	51-75% sand with gravel

For this study, *Polypedilum ?articola* was not considered a suitable indicator species as none of its microhabitat requirements matched those of the community (Table 8.7). The elmid larva, *Peloriolus granulosus*, had a range of depth and substrate requirements that was narrower than those of the community but within them (Table 8.7; composite SI curve data). However, it required slower water. The tanytarsinid, *Rheotanytarsus* sp. A, proved to be the most suitable species for a potential indicator, although only its substrate requirement was in a narrower range than that for highest community diversity (Table 8.7). Although these comparisons assisted in identifying a potential indicator species, this would have to be confirmed by comparison of the WUA-Q output for the species with that for community diversity (Chapter Nine).

A further means of determining overall invertebrate microhabitat requirements could be to ensure that the maximum requirement for each microhabitat variable was satisfied. For depth and velocity, this could be feasible, while substrate requirements would have to be assessed independently. In this study, however, microhabitat ranges were often very broad (Table 8.7), and it might be more suitable just to focus on the flow-related requirements for maximum community diversity. Certainly, if no obvious indicator species could be determined, this would be the most suitable option.

As discussed above (Section 8.11.1), it was hoped that the SI curves produced in this study would also assist in possibly identifying species which were representative of specific biotopes. Identification of specialised or narrow preferences for depth, velocity and channel index, such as the lack of suitability of sand but suitability of cobble for the species *Rheotanytarsus* sp. A, provides the first step towards this. However, detailed information on the physical microhabitat conditions characterising various biotopes would be necessary before "biotope indicators" could be identified.

8.12 GENERAL COMMENTS ON THE CONSTRUCTION AND INTERPRETATION OF SI CURVES

A series of standard ways of dealing with problems was devised and implemented for the purpose of creating the SI curves. However, these solutions are not necessarily the most suitable or correct ones. The construction of SI curves, particularly those for invertebrates, is a rapidly developing field within IFIM. There is thus much scope for evaluating and improving existing techniques, and developing and testing alternatives. Little specific information is provided in the literature on actual curve construction techniques, and SI curves have tended to be presented in their final form without any explanation of the construction procedures employed. A recent document by Bovee & Zuboy (1988) provides the first detailed account of some of the methods for developing SI curves, and mentions possible problems. However, there is as yet no existing comprehensive text on this topic.

The number of data points used in the construction of each curve was perhaps the fundamental and highest contributor to the problems experienced with the construction of SI curves. Possibly, the arbitarary threshold of 35 data points was too low for the construction of clear curves. This was particularly problematic with the creation of composite curves (Section 8.11.3), because the site-specific curves often comprised as few as two or three data points for utilisation and four or five for availability. However, the numbers of points for utilisation and availability, although very low, tended to be similar so there was less opportunity for shifts in curve shape associated with either low utilisation in conjunction with high availability or vice versa. It did mean, though, that the curves for utilisation and preference for a site were similar and might have resulted in overemphasis of preference. The other kind of situation that was problematic was where, for example, a single observation of high abundance at a particular depth corresponded with a single record of availability within the same depth class, so that it appeared that all available depths in this range were being utilised, (albeit based on one record of each). A very high preference would then have been accorded this depth class. This kind of bias was often encountered for the above curves, and it would be impossible to be sure whether the resultant shifts in suitability were only partially a function of this bias, without more observations of utilisation and availability. Such shifts thus require additional data for their verification.

It was clear that different methods of curve construction such as those used for interpolation, smoothing, and determining end point values, produced different curve shapes. Moreover, it was not always simple to predict whether or not a different method would produce a different or similar curve. For instance, no assessment was made here of the differences in curve shape that could result from the use of different frequency class intervals. Class intervals selected were felt to be sufficiently wide to prevent the generation of high numbers of outliers, while being narrow enough to sensitively detect trends in the data. This could be verified in future through the construction of curves from frequency histograms of different class intervals using the same data set, as was done by Cheslak & Garcia (1988). In this study, it was particularly useful to retain the same class intervals for all SI curves for a particular variable to facilitate comparisons between curves. Although there were no obvious problems arising from the choice of class interval, it may have been useful to have increased the width of the outermost classes to reduce the occurrence of potential outliers of high suitability or to have used a curve construction method that smoothed the raw data without a need for grouping into classes, for example running filters (Section 8.8.3). However, these approaches do not seem to be widely used (Cheslak & Garcia 1988).

Curve smoothing (see Sections 8.8.3 and 8.9.4) was avoided, where possible, largely because of the uncertainty associated with three main issues: deciding on the smoothed values of curve end points (Section 8.11.3); the differences in the results obtained when using one or more passes of the filter used (the use of different filters would also produce differences in curve shape; Section 8.11.3); and the relative merit of smoothing only once or at all, versus interpolation where the broadest curve outline was taken as the curve. It was considered likely that the use of interpolation rather than smoothing would result in a more generalised curve, providing a more conservative if not as accurate an estimate of suitability.

The tails of the SI curves presented one of the greatest problems of curve construction for the depth and velocity curves. This was largely due to the high degree of uncertainty associated with the suitability values of the end class intervals of each curve. This was especially true of the upper tail of each curve, which tended to be more poorly defined in terms of data than the rest of the curve. The numbers of data points in each class interval were low, and there were often classes without sampled observations and/or with outliers of low numbers of data points of high suitabilities (Section 8.11.3). For the lower tail, it would possibly have been easier to determine the end points if the zero values for depth and velocity had been considered separately from the rest in the first class interval.

Approaches for dealing with upper and lower curve tails were thus necessarily different, and each tail had to be evaluated independently. There is no guidance in Bovee (1982; 1986), or Bovee & Zuboy (1988) to suggest that there is a more acceptable way of dealing with these problems. Therefore, it would seem appropriate at present to use all the raw data available to assist in decisions regarding the final shape of the curve. In future, the method of curve construction that would probably be most suitable for use with data sets comprising high numbers of observations would be running filters, while frequency analysis would likely produce the simplest and possibly most accurate representation of microhabitat suitability with more limited data.

From the curves presented above, it was not possible to determine whether or not preference curves were more faithfully reflecting species microhabitat requirements than utilisation curves. There is still much debate regarding this issue and further work should be done on this topic before either of these types of curves is preferentially selected. If adequate records of available and utilised microhabitat conditions are made, preference curves should, in theory, provide more accurate results.

An equally important question that needs to be resolved is whether or not it is acceptable to use combined data for a species occurring at several sites along a river. The comparison made in this study between composite and combined data for *Peloriolus granulosus* (Section 8.11.3) suggested that the composite data more effectively accounted for the differences in physical character of each site. It would thus seem more appropriate to construct site-specific and then composite curves, despite the extra data manipulation involved. This would produce two sets of equally valuable information on the requirements of target species.

An observation regarding the curves that was discussed in Chapter Seven (Section 7.6.5), that of the assumed independence of depth, velocity and channel index, bears mention again here. In several cases, the results from the SI curves suggested that there were inter-relationships between microhabitat variables. An example is provided by the SI curves for *Rheotanytarsus* sp. A (Section 8.11.3.3) where the high preference for shallow water could have been associated with a simultaneous requirement for bedrock areas, while the similarly high preference for deeper water could have been dependent on the substrate comprising cobble. The interdependence of microhabitat variables requires further consideration, and research effort should be directed at devising alternative methods of representing these data. Further consideration should also be given to the scope for incorporating other microhabitat-related variables into SI curves or some other format for use in PHABSIM II (see Chapter Seven).

A final consideration is the degree of transferability of the SI curves; this is a much discussed issue (Bovee & Zuboy 1988). For instance, the curves produced above are only representative of mid-summer conditions, and in the case of the site-specific curves, each represents only a particular site. Decisions need to be made on the temporal and spatial limits of transferability. For example, it would need to be determined at what time of year a summer curve set is no longer appropriate and an autumn set should be used. In a spatial context, decisions need to be made regarding how far upstream and downstream the SI curve for any site represents, or whether or not the curves can be applied to other rivers. Transferability undoubtably needs to be addressed to avoid misrepresentation of the microhabitat requirements of the target species or community.

In conclusion, the SI curves presented in this study are the most representative curves based on available information. Refinements of these curves could be made in future with the collection of additional data on utilisation and availability.

8.13 THE LINK BETWEEN MACROHABITAT AND PHYSICAL MICROHABITAT

As discussed for the fish data in Chapter Seven (Section 7.7), in a complete IFIM study the PHABSIM II results produced using the SI curves should be extrapolated upstream and downstream of each PHABSIM II site, on the basis of the suitability of macrohabitat conditions in each macrohabitat zone identified for the study river (see Chapter Five). This is necessary in order to provide an estimate of the total habitat available to the target species and how this is likely to change with water-resource developments. The actual link between microhabitat and macrohabitat can only be made once PHABSIM II has been used to produce the WUA-Q area outputs (Chapter Nine).

There is a greater likelihood that the link could be made for the benthic macroinvertebrates than for the fish, as the SI curves are for species occurring in the mainstream (unlike the situation with the fish data; Section 7.7). As tolerances for existing and future macrohabitat conditions are liable to differ for each invertebrate species, it is essential that macrohabitat zones are defined in terms of the species-specific ranges of tolerance. For the present situation, as the distribution ranges of the species are known along the river and as biological zones have been established (Figure 5.12 and Section 8.6.2), the extent of extrapolation either side of each PHABSIM II site could be determined. However, an estimate would need to be made of the length of river for which one PHABSIM II site was appropriate and the place at which it became more appropriate to apply the results from the second PHABSIM II site. For example, for the elmid larva *Peloriolus granulosus*, the distribution range extends from Visgat to Kriedouwkrans, so it is able to tolerate present conditions in this section of river. There are two PHABSIM II sites within this section, at Grootfontein and Kriedouwkrans. The site at Grootfontein could either be assumed to be wholly or partially representative of the upper river from Visgat to some point downstream. The site at Kriedouwkrans would be representative down to Clanwilliam Dam and to some point upstream. Once the extent of extrapolation of each of the WUA-Q outputs representing the two sites was determined, total habitat could theoretically be determined by multiplying WUA by river length.

However, even if this procedure could be properly applied for the present situation, it is not possible for the future situation after water-resource development. This is a result of the difficulty in establishing future macrohabitat zones (see Chapter Five) and of knowing exactly which environmental variables are restricting species distributions. Thus, a present-day link between microhabitat and macrohabitat would be possible for the invertebrates, but without any ability to predict future extents of extrapolation of the WUA-Q results it was not considered a worthwhile exercise.

8.14 SUMMARY OF THE APPLICABILITY OF THIS COMPONENT OF IFIM

The development of SI curves for benthic macroinvertebrates has initiated some of the first quantitative studies of the microhabitat requirements of these animals in this country, and has brought with it an increased understanding of their flow-related requirements. In accordance with previous knowledge gained worldwide in this way, the focus on invertebrate SI curves has begun shifting somewhat, to include further assessment of those physical habitat variables which are the most suitable descriptors of microhabitat. Researchers elsewhere have started moving from studies of the standard variables of water depth, average velocity and substrate/cover, to a combination of these with other hydraulic variables which more directly influence the physical microhabitat of benthic macroinvertebrates. Certainly, cognisance should at least be taken of near bottom velocities and other variables to which benthic macroinvertebrates are directly exposed. Much progress still has to be made in adequately describing physical microhabitat at such a detailed level in this country, and the kinds of SI curves described here represent only the first steps.

As with SI curves for fish, however, invertebrate SI curves cannot provide all the information needed to develop a comprehensive instream flow recommendation for an entire riverine ecosystem. Furthermore, these curves have limited transferability, so creating a full picture of the year round instream requirements of a species is demanding in terms of time and data requirements. This is especially true if the instream flow requirements of the species are to be expressed in the form of a time series.

Despite the many limitations and problems associated with SI curves, they do provide a structured and fairly objective way of quantifying the responses of benthic macroinvertebrates to flow-related conditions in rivers. The approach of using SI curves also possesses considerable potential for adaptation for better describing the instream flow requirements of the biota, as discussed above, either within IFIM or independently.

9. ASSESSING IFIM (STEPS 12-15): RUNNING PHABSIM II

9.1 INTRODUCTION

The hydraulic programs in PHABSIM II are difficult to master and use well, even for an experienced hydraulic modeller. For those with a largely ecological training, and without the benefit of the courses run by the Instream Flow Group of the U.S. Fish and Wildlife Service, they are particularly daunting. In such cases, the PHABSIM II tutorial manual (Milhous *et al.* 1990, and later updated versions) is extremely useful, allowing the modeller to understand the basic sequence of programs to follow, and to interpret their outputs. However, the tutorial is limited in its usefulness as it does not advise on how to implement the more specialised options available in the model, or to deviate from the explained pathway in order to describe unusual local hydraulic conditions. Additionally, although the link-up with the habitat programs is relatively easy, there is little help with several aspects of these programs, such as the correct creation and interpretation of SI curves for substrate and cover.

Chapter Three and Figure 3.6 describe the sequence of events that constitute a complete run of PHABSIM II, and outline many of the program options. More detailed explanations are given in the PHABSIM II manual (Milhous *et al.* 1989) and the PHABSIM II tutorial (Milhous *et al.* 1990). Essentially, data on the transects established at the study site and on the hydraulics at those transects at different discharges are used to calibrate the chosen hydraulic program within PHABSIM II. The program is then used to simulate cell-by-cell hydraulic conditions over a range of unmeasured discharges of interest for making the instream flow requirement (or QARDs - see Section 3.16.1). Specifically, only depth and velocity conditions are simulated in the hydraulic programs, as the channel index (CI) does not change with changes in discharge in the model although it does in reality, and is not used until the link-up with the habitat programs. The CI values for each cell - or anything but a blank - are necessary in the hydraulic input file, however, before the hydraulic programs will run. With the depth, velocity and substrate-cover conditions in each cell known for each QARD, one of the habitat programs is selected by the user and used to link this information with that on the requirements of the target species in terms of these three variables. The composite suitability of each cell at each QARD is calculated from this link-up (see Section 3.14) and is then combined with the composite suitability values of all the other cells at the same QARDs to provide an output of changes in Weighted Usable Area (WUA) with changes in discharge (WUA-Q plot).

Throughout the running of the model, guidance was sought from an experienced hydraulic modeller, W. S. Rowlston of DWAF. He provided insights as to which features of PHABSIM II were common to all hydraulic models and which were unique to it (King & Rowlston 1991). He also spent considerable time learning aspects of PHABSIM II, using data from Grootfontein, the most upstream PHABSIM II site in this study (Figure 4.4).

In this Chapter, four sequences of activities are reported upon. Firstly, some general notes about running the model are given. These were produced by Mr Rowlston after considerable testing of the available options in the model, as well as investigations of how it used the data and computed some of its outputs. The understanding gained guided his final choice of how to create the hydraulic data sets used in subsequent runs of the model. Secondly, two hydraulic simulations for transects GR695 and GR840 at Grootfontein (Table 6.1) were produced: one by the authors of this report, and one by Mr Rowlston after some manipulations of the input data and the program options to produce the most accurate possible simulations of hydraulic conditions at those transects; due to time constraints these were the only transects at any of the three sites for which he was able to complete such simulations. Both outputs were linked to the same habitat files and the resulting WUA-Q plots were compared, in order to obtain some understanding of the different outputs that might result simply due to the difference in skills of the hydraulic modellers. Discussions under this topic are linked to the two sets of activities through the bracketed initials of the modellers concerned: [JMK] and [WSR]. Thirdly, WUA-

Q plots were produced for all three PHABSIM II sites, using the complete set of transects at each site and the input options identified by [WSR] but without the input data being manipulated by him. This was done to obtain an insight into how PHABSIM II might highlight differences in available physical microhabitat at three essentially very different sites (Table 4.3). Finally, a critique of the model's output is given, followed by a summary assessment of the whole modelling exercise.

9.2 GENERAL NOTES ON HYDRAULIC SIMULATIONS USING PHABSIM II

The following notes were made by [WSR] while testing the model with data from the Grootfontein site, and are designed to provide feedback on how PHABSIM II was used and on problems that remained unresolved, rather than to be a step-by-step guide on how to operate the model. Examples using the Grootfontein data are used at some points. The same procedure of data assessment and manipulation should be made at each PHABSIM II site, and might involve additional or different procedures depending on the hydraulics of the site and the quality of the collected data. The notes will be of more interest to those who have some familiarity with the model than to those with little or no relevant experience of it. King *et al.* (in prep.) also provides useful comments on use of the model, made by Dr R.T. Milhous during his visit to South Africa.

9.2.1 INPUTTING DATA

As PHABSIM II does not use metric data, all field measurements have to be converted to imperial units. This is best done with a spreadsheet, from which the data can be directly converted into a free-format file for use in the hydraulic program IFG4. Some simple editing is needed in this second stage, but the process saves time as long as the layout of the final input file is adhered to.

9.2.2 MEASURED AND CALCULATED DISCHARGES

The model contains two numbers for each calibration discharge: that provided by the modeller ("given"), which is either computed from field measurements of average cell depth and velocity or derived from a nearby gauging station; and that computed by the model ("calculated") using as water depth, for each cell, the difference between the measured water surface elevation (WSL) and the elevation of the channel bottom. The use of gauging station data assumes a constant discharge in the reach throughout the data-gathering exercise. The difference between given and calculated discharges can be considerable, and is a measure of, *inter alia*, the validity of the assumption of a flat WSL across a transect.

Milhous *et al.* (1990) recommended that all calculated discharges should be within 25% of the mean given discharge for a site. However, this check can only be done if the discharge is similar at all transects and so a value for mean discharge makes sense. In this study, discharges occasionally fluctuated through the day at one or more sites, due to dam releases and irrigation activities, and so a value for mean discharge could bear little relation to the actual values measured at the transects. Each transect was thus allocated its own given discharge, based on the field measurements. This was then usually quite close to the discharge value calculated by the model.

9.2.3 WATER SLOPE

When creating the IFG4.IN4 input file for the hydraulic simulation, the water surface slope or, preferably, the energy slope is required, but it is not clear how PHABSIM II uses this information. When using IFG4, a stage-discharge relationship is derived from the calibration data as the first step of the hydraulic simulation, but this is essentially a curve-fitting exercise. No information on the hydraulics of the system is used, as an exponential curve is simply fitted to measured pairs of data on discharge and WSL. However, when [WSR] tested MANSQ, where changes in slope should make a difference to the predicted WSLs, they did not seem to, leading to confusion about how and why the data on slope are needed.

9.2.4 INPUT-OUTPUT COMMANDS (IOCs)

Input-output commands (IOCs) are used to choose the desired options for program operation in both the hydraulic and habitat programs. They form an integral part of the hydraulic and habitat input files, and must be decided upon as these files are being created. Of the 22 IOCs listed for IFG4 (Milhous *et al.* 1989) two (18 and 21) are not used, and six (1-4, 13, 19) simply offer the option for plots, tables or computational and calibration details to be printed. All but one of the remainder (that is, 13 commands) deal with details of the hydraulic simulation, and ten of these require a good understanding of hydraulics in order to make sensible choices. Of these 13, and after considerable testing of the programs, [WSR] remained uncertain about aspects of seven of the options (6, 7, 9, 11, 12, 14, 15). Uncertainties included such aspects as not understanding: the need for an option to set SZF to zero (option 7); the theory related to an option for evaluating negative velocities (option 9); and the implications of various options linked to velocity and the roughness coefficient (options 14 and 15).

9.2.5 MANNING'S N

There are three opportunities for the modeller to influence the "n" values used in PHABSIM II. All "n" values can be supplied, based on consideration of the physical size of roughness elements in the channel via IOC(12). Use of this option also allows the user to specify "n" values for wet cells, with the program calculating values for initially dry cells which become wet at higher discharges. The modeller can specify both maximum and minimum values for "n" via IOC(15), or allow the "n" value to vary as a function of depth via IOC(16), by specifying a beta coefficient in an exponential relationship. Alternatively, any or all of these can be performed automatically by the program. [WSR] found that the values of "n" estimated by "normal" hydraulic methods often differed considerably from those computed within PHABSIM II, and it was subsequently confirmed (R.T. Milhous pers. comm.) that this parameter should rather be regarded as a a "velocity distribution coefficient". As a consequence, it was decided to allow all operations in respect of this parameter to be computed internally, and also for "n" to remain constant with depth, as [WSR] was not confident of being able to supply an appropriate beta coefficient in the "n"-depth relationship. The implication of these decisions is that in simulations there was little or no control over the distributions of velocities across any one transect.

9.2.6 CALIBRATION OF DISCHARGE DATA TO WATER SURFACE ELEVATIONS

In the calibration of the model, using measured data on discharge and WSLs, equations are produced that describe the relationships of discharge to velocity, depth, wetted width and a "conveyance factor" (CFAC). According to Milhous *et al.* (1990), the beta values in these equations, which adjust the shape of the curves described by the equations, have a range of acceptable values which can be used to check the quality of the hydraulic input data. It should be noted that these beta coefficients are empirical, and apply to rivers in "non-tropical areas". Guided by this information, [WSR] found that a combination of hydraulic models was needed to produce acceptable WSLs for different transects in the simulations or for different QARDs at any one transect; sometimes the stage-discharge relationship derived by IFG4 was used and sometimes, guided by the match with subsequent velocity simulations (see Section 9.2.7), a combination of MANSQ and IFG4 was used for different parts of the QARD range. The WSLs predicted by this combination of programs have to be entered on the WSL line in the IFG4.IN4 input file, using IOC(8)=1 while, if only IFG4 is used and IOC(8)=0, a stage-discharge relationship will be derived and the WSLs so produced will be used in the hydraulic simulation.

Producing accurate WSLs is a time-consuming and complicated task. Without the expertise and time to understand the significance of the different beta values, to know what to do when the data produces beta values outside the recommended ranges, and to be able to use multiple programs to produce the best outputs, some researchers who are not experienced hydraulic modellers could be reduced to pressing buttons and simply hoping that the model produces an output, irrespective of its quality.

9.2.7 CALIBRATION OF DISCHARGE DATA TO CELL VELOCITIES

Once WSLs have been acceptably simulated, so that the depth of water in each cell at each QARD is known, the second part of the calibration procedure is to accurately simulate the velocities occurring in each cell of each transect at each QARD.

[WSR] attempted, for three transects at Grootfontein, calibrations to the low-flow velocity data set and the moderate-flow velocity data set (see Section 6.1.1), as well as to both data sets together. He found, for two relatively smooth-flowing runs where the bed elements were smaller than the water depth and therefore not protruding above the water surface that:

- when calibrating to the low-flow data set, the measured low-flow velocities were simulated exactly and the measured moderate-flow velocities tolerably well

- when calibrating to the moderate-flow data set, the measured moderate-flow velocities were simulated exactly and the measured low-flow velocities tolerably well

- when calibrating to both sets, the measured low-flow velocities were simulated exactly and the measured moderate-flow velocities tolerably well

It is not clear from these results if the model continues to use only one velocity data set, even if more than one are provided, although it appears that it does. One might conclude that either set would be equally acceptable in terms of its accuracy, and the decision on which one to use would be guided by which discharge was closest to the discharges of concern in the river and should therefore have the most accurately simulated velocities, or by which data set was believed to have the most accurate field measurements.

However, for a shallow, turbulent riffle, with bed elements often far larger than the water depth and therefore protruding above the water, calibrations were less straightforward. Three velocity sets had been collected for this transect, and there was no clear, monotonic increase in cell velocities with discharge and stage. Velocity calibration was attempted to all three data sets separately (the choice recommended by Milhous *et al.* 1990), and then to various combinations of two sets, and then to all three sets. Simulating velocities for any one calibration discharge reproduced the relevant measured velocities well, but there was almost no correlation between measured and simulated values for the other calibration discharges. Using more than one data set, in various combinations, produced variable results but still failed to reproduce all measured velocities with any degree of accuracy. Considering the hydraulic complexity of an area of shallow water that is flowing fast over and around cobbles and boulders, this result is not altogether surprising.

[WSR] concluded that calibration to either the low-flow or moderate-flow velocity data set would produce a very good representation of the velocities measured at that discharge. It would also produce simulated velocities for other discharges that were a fair representation of those measured, except in rocky areas of shallow turbulent flow. No generalisations were possible about calibrations to the high-flow data set, as this was only available for one of the three transects he studied. He then used the moderate-flow data set for velocity calibrations, in preparation for the hydraulic simulations.

After the hydraulic input data have been accepted as satisfactory, the hydraulic simulation can be run. As well as producing the required data on depth and velocity for each cell at each QARD, the output includes a velocity adjustment factor (VAF) for every transect at every QARD that has been calculated by the model. These VAFs are used to calculate the cell-by-cell velocities which will be used in the habitat simulation. Though difficult to be certain, it is thought that VAFs are derived in the following way. For any stated QARD there will be a simulated WSL. This WSL and data on stream geometry are used to calculate the wetted cross-sectional area. Simulated velocities across the transect, presumably calculated using the "n" value for each cell, are then used to calculate the discharge linked to this WSL. The ratio between the calculated discharge and the original QARD is the VAF, which is thus apparently used to "determine the correct velocities for the flow at a cross-section" Milhous *et al.* (1990). The aim is to produce VAFs as close as possible to unity.

It was not clear to either [WSR] or [JMK] how the VAFs are derived or used within the hydraulic program, but in the investigatory hydraulic simulations described in Section 9.3 they remained within the values of 0.1-10.0 recommended by Milhous *et al.* (1990), but not always within the range 0.8-1.2 later recommended by R.T. Milhous (pers. comm.).

9.3 PRODUCTION OF HYDRAULIC SIMULATIONS AND WUA-Q PLOTS FOR TARGET FISH AND INVERTEBRATE SPECIES, USING TWO DIFFERENT MANIPULATIONS OF THE SAME HYDRAULIC DATA

The two transects studied by [WSR] - GR695 and GR840 at Grootfontein - were used for the purpose of comparing WUA-Q plots produced by a skilled and an unskilled hydraulic modeller. The following account details the hydraulic conditions at these transects that presented modelling problems and how these were dealt with, the programs within PHABSIM II used for the hydraulic and habitat simulations and the WUA-Q plots produced by both modellers for the target fish and invertebrate species.

The PHABSIM II site at Grootfontein presented many problems for hydraulic modelling, including the presence of many dry secondary flood channels, some of which are shallower and others deeper than the main channel, and a double-channel section with the two channels having different WSLs (see Chapter Six). The first of these features is a problem because PHABSIM II apportions water and flow to secondary channels as soon as the WSL for the transect rises above the lowest part of the bed of that channel. However, most secondary channels at Grootfontein are isolated from the main channel until high discharges overtop the banks, and so may remain dry while the WSL in the main channel is higher than their beds. Alternatively, they may contain stagnant water from previous high-flow events which would not automatically start to flow as discharges rise, again, because of their isolation.

The second feature, that of multiple channels with different WSLs, is a problem because PHABSIM cannot model multiple WSLs across one transect, though IOC 18 in the program IFG4 implies that it can. It cannot calculate a flow split between such channels, nor can it model the transect as a single computational entity even if the modeller defines the flow split.

Thus, because transect GR628 had two channels with different WSLs, the seven transects at Grootfontein could not be simulated by PHABSIM II as a single continuous reach. The solution proposed by [WSR] was that the total reach should be divided into three sub-reaches; one consisting of transect GR628, and the other two consisting of the groups of transects upstream or downstream of GR628. Implicit in this approach was the necessity to recreate GR628 as two different transects and to define the partial discharge allocated to each, both of which are tasks for an experienced hydraulic modeller. This work is still incomplete and, for the moment, remains as a learning exercise of the capabilities and limitations of PHABSIM II.

For the purposes of this report, the two transects upstream of GR628, which had been extensively studied by [WSR] in terms of their hydraulics, were then used for comparison of WUA-Q outputs produced both with and without manipulation of the hydraulic data. Of the two transects, GR840 described a riffle and GR695 a deep, slow, stony run with some slightly shallower, faster flow near one water's edge. They thus represented the two most common types of biotopes available at Grootfontein.

In a standard PHABSIM II run, with only these two transects being modelled, no microhabitat would be simulated downstream of the most downstream transect (GR695) or upstream of the most upstream one (GR840). Thus, only the reach between them would have been modelled. To expand the area modelled as much as possible, [WSR] thus created dummy transects downstream of GR695 and upstream of GR840, which extended the area represented by them to the limits deemed geomorphologically acceptable. The dummy transects were geometrically identical to their neighbouring real sections, and their weighting factors were designed to ensure that the lengths of channel represented by them were negligible, while the lengths reaching toward them and represented by their real neighbouring transects were enlarged by this procedure.

In the two hydraulic simulations of transects GR695 and GR840, [JMK] created a data set that included the given (measured) discharges for both transects, which were respectively 17% and 3% different to those calculated by PHABSIM II (see Section 9.2.2), while [WSR] created a data set that included the values calculated by PHABSIM II, in order to reduce confusion while analysing the model's outputs.

9.3.1 RUNNING PHABSIM FOR TRANSECTS GR695 AND GR840

The choices of programs that can be followed in a PHABSIM II run are outlined in Chapter Three and detailed in Milhous *et al.* (1989). For the two transects dealt with here, the following sequence of programs was run:

• IFG4IN	created the hydraulic input data file
• REVI4 and CKI4	checked the quality of the input data
• IFG4	ran the hydraulic simulation; produced Tape 3 (unformatted data file of transect and reach data) and Tape 4 (unformatted data file of discharge and velocity data) files
• I4VAF	checked velocity adjustment factors
• GCURV	created the input file of habitat suitability indices
• LPTCRV	checked the accuracy of the input data on habitat suitability indices
• CRVFIL	converted the GCURV file to an unformatted form
• HABINE	created an options (IOC) control file for the habitat program
• HABTAE	ran the habitat simulation, linking the unformatted data on the Tape 3, Tape 4 and CRVFIL files
• LPTHQF	produced WUA-Q plots from HABTAE output files

HABTAE was used because it is the most sophisticated of the habitat programs and offers the most options (see Section 3.17.2). Running the habitat programs is straightforward, compared to the difficulty that can be experienced with the hydraulic programs, but the IOC command choices that need to be made should still be done by an experienced ecologist with a good understanding of what PHABSIM II will then do with the data.

9.3.2 COMPARISON OF IFG4 OUTPUTS AND WUA-Q PLOTS FOR TRANSECTS GR695 AND GR840

[WSR] made four major changes to the original IFG4.IN4 data set for the two Grootfontein transects:

- for transect GR695, the stage of zero flow (SZF) was changed from 812.08 ft to 816.00 ft, to account for a backwater effect from the deep mainstream channel with the higher WSL on downstream transect GR628
- for transect GR695, a dry secondary channel was excised, to avoid the problem of PHABSIM II simulating it filling as WSLs rose despite the fact that it was still isolated from the main channel
- for both transects GR695 and GR840, the given and calculated discharge were made the same, to reduce confusion when analysing the output of the hydraulic simulation
- for both transects, the slopes were changed from 0.0001 to 0.00023, based on his investigations of WSL for these two transects

Comparison of the review (REVI4) files for the two IFG4.IN4 data sets, before the hydraulic run was done, revealed very similar assessments of their quality, except for one important point. Both data sets had, for both transects, similar values for the beta coefficients for width, velocity, depth and CFAC. The same coefficients in both data sets were either within, or just outside of, the range of acceptable values given by Milhous *et al.* (1990). However, the major difference in the two reviews was in the beta values produced for the stage-discharge relationship for transect GR695. That in the original data set was 9.796, well outside the recommended range of 2.0 to 4.5, while that for the modified data set was an acceptable 2.535. Milhous *et al.* (1990) identified errors in the SZF as one of the four possible reasons for unacceptable beta values in the stage-discharge equation. [WSR] detected the incorrect SZF through an unacceptably high beta coefficient and, using hydraulic considerations, corrected it to produce an acceptable beta value.

After this review of the input data, hydraulic simulations were completed using both data sets in IFG4. These produced similar VAFs that were well within the range recommended by Milhous *et al.* (1990) (see Section 9.2.7). Those for GR840 were closer to 1.0, (0.800-0.997 for [WSR]; 0.890-1.456 for [JMK]), and therefore better, than those for GR695 (0.222-3.69 for [WSR]; 0.259-4.255 for [JMK]). The unformatted files Tape 3 and Tape 4 for each data set were linked to the same files on habitat suitability indices for the target fish and invertebrate species, using the habitat program HABTAE, to produce WUA-Q plots. The information from which the files on habitat suitability indices were created is illustrated in Figures 7.4 to 7.6 (fish) and Figures 8.9 and 8.12 to 8.14 (invertebrates).

9.3.2.1 HABTAE outputs - Total wetted area

The outputs from both sets of hydraulic-habitat runs for transects GR695 and GR840 indicated that similar amounts of total wetted area were available at any one discharge over the lower QARD range. However, the output produced by [JMK] from the unmodified data set showed a sharp increase in wetted area at about 10 $m^3 s^{-1}$ (Figure 9.1). As a result, the unmodified data set showed more wetted area to be available at higher QARDs than did the modified data set. Presumably, this result reflects the two major difference between the two data sets, namely, the addition of dummy transects to the modified data set and the change in the SZF.

9.3.2.2 HABTAE outputs - WUA-Q plots for the target fish species

The plots of WUA-Q for *Austroglanis gilli* adults and juveniles produced from the modified and unmodified hydraulic data sets (Figure 9.2) showed essentially the same trends. Both outputs indicated that more physical microhabitat was always available for juveniles than for adults, and that the sharp loss of WUA as discharges decreased was at a slightly lower discharge for the juveniles (about 0.7 $m^3\ s^{-1}$) than for the adults (about 2.0 $m^3\ s^{-1}$). The unmodified data set showed slightly less WUA to be available for both adults and juveniles at all discharges than did the modified data set, and also showed a peak value for WUA for the adults, at about 2.0-4.0 $m^3\ s^{-1}$, that was much lower than that predicted using the modified data set. These results may have been due to the modified data set describing more riffle, through its dummy transects, than the unmodified data set; riffle is the favoured biotope of *A. gilli*.

Comparison of the two WUA-Q outputs for *Barbus calidus* adults and the two for *B. calidus* juveniles (Figure 9.3) revealed that the modified and unmodified data sets produced similar shaped plots for any one life stage, but that the two life stages occupied reversed positions. Using the unmodified data set, the adults were shown to always have more WUA than the juveniles, with a peak at about 1.6 $m^3\ s^{-1}$, while using the modified data set they almost always had less WUA than the juveniles, but still with a peak at about 1.6 $m^3\ s^{-1}$. WUA for the juveniles peaked at 0.6 and 1.0 $m^3\ s^{-1}$, using the modified and unmodified data sets respectively. A major difference between the two outputs was the amount of WUA, with the simulation from the modified data set indicating that WUA for both life stages would be about double that indicated using the unmodified data set. Linking this knowledge with the outputs for *A. gilli* provides an insight into which might be more accurate. The output from the modified data set indicated that there would be more WUA for both life stages of *B. calidus* at zero discharge than for both life stages of *A. gilli*, which seemed reasonable as the former are pool dwellers while the latter inhabit the riffle areas that would likely be the first areas to dry out with decreasing flows. The output from the unmodified data set indicated that there would be more WUA for *A. gilli* juveniles at zero discharge than for both life stages of *B. calidus*, which seemed less probable for the reason stated above. The modified data set thus seemed to produce a more acceptable result.

Comparisons of the WUA-Q outputs from both data sets for *Barbus serra* juveniles and *Micropterus dolomieui* juveniles revealed the same kinds of similarities and differences as described for *B. calidus* (Figure 9.4). For *B. serra*, both outputs revealed a peak WUA at 1.0 $m^3\ s^{-1}$, with values dropping off at higher discharges and ample WUA at zero discharge. Simulations using the modified data set, however, produced a peak value for WUA that was almost double that produced using the unmodified data set, though the WUA values linked to the higher QARDs were much more similar. The outputs for *M. dolomieui* showed the same kinds of trends as those for *B. serra*, with both data sets producing peak WUAs at the same discharge of about 1.0 $m^3\ s^{-1}$. However, the difference between peak WUA values using the modified and unmodified data sets was even greater than for *B. serra*.

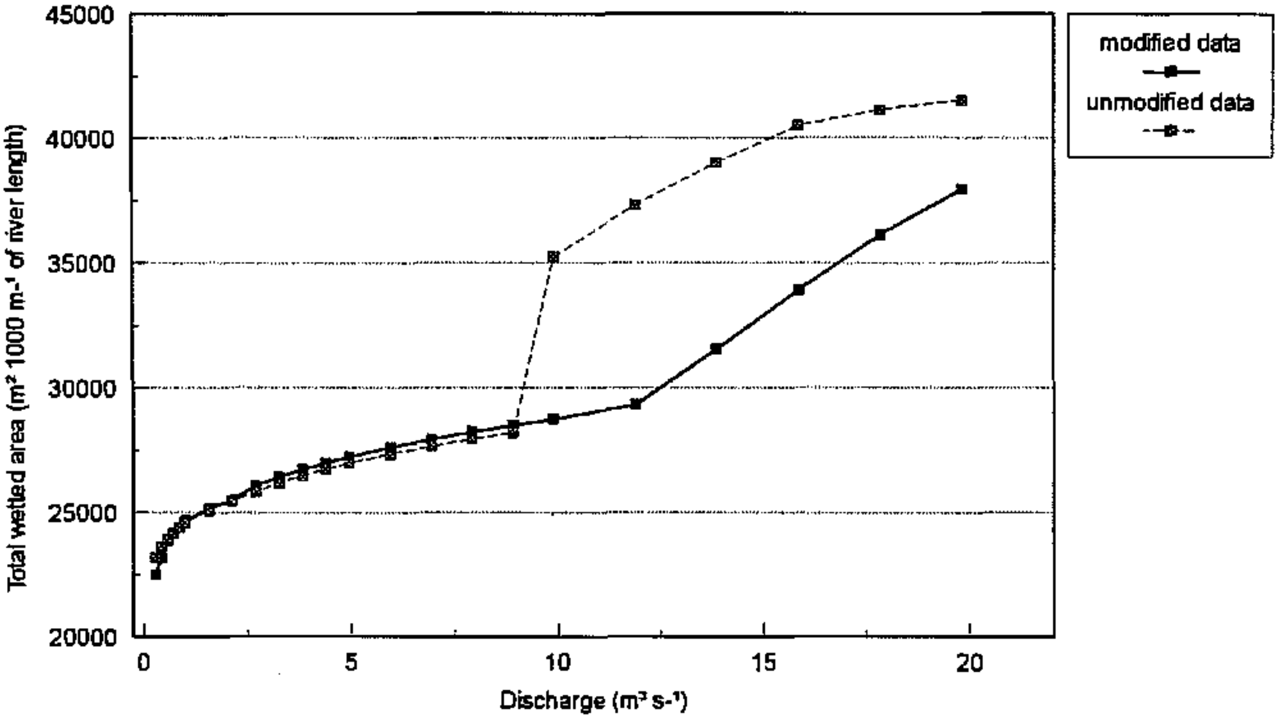


Figure 9.1 PHABSIM II predictions of change in total wetted area with discharge at Grootfontein, using data from transects GR695 and GR840. See text for details

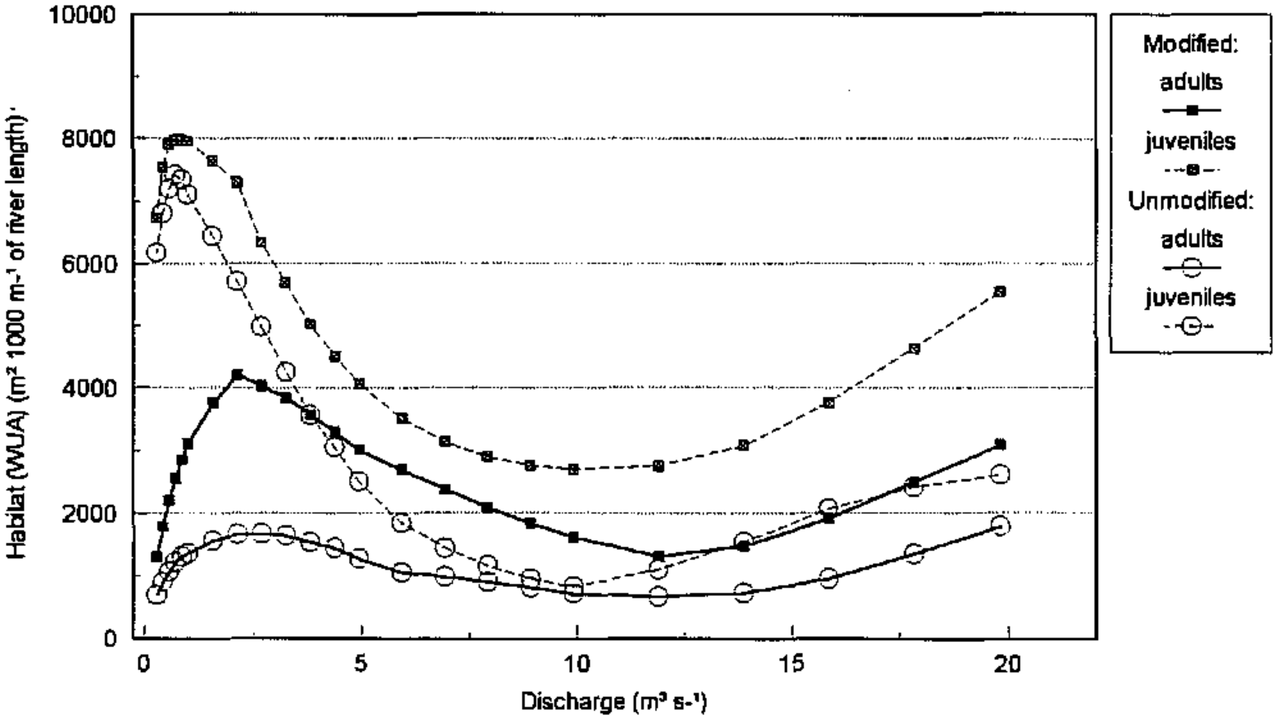


Figure 9.2 PHABSIM II predictions of change in WUA with discharge for *Austroglanis gilli* at Grootfontein, using data from transects GR695 and GR840. See text for details

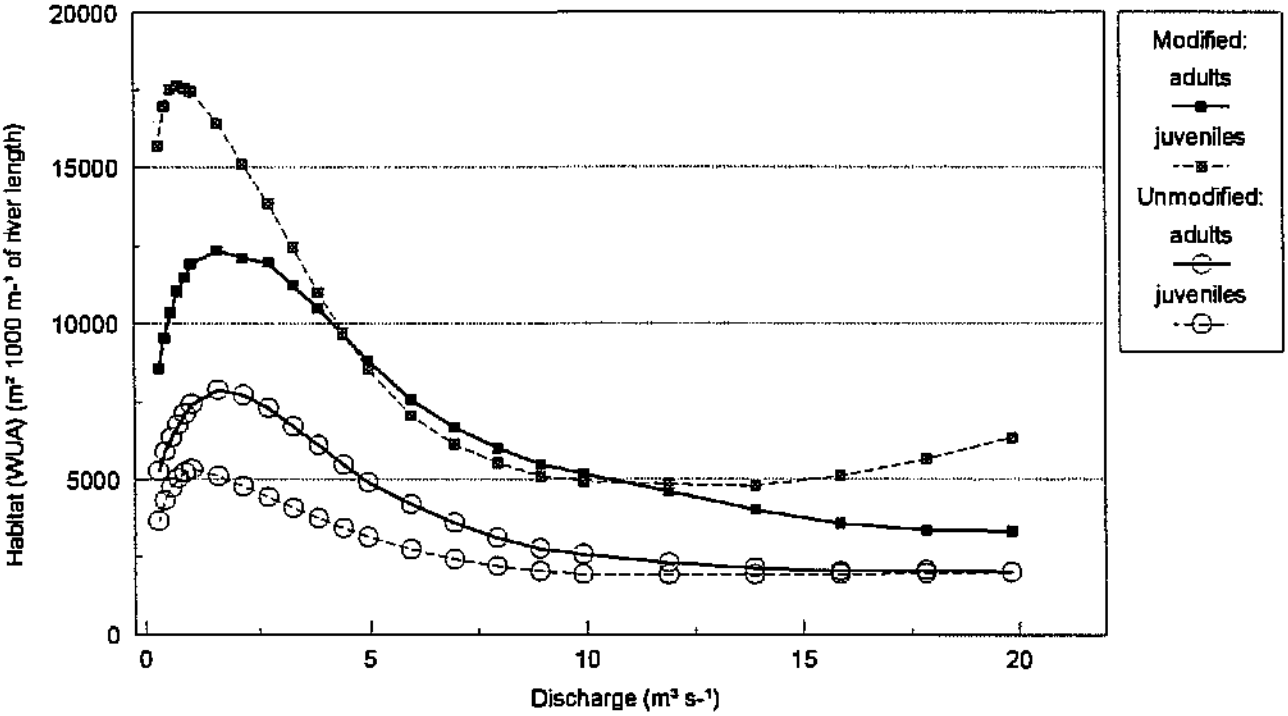


Figure 9.3 PHABSIM II predictions of change in WUA with discharge for *Barbus calidus* at Grootfontein, using data from transects GR695 and GR840. See text for details

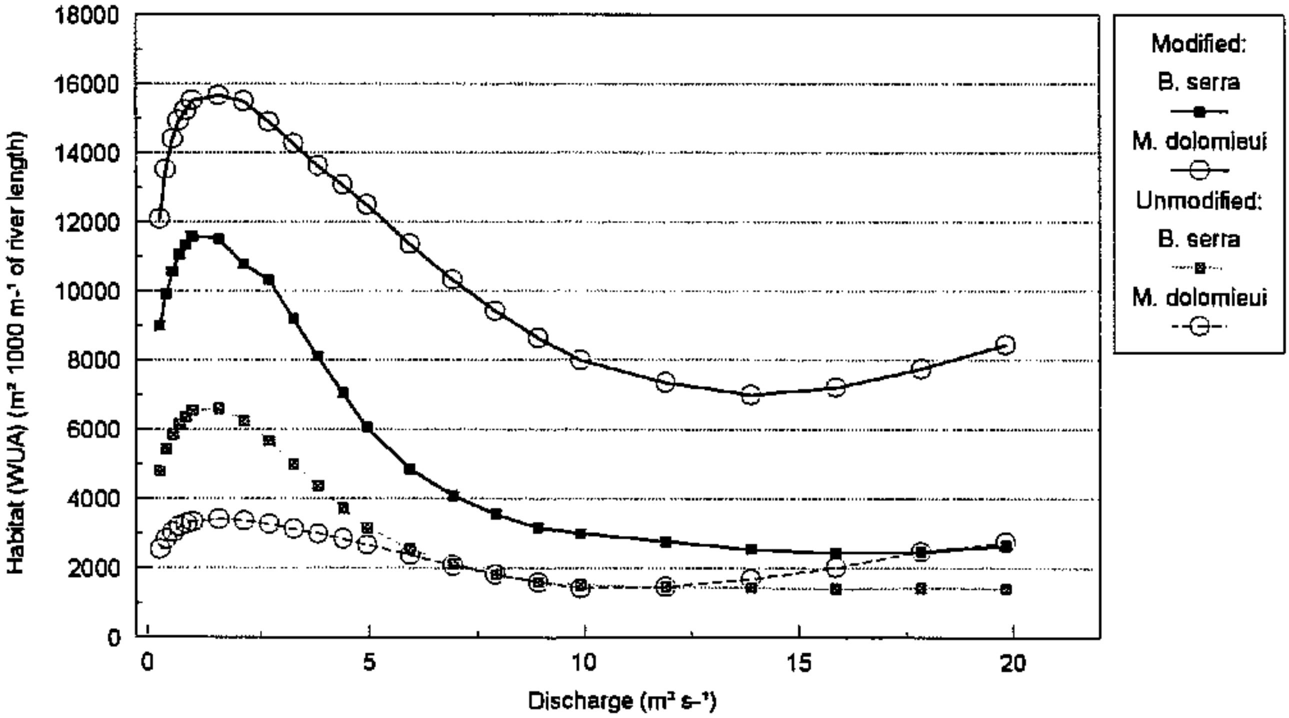


Figure 9.4 PHABSIM II predictions of change in WUA with discharge for *Barbus serra* and *Micropterus dolomieui* at Grootfontein, using data from transects GR695 and GR840. See text for details

In conclusion, simulations using the unmodified data set resulted in WUA-Q curves that were similar in shape to those produced by the modified data set. Their predictions of absolute amounts of WUA were probably less trustworthy, as were their values for WUA at zero flow, which is where most accuracy might be needed. However, if the objective was to search for **trends**, or the discharge below which WUA decreased rapidly, the unmodified data set seemed to produce much the same answers as the modified data set. It should be remembered, though, that Mr Rowlston was not involved in the choice of transects or any of the gathering of data, which limited his ability to produce an improved description of the hydraulics of the reach. His results might have differed more from those produced from the unmodified data if he had been at least partially responsible for the field selection of the transects (see Section 6.4).

9.3.2.3 HABTAE outputs - WUA-Q plots for the target macroinvertebrate species

The WUA-Q plot for highest community diversity, using the modified hydraulic data set (Figure 9.5), showed that the highest WUA occurred at very low discharges of about 0.3 $m^3 s^{-1}$, and sharply decreased with increasing discharge to maintain a stable low WUA above about 3.3 $m^3 s^{-1}$. The unmodified data set produced a similarly high WUA at low discharges and a similar sharp decrease in value to stabilise at about 3.0 $m^3 s^{-1}$. However, above about 10.0 $m^3 s^{-1}$ the curve shape deviated from that created using the modified data set, with WUAs increasing sharply again and continuing to increase with increasing discharge. This trend could probably be attributed to the fact that the WUA-Q plot produced using the unmodified data set predicted higher total wetted area at higher discharges (above about 8.0 $m^3 s^{-1}$) than did that produced from the modified set (Figure 9.1). WUA for highest community diveristy attained far higher values than did that for any of the target species (see below).

WUA-Q outputs for the target species *Rheotanytarsus* sp. A revealed the same trend in WUA at higher discharges as did the plots for community diversity (Figure 9.6). Again, WUA increased sharply after 10.0 $m^3 s^{-1}$, on the plot derived from the unmodified data set. In contrast, the plot derived from the modified data set indicated that WUA decreased rapidly to zero at 14.0 $m^3 s^{-1}$ and remained zero for all higher discharges. Another obvious difference between the two plots for *Rheotanytarsus* sp. A was that the modified data set produced a prediction of higher WUAs at the lower end of the discharge range (0.4-2.0 $m^3 s^{-1}$), with a less severe loss of WUA as discharges increased, than did the unmodified data set. Although the plots for *Rheotanytarsus* sp. A followed a similar trend to those for highest community diversity, WUA was generally far lower for the former.

WUA-Q plots for the elmid larva *Peloriolus granulosus* (Figure 9.7) revealed that the differences between the modified and unmodified data sets had less influence on the upper part of the WUA curve than it did on the plots for highest community diversity and *Rheotanytarsus* sp A. However, use of the unmodified data set still led to a predicted (smaller) increase in WUA above about 10.0 $m^3 s^{-1}$, which use of the modified data set did not. As with the previous plots, this was about the discharge at which the unmodified data set produced a simulated increase in total wetted area that was not was produced when using the unmodified data (Figure 9.1). Additionally, the plot produced using the modified data indicated that WUA for *P. granulosus* was zero at discharges equal to and above 20.0 $m^3 s^{-1}$, whereas the plot produced using unmodified data showed that WUA was still available at these higher discharges. Both WUA-Q plots were similar in shape at lower discharges, predicting high WUAs for *P. granulosus* at very low discharges. Although this species typically inhabits riffles and run areas, and might therefore be expected to be less tolerant of very low flow conditions,

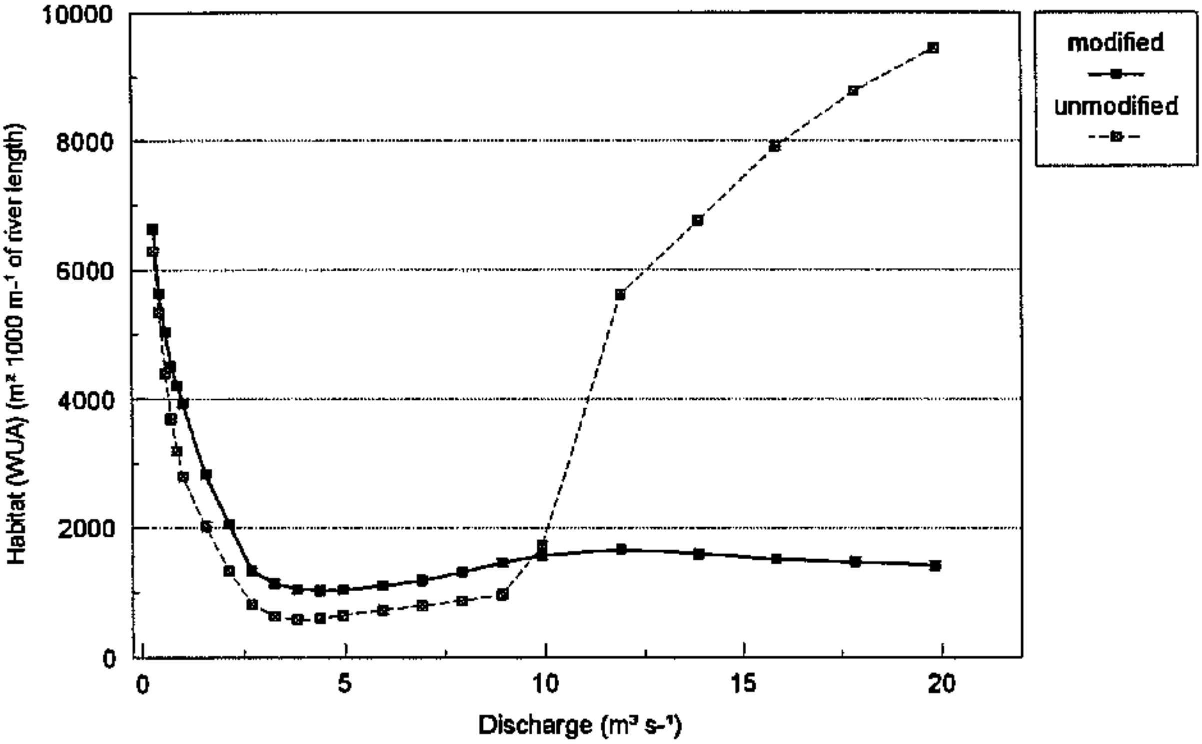


Figure 9.5 PHABSIM II predictions of change in WUA with discharge for highest benthic macroinvertebrate community diversity at Grootfontein, using data from transects GR695 and GR840. See text for details

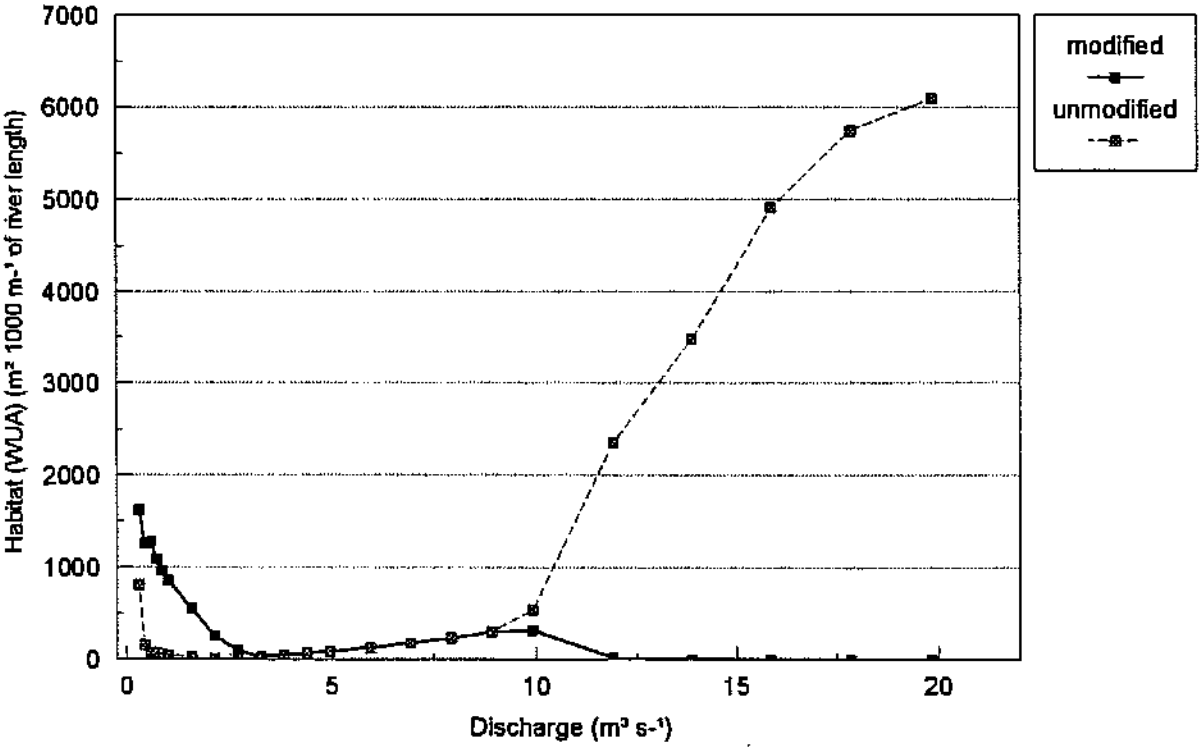


Figure 9.6 PHABSIM II predictions of change in WUA with discharge for the chironomid larva *Rheotanytarsus* sp. A at Grootfontein, using data from transects GR695 and GR840. See text for details

these results confirm evidence from the SI curves for this species (Section 8.11.3; Figure 8.12) that during summer at least, it can tolerate low and zero velocities.

The final target invertebrate species for which a comparison was made was the chironomid larva *Polypedilum ?articola*, which exhibited a widespread distribution along the entire study area, and had the least specialised microhabitat requirements of all the target invertebrate species (Section 8.11.3; Figure 8.14). The WUA-Q plot for this species produced from the modified data set (Figure 9.8) showed similar trends to that for *P. granulosus* for the upper end of the WUA-Q curve, with a gradual decrease to zero WUA at about 20.0 m^3 s^{-1}. The plot produced from the unmodified data set showed the same increase in WUA above 10 m^3 s^{-1} as had previous plots (Figures 9.5 to 9.7). The two data sets produced very similar WUA-Q curves below about 9.0 m^3 s^{-1}, with the same sharp increase in WUA as discharges decreased toward zero that had been predicted for the other invertebrate species. *P. ?articola* was generally predicted as having low amounts of WUA, although lowest WUA overall was predicted for *Rheotanytarsus* sp. A.

9.4 COMPARISON OF THE HYDRAULIC SIMULATIONS AND WUA-Q PLOTS FOR THE THREE PHABSIM II SITES, USING SELECTED TARGET FISH AND INVERTEBRATE SPECIES

Within the scope of the project it was not possible for the hydraulic data for all transects for all three PHABSIM II sites to be assessed and modified by an experienced hydraulic modeller. However, the exercise described in Section 9.3 indicated that **trends** in the WUA-Q plots might be revealed using unmodified hydraulic data even if the **details** were of more questionable accuracy. Hydraulic outputs for the three sites were therefore produced by the authors of this report, in order to search for trends in the amounts of WUA available in three very different parts of the river. It is acknowledged that, for the target species used in the exercise, macrohabitat conditions might have been unsuitable at one or more sites anyway (see Chapter Five), and so no attempt was made to interpret anything more than trends in the availability of physical microhabitat.

The three sites used in the hydraulic simulations in PHABSIM II are described in Chapter Four, and the 17 transects which describe them in Chapter Six. The hydraulic data used as input to the model are listed in Appendices 6.2 to 6.4. Two of the target fish species and two of the target macroinvertebrate species were chosen to provide input on habitat. In order to assess the widest possible range of changes in WUA with discharge, target fish species were selected that had obvious differences in their preferred habitats, while the choice of target invertebrate species was based on their representativeness of the invertebrate communities. Of the two fish species selected, *A. gilli* is a riffle dweller with a preference for cobble beds, while *B. calidus* inhabits quieter waters over a wider range of substrates. The invertebrate community with the highest diversity was selected to indicate the requirements of the invertebrates as a whole, while *Rheotanytarsus* sp. A had quite specific velocity and substrate preferences and was also a possible indicator species for the most diverse invertebrate community. The information on suitability of the physical microhabitat which was used as input to the model is illustrated in Figures 7.4 and 7.5 (fish) and Figures 8.9 and 8.13 (macroinvertebrates). The sequence of programs run is given in Section 9.3.1.

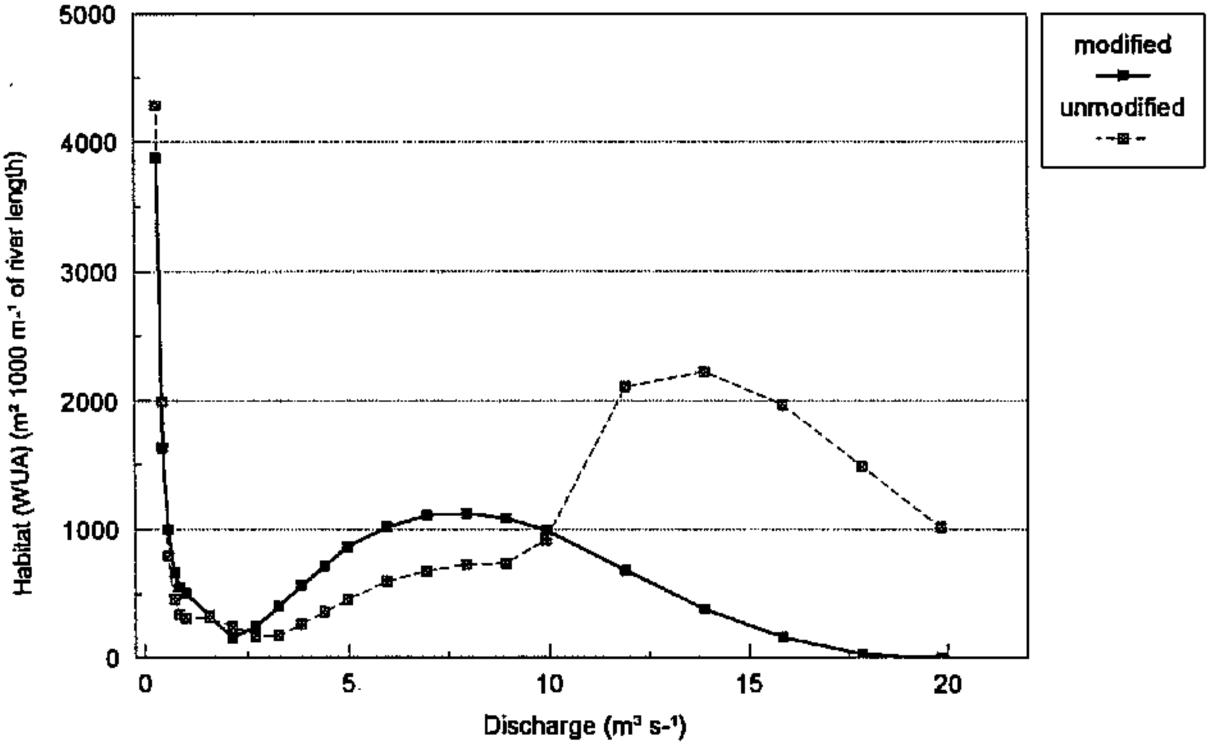


Figure 9.7 PHABSIM II predictions of change in WUA with discharge for the elmid larva *Peloriolus granulosis* (composite SI data) at Grootfontein, using data from transects GR695 and GR840. See text for details

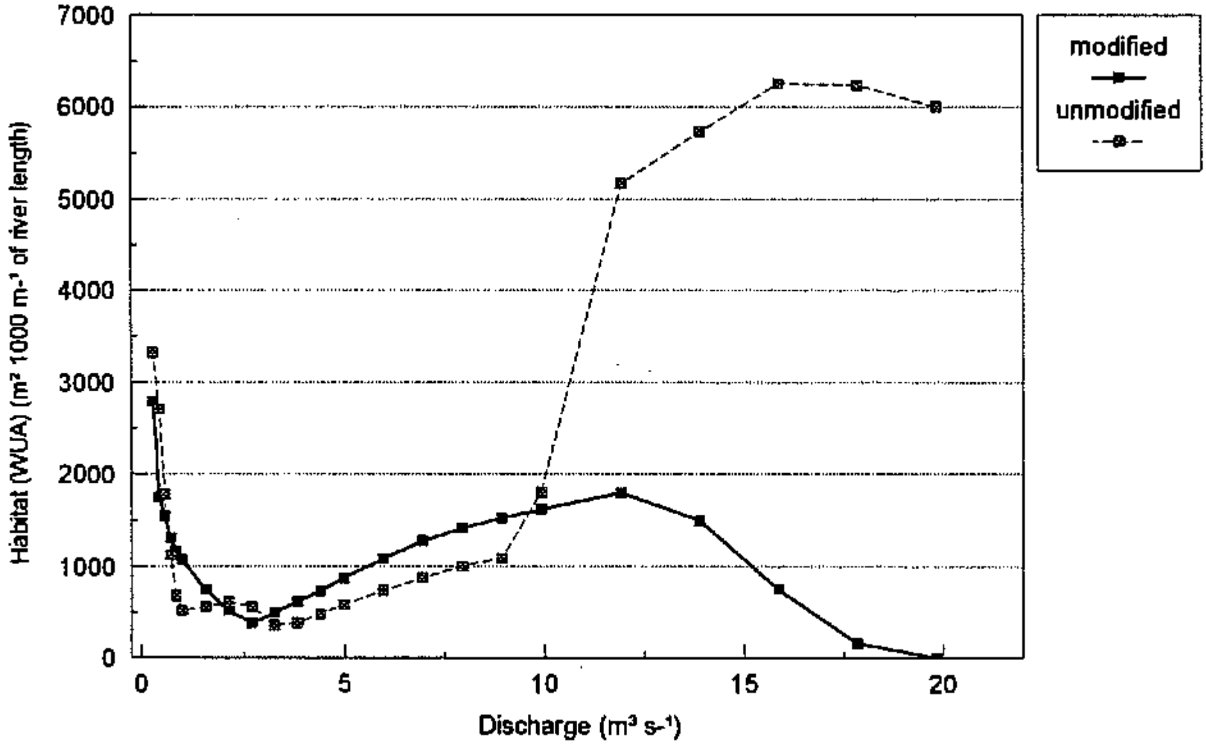


Figure 9.8 PHABSIM II predictions of change in WUA with discharge for the chironomid larva *Polypedilum ?articola* at Grootfontein, using data from transects GR695 and GR840. See text for details

9.4.1 PRODUCTION OF THE HYDRAULIC SIMULATIONS FOR THE THREE PHABSIM II SITES

For each of the three PHABSIM II sites, the hydraulic input data was reviewed and is commented upon here. Problems revealed in the review process are detailed, so that the quality of the input data can be judged, but modification of the data to improve their quality is beyond the scope of this report.

9.4.1.1 Grootfontein

All seven transects were used for the hydraulic run for Grootfontein, despite the difficulties known to be linked to transect GR628 (see Section 9.3). As each of its two channels had a different WSL and as only one could be used in the model, that for the deeper of the two channels was used because more calibration WSLs were available for it. Four of the transects had beta coefficients for width, depth, velocity and CFAC that were within, or just outside of, the range of values deemed acceptable by Milhous *et al.* (1990). Transects GR276, GR302 and GR628 had very low values for the beta coefficient for depth (0.035, -0.104 and 0.042 respectively), compared with the acceptable range of 0.25-0.50. The beta coefficients for the stage-discharge relationship were within the acceptable range of 2.0-4.5, except for the transect with the double channel (GR628) and the next upstream one (GR695). The cause of these anomalies has been discussed in Section 9.3.2. The data set was used in this condition for an hydraulic simulation, and produced a "normal run", with VAFs that were mostly acceptable (Milhous *et al.* 1990), ranging between 0.170 and 3.957, but with unacceptably low ones (0.055-0.090) for three cells at the edge of transect GR628.

9.4.1.2 Kriedouwkrans

All five transects were used for the hydraulic run for Kriedouwkrans. Two of the transects (KR000 and KR497) had beta coefficients for depth, velocity, width and CFAC that were within, or just outside, the acceptable range. Two others showed the same pattern, except for low beta values for depth (KR119 = 0.090; KR352 = 0.080). Transect KR166 also showed the same pattern for beta values for width and depth as the others, but had negative beta values for velocity and CFAC (-0.114 and -0.375 respectively, as against acceptable ranges of 0.30-0.60 (velocity) and 0.00-0.60 (CFAC)). It is not clear whether a negative CFAC value is a problem; this question is posed in the tutorial (Milhous *et al.* 1990), but not answered. If it is not a problem then the CFAC value is within acceptable limits. This transect described a bedrock rapid, where accurate field measurements were difficult to make. The beta coefficient for the stage-discharge relationship was just outside the acceptable range for all transects except KR166, where it was within range. The data set was used in this condition for the hydraulic simulation, and produced a "normal run" with VAFs ranging between 0.168 and 2.244.

9.4.1.3 Klawer

The Klawer hydraulic data set presented two problems that were not encountered for the other two PHABSIM II sites. Firstly, the low-flow calibration data set revealed that for all five transects, the discharge value was lower than that in the moderate-flow calibration data set, while for four of the five transects the low-flow WSL was higher than the WSLs in the moderate-flow data set. One possible explanation was that the headstakes had shifted in elevation in the soft sands of that area, but this seemed unlikely as they had been concreted in place. A more likely explanation was that discharges had been changing during the day due to upstream releases from Bulshoek Dam or abstractions for irrigation purposes; both were likely occurrences during this dry, low-flow period. WSLs were measured for all transects early in the day, and velocity readings taken later on the same day. Bovee & Milhous (1978) recommend that WSLs be checked through the day where it is suspected that they might be changing, and this clearly should have been done. In the event, it was decided to excise the low-flow calibration data (February/March) from the data set.

The second problem was that the second-most downstream transect produced unacceptably low VAFs (all but two were <0.1, and some were <0.01). This transect was on a large bend in the river channel. As the channel bottom is uniformly flat and sandy throughout this site, it was decided to excise the two most downstream transects (KL000 and KL130) from the hydraulic data set as they did not represent unique conditions undescribed by the other transects.

A review of the data sets for the three remaining transects revealed beta coefficients for width, depth and velocity that were within, or just outside, of the recommended range. Transects KL256 and KL1048 had low beta values for CFAC (-0.050 and -0.109 respectively)(see comment on CFAC for Kriedouwkrans). All three transects had acceptable beta values for the stage-discharge relationship. The data set was used in this condition for the hydraulic simulation, and produced a "normal run" with the best VAF values of all three sites: 0.668-2.143.

9.4.2 COMPARISON OF THE WUA-Q PLOTS FOR THE THREE PHABSIM II SITES

9.4.2.1 HABTAE outputs - Total wetted area

Comparison of the relationship between total wetted area and discharge for the three sites (Figure 9.9) suggested that less total wetted area was available at zero and very low discharges at Klawer than at Grootfontein and Kriedouwkrans. This is possibly a reflection of the lack of hydraulic controls such as riffles, and of resultant upstream pool-like areas, in the flat sandy channel at the Klawer site. Indeed, total wetted area over the full QARD range was less at Klawer than at the other two sites, perhaps reflecting its deeply incised channel between steep sand dunes. Also, Kriedouwkrans had more total wetted area than Grootfontein at all discharges, with the two curves converging at the lowest discharges simulated.

9.4.2.2 HABTAE outputs - WUA-Q plot for the target fish species

Predicted WUA for *A. gilli* adults decreased downstream along the river, with no WUA available below 1.6 $m^3 s^{-1}$ at Kriedouwkrans, and none available at any discharge at Klawer (Figure 9.10). This is understandable, considering the species' preference for riffles. WUA was available for the adults at Grootfontein, even at zero discharge, presumably because rocky areas, if not riffles, would still have been inundated. Predicted availability of WUA for *A. gilli* juveniles was higher than for the adults, and was always higher at the rocky upstream site, Grootfontein, than at the other two sites (Figure 9.11). As with the adults, high amounts of WUA were available for the juveniles at Grootfontein, even at zero discharge. The expected downstream disappearance of WUA for the juveniles did not materialise, perhaps because

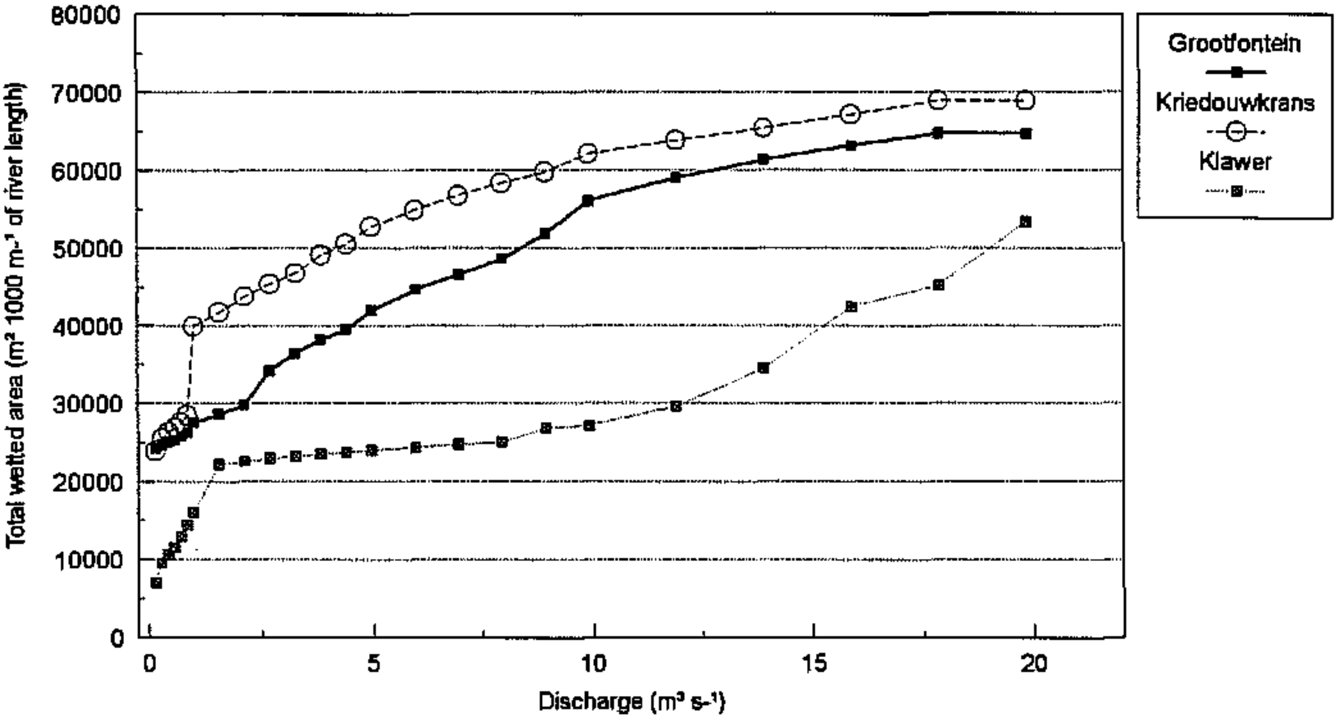


Figure 9.9 PHABSIM II predictions of change in total wetted area with discharge at Grootfontein, Kriedouwkrans and Klawer, using unmodified hydraulic data. See text for details

some of them had been found on sandy substrates and this information was reflected in their SI curves (Figure 7.4). The presence of sandy substrates at the lower sites thus seemed to obscure any habitat requirements based on depth and velocity. However, the lack of WUA for *A. gilli* adults at Klawer would have precluded the presence of the species this far downstream. For both Grootfontein and Klawer, the WUA-Q plots for the juveniles were bimodal, possibly reflecting increases in WUA at higher discharges as new bank areas were flooded.

WUA-Q plots for *B. calidus* showed different trends than those for *A. gilli*. At zero discharge, WUA for *B. calidus* adults was predicted as being available at both Grootfontein and Kriedouwkrans, presumably because of the presence of residual pools in rocky areas as flow ceased (Figure 9.12). No WUA was available at Klawer below about 1.6 m^3 s^{-1}, possibly because depths would then become too shallow over the flat sandy bed. Above about 4.0 m^3 s^{-1} the differences between sites diminished, perhaps because the adults can exist over a wide range of substrates once sufficient depth of water is present. With the juveniles able to inhabit shallower water than the adults and with their recorded marked preference for quiet, sandy areas as well as their ability to live in pools, far more WUA was available for them at Kriedouwkrans than at either other site (Figure 9.13). As with *A. gilli* juveniles, bimodal WUA-Q plots were predicted for Grootfontein and Klawer, for both juvenile and adult *B. calidus*. The peaks and troughs of the plots were not necessarily at the same QARDs as for *A. gilli*, but might still have been reflecting suitable habitat appearing and disappearing at different discharges.

9.4.2.3 HABTAE outputs - WUA-Q plots for the target invertebrate species

Initially the WUA-Q plots for highest community diversity were compared for the three sites. The microhabitat requirements for this highest diversity community include shallow to moderately deep water, a broad velocity range including very low and high values, and a combination of sand and cobble substrate (Figure 8.9). The highest diversity was predominantly associated with cobble riffles and runs, and bedrock/cobble pools and runs (Section 8.10.1). Secondly, WUA-Q plots for the target species *Rheotanytarsus* sp. A were compared, mainly because it had similar SI curves (Figure 8.13) to those for the most diverse community and was thus a potential indicator species for the community (see Section 8.11.4). *Rheotanytarsus* sp. A also exhibited fairly clear microhabitat preferences, especially for velocity and substrate. Moderate to high velocity areas were suitable, as were shallow runs or rapids over bedrock and deeper-water cobble runs and riffles. Sandy bed areas were unsuitable, and near zero velocities only marginally suitable.

For the WUA-Q plots for highest community diversity (Figure 9.14), predicted WUA decreased downstream, but not in a simple way as had total wetted area (Figure 9.9). At very low discharges (about 0.3-0.7 m^3 s^{-1}), WUA was highest at Grootfontein, and lowest at Kriedouwkrans, while at slightly higher discharges (1.5-4.5 m^3 s^{-1}) WUA was highest at Kriedouwkrans and Klawer and lowest at Grootfontein. Above about 5.0 m^3 s^{-1} the same pattern emerged as illustrated by total wetted area: the highest values were for Grootfontein and lowest values for Klawer. However, the shape of the curves differed, with total wetted area (Figure 9.9) increasing with increases in discharge, at all three sites, while WUA for the most diverse community showed no such direct relationship at any of the three sites. Between about 5.0-12.0 m^3 s^{-1} WUA increased at Grootfontein and Kriedouwkrans, and then decreased at higher discharges, while the reverse happened at Klawer. The low WUA at Klawer between 5.0-12.0 m^3 s^{-1} was probably due to increasing velocities producing a highly mobile and

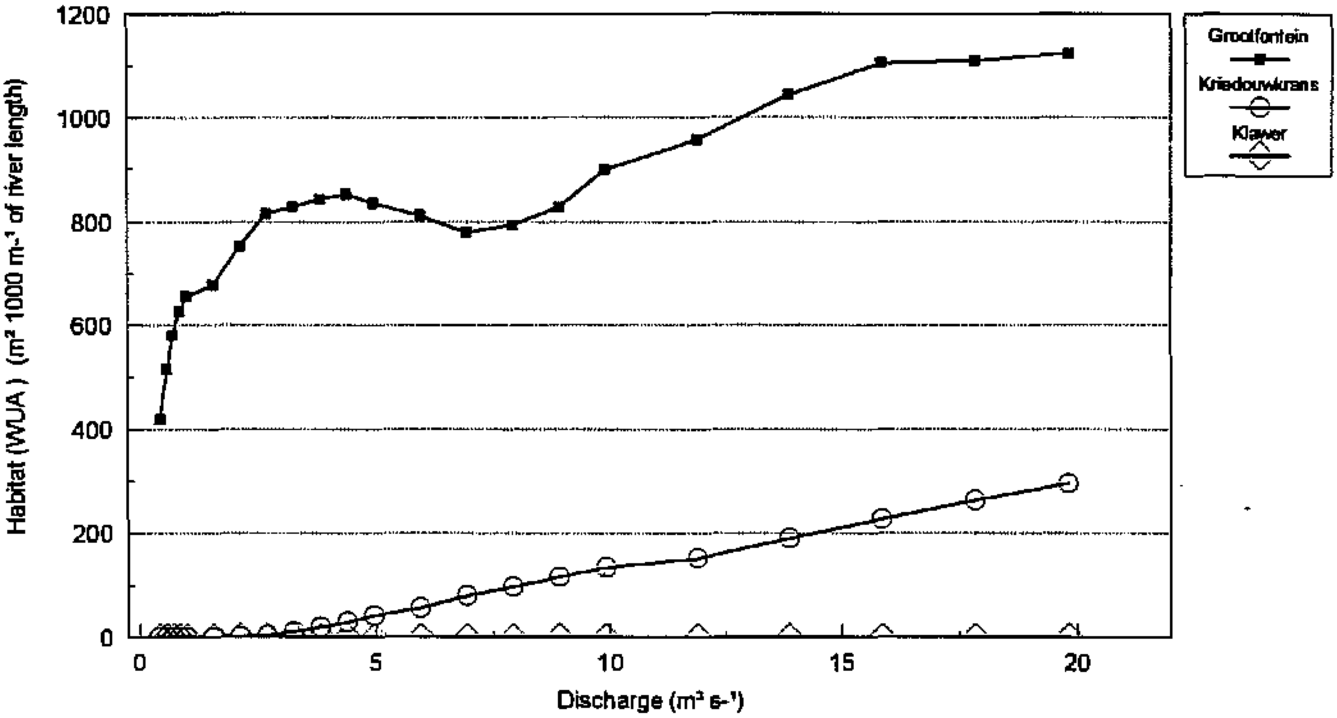


Figure 9.10 **PHABSIM II predictions of change in WUA with discharge for *Austroglanis gilli* adults at all three PHABSIM II sites, using unmodified hydraulic data. See text for details**

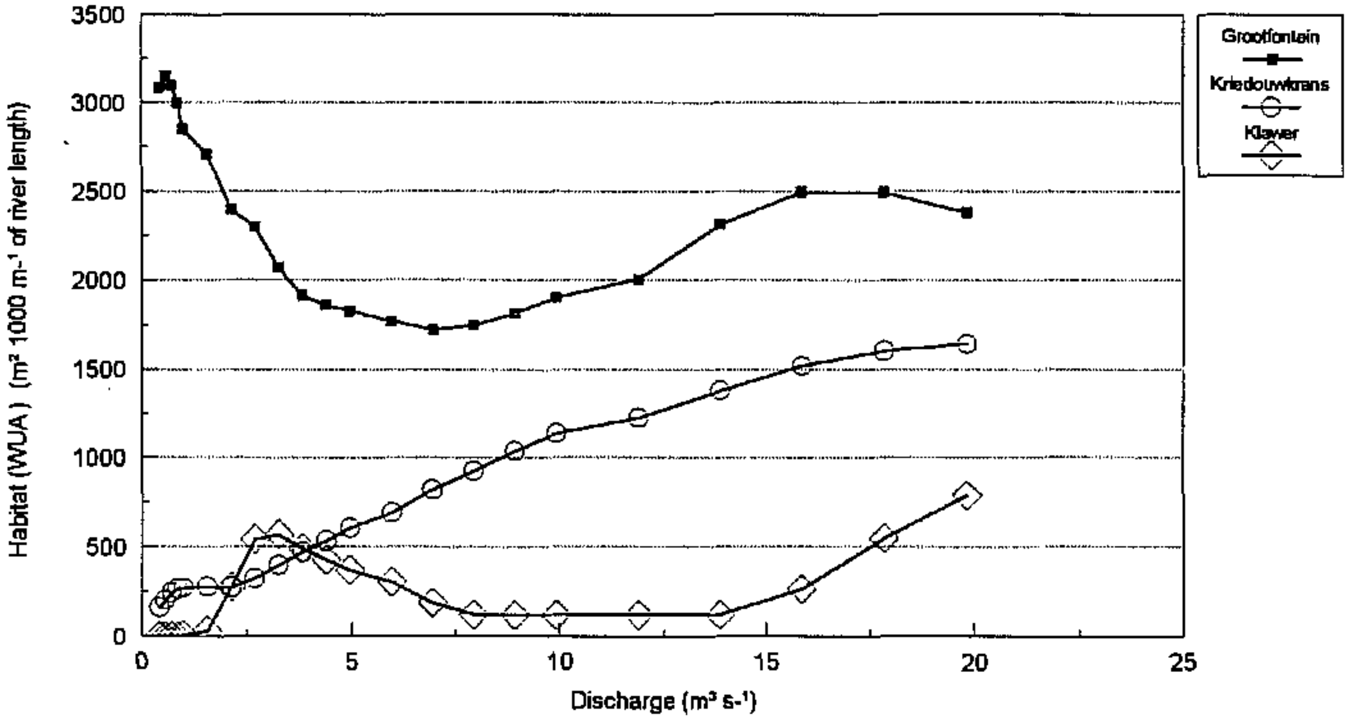


Figure 9.11 **PHABSIM II predictions of change in WUA with discharge for *Austroglanis gilli* juveniles at all three PHABSIM II sites, using unmodified hydraulic data. See text for details**

unstable sand bed, with little refuge and a stressful environment for the invertebrates. In contrast, cobble at Grootfontein and fragmented bedrock areas at Kriedouwkrans would still have been providing refuge at those discharges.

The most obvious trend shown by the WUA-Q plot for *Rheotanytarsus* sp. A (Figure 9.15), was the absence of any WUA for the species at Klawer, presumably because sand is a totally unsuitable substrate for it. The WUA-Q plot thus reflected the species' present distribution, which does not extend further downstream than Bulshoek. At discharges lower than 0.4 m^3 s^{-1}, more WUA was available at Grootfontein than at Kriedouwkrans, but at slightly higher discharges (0.6-0.8 m^3 s^{-1}) both sites supported about the same WUA. The high WUA at Grootfontein at low discharges was unexpected, as *Rheotanytarsus* sp. A showed little preference for low-velocity areas. However, the presence of suitable substrate conditions could have masked this factor. A second clear trend emerging from the WUA-Q plot was that WUA progressively increased at discharges above 0.8 m^3 s^{-1} at Grootfontein, but not at Kriedouwkrans. This was expected, as Kriedouwkrans has far less of the preferred substrate - cobble - than did Grootfontein and less of the hydraulic cover that cobble provides. The very low overall WUA values for Kriedouwkrans support this argument, as does the fact that *Rheotanytarsus* sp. A was found in lower abundances and more patchily distributed at Kriedouwkrans than at Grootfontein.

The WUA-Q plots for *Rheotanytarsus* sp A (Figure 9.15) were compared with those for highest community diversity (Figure 9.14), because the previous comparison of SI curves (Section 8.11.4) had shown this species to be a possible indicator species representing community requirements. Clearly, the species would only be suitable as an indicator for the section of river above Bulshoek, which represents the lower limit of its distribution. For both Grootfontein and Kriedouwkrans, there were consistently far higher (by an order of magnitude) WUAs for the community of highest diversity than for *Rheotanytarsus* sp A. The general trend of the WUA curve was similar for both at Grootfontein, though, with high WUAs at near-zero discharges, followed by a sharp decrease. WUA then increased steadily for both plots at discharges above about 3.0 m^3 s^{-1}. Comparison of the two plots for Kriedouwkrans revealed the same increase in WUA from near-zero to low discharges, the reverse trend from that at Grootfontein. The similar trends evident in the two WUA-Q plots lend support for the suggested use of *Rheotanytarsus* sp. A as an indicator species for summer. However, until this is verified using additional data, it would perhaps be more acceptable to use the WUA-Q plot for highest community diversity as an indication of invertebrate instream flow requirements.

9.4.2.4 Use of the HABTAE outputs for the target fish and invertebrate species in this study and in other studies to make an instream flow assessment for the Olifants River

A comparison of all the WUA-Q plots (Figures 9.1 to 9.15) was done to determine the low discharge below which wetted area and WUA decreased sharply. This discharge was seen as one of the more reliably identifiable ones, when hydraulic simulations could not be done by an experienced modeller. In this report it is termed the **critical minimum discharge**, below which discharges should never be allowed to drop.

Both sets of analyses for Grootfontein (Sections 9.3.2 and 9.4.1) revealed that at discharges below 1.0-2.0 m^3 s^{-1} wetted area and WUA decreased sharply for all four target fish species,

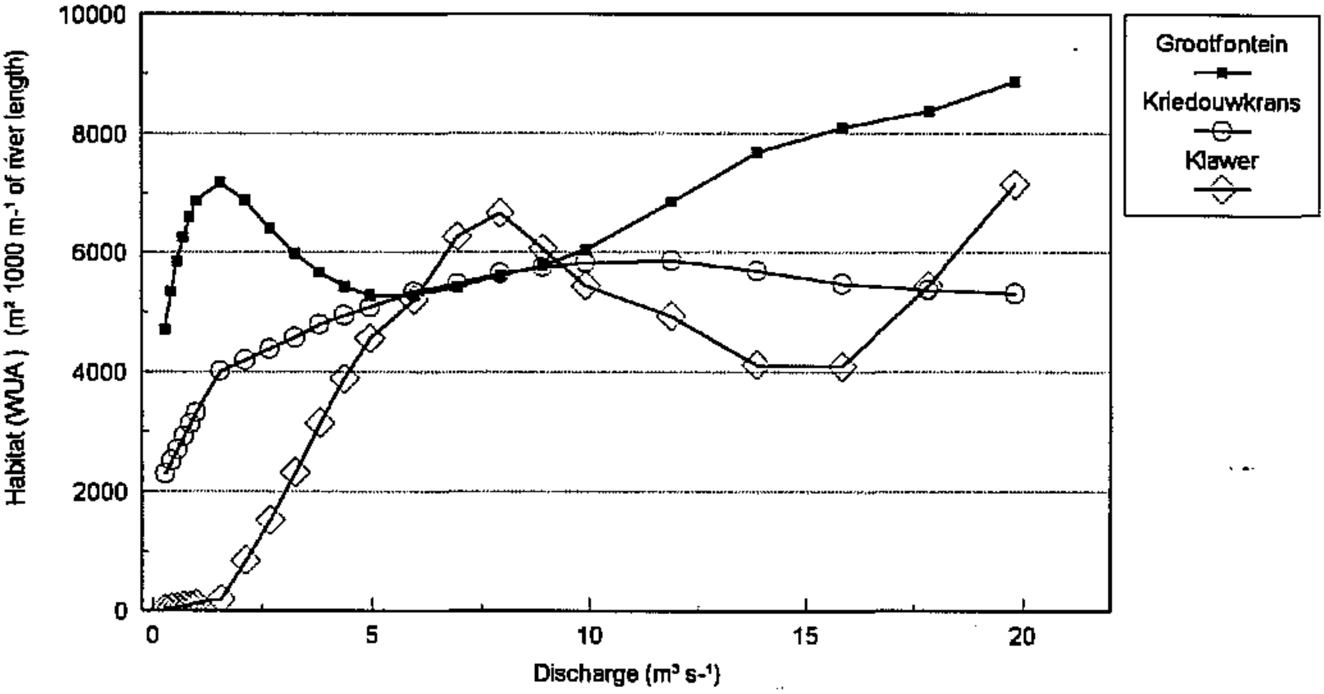


Figure 9.12 PHABSIM II predictions of change in WUA with discharge for *Barbus calidus* adults at all three PHABSIM II sites, using unmodified hydraulic data. See text for details

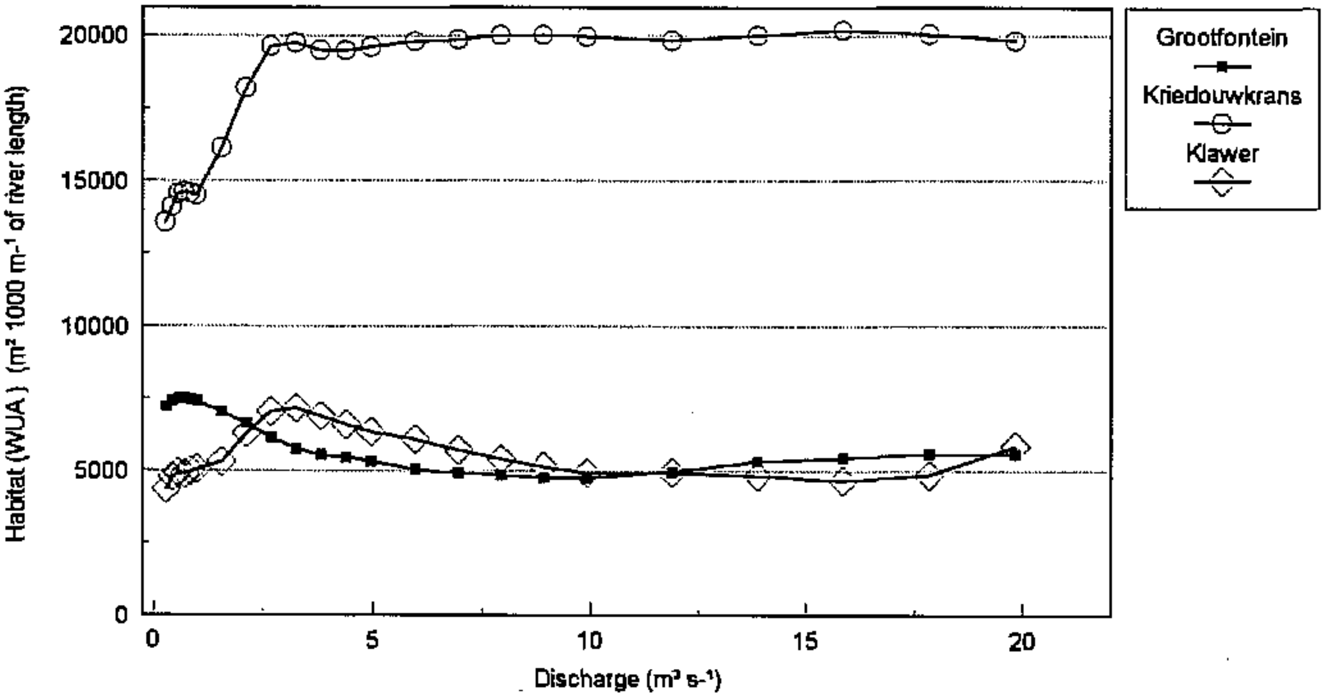


Figure 9.13 PHABSIM II predictions of change in WUA with discharge for *Barbus calidus* juveniles at all three PHABSIM II sites, using unmodified hydraulic data. See text for details

except for juvenile *A. gilli* and *B. calidus*; their WUA showed a sharp decrease at 0.6-0.7 $m^3 s^{-1}$. The invertebrates showed sharp gains in WUA as discharges fell to near-zero or zero, which may be an anomolous result of the fact that much of the channel has slow flowing water in summer. There is no obvious way of deciding which of these sets of results should be used to guide a recommendation on the critical minimum discharge. A customary guideline - the amount of data incorporated in the result - would favour use of the invertebrate figure, while knowledge of the channel shape and the wetted area-Q relationship would favour the fish figure. These results indicate the dangers of relying on one component of the biota for making a recommendation.

Values for the critical minimum discharge for Kriedouwkrans are more similar, though many WUA-Q plots show WUA steadily decreasing as discharges drop, with no obvious inflection point. All the values identified on the plots, even those for the invertebrates but excepting that for *B. calidus* juveniles, were between 0.6-1.6 $m^3 s^{-1}$. This agrees well with the figures of 0.9 and 1.0 $m^3 s^{-1}$ given by Gore *et al.* (1991) and Fouts (1990) respectively. The value for *B. calidus* juveniles was a little higher at 2.4 $m^3 s^{-1}$.

The values for the critical minimum flow at Klawer, identified from the WUA-Q plots of the target species that occurred there, were all between 1.0-1.6 $m^3 s^{-1}$. All three PHABSIM II sites thus emerged with very similar values for the critical minimum discharge for the summer months.

9.4.3 SUMMARY AND COMMENTS ON THE INSTREAM FLOW ASSESSMENT FOR THE OLIFANTS RIVER

In summary, the range of low to zero discharges revealed the most interesting, and probably most important, WUA-Q relationships. Many of the trends shown in the plots and related to the lower QARDs were interpretable, and made sense in terms of the recorded physical microhabitat requirements of the species. Trends relating to the higher QARDs were less obvious and interpretable, with increases in WUA at high discharges not necessarily being related to bank overspill of the main channel, but often seeming to be linked with quite small changes in bank slope.

Generally, the plots for all sites indicated that only an extremely low percentage of the total wetted area provided WUA. This was a surprising result, and suggested that microhabitat requirements might be more complex than apparent when considering each SI curve independently. It is beyond the scope of this project to investigate this phenomenon further, but it is felt that reduction of the channel index code to one digit would probably reduce the difference between total wetted area and WUA as it would result in a much higher number of matches between hydraulic cells and the composite microhabitat requirements.

The various plots indicated that the sites acquired total wetted area at different rates with increasing discharge, as a result of channel shape. They also illustrated that the amount of WUA along the river changed differently for different species, depending on their microhabitat requirements and on changes in such features as the depth and velocity of the water and the proportion of substrates of different particle size along the river. The plots indicated low discharge thresholds or critical minimum discharges, below which WUA decreased rapidly for the fish species. Such an obvious inflection point was far more difficult to identify for the invertebrate species, for reasons not fully understood but possibly related to their ability to use

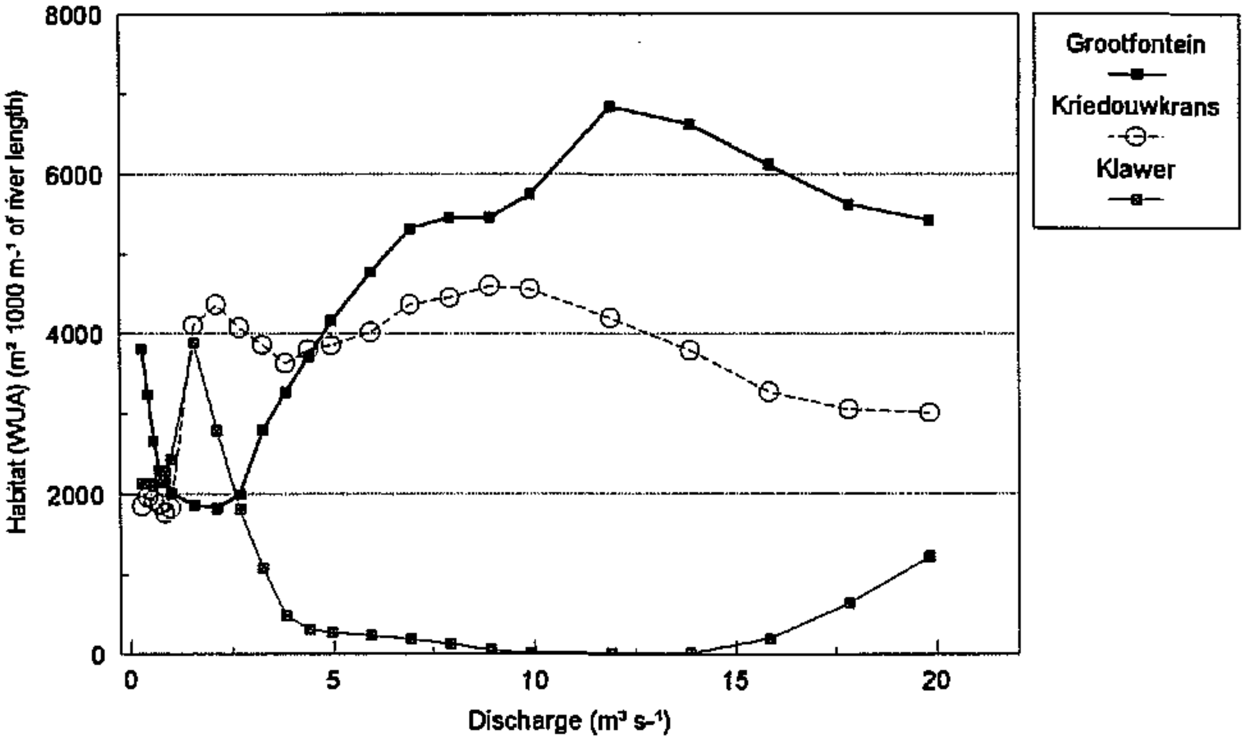


Figure 9.14 PHABSIM II predictions of change in WUA with discharge for highest benthic macroinvertebrate community diversity at all three PHABSIM II sites, using unmodified hydraulic data. See text for details

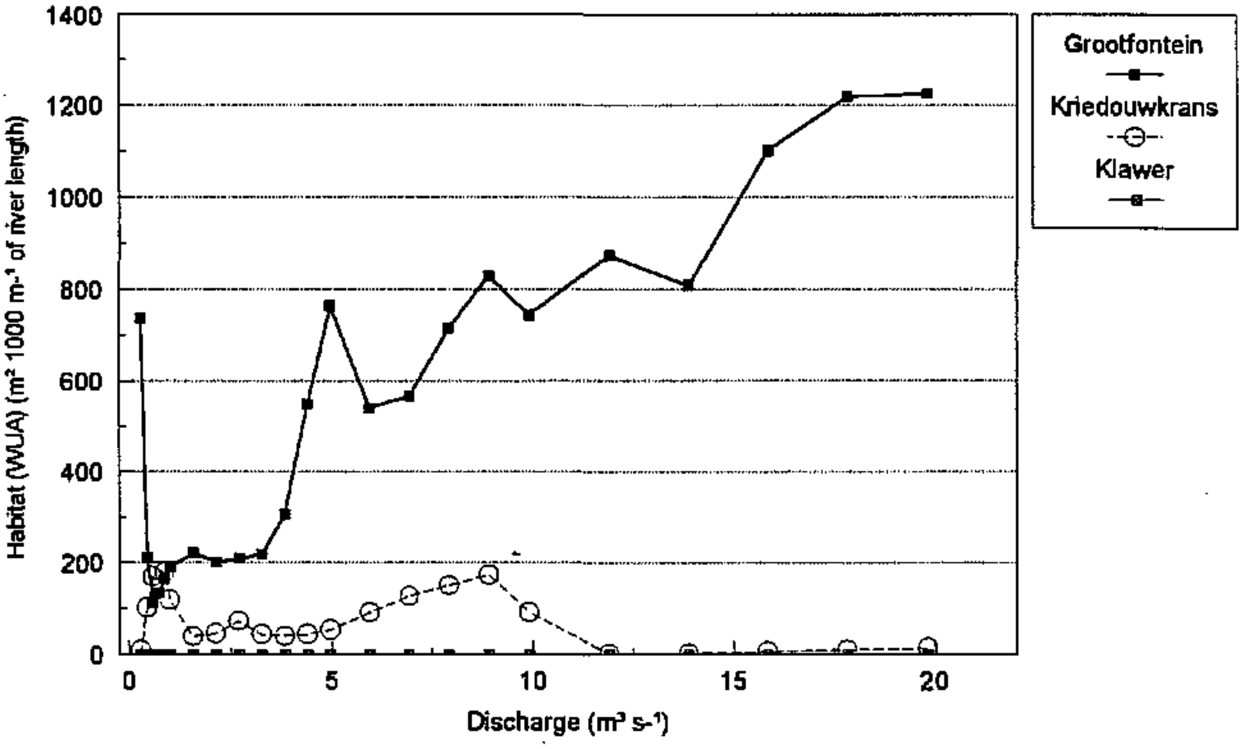


Figure 9.15 PHABSIM II predictions of change in WUA with discharge for the chironomid larva *Rheotanytarsus* sp. A at all three PHABSIM II sites, using unmodified hydraulic data. See text for details

areas of zero or near-zero velocity. As a result, in this study results from the two target components of the biota indicated different critical minimum discharges for the Grootfontein site, with no way of knowing which might be a better figure to negotiate for. Finally, the plots suggested that there can be quite different WUA-Q relationships for life stages of any one species, and so a species cannot be catered for by studying the needs of only one life stage.

In terms of the objective of using PHABSIM II, very little was gained over that already known. With only summer data used for the exercise, and with the warning from Dr R.T. Milhous regarding the restrictive use of the model where little biological data exists (see Section 9.5), it was felt that tentative identification of the critical minimum discharge for summer was all that could be attained. For all three PHABSIM II sites this was about 1.0-1.6 $m^3 s^{-1}$, which was very close to the figures already given by Fouts (1990) and Gore *et al.* (1991) from their much more limited work. During this project, however, invertebrate data for the three other seasons were also collected. These will be used as the basis of an investigation of seasonal differences in physical microhabitat requirements and WUA-Q relationships, and are not reported upon in this document.

9.5 CRITIQUE OF THE OUTPUT FROM PHABSIM II

The criticisms regarding PHABSIM II and its output are many and are dealt with in Tharme (in prep.). They mainly cover the complexity of the model; the potential for producing widely different outputs from it due to the large number of options available; the problem that PHABSIM II is not an ecological model and therefore can only predict how physical microhabitat will change with changes in streamflow and not how species will react to those (and other) changes; the fact that although PHABSIM II is not an ecological model it is sometimes used as one anyway, to predict species distribution, abundance or biomass; the problem that PHABSIM II outputs on their own cannot provide an holistic assessment of instream flow requirements; and the question of whether or not the three variables depth, velocity and channel index adequately describe a species' habitat.

Most of the criticisms relate, in some way or other, to the accuracy and meaning of the WUA-Q plot. The author of PHABSIM II, Dr R.T. Milhous, states (pers. comm.) that in countries such as South Africa where so little is known of the biota, PHABSIM II should be used with caution. He feels that the model should be used only to investigate the broad kinds of flow-habitat relationships that exist in a river and not for detailed investigations of losses and gains in WUA for specific species. He suggests that it should rather be used as a guiding and investigatory tool, with its outputs used in conjunction with professional judgement.

The SI curves for fish and invertebrates created and described in this project illustrate some of the difficulties associated with little biological knowledge. Most of the curves are based on few data points, represent at best a first guide to habitat requirements, and could change in shape, and hence in the suitabilities that they describe, if considerably more data points were added. The information they provide is also limited and simplistic, as outlined in Section 7.8, although they did show worthwhile trends in depth, velocity and substrate-cover requirements that had not been previously described in a structured way. However, even if it was universally accepted that the kinds of input data and outputs presently associated with PHABSIM II were the most appropriate ones, the tentative nature of the SI curves created in this project would still place doubt on the accuracy of the WUA-Q plots. This situation is likely to pertain Pfor most rivers and riverine species in South Africa through lack of relevant data. In the search for a solution to this problem, two sets of observations regarding the WUA-Q plots have emerged.

9.5.1 HYDRAULIC MEASUREMENTS: WETTED PERIMETER AND CRITICAL DEPTHS

Under the circumstances of WUA-Q plots being used to identify trends rather than provide specific details, the most useful information emanating from them seemed to be identification of the discharge below which habitat started to disappear rapidly (see Section 9.4.2.4). However, this critical minimum discharge, which was about 1.0 $m^3 s^{-1}$ at Grootfontein and 1.6 $m^3 s^{-1}$ at Kriedouwkrans could possibly also be identified from a plot of wetted perimeter versus discharge. Such information can be accessed through the AVDEPTH and AVPERM programs in PHABSIM II, which require WSL and discharge data, but not velocity data, as input. Plots of wetted perimeter versus discharge for two riffles and two runs at Grootfontein (Figure 9.16) revealed that appreciable amounts of wetted perimeter persisted in the runs, even at zero discharge, but that riffles rapidly lost wetted perimeter below a certain low discharge. This discharge was roughly the same as that identified for Grootfontein from the WUA-Q plots (Section 9.4.2.4) and so could also be seen as the critical minimum discharge. However, the value from the plot of wetted perimeter has the advantage, or disadvantage depending on the viewpoint, of not being dependent on biological data. For arid and developing countries such as South Africa, with limited biological data but large-scale water-supply problems, a realistic interim management option might be to manage river flow at the biotope level, using information on wetted perimeter as described here.

Other information that would be equally useful can also be gleaned from the standard PHABSIM II input data. For instance, depth data across the two riffles illustrated in Figure 9.16, plotted over a range of discharges, revealed quite different depth distributions. Riffle GR276 retained areas of relatively deep water, even at very low discharges, mainly because it decreased in width with falling flows and eventually lost one channel (Figure 9.17). Riffle GR840, on the other hand lost little wetted perimeter as discharges decreased over the simulated range of flows, because widths remained much the same while depths decreased more or less uniformly across its width (Figure 9.18). During low flows GR840 would probably offer less refuge for fish than GR276 because of its shallowness, and could perhaps block fish passage along the river. It might thus be seen as a **critical riffle**, where both wetted area and depth needed to be considered, and which could be used to guide management decisions on low flows for the whole river reach.

Management of river flow based solely on hydraulic measurements would be unacceptable in anything but the short term, and clearly, directed research on many aspects of riverine biota and their reaction to flow changes is urgently needed. However, the above illustrations highlight the fact that the plots of WUA-Q are not the only, or even necessarily the most interesting and useful, information that can result from the input and output data related to PHABSIM II.

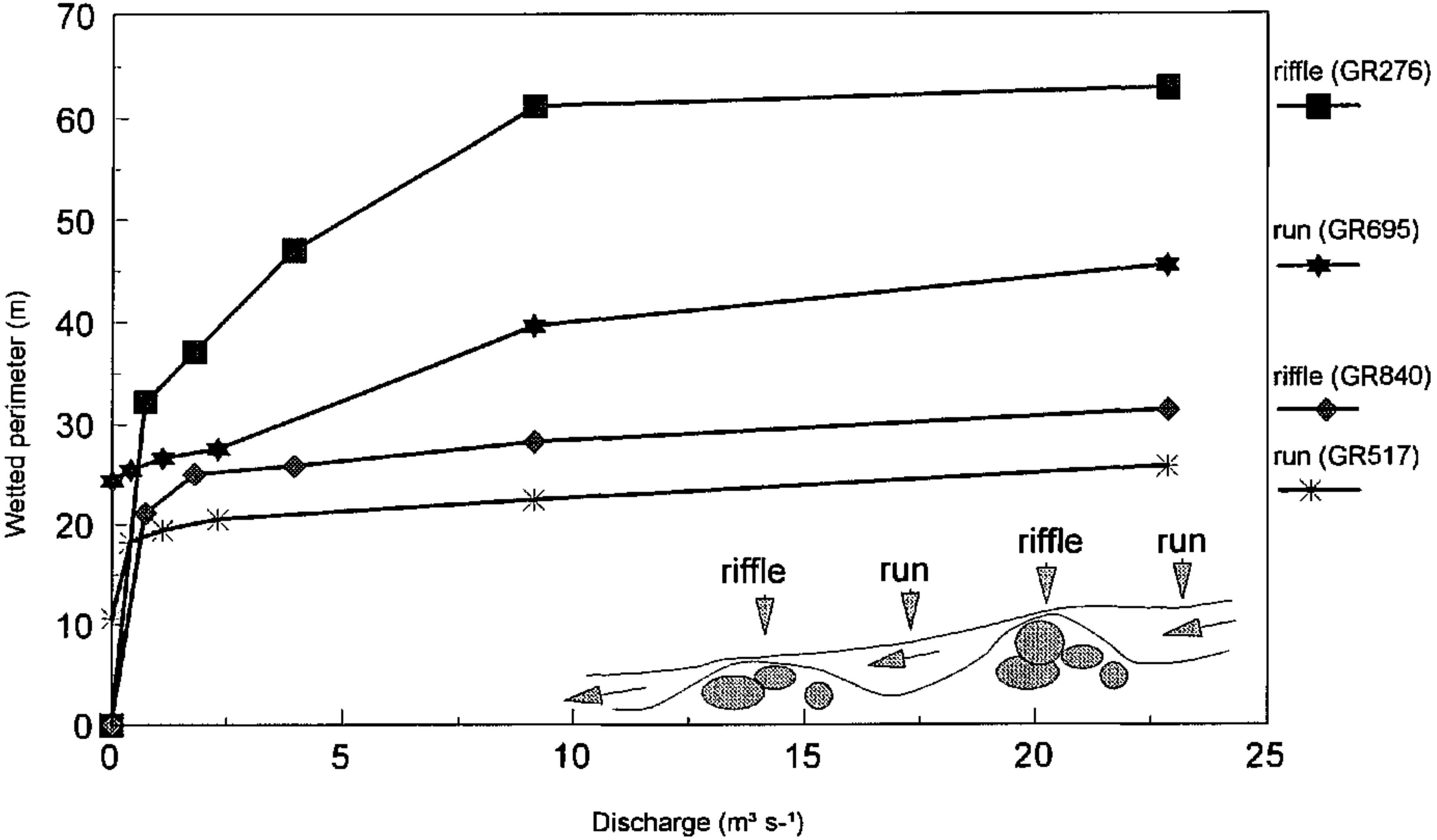


Figure 9.16 The relationship between wetted perimeter and discharge for four transects at Grootfontein

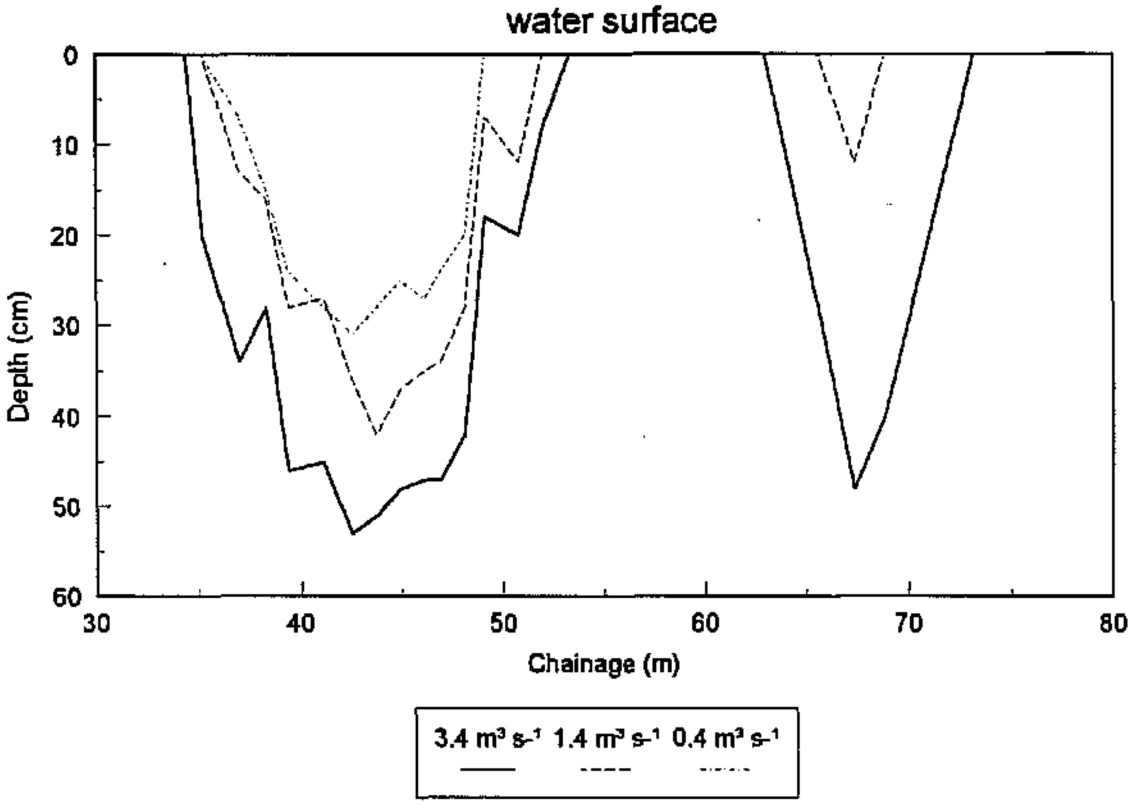


Figure 9.17 The distribution of water depths across transect GR276 at three discharges

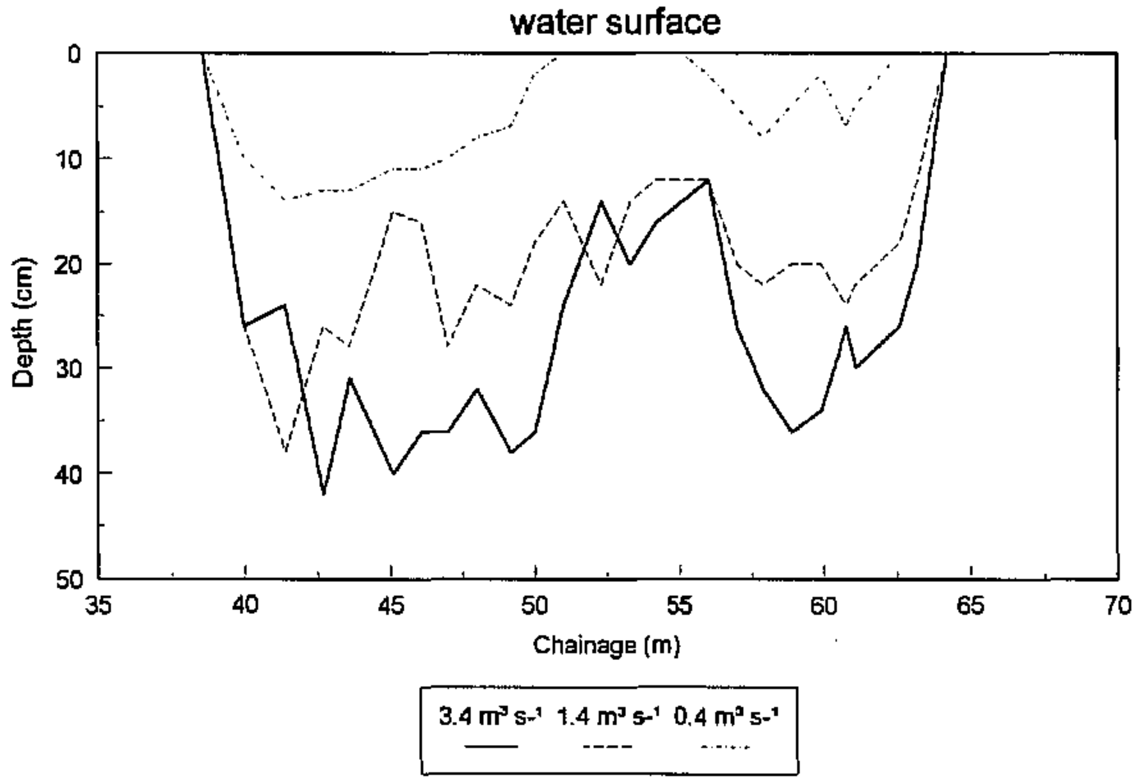


Figure 9.18 The distribution of water depths across transect GR840 at three discharges

9.5.2 INTERPRETATION OF WEIGHTED USABLE AREA

It is difficult to determine from the manuals on PHABSIM II what the units of WUA are. The WUA-Q plots produced by the model have discharge on the X-axis and WUA on the Y-axis. The program HABTAE produces numbers on the Y-axis, but simply labels them "Habitat". Other information provided by the habitat programs includes a table of "Q vs. available WUA per 1000 ft of stream", which still does not indicate the units of WUA. Other authors have given a variety of units for the Y-axis, including m^2 1000 ft^{-1} of river length (Bietz & Kiell 1982) ft^2 1000 ft^{-1} (Bullock *et al.* 1991), m^2 (Orth & Maughan 1982; Shirvell 1986), ft^2 (Prewitt & Carlson 1979) and m^2 km^{-1} (Bain *et al.* 1982). The actual PHABSIM II output of WUA **appears** to be in ft^2 1000 ft^{-1}, which is a measurement of area.

However, there is no obvious explanation from the authors of IFIM as to how WUA is computed from the input data. Gan & McMahon (1990) explain that "a 10 m^2 area of streambed with preference index values of 0.90, 0.85 and 1.0 for depth, velocity and substrate respectively would have a net suitability of use of 0.90 x 0.85 x 1.0 = 0.765. Thus, 7.65 m^2 of streambed of the 10 m^2 area may be regarded as being suitable for use and called the weighted usable area (WUA) for the particular section of stream". Summing the WUA values for all the cells gives the WUA of the entire stream reach, and repeating this for a range of discharges produces the WUA-Q plot. Shirvell (1986) appears to make the same interpretation.

The above interpretation appears to indicate that 7.65 m^2 of the cell is 100% suitable, whereas a more correct interpretation would seem to be that all (10 m^2) of the cell is 76.5% suitable. The first interpretation produces WUA in units of area, whereas the second interpretation produces WUA in units of suitability or "worth". Thus, the cell described by Gan & McMahon is said to have a net suitability of use of 0.765, which presumably means that its "worth" as habitat is 76.5% of that theoretically possible. At a different discharge, it would presumably have a different "worth". In other words, the "worth" of the cell is changing with changes in discharge, not its area, and so expressing WUA in units of area seems inappropriate. PHABSIM II produces WUA in units of area rather than units of "worth", which seems to confirm that it uses the interpretation given by Gan & McMahon.

The following example further explores the problem and the two interpretations of WUA. Four cells, each of 1000 ft length and 10 ft width, have composite (net) suitability (CSI) values of 0.6, 0.4, 0.2, 1.0 respectively (Figure 9.19). Using Gan & McMahon's explanation (which is assumed to be the official IFIM one and if it is understood correctly), the cells would produce WUAs of 6000 ft^2, 4000 ft^2, 2000 ft^2 and 10 000 ft^2 respectively, or a total WUA of 22 000 ft^2 1000 ft^{-1} of river length.

If 20 cells are each provided with SI values for three different discharges (Figure 9.20) (arbitrary values chosen), three points on a WUA-Q plot can be calculated in the same way (Figure 9.21). If the alternative interpretation is used, however, at each discharge the percentage of cells in each of several different "worth classes" can be determined (Figure 9.22). This would be a more confusing output for a manager to understand, but would be more ecologically meaningful. It would also present a challenge to ecologists to assess if, for instance, Q_1 or Q_3 was the ecologically more acceptable discharge. Q_3 produces the higher WUA (Figure 9.21) and more cells that are 90-100% suitable than Q_1 (Figure 9.22) but, unlike Q_1, also produces some cells that are completely unsuitable.

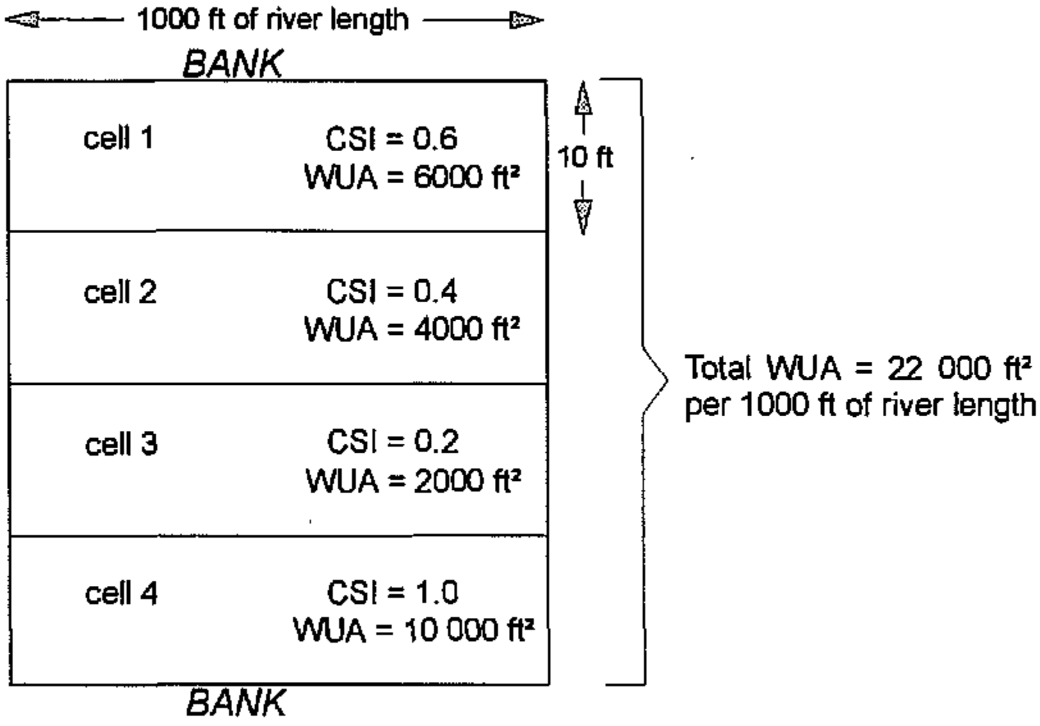
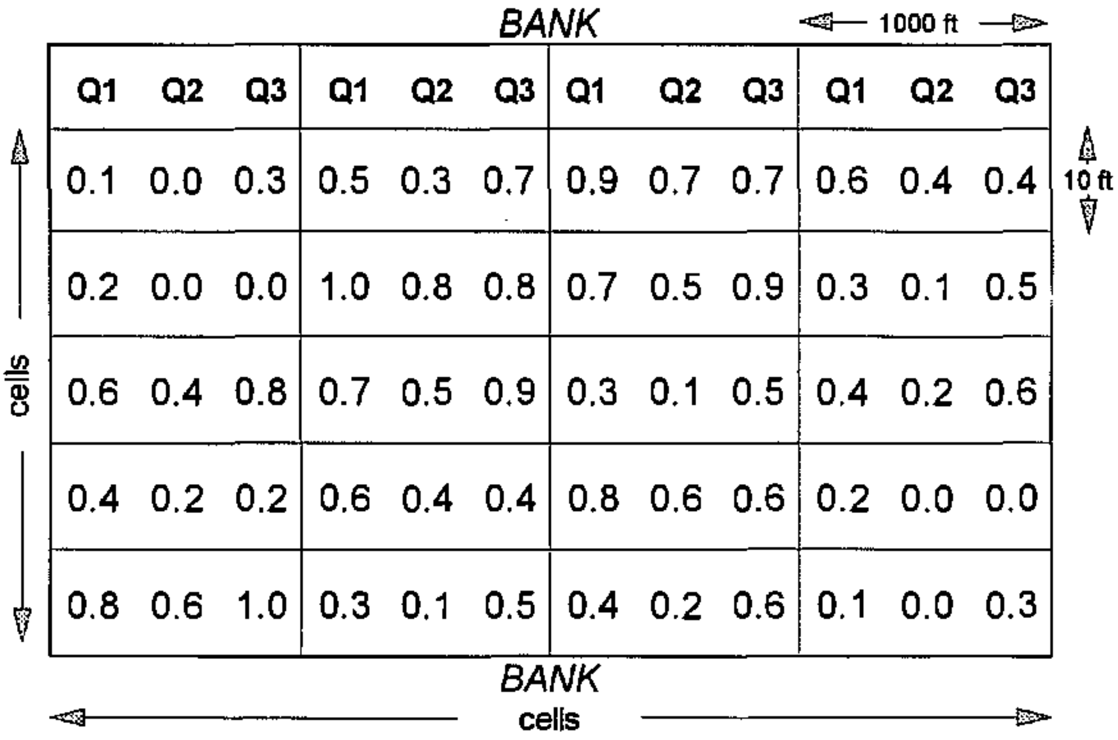


Figure 9.19 The presumed method by which PHABSIM II converts composite suitability values (CSI) for cells to WUA



Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3
0.1	0.0	0.3	0.5	0.3	0.7	0.9	0.7	0.7	0.6	0.4	0.4
0.2	0.0	0.0	1.0	0.8	0.8	0.7	0.5	0.9	0.3	0.1	0.5
0.6	0.4	0.8	0.7	0.5	0.9	0.3	0.1	0.5	0.4	0.2	0.6
0.4	0.2	0.2	0.6	0.4	0.4	0.8	0.6	0.6	0.2	0.0	0.0
0.8	0.6	1.0	0.3	0.1	0.5	0.4	0.2	0.6	0.1	0.0	0.3

Figure 9.20 Composite suitability values at three different discharges for 20 cells, interpreted in two different ways (see Figures 9.21 and 9.22)

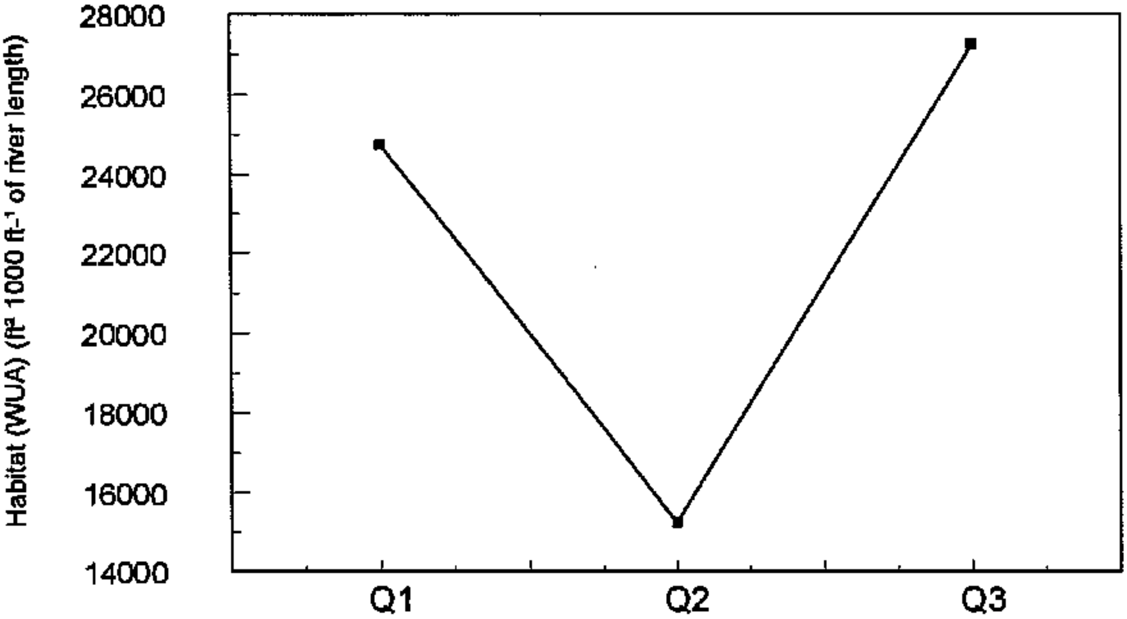


Figure 9.21 Standard WUA-Q plot produced by PHABSIM II created using the data illustrated in Figure 9.20

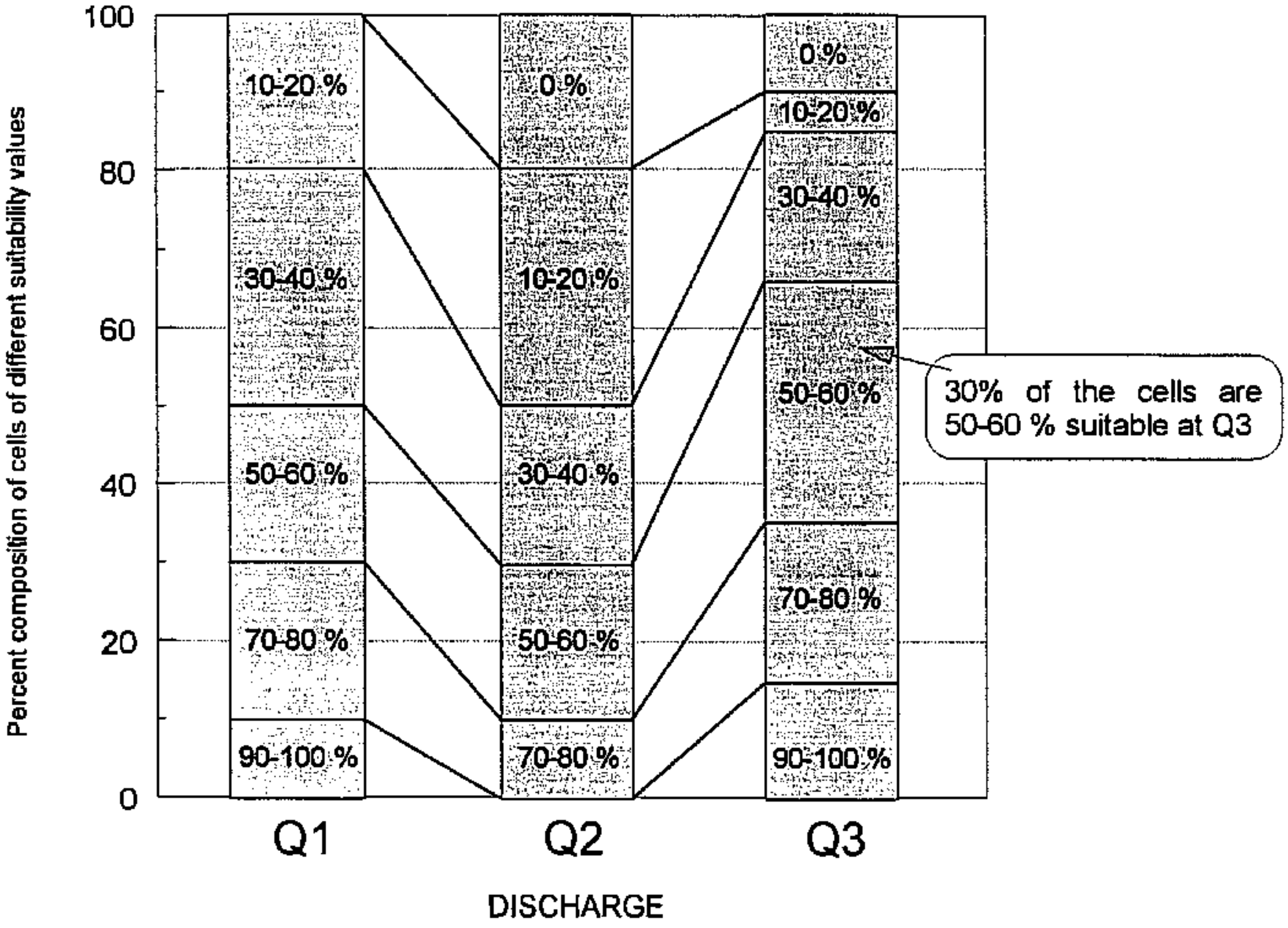


Figure 9.22 An alternative interpretation of the data illustrated in Figure 9.20 based on changes in the habitat "worth" of cells with changes in discharge

Such an output would have to be linked with information on total wetted area in order to indicate how the total wetted habitat was expanding or shrinking with changes in discharge.

The PHABSIM II manual (Milhous *et al.* 1989) contains the program LSTHCF within its Effective Habitat suite of programs which lists the model's output in the form needed to create figures such as Figure 9.22. However, such information does not seem to be used in scientific papers reporting on PHABSIM II studies. Dr R.T. Milhous (pers. comm.) agrees that the interpretation illustrated by Figure 9.22 is correct and that the reason for its lack of use is probably difficulty of interpretation compared with the simple WUA-Q plot. It is beyond the scope of this project to investigate how satisfactory a substitute the WUA-Q plot is for the more complicated version of the WUA-Q relationship represented by Figure 9.22, which is felt to be more correct.

9.6 SUMMARY OF THE APPLICABILITY OF THIS COMPONENT OF IFIM

There are several main areas of difficulty with using PHABSIM II. Firstly, there appears to be no text explaining the theoretical concepts incorporated into the model's programs, or giving a simple explanation of the sequence of events in terms that could be understood by anyone likely to want to use the model. This leads to considerable confusion with respect to understanding the relative importance of the various input data and how they are used, as well as difficulty in interpreting the outputs. For instance, without such a text it remains unclear how velocities are simulated across any one transect, what the velocity distribution factor "n" is, what the theory behind the various beta coefficients is and how their acceptable ranges were determined, or why WUA is interpreted in the way illustrated in Figure 9.21. Many other uncertainties of this nature remain at the end of this project.

The manual for PHABSIM II (Milhous *et al.* 1989) is large and quite repetitious. Where reference is made in it or in the PHABSIM II tutorial (Milhous *et al.* 1990) to further explanations, they are often repeats of information already given and not more detailed treatments of the topic. The error message lists in the manual are essential but were found by chance; they are not indexed at the front of the manual, and not presented in one place but as one or two pages of text interspersed with sample printouts and other data for some of the programs.

Actual running of the model is extremely confusing for the uninitiated. It is extraordinarily user-unfriendly, sometimes producing error messages that bear no relation to the error or, often, no error message at all, but simply leaving one with a program that will not run. Reams of files are created and are difficult to keep track of, as the syntax naming the sequence of files called-up or created in any program run is not automatically printed as part of the program output. Large numbers of printouts are also produced, much of their content being repetitious and unnecessary. The model has many redundant or invalid routines and badly needs some house-keeping. Dr R.T. Milhous (pers. comm.) agrees with this, but feels that this will not be done within the U. S. Fish and Wildlife Service. In a country such as South Africa which uses metric units, field measurements have to be taken in metric units, converted to imperial units for use in PHABSIM II, and then converted back to metric units for interpretation and presentation of the results, increasing the source of potential errors.

The hydraulic simulations within PHABSIM II should be done by an experienced hydraulic engineer, and the choices within the habitat programs made by an experienced freshwater ecologist, who should also interpret the WUA-Q plots and use them in the recommendation of an instream flow. Implicit in these requirements is the need for such specialists to also guide collection of the most suitable field data. Without skilled inputs such as these at every stage of the work, and without the necessary explanations of the theoretical side of PHABSIM II, there is the danger that the model will be used without understanding and produce outputs of questionable meaning. In this respect, it also seems important that the various options that were chosen in both the hydraulic and habitat programs, and why they were chosen, should be recorded in any report of such work, something that seems never to have been done.

The authors reached a basic understanding of the model only toward the end of the work reported here. At this stage, experimental investigations could begin of how it functions and how the output can be affected by different programs or options within programs. For instance, a suggested solution of the problem of secondary channels that should not be simulated by PHABSIM II as filling up until bank overtopping occurs (Section 9.3) was to raise the elevation of such channels. Additionally, investigation of the effect of combining the three SI curves in different ways (Section 3.11), or of creating a CI code with one or three digits, could be informative. The habitat programs need expert input from ecologists as much as the hydraulic programs do from hydraulic modellers. Investigations of the different WUA-Q plots produced when the habitat programs are used by experienced ecologists or those with no ecological training would be interesting. None of these investigations were possible in this project.

A final point concerns the failure to make the microhabitat-macrohabitat link in this project. For the fish, the link could not be made at all because the target species do not occur in the main stream and there is insufficient knowledge of their ranges of tolerances to accurately predict where they could exist in it in the present or the future (Section 7.7). Such knowledge on macrohabitat is available for the target invertebrate species, as they already exist in the mainstream (Section 8.13). However, for both fish and invertebrate target species, no assessment of future macrohabitat could be made, and so no link up with the PHABSIM II predictions of available microhabitat were possible for future scenarios.

These kinds of problems with macrohabitat assessment may well limit the situations in which IFIM can be applied. Certainly, in this study, use of PHABSIM II could not be justified on the basis of a consequent link-up with macrohabitat zones. PHABSIM II could still be used as a stand-alone method, but without the link to present and future macrohabitat zones its use would be reduced. It could be used to describe present physical conditions and the present WUA-Q relationship for a reach of unknown length around the study site and, based on the assumption that macrohabitat zones would not change with a water-resource development, could also be used to make predictions of how the WUA-Q relationship would change at such a time. If in the future macrohabitat zones were likely to change, however, use of PHABSIM II to predict future WUA-Q would have to be done with caution.

10. ASSESSING IFIM: SUMMARY ASSESSMENT OF THE INSTREAM FLOW INCREMENTAL METHODOLOGY

10.1 SUMMARY OF THE SEQUENCE OF STEPS IN IFIM, AND THEIR PRACTICALITY

The Instream Flow Group of the U.S. Fish and Wildlife Service at Fort Collins has been developing the Instream Flow Incremental Methodology for more than a decade. In essence, IFIM was designed to allow a complete evaluation of the effects of incremental changes in flow on the stream environment. Starting from the time that a water-resource development is proposed that will affect the flow regime of a river, a series of approaches and techniques are provided that take the researcher from initial identification of the objective to be achieved with an IFIM study, to the final use of the research done. This occurs in negotiations for the required amount of water for the river after the water-resource development has taken place. The steps are described in Chapter Three, and the way in which they were done in this project is described in Chapters Four to Nine. Each of these latter Chapters contains a summary assessment of the extent to which the step(s) that it deals with could be carried out. The major steps are listed below, each with a short comment; the Chapter summaries should be referred to for more comprehensive assessments.

> *Assessment of the catchment, in order to determine if it is presently driving changes in the river or is likely to do so after the water-resource development*

The concept of catchment equilibrium is sound in theory but difficult to work with. Catchment equilibrium is not easily assessed when there is little or no historical information upon which to assess change. Also, if catchment change is occurring, it will usually be impossible to either stop it or wait for it to reach a new equilibrium condition. This prompts the query of the limited validity of any simulations of river conditions in a changing catchment and river, which presumably the IFIM requirement for the catchment to be in equilibrium was designed to circumvent.

> *Determination of the extent of the area of concern (study area) and of the representative reaches and study sites within the study area*

The guidelines are a little confusing regarding terms such as reaches, but do help structure the determination of the study area and the selection of sites. The methodology provides a useful function in alerting the researcher to the great range of factors that should be considered when setting up an instream flow study.

> *Determination of the riverine species whose microhabitat requirements will represent the conditions wished for in the post-development river (target species)*

In North America the target species will usually be those of commercial or recreational importance about which concern is being expressed. It is less obvious which species to select if the aim is to maintain a "healthy" river (a common aim in South Africa), and there is little recognition in IFIM of the fact that virtually nothing might be known of the biota with which to guide the choice. Such a situation is likely to pertain for most water-resource developments in South Africa.

> *Description of the present* **macrohabitat** *zones in the river, in terms of hydrology, geomorphology, water chemistry, temperature and the biota. Prediction of the future macrohabitat zones after the water-resource development. These theoretically allow estimates to be made of the present and future extent to which these variables will restrict distribution of the target species along the river as a whole.*

Present macrohabitat conditions along the river can be documented, but predicting how these will change with the water-resource development requires sophisticated models of several different kinds. Meeting such requirements has serious implications in terms of project expertise, time and finances. Without such models, predictions will be at a coarser resolution, but even with them, predictions may not be at a sufficiently fine resolution for satisfactory ecological interpretation. If accurate predictions could be made, the concept of macrohabitat zones remains difficult to use because different species might perceive large or small longitudinal changes in any of the macrohabitat variables differently. Each species could therefore have its own macrohabitat zones, and so these are unlikely to exist as discrete zones that are common to all species. If satisfactory macrohabitat zones cannot be identified, the link with the output of the model PHABSIM II (see below) cannot be made, and so any anticipated change in **total** habitat for the target species with development cannot be quantified.

> *Description of channel morphology, and cell-by-cell descriptions of hydraulics and substrate-cover (CI) conditions at the study sites. This information is used in PHABSIM II, which models changes in physical microhabitat with discharge for the target species.*

The main point of caution is that the channel transects, created and then used to describe channel morphology and hydraulics, should be selected with the help of an experienced hydraulics engineer.

Measurement of the conditions most often used by the target species, in terms of water depth, water velocity and CI (physical microhabitat)

Determination of the microhabitat requirements of riverine species is a young field of study, with almost all of the relevant development of concepts and techniques having occurred since the mid-1980s; it thus displays all the stimulation, controversy and confusion inherent in such fields. Confusion exists because techniques are changing, being refined, or sometimes abandoned, faster than the scientific community can be informed through the international literature. Controversy appears regarding the extent to which the three microhabitat variables - velocity, depth and CI - act independently in influencing where species occur and, indeed, whether or not they are the principal variables involved. They are the only options readily available for input to PHABSIM II, and ecological influences such as competition are ignored. Proponents of IFIM argue that PHABSIM II is not an ecological model, merely predicting the amount of physical microhabitat that will be available over a range of flows and not how that microhabitat will be used.

Shirvell (1986), however, comments that two criteria need to be met by microhabitat variables incorporated into a model such as PHABSIM II: the variables must be amenable to objective quantification, and it must be possible to model the way in which their influences on habitat selection change with incremental changes in discharge. As research continues on the relevance and proper use of the three presently-used variables, other potentially useful variables such as food sources and biological interactions may deserve similar attention. Perhaps they can be used in PHABSIM II, and even if they cannot, much can be learnt about microhabitat requirements by using the same approaches of quantification and determination of their relationships, if any, to discharge.

These, and other issues touched on in this report, remain unresolved by the international community, though not unacknowledged. They do not detract from the study of microhabitat requirements, however, but rather serve to highlight a developing field of study rich in structured approaches, innovative ideas and new close contacts with river ecosystems as species are observed in their natural environments.

Use of the model PHABSIM II to simulate hydraulic conditions, and to link these with values of CI (channel index, that is, substrate and cover conditions) for each cell, in order to produce a description of cell-by-cell microhabitat *conditions in terms of water depth, water velocity and CI over a range of unmeasured discharges. The model is then used to predict the amount of microhabitat (weighted usable area - WUA) that will be available to the target species over a chosen range of flows*

PHABSIM II is extremely difficult to understand and use well. For those with the skill and time to learn and use it properly, it does seem to offer an exciting number of options for studying the changing patterns of flow in a river and how these might influence habitat availability. It is probably the best of a very few hydraulic models worldwide that attempt to describe river conditions at the level of resolution required for ecological studies. The simplistic and commonly used output, Weighted Usable Area, overshadows another output from the model that might be more difficult for managers to understand and more useful and challenging for ecologists to interpret.

> *Linkage of microhabitat and macrohabitat data in order to assess if the amount of total habitat will change as a result of the water-resource development.*

This could not be done in this project, due to the inability to satisfactorily designate macrohabitat zones. The most that seemed acceptable was to recognise that the hydraulic simulations done by PHABSIM II were representative for short sections of river of unknown length upstream and downstream of the study site. While extrapolations over longer lengths of river might be acceptable for coarse-level hydraulic simulations, it is not known what affects such extrapolations would have on the outputs of a model simulating at the biotope-level of resolution. Uncertainty regarding the extrapolation of PHABSIM II outputs on microhabitat and the failure to delineate present or predict future macrohabitat zones, meant that the link between microhabitat and macrohabitat to show present and future total habitat could not be made.

10.2 POSITIVE AND NEGATIVE ASPECTS OF IFIM

It appears that little housekeeping of the basic approach in IFIM has been done during its development, leading to an already complex methodology becoming even more so due to the inclusion of terms, concepts and techniques that later became redundant. The many IFIM manuals available at the beginning of this project contain detailed information, advice and techniques, and awareness only developed gradually that substantial parts of what is presented remain as untested concepts. In North America, a network of IFIM practitioners seems to keep abreast of new developments in the field and, presumably, researchers in other countries who have attended the IFIM courses also receive updates. None of these has been available to the authors of this report, although Dr R.T. Milhous has become an excellent contact in the last few months of the project. It should be stated, therefore, that the impression gained that IFIM is a rather confusing and incomplete methodology may be to due, to some unknown extent, to South African researchers being isolated from its main area of use and development.

It became clear that IFIM, in the form studied here, cannot provide a complete instream flow assessment in the way needed in South Africa. The South African Department of Water Affairs and Forestry now requires from river scientists, for any proposed dam, a comprehensive recommendation on the modified flow regime that should be released from the dam for maintenance of the downstream river in some predetermined state. This requirement goes far beyond the traditional output of PHABSIM II, which is simply a description of the loss and gain of physical microhabitat with changes in discharge, for one or more chosen aquatic species. There is no indication, for instance, of how to build into a modified flow regime small flow pulses for serially-spawning fish, or large floods that might be required to mobilise sediments and scour substrates. A range of different magnitude flows might be required, however, to maintain a river in a "healthy" condition. This highlights a surprising gap in IFIM, namely, a comprehensive link with the natural hydrology of the river.

Hydrological data seem to be used in IFIM only in the assessment of macrohabitat zones and, to a minor extent, in guiding the QARD values chosen for simulation. There seems to be nothing linking the methodology with the whole suite of different flows that comprise the present/natural flow regime of a river. Yet the requirement for these flows, each of which has its own characteristics in terms of magnitude, timing, duration and frequency, needs to be addressed if the water resources of a river are to be developed in an environmentally sustainable way. The difference between what South African water managers need and what IFIM provides highlights the fact that IFIM was created for management at the species level whereas South Africa needs a methodology for managing river flow at the ecosystem level.

In this project, an enormous amount of work provided no more than an indication of the **trend** in loss and gain of microhabitat in mid-summer for a few chosen species, with changing discharge or increasing distance down the Olifants River. It should be noted, however, that a large part of this heavy work load was due to the paucity of relevant biological data, which will be common to all instream flow studies in this country, and to the fact that invertebrates as well as fish were used as target species. Invertebrate studies of this nature are far more labour-intensive than are fish studies. Even more of the work load consisted of learning the many skills required, such as land surveying and modelling with PHABSIM II. Probably the most relevant information emanating directly from the exercise, in terms of an instream flow assessment, was an indication, through loss of wetted area and microhabitat, of the critical minimum discharge for mid-summer. This was seen as the low discharge below which loss of wetted area accelerated. Still not obvious from this research is exactly how relevant and important this critical minimum discharge might be, how far above it discharges should be held in order to avoid detrimental reactions from the riverine ecosystem, how this level should change through the year, and what the requirements for floods and smaller flow surges might be in order to maintain the river at different degrees of "health".

In conclusion, from the perspective of geographically isolated users of IFIM, one of its major strengths is its value as a training tool. Though confusing and difficult to learn and follow, and incomplete in several ways, there is an extraordinary wealth of knowledge within its manuals. Whether working at the level of hydraulic studies, ecologial studies, or a combination of these, the manuals contain abundant details and practical tips to guide the user. In the same way, PHABSIM II, though user-unfriendly and without a structured text on its conceptual base, is a very useful tool for instream studies. Only towards the end of this project was the stage reached where it could be explored and tested constructively, and there are many rich avenues of investigation that could now be followed. In essence, IFIM, including its model PHABSIM II, creates a framework for studying catchments, river flow, water quality, river channels, biotopes and species in a structured way and, in doing so, guides researchers into a more comprehensive understanding of the relationships between them. Though IFIM remains incomplete, and should be seen as one part of the suite of tools that would be required for a complete instream flow assessment, those who initiated and developed it are commended for an initiative which can only be described as visionary.

Parallel with the later stages of this investigation, research began on alternative approaches for aiding instream flow assessments. These are designed to take into account the realities of the South African situation, where time, finances and biological data are likely to be very limited. The initial developmental stages of these approaches are documented in Chapters Eleven and Twelve.

11. THE USE OF DAILY FLOW DATA TO CLASSIFY SOUTH AFRICAN RIVERS

The senior authors of this Chapter are A. R. Joubert and P. R. Hurly

11.1 INTRODUCTION

One of the basic steps required when developing guidelines for sustainable development of the country's water resources, is to define more clearly, and group in terms of their flow patterns, the kinds of rivers that exist in South Africa. Extrapolations from known to unknown situations can then be made with greater confidence and precision, and it may be possible to seek generalisations on recommended modified flow patterns for any one group of rivers.

A variety of classifications is available worldwide which group rivers, either based on flow data alone, on flow data and catchment characteristics, or on some combination of these and chemical and biological data. The first two categories are most often used when common flow patterns are sought, and research using them has fallen into two main kinds. Some researchers grouped rivers for a specific purpose, such as for regional flood frequency analysis (Wiltshire 1986) or for regional flow duration characteristics (Mimikou & Kaemaki 1985). Others were more general in their approach, seeking to group rivers by geographic region or type: Poff & Ward (1989) for North America; Hughes (1987), Hughes & James (1989) and Nathan & McMahon (1990) for Australia; Mosley (1981) and Jowett & Duncan (1990) for New Zealand; and Haines *et al.* (1988) for a global treatment. Few used flow data alone, and only one group (Poff & Ward 1989) concentrated exclusively on daily flows.

In previous work on grouping South African rivers, hydrological regions have been proposed, but these have been based mainly on runoff derived from rainfall data (Midgley *et al.* 1983). Regions or types of rivers, based solely on flow data, have received little attention. Kovac's (1988) work on flood regions is the only work known by the authors that relates flow characteristics to regions in South Africa. This lack of literature on regional flow analysis appears to be due not only to the unreliability of some of the flow data, compared to rainfall data, but also to the limited length of many data sets. Additionally, grouping rivers by region or flow type requires data on virgin flow patterns, as the use of data based on present modified flow patterns could result in rivers being grouped without meaning and without reflection of local climatic and other conditions. Relatively few of the country's gauging weirs have long data sets of virgin flow, and those that do are mostly restricted to the uppermost reaches of rivers in areas of high rainfall. Hence, rainfall data have been the basis of most analyses dealing with trends in river flow (Midgley *et al.* 1983; van Biljon *et al.* 1987).

Rainfall patterns and runoff patterns may be different, however, with a period of rainfall manifesting itself quite differently in river flow, depending on, *inter alia*, whether or not the catchment was already saturated. Additionally, the rainfall:runoff ratio varies considerably across the country, depending on climate, vegetation, geology, slope and other features of the landscape (Table 11.1), and without any obvious regional trend that would allow generalisations to be made. Inter-annual coefficients of variation for precipitation (CVP) are, in general, much lower than those for flow. In addition, a particularly high or low coefficient of variation for flow (CVR) is not necessarily reflected in a correspondingly high or low value of CVP in the same region. Thus, precipitation is an insensitive indicator of flow patterns, although broad seasonal patterns of rainfall will be reflected in flow. In investigations dealing with large-scale problems such as water yields and flood management, these differences may not be important or can be accounted for; information is usually required at the level of monthly averages or predicted flood peaks and so indirect information supplied by rainfall data may suffice.

An understanding of the ecological functioning of river systems, however, may well require high-resolution information on the characteristics of river flow throughout the year and how these affect conditions for the riverine biota. Values for mean monthly flow, for instance, would be inadequate for ecological studies, as they give no indication of whether or not flow

Table 11.1 Runoff as a percentage of precipitation and coefficients of variation of precipitation (CVP) and runoff (CVR) for some South African rivers and regions. Corresponding (DWA 1990b) drainage regions are provided (modified from Braune & Wessels 1981)

Region/River	Rainfall:Runoff	CVP	CVR	Drainage region
West/ NW Transvaal	3.5	0.17 - 0.28	0.4 - 1.48	A1 - A3
NW Transvaal	1.7	0.22	0.98	A4 - A7
Soutpansberg	8.9	0.26	1.08	A8 - A9
Olifants River (Tvl)	5.7	0.17 - 0.34	0.67 - 0.99	B1 - B7
Letaba and Shingwedzi Rivers	6.5	-	-	B8 - B9
Vaal River before Vaal dam	7.7	0.14 - 0.23	0.82 - 0.92	C1 + C8
Vaal River to Orange River	2.7	0.17 - 0.31	0.84 - 2.33	C2 - C7+C9
Orange and Caledon Rivers	14.0	0.19 - 0.32	0.56 - 2.25	D1 - D2
Orange River before Vaal River	1.6	0.33	1.97	D3
Lower Orange River	0.3	0.48	1.62	D4 - D8
Olifants River (W Cape)	38.7	0.27	0.53	E1
Doring and Sout Rivers	5.2	0.25 - 0.29	0.61 - 0.73	E2 - E4
Namaqualand	1.9	-	-	G
SW Cape	17.1	0.17 - 0.28	0.33 - 0.64	G
Breede River	20.2	0.20 - 0.25	0.26 - 0.72	H
Gouritz River	6.0	0.23 - 0.36	0.67 - 1.44	J
Outeniqua River	12.2	0.23	1.32	K
Gamtoos River	5.9	-	-	L
Algoa River	9.2	-	-	M
Sundays River	4.2	0.28	1.54	N
Groot Boesmans River	2.7	-	-	P
Great Fish River	4.5	0.18 - 0.29	0.8 - 1.12	Q
Amatola River	9.5	0.19 - 0.29	0.82 - 1.16	R
Kei River	9.7	0.19 - 0.23	0.65 - 0.79	S
Bashee River	19.7	0.15 - 0.16	0.3	T
Southern Natal	19.0	-	-	U
Tugela River	17.9	0.14 - 0.22	0.37 - 1.11	V
Zululand	13.8	-	-	W1 - W3+W7
Pongolo and Usutu Rivers	14.2	0.14 - 0.22	0.39 - 0.59	W4 - W5
Umbuluzi Rivers	5.7	-	-	W6
Komati, Crocodile and Sabie Rivers	14.7	0.17 - 0.20	0.41 - 0.70	X

was uniform throughout the month, or indeed, if the river stopped flowing or dried up for part of that month. Flow characteristics for ecological studies are therefore probably best gleaned directly from flow records, and particularly from daily flow records, for these reveal details of high and low flow events, both of which are thought to play central roles in structuring riverine ecosystems (Poff & Ward 1989).

The models commonly used by hydrologists in South Africa to predict river flow, such as the Pitman (Pitman & Kakebeeke 1991) and ACRU (Schulze 1989) models, are not ideal for gaining this kind of ecological perspective on river flow for several reasons. In addition to their being based largely on rainfall and catchment characteristics, they are also complicated, expensive and rely on concepts not commonly well understood outside the hydrological discipline, and are thus difficult for ecologists to use effectively at this stage. Additionally, these models may not provide output at the level of resolution required for ecological work, although they can provide a very useful insight into the major features of the flow regime being studied. Nevertheless, river ecologists are increasingly turning to hydrological records and models to aid in their assessments of the environmental water requirements of rivers, but are hampered by this lack of appropriate information. A need was recognised for a simple approach to grouping South African rivers by flow regimes, based on readily accessible data and on criteria which would have direct relevance to the functioning of the riverine ecosystem.

The work reported on in this Chapter thus centred on an investigation of the daily flow records held by DWAF, in order to determine if they could be used to group, either by geographical region or by flow type, the rivers of South Africa. Further, it was hoped to identify the specific characteristics of flow which distinguished each resulting group, and to assess the general usefulness of the groups for river ecologists and water managers.

11.2 DETAILS OF THE DAILY FLOW DATABASE

by A. R. JOUBERT

11.2.1 AVAILABILITY OF DATA AND THE CHOICE OF GAUGING STATIONS

DWAF has listed every gauging weir that it manages on the rivers of South Africa (DWA 1990b). From this, weirs were selected which, according to DWAF regional technicians and subsequent checking of gauging station positions on maps supplied by the Hydrological Research Institute of DWAF, were situated upstream of all major impoundments or abstractions and had a minimum record span of 20 years. The process of selection was not exhaustive with regards to checking upstream alterations to flow patterns, as subsequent non-homogeneity tests (see Section 11.2.2) would indicate which gauges were recording flow that was changing with time. In total, 352 gauging weirs were selected, and their daily flow data obtained from DWAF on magnetic tape. A programme was written to remove all years with missing data, thus reducing the number of stations with the required number of data years. In addition, the data were changed from calendar to water years (October to September) for each station so that any one wet season was not split over two years.

Two different sets of flow variables were derived from the daily flow data for the gauging stations selected (Section 11.3), one describing seasonal patterns of flow, and one describing flow type in terms of such characteristics as predictability. All variables were initially derived for all stations, but the second set of variables required longer data sets to derive reliable estimates than did the first set of variables. As many areas, especially in arid regions, did not have gauging weirs with long records, the number of years of data required for stations in all areas was thus reduced as follows.

For the analysis of the variables describing seasonal patterns of flow, 279 stations with a minimum of five years of data, and an average of 17.5 years were used, after removal of non-homogeneous stations. For the analysis of the variables describing flow types, 204 homogeneous stations with a minimum of ten years of data and an average of 20.7 years were used. Recognising that longer data sets are required for arid areas than for wetter ones in order to accurately reflect the natural flow patterns, the shorter data sets were still used, as the alternative would have been to exclude some parts of South Africa from the analysis. The minimum numbers of years used here compare well with the number used in those studies mentioned in Section 11.1 (discussed further in Section 11.7).

11.2.2 TESTING FOR NON-HOMOGENEITY OF THE DAILY FLOW DATA

Non-homogeneity in daily flow records occurs where changing upstream patterns of abstraction and land-use change the runoff pattern recorded by the flow gauging station over the gauged time period. In order to further assess if the chosen gauging weirs were recording relatively natural flow, they were tested for non-homogeneity in the following way. Dent *et al.* (1987) derived 712 homogeneous climate regions for South Africa, and identified a representative rainfall gauge for each of these regions. The Computing Centre for Water Research (CCWR) at the University of Natal supplied the names and co-ordinates of the 712 representative rainfall stations. For each of the original 352 flow gauging weirs the closest rainfall station in the same catchment was identified, using the routine NEAR from ARC/INFO (ARC/INFO 1991). Each resultant pair of weir and rainfall stations was verified as being in the same catchment, by overlaying the respective maps.

The pairs of rainfall and flow gauging stations were used to create double mass plots, plotting cumulative monthly flow against cumulative monthly rainfall for each station (W. Zucchini, Statistical Sciences, University of Cape Town, pers. comm.). Where breaks in the plots occurred which were obvious by visual assessment, the flow gauging station concerned was either excluded from the analyses, or the data after the break were excluded, where this was possible. The stations remaining after this exercise were felt to be recording reasonably natural flow.

11.3 FLOW VARIABLES DERIVED FROM THE DATABASE

by A. R. JOUBERT

Many possible ways exist to group and characterise rivers, depending on the end-use of the classification. As a starting point, two methodologies previously used elsewhere in the world

(Haines *et al.* 1988, and Poff & Ward 1989), were employed. Many of the variables used by them were felt to be important ecologically, and it was hoped that they would themselves be useful as descriptors of the rivers.

Two sets of variables were derived from the database, each of which described different aspects of river flow. The first set was related to the main characteristic of river flow which differs across the country, namely, the seasonal flow pattern. The north-eastern parts of the country tend to have peak flows in summer, while in the southern and south-western parts flows tend to peak in winter. Transitional areas occur in between. Superimposed on this is a pattern of perennial rivers, mainly in the east, south and south-west, and non-perennial rivers in the more arid areas.

Both of these patterns can be represented at a coarse resolution by the proportion of total flow occurring in a river per calendar month. Thus, the first set of variables derived from the database described the timing of seasonal changes in flow, and whether these were relatively moderate or severe. It was hoped that analysis of this set of variables would group gauging stations to reveal **regions** with similar **seasonal flow patterns.**

Seasonal patterns of flow give little indication of the general characteristics of flow at the daily level. In semi-arid countries such as South Africa and Australia, however, river flow at the daily level exhibits a wide range of predictability, degree of cessation of flow, and variability (J. M. King, Freshwater Research Unit, University of Cape Town, pers. comm. and T. A. McMahon, Monash University, Australia, pers. comm.). The second set of variables derived from the database was thus selected to describe characteristics of flow such as these. Analysis of these variables would, it was hoped, group stations recording similar **types of flow**. These groups would not necessarily be restricted to specific geographical areas.

Combining the two sets of variables at the outset could either have obscured the underlying seasonal patterns, or grouped stations that recorded flows that were similar in terms of seasonal patterns but quite different in terms of types of flow. Analysing the two sets of variables separately served to describe each station's flow more fully, as each station could be placed in a seasonal group, and then its flow record analysed for flow type. The variables were derived as described below.

11.3.1 SEASONAL FLOW PATTERNS

The average flow of each calendar month, as a percentage of the average annual flow of the flow record, was derived for each of the 279 stations with more than five years of data. Each station thus had twelve variables which together described the seasonal pattern of flow.

11.3.2 FLOW TYPES

Several of the studies mentioned in Section 11.1 derived hydrological variables for the purpose of grouping similar rivers in some way. Of these, only Poff & Ward (1989) used daily flow data to derive hydrological variables, some of which were thought to be of ecological significance. Their variables (Table 11.2) formed the basis of the second set of analyses. One, dealing with flood predictability, was excluded because one such measure was already included. The remaining variables were divided into three categories, which described river dimensions, general characteristics of flow and characteristics of floods (Table 11.2). *The*

Table 11.2 **The variables derived from daily flow data to describe flow characteristics of rivers. These are the same as the variables used by Poff & Ward (1989) who used an additional measure of flood predictability. The shaded variables were used in this study to determine the final groups of gauging stations for the analysis of flow types (refer to text for details).**

River Dimensions

GRMEAN - grand mean daily flow over the period of record
SPMEAN - GRMEAN divided by catchment area
ZFLOW - average flow taken only for days of flow
GRMIN - average annual minimum over the period of record
GRMAX - average annual maximum over the period of record

General Characteristics

[illegible] - average [illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Flood Characteristics

FLOFRQ - number of floods (GRMAX/GRMEAN) per year
FLOINT - median number of days between floods
FLODUR - mean duration of floods
FLOPRD - the maximum proportion of floods occuring in a sixty day period
MEDDAY - the median day of the year on which floods occur

values of all the variables were derived from the natural logarithms of the daily flow data. To accommodate zero flow values, and to avoid negative logarithms, each value was multiplied by 2000, and 1 (which was half of the smallest resulting value) was added to each product (W. Zucchini, Statistical Sciences, University of Cape Town, pers. comm.). The variables were derived using FORTRAN programs, most of which were adapted from those used and supplied by Poff & Ward.

Two hundred and four stations with records ten or more years long were retained in the database for the analyses. Even with this length of record, some stations may have contained data from a dry or wet period only, due to the quasi-cyclical nature of dry and wet spells in southern Africa (Tyson 1986). However these approximately nine-year long spells do not consist exclusively of dry or wet years (Tyson 1986), and with an average record length of 20.7 years, it is reasonable to assume that most stations would have included years representative of both dry and wet spells.

All the variables listed in Table 11.2 were derived and used for the initial exploratory analyses. Of these variables, GRMEAN, SPMEAN, GRMAX, GRMIN, ZFLOW and MEDDAY were not used in the final analyses. They either were not descriptors of characteristics of flow but of size (GRMEAN, SPMEAN, GRMIN, GRMAX, ZFLOW) or were not useful due to the nature of the variable (MEDDAY is cyclical). These variables are included here, together with descriptions of their derivation, for the sake of completeness, and as they are held as part of the database of flow-derived variables formed from this study.

Subsequent to the initial analyses, which used all the derived variables and helped to determine their relative importance and effects, those components of the flow regime that were judged to be of ecological significance were the only ones used in subsequent analyses (Table 11.2). These were: the coefficient of variability of intra-annual flow (GRCV) and the number of days of zero flow a year (ZERODAY), which both reflect the degree of cessation of flow; the predictability of flow (PRED and PROP) and of floods (FLOPRD); the frequency of floods (FLOFRQ); and the duration of and intervals between floods (FLODUR and FLOINT). Further details of how the variables were derived are given below.

11.3.2.1 River dimensions

The overall mean, here referred to as the grand mean flow (GRMEAN), is the average of the natural logarithms of the daily flow at the station, taken over the entire period of record. Dividing this value by the catchment area, to get the specific mean annual flow, SPMEAN, gave an indication of the rainfall:runoff relationship of the upstream catchment. ZFLOW described the mean flow based only on flows which were above zero. GRMIN, is the mean of the annual minima over the period of record, while GRMAX, is the mean of the maxima, both derived using the natural logarithms of daily flow.

These variables were not included in the final analyses as they are not descriptors of flow characteristics, but of the size of the river. While size is of obvious importance, a description of flow types based on hydrological characteristics such as the degree of cessation of flow, and predictability, is of more interest and use to ecologists in aiding understanding of the responses of the biota to flow patterns. In addition, the variables describing river size tended to dominate the exploratory analyses, thus masking the effect of other variables. GRMIN divided by GRMEAN could have been used as a ratio to describe the extent of changes in flow during the water year. A low value would have indicated a flow pattern with an extreme change from wet to dry seasons. However, GRCV adequately described this aspect of variability, and for the purposes of this analysis an extra measure of variability was regarded as superfluous. Although not used directly in the final analyses, GRMAX and GRMEAN were used to derive certain other variables described below.

11.3.2.2 General characteristics of flow

A non-temporal measure of overall flow variability is the intra-annual coefficient of variation (GRCV). This is derived by taking the mean over the years of record of the intra-annual coefficients of variation. GRCV thus measures within-year variability and not variability between years.

Temporal predictability and variability of flow are described by the three variables PRED, CONST and CONT, all of which have values between zero and one. According to Colwell's (1974) predictability index, predictability (PRED) consists of two components; constancy (CONST) and contingency (CONT). Constancy is the part of predictability due to flows which remain similar throughout the year. Contingency is that part of predictability which is due to a predictable seasonal regime. In other words, where high flows occur at a predictable time of year, contingency will be high. PROP is the proportion of predictability due to constancy, or simply CONST divided by PRED. A high value indicates that predictability is mainly due to constant flow throughout the year while a low value indicates that predictability is due to predictable seasonal changes in flow.

To derive Colwell's predictability index, the natural logarithms of the daily flow data were initially modularised by dividing by GRMEAN. These *l*n-modularised flow values were then divided into 11 categories of flow magnitude (0.0-0.10, 0.11-0.25, 0.26-0.50, 0.51-0.75, 0.76-1.00, 1.01-1.25, 1.26-1.50, 1.51-1.75, 1.76-2.00, 2.01-2.50, larger than 2.5). For each month of the water year, the number of times a particular category of flow occurred was counted. This could have been done using each day of the year rather than each month, but it was felt that for this analysis a division into days would be at too fine a level of resolution.

From the array of 12 months (columns) by 11 categories of flow (rows), the degrees of constancy and contingency were determined. Contingency is lowest when the columns (representing time of year) of the data matrix are homogeneous, that is, when the probability of occurrence of each flow state is independent of the time of year (Colwell 1974). Constancy is at its lowest when the row totals (magnitude of flow) are equal, since this means that all magnitudes of flow occur at any time of the year. Constancy thus will be at its highest when only one magnitude of flow occurs throughout the year, or when only one row has values greater than zero (Colwell 1974).

11.3.2.3 Flood characteristics

Five variables describing characteristics of floods were derived (Table 11.2). In order to derive these a definition of a flood was required for each station. The flood threshold value for each station was taken as the mean, over the period of record, of the annual maxima of the natural logarithms of the daily flow values (GRMAX). This corresponds fairly well with the 50% exceedance probability or two-year return period for floods (Poff & Ward 1989) for normally distributed annual maxima. The two-year return period for floods, should, in turn, correspond to the average return period of bankfull discharge (Poff & Ward 1989). The return period of bankfull discharge is usually between two and five years in South Africa, with 2.3 years as an acceptable average (Z.P. Kovacs, DWAF, pers. comm.). As ecologically significant substratum movement occurs at flows less than bankfull discharge (Richards 1982, Leopold *et al.* 1964 cited in Poff & Ward 1989), the two-year return interval seems a reasonable standard to use, while acknowledging that the actual return period for bankfull discharge for rivers in South Africa is very variable.

It is important to note, however, that only for normally distributed data will the mean be the equivalent of the two-year return flood. For positively skewed annual maxima, the bias in the mean will be reflected in a lower return interval (for example one in every five years). For negatively skewed annual maxima, the mean will reflect a higher return interval. The mean of the annual maxima is thus more a measure of the skewness of the annual maxima, than the threshold for a two-year return flood.

This flood threshold value was used to determine the variables describing flood characteristics (Table 11.2). Flood characteristics were defined by: FLOFRQ, the number of floods per year (floods lasting more than one day were taken as one flood); FLOINT, the median number of days interval between floods (if the interval was two days or less, then the floods before and after were regarded as one flood); FLODUR, the mean duration of floods; FLOPRD, flood predictability, and MEDDAY, the median day of the year on which floods occurred. MEDDAY was not used in the final analyses, as it is a cyclical variable which, even with the data arranged in water years, may be problematic.

FLOINT will generally be decreased for negatively skewed data, and increased for positively skewed data, for the reasons described above, while FLOFRQ will be increased for negatively skewed data.

FLOPRD was calculated by counting the number of floods occurring on each day of the year over the period of record, thus forming a 365-day array of counts, and then finding the maximum proportion of flood days occurring in any 60 day period. A high proportion of flood days occurring in a certain 60-day period therefore indicates a predictable flood time. This variable is not affected by skewness of the data.

11.3.3 TERMINOLOGY USED TO DESCRIBE KINDS OF FLOW

There are no ecologically recognised definitions of terms such as perennial, seasonal and episodic flow and the boundaries between them are necessarily vague as they form parts of a continuum. The terms presented here conform to a generally accepted understanding of them, and became the starting definitions for the analyses. During the course of the study, they were further defined (see Section 11.6.2.2), and a new term quasi-perennial-seasonal was created in order to describe flow patterns not explained by any of the other terms.

Starting definitions

- EPISODIC - Flow that only occurs after rainfall episodes; flow does not necessarily occur every year

- EXTREME SEASONAL - Flow that usually occurs for less than half the year, every year, during the same season(s)
- SEASONAL - Flow that usually occurs for more than half the year, every year, during the same season(s)
- QUASI-PERENNIAL-SEASONAL - Flow that in some years continues all year, but in other years ceases for anything from a few days to most of the year
- PERENNIAL - Flow that usually continues all year, every year
- FLASHY - Flow with frequent floods of short duration

11.4 TWO METHODS FOR GROUPING RIVERS IN SOUTH AFRICA

The variables described in Section 11.3 were then used to group or classify rivers. Using the same database and the same flow-derived variables two researchers followed different approaches and methods to group the rivers (Figure 11.1).

The first researcher used and adapted methods applied elsewhere (Haines *et al.* 1988; Poff & Ward 1989) to group rivers. Non-hierarchical cluster analysis and stepwise discriminant analysis were used to derive the groups. In this method the researcher decides on the number of groups to be formed, the variables used, and the options used within the computer software packages. These decisions control the formation of groups. Once these choices have been made, the algorithms used in the software packages determine the groups formed. The object of the method was to assess if the resulting groups were useful, interpretable and meaningful, when explained in terms of the variables forming them. If so, these variables and the groups formed would serve as a source of information for managers and researchers.

The second researcher used an approach which has, as far as is known, not previously been used to group rivers. The stations are represented on a series of two-dimensional plots using the covariance biplot or correspondence analysis techniques. These are scaling techniques in the class known as basic structure or singular value decomposition display techniques. Principal components analysis is a well known member of this class of techniques. The aim of all these techniques is to summarise, in as few dimensions as possible, the information contained in all the variables. The more highly correlated the variables, the better the techniques will work.

Once the variables to be used have been chosen, plots are generated and the researcher forms the groups, as in other ordination techniques, by inserting boundaries on the plots. The process is iterative and allows the researcher to take into account information, such as geographical location, which is not incorporated in the plot and to consider information from several plots at once. Thus the process is not objective. To an extent the final groups will reflect the bias of the researcher. The computer programs provide the researcher with the tools to make the decisions, but they do not make the decisions.

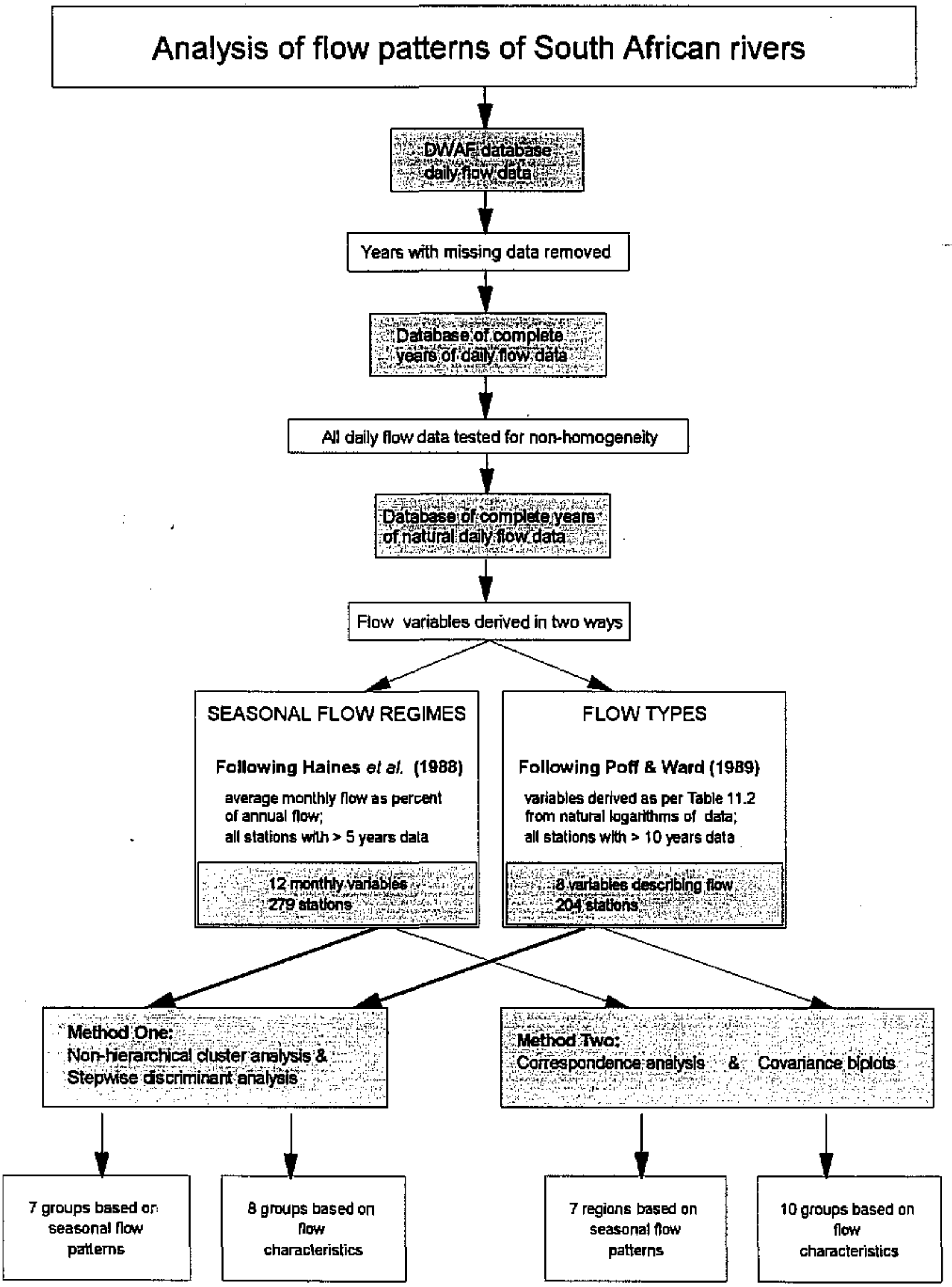


Figure 11.1 Flow chart showing the steps taken and methods used in the analysis of flow patterns of South African rivers

Each researcher, using his or her adopted method, grouped the gauging stations in the two ways described, that is, by seasonal flow patterns and by flow types (Figure 11.1).

11.5 METHOD ONE: ANALYSIS OF FLOW PATTERNS USING CLUSTER AND DISCRIMINANT ANALYSES

by A. R. JOUBERT

11.5.1 METHODOLOGY

A similar approach was used to derive groups of gauging stations from both the variables describing the seasonal flow pattern and those describing flow characteristics. The software programs used were BMDP-KM non-hierarchical K-means cluster analysis and BMDP-7M stepwise discriminant analysis. These programs, the statistical assumptions made within them, and their applicability in this study are described in Appendix 11.1.

BMDP-KM, a non-hierarchical clustering technique, was used to derive the clusters or groups, as was done by Poff & Ward (1989). The distance measure used was the Euclidean distance. As this distance measure is sensitive to the units of measurements, all the variables describing flow characteristics were standardised by dividing each variable by its standard deviation (Afifi & Clark 1984; BMDP Manual 1990). In the analysis of seasonal flow patterns, the twelve variables used, that is, the monthly percentages of annual flow, did not require standardisation as the units of measurement are standard.

The number of groups, 'K', formed by BMDP-KM is user-defined and therefore arbitrary. A number of analyses were performed using different Ks, in order to determine sensible and interpretable groups and so as not to include groups which were too similar to the parent groups (i.e. the groups formed for K-1). This was a subjective process, where the interpretability of the resulting groups was the criterion to be satisfied. The discriminant analyses helped in determining the final number of groups based on percentage of cases misclassified, as described later.

In the analysis of the seasonal regimes, for each K, plots of the group profiles (Figure 11.2) gave a visual indication of the differences between the groups formed.

In the analysis of flow types, a preliminary interpretation of the groups of rivers formed for different Ks showed to some extent the K value that was most useful for obtaining meaningful groups (see Section 11.5.2.2). Visual interpretation of the cluster profiles was less useful here than for the seasonal analyses because of the differences in units and scale of the variables.

For both sets of variables (seasonal and flow types) a stepwise discriminant analysis, BMDP-7M, was performed to assess the importance of the different variables, and to help in determining the final number of groups to be formed (Afifi & Clark 1984; BMDP Manual 1990). Using the F-matrix from the discriminant analysis, differences between the group means were assessed in order to determine if the groups formed were significantly different, and which variables were important in separating pairs of groups. However, as the groups were formed by BMDP-KM in order to optimise distances between them, this was not a rigorous test of the significance of the differences between groups.

In the discriminant analysis, in order to test the reliability of the groups formed, a random subset of one-third of the stations was classified using the classification functions derived from the remaining two-thirds of the stations. In addition, a jack-knife classification procedure (whereby each case is classified using the classification function determined from all cases except that being classified) was performed (Appendix 11.1). The percentage of stations misclassified after using these two procedures gave an indication of the reliability of the groups formed, and helped in determining the final number of groups, by comparison with the number misclassified for other Ks.

The criteria used to establish the final number of groups, in approximate order of importance were:

- low number of misclassifications after using two thirds of the data to classify the remaining third and after the jack-knifing procedure (relative to the other Ks tested)
- interpretability
- sufficient difference from 'parent group', based on group means and on interpretability
- reasonably homogeneous groups based on the standard deviations and on the ordination plots of BMDP-KM and the canonical plots of BMDP-7M

11.5.2 RESULTS

11.5.2.1 Groups of stations based on seasonal flow patterns

Seven groups of gauging stations recording similar seasonal flow patterns were identified (Figure 11.2). These groups were fairly homogeneous and reflected clear differences in peak season flow, either in timing, in magnitude or both.

The cluster analysis showed three obvious regions of different seasonal flow patterns in South Africa; a winter peak flow region, a summer peak flow region and a transitional area. However, these three regions did not adequately explain the seasonal patterns of flow occurring in the subcontinent. At the other extreme, when eight or more groups were formed, there was very little difference between the group profiles of some of the new groups formed, and also between the new groups and the 'parent' group from which they were formed. Thus classification beyond ten groups was not analysed in any detail.

Based on the validation procedures in the discriminant analysis, K = 5 and K = 7 groups showed the least amount of misclassification (8 out of 297 misclassified, 97% correctly classified after jack-knifing), when compared with misclassification for K = 4, 6, 8, 9 and 10. Although the coefficients of variation of the groups formed with K = 5 were generally slightly smaller than those for K = 7 groups, the summer groups were more clearly separated and described by forming seven groups. Thus, seven groups of gauging stations, each distinctive but with high within-group similarity, were finally recognised for the seasonal flow analyses (Figures 11.2 and 11.3).

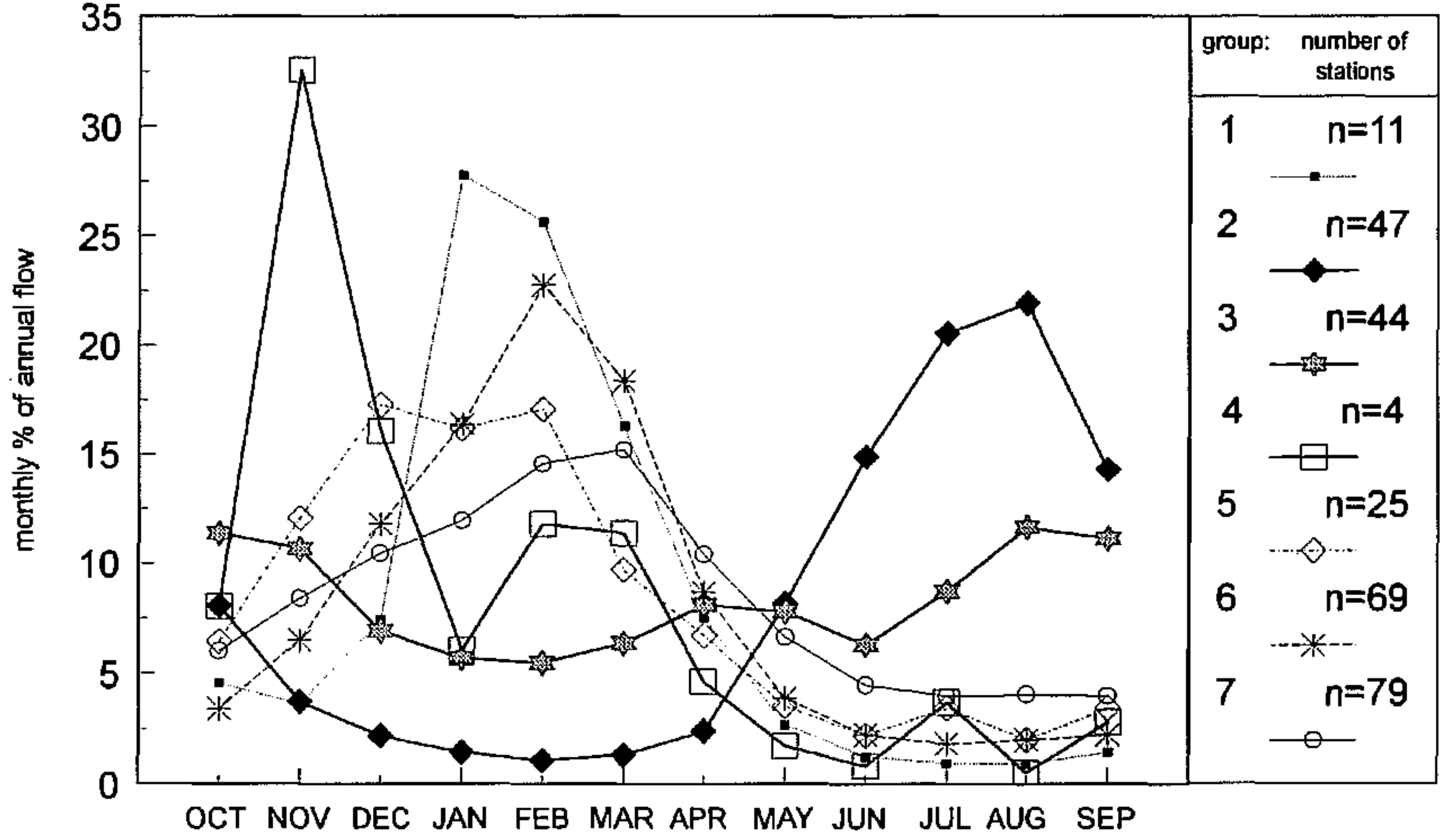


Figure 11.2 METHOD ONE: Profiles of group means for the seven groups of gauging stations determined using average monthly flow as a percentage of average annual flow

The relative importance of variables are given by the F-ratio from BMDP-KM and the F-matrix in the BMDP-7M output. The F-matrix, from the discriminant analysis, tests the equality of means for each pair of groups, while the approximate F-statistic tests the null hypothesis that the means of all groups are equal for all variables simultaneously. The critical value for the F-matrix after entry of the first three variables with 3 and 192 degrees of freedom was 2.65 (Table 11.3). Although, as has been mentioned, this is not a rigorous test of significance in this instance, the large values in the F-matrix indicate that the groups were well separated, and show the relative separation of pairs of groups at this stage. The minimum value in the F-matrix showed high significance (20.41 for group 5 and group 7) indicating that all groups were well separated by the first three variables, namely July, November and January. The importance of these variables is further shown by the first two canonical axes of the discriminant analysis. The first, consisting mainly of a July-February gradient, explained 79% of the variation, while the second axis, mainly January and November, explained an additional 11%.

The geographic distribution of the seven groups obtained from the above analyses, together with the group profiles and standard deviations (Figure 11.3), show that only two groups were geographically distinct. These were the winter peak flow region of the south-western Cape (Group 2) and the aseasonal/early spring region of the southern and eastern Cape (Group 3). Group 3 had monthly flows of between 5.47 and 11.63 percent of the mean flow, which Haines *et al.* (1989) regard as aseasonal. However, Group 3 exhibited a mild tendency towards increased flow in early spring.

The summer rainfall region, containing five groups, was not divided into clear geographic regions. The types of summer seasonal flow patterns were named: **moderate summer flow,** Group 5, with peak flows of up to 17% of annual flow extending from December to February; **midsummer extreme** (Group 1), with peak flows of over 25% of annual flow in January and February; **midsummer moderate** (Group 6), which had a February peak of just over 20% of annual flow; and **moderate late summer** (Group 7), which had a peak of around 15% of annual flow over February and March. To test whether the presence of the winter and spring groups affected the formation of the summer groups they were removed, and a BMDP-KM cluster analysis performed on the summer groups alone. The resulting clusters were very similar to those formed when the other groups were present.

The remaining group (Group 4) had an **extreme spring** peak flow in November of more than 30% of annual flow. This group consisted of only four stations, all occurring in the eastern Cape (Figure 11.3). All four stations had a poor database (five to ten years of record) and so were only tentatively postulated as part of the eastern Cape 'drought corridor'. In the same area, near East London, other stations grouped with the moderate late summer group (Group 7).

Stations in Group 7 occurred throughout the coastal belt of Transkei and Natal and into the eastern Transvaal. They were also scattered in the interior of the central Transvaal, the southern Orange Free State and the northern Cape. Stations of the midsummer moderate group (Group 6) occurred mainly inland of the coastal belt and mixed with those from Group 7 that occurred along the eastern Transvaal escarpment. Stations of the summer moderate group (Group 5) occurred mainly between the Natal and eastern Transvaal sections of the escarpment, and in the Orange Free State. The 11 stations of Group 1, all recording flow with

Table 11.3 **METHOD ONE: The F-matrix output from BMDP-7M after entry of the first three variables into the discriminant function (viz. July, November and January) showing that all groups are already well separated at this stage. The degrees of freedom are 3 and 192, giving a critical value of 2.65. The groups 100 to 700 arose from a random subsample of one-third of the stations which was used for validation (i.e. group 100 consists of those stations from group 1 which were in the subsample. These subsample groups are clearly closely related to the main sample - refer to text for details)**

		GROUPS							Subsample					
		1	2	3	4	5	6	7	100	200	300	400	500	600
GROUPS	2	207.26												
	3	128.18	112.44											
	4	126.66	127.94	69.54										
	5	50.17	215.78	47.86	66.73									
	6	44.04	380.92	109.19	111.69	26.03								
	7	78.30	261.91	40.64	91.06	20.41	26.68							
Subsample	100	4.32	100.09	50.56	90.37	17.66	8.13	22.22						
	200	160.11	0.82	56.83	111.25	129.65	187.25	132.23	81.45					
	300	106.83	79.62	0.20	60.86	31.64	67.52	24.73	44.94	46.72				
	400	36.43	33.63	13.93	1.63	12.74	22.90	17.60	27.41	30.73	12.61			
	500	25.25	89.92	25.38	46.75	0.84	11.27	11.74	11.59	70.29	20.56	10.86		
	600	35.22	210.79	62.10	99.43	15.65	0.02	12.54	7.13	129.80	45.58	21.77	9.09	
	700	60.89	184.97	30.72	84.62	11.46	11.67	0.46	17.86	105.25	21.35	17.18	8.70	6.97

extreme midsummer peaks, occurred scattered throughout the Transvaal and Orange Free State. All the derived variables on monthly proportions of flow for the 279 gauging stations used in these analyses are given in Appendix 11.2.

11.5.2.2 Groups of stations based on flow types

Using the same analytical techniques and the eight variables described in Section 11.3.2, namely GRCV, ZERODAY, PRED, PROP, FLOFRQ, FLODUR, FLOINT and FLOPRD, eight groups of rivers (A - H) with similar flow characteristics were identified (Figure 11.4). The derived variables for the 204 stations used in the analyses, together with the stations' group membership, are given in Appendix 11.3.

The number of misclassifications, after verification in the discriminant analysis, was 12 out of 204, or 93% correctly classified after jackknifing. The result is biased by using the same variables to derive the discriminant functions as those that were used to formulate the groups (Afifi & Clark 1984), and by using a stepwise procedure. However, a figure as high as 93% correctly classified after cross-validation and jackknifing (Section 11.5.1 and Appendix 11.1) indicates that confidence can be placed in the groups formed.

The hierarchy of variables (based on the F-ratios from BMDP-KM) which described the eight groups formed from these eight variables was as follows (Table 11.4):

- ZERODAY.........average number of days of zero flow per year
- GRCV ....coefficient of variation of annual flow
- FLODUR............the mean duration of floods
- PROP ....the proportion of PRED due to CONST
- FLOINT ....the median interval between floods
- PRED.................overall predictability
- FLOFRQ ....flood frequency
- FLOPRD ....flood predictability

According to the F-ratio of BMDP-KM and the **initial** F-to-enter of the discriminant analysis, the variables explaining the most variance were ZERODAY and GRCV, which were indicative of the degree of intermittency and overall variability of flow. However, the two variables were closely related, with the result that once ZERODAY had entered the discriminant function in the discriminant analysis, very little of the remaining variance was explained by GRCV, and so GRCV then entered the discriminant function last.

ZERODAY, the first variable to enter the discriminant function, separated Group A from all other groups, and Groups B and G from all groups except each other (Table 11.4). Group A contained mainly stations recording extreme-seasonal flow and a few recording episodic flow. Group B contained a mixture of stations, some of which were recording extreme-seasonal flow patterns while others were recording quasi-perennial-seasonal and perennial flow. The mixture of flow types within one group was due to the effect of other variables, as explained later. Most stations in Group G recorded quasi-perennial-seasonal flow, but a few recorded seasonal flow.

The initial division of rivers by ZERODAY thus concerned the degree of flow cessation, and separated groups with stations recording mainly episodic, extreme-seasonal and seasonal flow

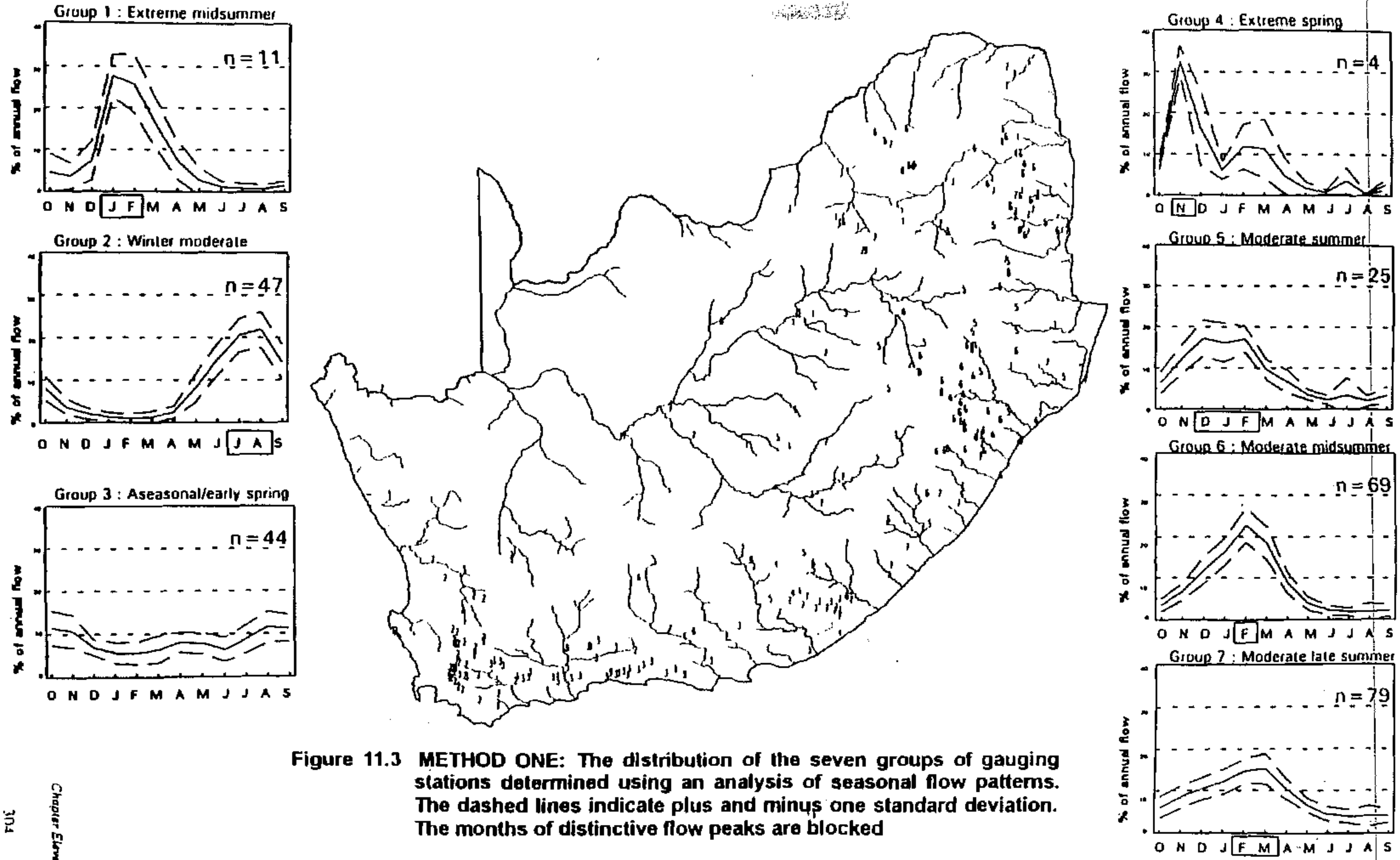


Figure 11.3 METHOD ONE: The distribution of the seven groups of gauging stations determined using an analysis of seasonal flow patterns. The dashed lines indicate plus and minus one standard deviation. The months of distinctive flow peaks are blocked

(Groups A and B) from those with stations recording mainly quasi-perennial-seasonal flow (Groups D, H) and those with stations recording completely perennial flow (Groups C, E, F). Group G stations grouped with Group A and B, rather than with the other quasi-perennial-seasonal groups (D and H), because of its higher values for ZERODAY.

The second variable to enter the discriminant analysis, and therefore the second most important variable overall, was FLODUR. This variable separated Group B from Group G and increased the separation of Group B from all other groups. As a result of the grouping together of stations based on their recording of comparatively long durations of floods, Group B included five extreme-seasonal, three quasi-perennial-seasonal and five perennial stations, all of which had values for FLODUR of more than 7.9 days. However, other than in this instance, FLODUR was not of particular importance in distinguishing groups.

Removing FLODUR from the analysis improved the homogeneity of the groups with respect to degree of flow cessation. However, FLODUR and FLOINT were, together with FLOFRQ, indicators of the degree of flashiness of flow. Therefore, although their inclusion in the analyses did not necessarily result in the most well-defined flow groups, their role as descriptors of ecologically important flow characteristics was felt to be sufficient to warrant their retention in the analyses.

The next variable to enter the discriminant analysis was PROP, the proportion of predictability due to constancy. Group D, which had the lowest value of PROP, was separated from all other groups by this variable and therefore had the highest degree of predictability due to contingency, or seasonal predictability. FLOINT, the next variable to enter, separated group C from groups F and E. Group F contained only three members and these were distinguished from the rest by extremely long intervals between floods.

The eight groups formed can be broadly categorised into three supergroups (Table 11.4): stations recording mainly **extreme-seasonal** but also episodic flow; a **mixture** of stations recording extreme-seasonal, quasi-perennial-seasonal and perennial flow, divided into four subgroups; and a **perennial** supergroup of stations divided into three subgroups. These are discussed below, with reference to the group means and standard deviations (Table 11.4), and regional trends (Figure 11.4).

I. EXTREME-SEASONAL SUPERGROUP

Fourteen of the stations in **Group A** recorded extreme-seasonal flow, while four recorded episodic flow. At all stations the flow had a high degree of constancy (PROP) due, in this instance, to flow being zero for much of the year. The stations are located in the interior of the sub-continent, from the southern Karoo, curving through the interior of the eastern Cape, to the Orange Free State and the Transvaal.

II. MIXED EXTREME-SEASONAL, QUASI-PERENNIAL-SEASONAL AND PERENNIAL SUPERGROUP

II.1 Short intervals between floods

- **Group B** was a mixed group of 13 stations recording extreme-seasonal (five stations), quasi-perennial-seasonal (three stations) and perennial (five stations) flow. All of these stations

Table 11.4 METHOD ONE: Group means (large numerals) and standard deviations (smaller numerals) of the selected flow characteristics of the eight groups of gauging stations determined using BMDP-KM cluster analysis. Boxes around the means indicate the distinguishing characteristic of the group. The variables are in descending order of overall importance except for GRCV which, in the discriminant analysis, explains the same variance as does ZERODAY and is therefore of least importance overall

	EXTREME SEASONAL	EXTREME SEASONAL to PERENNIAL				PERENNIAL		
	GROUP: A	B	G	D	H	E	C	F
VARIABLE:	number: 18	13	36	18	33	30	51	3
GRCV	4.031 1.647	0.987 1.207	0.713 0.471	0.535 0.207	0.315 0.246	0.152 0.052	0.170 0.195	0.167 0.095
ZERODAY	$\boxed{310.714}$ 34.943	$\boxed{106.098}$ 120.603	$\boxed{74.665}$ 66.384	39.903 40.488	16.603 31.277	1.625 3.582	6.049 30.699	8.197 13.773
FLODUR	2.584 1.889	$\boxed{10.866}$ 2.373	2.930 1.476	1.641 0.425	1.783 0.610	2.698 1.248	2.750 1.437	2.173 0.548
PROP	0.975 0.023	0.903 0.059	0.733 0.113	$\boxed{0.510}$ 0.098	0.890 0.071	0.883 0.075	0.858 0.055	0.889 0.040
FLOINT	147.694 124.419	36.615 49.686	50.026 33.996	$\boxed{332.944}$ 102.336	$\boxed{195.061}$ 102.674	44.967 34.602	$\boxed{204.000}$ 127.191	$\boxed{709.500}$ 111.561
PRED	0.827 0.105	0.642 0.167	$\boxed{0.342}$ 0.125	$\boxed{0.401}$ 0.121	$\boxed{0.447}$ 0.137	0.676 0.157	0.680 0.096	0.634 0.161
FLOFRQ	1.309 0.456	2.185 0.770	1.704 0.431	0.800 0.200	1.026 0.199	$\boxed{2.024}$ 0.577	0.947 0.223	0.497 0.144
FLOPRD	0.553 0.152	0.542 0.146	0.610 0.130	0.644 0.145	$\boxed{0.437}$ 0.072	0.595 0.108	$\boxed{0.741}$ 0.102	0.479 0.101

recorded floods of long duration and were thus grouped together due to the effect of the variable FLODUR. The average flood duration for the group was 10.9 days and the minimum duration 7.9 days, compared to the means for the other groups which were all less than 3.0 days. There was also a high degree of constancy, with an average of 90% of PRED being due to CONST. The intervals between floods were generally short, which led to a medium to high flood frequency. The five stations in Group B that were recording perennial flow occurred in the eastern Transvaal and Natal, while the eight stations recording extreme-seasonal and quasi-perennial-seasonal flow were scattered across the country.

- **Group G** consisted of 38 stations, most of which were recording quasi-perennial-seasonal flow, but 13 were recording seasonal flow and six perennial flow. Overall predictability of flow was lowest of all groups with an average of 0.34. There were short intervals between floods, and therefore a medium to high flood frequency with an average of 1.7 floods per year. The inclusion of six perennial stations appeared to be due to their recording flow with low predictability. Flood durations were shorter than for the stations of Group B, and constancy was medium to low with PROP having an average of 0.73. These stations occurred throughout the country, except along the Transkei and Natal coastal belts and to the east of the escarpment in the Transvaal.

II.II Long intervals between floods

- Twenty two stations in **Group H** recorded perennial flow, while eleven recorded quasi-perennial-seasonal flow. All had flow with a very low overall predictability (average = 0.45), very little of which was due to predictable seasonal changes, and hence there was a high mean value for PROP (0.89). Flood predictability was also low. The intervals between floods tended to be medium to long, although the range was large (minimum 39 days, maximum 442 days, mean 195 days), and thus flood frequency (FLOFRQ) was low (min 0.67, max 1.57, mean 1.03). The rivers occurred almost exclusively along the southern and eastern Cape coastal belt.

- Eleven of the 18 stations in **Group D** were recording quasi-perennial-seasonal flow, while the remaining seven were recording perennial flow. All recorded flow with a very low constancy, as seen by the low average value for PROP (0.51). These stations therefore recorded flow with the highest degree of seasonal predictability of all the groups. There were medium to long intervals between floods, with an average interval of 332 days, and a very low flood frequency of 0.8. Only one group (Group F) had a lower average FLOFRQ. Group D stations occurred mainly in the south-western Cape. The one exception was station A6H012 in the north-western Transvaal.

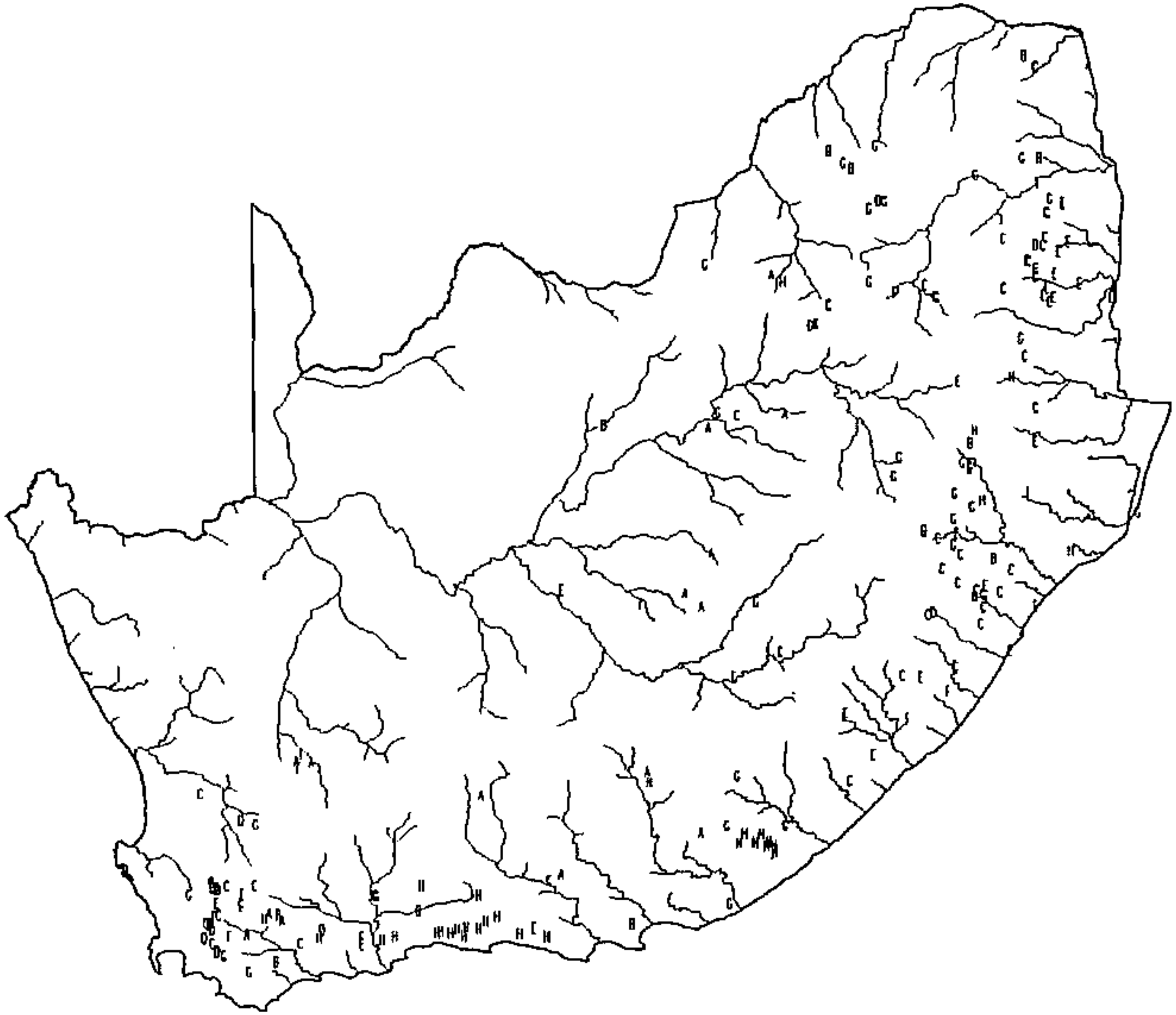
III. PERENNIAL SUPERGROUP

Stations in the perennial supergroup (Groups E, C and F) recorded medium to low flood durations of between 1.1 and 6.4 days, a high degree of constancy averaging at 0.88, and medium predictability of about 0.68. Days of no flow were recorded at all stations, even where flow was thought to be continuous, probably due to gauging weir inaccuracies. To compensate for this, stations recording an arbitrary value of not more than ten days of zero flow a year were regarded as perennial.

Groups C and E stations differed in the intervals between floods (FLOINT), but the variable FLOFRQ was most important in separating them. Group F stations recorded flows that were similar in most respects to those recorded by Groups C and E, and may be a small aberrant group.

- The 30 stations in **Group E** recorded short intervals between floods and thus a high flood frequency with an average of 2.0 per annum. They occurred throughout the country but mainly to the east of the escarpment, and in the south-western Cape.

- **Group C**, the largest group, consisted of 51 stations, 49 of which recorded perennial flow. All stations recorded medium to long intervals between floods, very low flood frequencies and a high flood predictability of 0.74, which was the highest of any group. One station recording extreme-seasonal flow and one recording quasi-perennial-seasonal flow were included, because of their long intervals



EXTREME SEASONAL

A Predictable low/zero flow conditions

MIXED

B Long flood durations

C Unpredictable

D Strongly seasonal

H Unpredictable flow and floods

PERENNIAL

C Frequent floods

E Predictable infrequent floods

F Long intervals between floods

(Refer to Table 11.4 and text for details)

Figure 11.4 METHOD ONE: The distribution of the eight groups of gauging stations determined using an analysis of flow characteristics between floods and relatively high values for FLOPRD. Group C stations are distributed similarly to those in Group E, that is, mainly along the escarpment and in the south-western Cape.

- **Group F** contained only three stations. These recorded a slightly lower flood duration than the stations in Groups E and C, but extremely long intervals between floods, and thus very low flood frequencies. In other respects the stations recorded similar flow to Group C. The three stations are on the Waterkloof River in the south-western Cape, the Buffalo River in the eastern Cape near its source and the Mtamvuna River in southern Natal. No explanation could be found for the exceptionally long intervals between floods for these rivers.

The standard deviations of the eight variables for the groups formed (Table 11.4), give an indication of the homogeneity of the groups. This information, together with that in Figure 11.5, serves to illustrate the fact that certain derived variables, while not important overall, became the ones that divided two similar groups. For example, group C was separated from group H mainly by the variable FLOPRD, which was the least important variable overall.

As a result of the formation of groups in this way, high standard deviations occurred for certain variables in some groups. For example, for Group B, ZERODAY had a mean of 106 and standard deviation of 120. This was due to the effect of FLODUR, a variable which was less important overall than ZERODAY. FLODUR was the most important variable describing this group and, in contrast to ZERODAY, had a relatively small standard deviation of 2.37 days and a mean of 10.87 days. In contrast, for Group A, where ZERODAY was the most definitive variable, the standard deviation was relatively small (34.9 days compared to a mean of 310.7 days). Thus, the homogeneity of the groups, the high percentage correctly classified, and the good separation achieved between groups, were due to the effect of one or more specific linking variables for each group, which had relatively small deviations from the mean. A different variable or subset of variables defined each group and the homogeneity of a particular group was not reflected by homogeneity of all variables within the group. As a result, variables less important in defining a particular group may have had large ranges and standard deviations.

11.5.2.3 General comments on the seasonal groups and flow-type groups formed

There are some obvious similarities between the geographical distributions of the groups of stations formed with seasonal or flow-type variables and the altitudes and climatic regions of southern Africa. Thus, according to both sets of variables, the stations along the subtropical coast and the plateau slopes of Transkei, Natal and the Eastern Transvaal recorded similar flow. The seasonal groups which predominated in this area were moderate midsummer (Group 6) and moderate late summer (Group 7), and the flow-types were the three perennial groups (C, E and F).

The southern and eastern Cape coastal belt was clearly distinct in both groupings. Stations in this region recorded aseasonal flow or a slight early spring peak (Group 3), and had a flow type (Group H) not commonly found elsewhere in the country. Overall predictability was very low, with a fairly high flood frequency, and the flood predictability was lowest of all groups.

The western Cape contained exclusively Group 2 stations (winter peak flow) and was dominated by Group D flow types (low overall predictability, with high seasonal predictability).

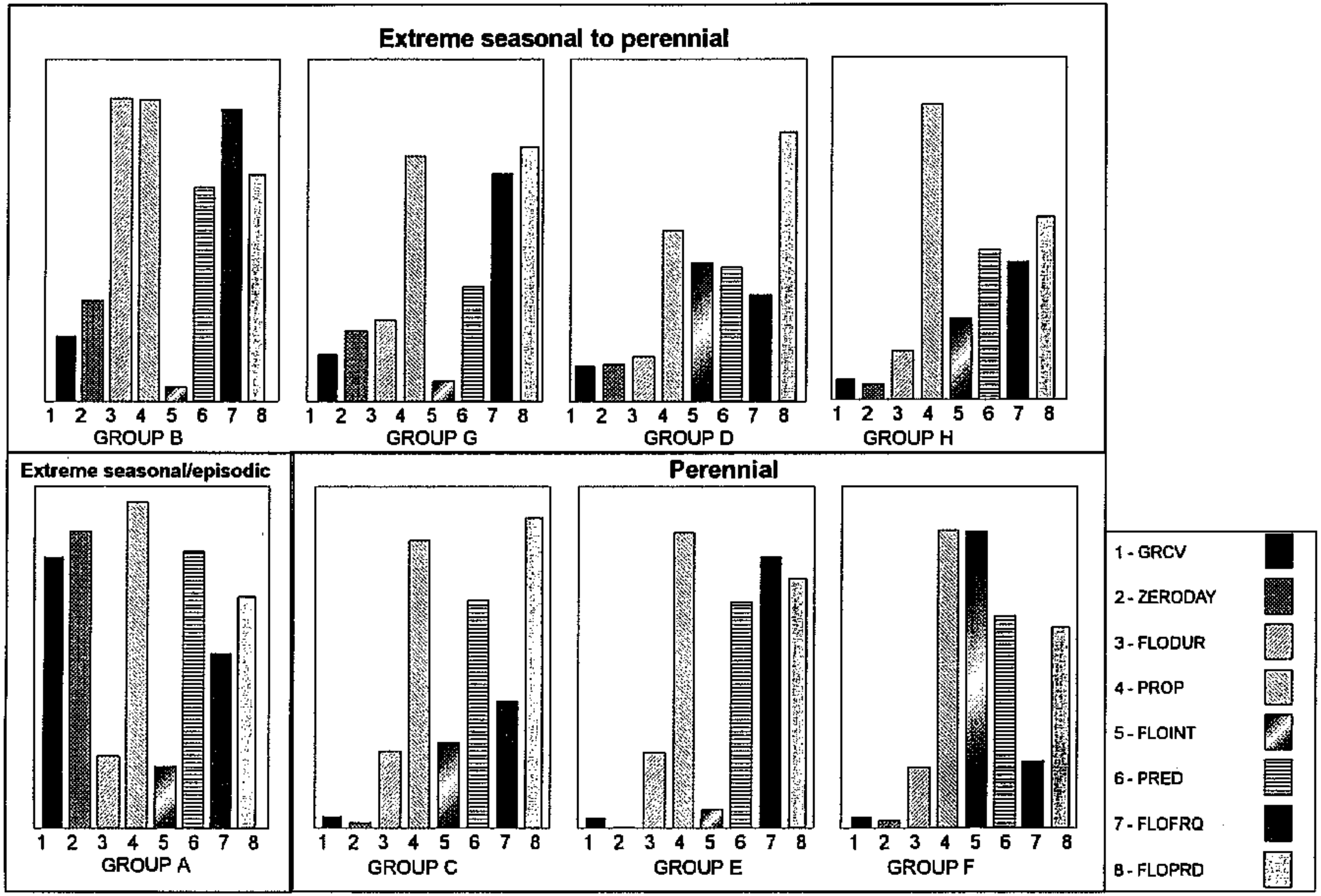


Figure 11.5 METHOD ONE: Group profiles of the means for the eight variables describing flow characteristics. Each variable is represented using its own scale in order to highlight differences between groups

11.5.3 DISCUSSION

11.5.3.1 Comparison with other studies

As any variable can be used to form groups by cluster analyses or other classification methods, it is important to select those relevant to the purpose of the classification. The variables used should be properties of the objects being classified and not those thought to affect the objects of interest (Grigg, 1967 cited in Mosley 1981). In accordance with this principle, the monthly flow percentages calculated in this study directly reflected seasonal patterns of flow, and therefore were used in preference to indirect variables such as monthly rainfall-runoff ratios or the median day of the annual flood. The variables derived for the analysis of flow types were also direct reflections of properties of flow, and were not, as was the case in other studies, catchment characteristics assumed to influence flow in a certain way.

Comparison of seasonal flow groups

Using monthly flow percentages, Haines *et al.* (1989) defined 15 seasonal flow patterns in their global classification, six of which occurred in southern Africa in three broad regions.

According to their analysis, flow patterns in the the western Cape consisted of moderate and extreme winter flow, those in the the eastern Cape of moderate or early spring flow, and those in the rest of the country either moderate midsummer or midsummer flow. Two of the groups identified by them as occurring in southern Africa, extreme winter and moderate spring, were not identified in this study. However, with K = 9 an extreme winter group did arise which corresponded to their extreme winter flow pattern. Three groups found in this study; Group 1 (extreme midsummer), Group 4 (extreme spring) and Group 7 (moderate late summer) were not found by them as occurring here, although their equivalent of moderate late summer flow did occur further north.

The differences between the results of the two studies are slight and are probably due mainly to the larger database used in this study. The clustering methods used were different but given the same database the results would probably not have differed markedly.

Comparison of flow types

Of the flow-type variables derived in this study, several other classificatory studies have found the coefficient of variation of annual flow to be one of the more important ones in separating types of rivers (Hughes 1987; Jowett & Duncan 1990). Most of these studies are assumed to have used coefficients of inter-annual variation, while in this study, guided by the variables defined by Poff & Ward (1989), coefficients of intra-annual variation were used. Comparisons of values for GRCV are therefore not meaningful.

Only Poff & Ward (1989) considered the remaining seven variables used in this study. The groups formed by the two studies are very different and they are not discussed in detail as associations based on comparison of group means could be spurious and misleading.

Poff & Ward identified nine groups of rivers: *harsh intermittent*, *intermittent flashy*, *intermittent runoff*, *perennial flashy*, *perennial runoff*, *winter rain*, *snow and rain*, *snowmelt* and *mesic groundwater*.

The high values of GRCV and ZERODAY for the extreme-seasonal group, Group A were not reflected in any corresponding group in Poff & Ward's study. According to the definitions used in this study, none of Poff & Ward's groups were extreme-seasonal as the values for ZERODAY were too low. Their closest equivalent was their *harsh intermittent* group. The mean GRCV and ZERODAY values for their *harsh intermittent* group were *1.51* and *96.2* respectively while those for Group A of this study were 4.03 and 310.7 respectively. The maximum value for GRCV in their data set was *1.95* compared with 8.79 in this study. A possible reason for the generally lower values for GRCV and ZERODAY in the United States of America is that snowmelt would contribute runoff to some rivers in arid areas, whereas it is unlikely that any extreme-seasonal South African rivers would have a similar runoff source (Figure 11.4).

The comparison of values for ZERODAY and GRCV thus suggested that harsher and more variable flow conditions exist in South Africa than in the United States of America, yet mean values for PRED and PROP were in general much higher in this study. This was partly due to the fact that for the extreme-seasonal rivers (mainly in Groups A and B) these high values were due to long periods of constant zero flow. In addition, Gan *et al.* (1990, cited in Gordon *et al.* 1992) found that Colwell's index is biased towards high values when short periods of record are used. They suggested that at least 40 years of data are necessary to stabilise this bias, while Bunn & Boughton (1990, cited in Gordon *et al.* 1992) found a minimum of 10 to 15 years to be sufficient.

In general the values for FLOFRQ in this study were higher than the values in Poff & Ward's study. It is not known whether this is a reflection of real differences in flood frequency between the two countries, or of possible skewing of the South African data (Section 11.7).

As a result of climatic differences, it was expected that the two studies might produce some dissimilar groups. The differences in group means and in the range of values for the variables derived supported this, highlighting one of the differences that seems to exist between rivers in semi-arid areas and temperate areas, namely a far higher degree of variability (T.A McMahon, University of Melbourne, Australia, pers. comm.).

11.5.3.2 Usefulness of the groups for management purposes

Grouping rivers by broad geographical regions with different flow patterns has many obvious benefits for scientists and managers but, for ecological purposes, it is often necessary to gain additional insights into flow patterns as has been attempted here by the analysis of flow types. Characteristics of flow such as predictability are, however, unlikely to enable rivers to be grouped into clear geographical regions. Cognisance should also be taken of the fact that however convenient boundaries may be, they are very seldom realistic or accurate, as transitions may occur gradually across the country for certain variables, and abruptly within catchments for others. A boundary between regions is thus, usually, an artificial management tool and not a physical reality.

It had initially been hoped that the results of this study would help in the assessment of flow requirements for rivers on a regional basis. Regionalisation of rivers would have allowed extrapolation from known to unknown rivers within any one region. However, the only clear regions formed in this study were seasonal ones for the western and eastern Cape (Group 2 and 3), and a flow-type one for the eastern Cape (Group H). This is in agreement with Mosley (1981), who found that any one geographical area contained a mosaic of completely different hydrological regimes.

Generalisation or extrapolation to ungauged sites would be possible in some cases, particularly in more clearly homogeneous regions such as the western or eastern Cape, but in other regions this may not be possible. The different positions of stations within their subcatchments, and possible differences in source of flow, may explain why different groups are represented within any one drainage region, but these analyses have not been done. However, the flow characteristics at a particular station can be described to some extent by the station's group membership as well as by its individual variables. Thus, for each station, derived variables, summary statistics and group membership have been placed in a database which can be used by researchers and managers, thereby to some extent obviating the need for geographically defined regions.

In order to be able to extrapolate within drainage regions or between types of river, further study of the groups will be necessary (see Section 11.7), and ground-truthing of the groups formed would be useful. Data from stations with few years of data should be further examined to determine if the years were in a predominantly wet or dry period or if all types of flow were represented. In addition, the group membership of rivers within the same catchment, and upstream and downstream sites on the same river, need to be further analysed for patterns and, where they group differently, for explanations.

11.6 METHOD TWO: ANALYSIS OF FLOW PATTERNS USING THE CORRESPONDENCE ANALYSIS AND COVARIANCE BIPLOT TECHNIQUES

by **P. R. HURLY**

11.6.1 METHODOLOGY

11.6.1.1 Analysis of seasonal flow using correspondence analysis

Correspondence analysis was developed in France during the 1960s under the name "analyses des correspondances". It has been described in English by Greenacre and Underhill (1982), Greenacre (1984) and Underhill and Peisach (1985).

Correspondence analysis is restricted to matrices such as contingency tables where all the elements are non-negative. It must be meaningful to add across the columns in any given row so that the rows can be normalised by dividing by the row total. The examples used in Underhill and Peisach (1985) are actually more suited to analysis using the covariance biplot technique where no attempt is made to normalise the rows. In their examples it does not make sense to add the values in a row. The same situation arises in the analysis of flow characteristics where the covariance biplot technique was used instead (see Section 11.6.1.2).

The correspondence analysis technique attempts to summarise the information contained in many variables in only a few dimensions. It works best when the variables are highly correlated and it will be completely unhelpful if the variables are independent.

The matrix of monthly percentages of annual flow was ideally suited to analysis using the technique. Essentially each station has a 'profile' - the pattern of twelve monthly values (totalling 100) for the station. An average profile can be calculated by taking the mean over all the stations for each month. For each station, a variance can be calculated by summing the (twelve) squares of the deviations of the monthly values (columns) for the station from the average profile. Summed over all the stations (rows) this value is called the inertia.

Correspondence analysis treats the rows (which are stations in the present case - hereafter the present case is shown by appropriate text in brackets thus '(stations)') and columns (months) of a data matrix as two clouds of points in a high-dimensional space and projects them on to a lower-, usually two-, dimensional space in such a way that as much as possible of the inertia in the data matrix is 'explained' by being decomposed along the axes of the lower-dimensional space. If, on any plane on which the points are projected, the points representing several columns (months) cluster together then the values (monthly percentages of total flow) for those columns (months) are, in a certain sense, similar for all the rows (stations). The values for the columns whose points cluster together would be highly correlated with each other. If the points representing several rows (stations) lie close together then those rows (stations) have, in a certain sense, similar profiles.

The simultaneous display of the rows (stations) and columns (months) enables one to gain understanding as to why the rows (stations) cluster in certain parts of the plot. If a point representing a row (station) lies in the same direction from the origin of the axes as a point representing a particular column (month), then the row (station) is characterized by an above average value of the variable (monthly percentage of total flow in the present case) for that column (month). Similarly a row (station) point which lies in the opposite direction from the origin as a particular column (month) point is characterized by a low value of the variable for that column (month).

The correspondence analysis option in the program SVDD (Underhill 1990) was used. If there are n columns, the program calculates n orthogonal axes in an n-dimensional space and orders these axes in decreasing order of the amount of inertia which they explain. Usually the first few axes explain almost all the inertia - the first few dimensions contain almost all the information - and the remaining axes can be ignored. Often, only the plot of the first two axes is useful in demarcating groups of rows or columns.

The SVDD program prints, inter alia, the fraction of the inertia explained by each axis, the proportion of the inertia explained by each axis which is due to each column, the coordinates of each column and each row on each axis, and two-dimensional plots - Axis 1 versus Axis 2, Axis 1 versus Axis 3 and so on - of points representing the rows and the columns.

The monthly percentage flows for the stations were used as input to the program without any form of standardising or preprocessing. The data set used consisted of 279 stations, all but one of which were in common with the stations in the data set for the cluster and discriminant analysis method (see Section 11.5.2).

11.6.1.2 Analysis of flow characteristics using the covariance biplot

The covariance biplot technique (Greenacre and Underhill 1982) differs from the correspondence analysis technique in that the rows are not normalised. Deviations from the means for each column are used to calculate the inertia. Interpretation of the covariance biplot is not the same as for the correspondence analysis biplot but the differences are of no consequence to the present use of the biplots of the two techniques.

The covariance biplot option in the program SVDD (Underhill 1990) was used. The same eight variables - GRCV, ZERODAY, PRED, PROP, FLOFRQ, FLODUR, FLOINT, and FLOPRD - were used as were used in the analysis using Cluster and Discriminant Analysis (see Section 11.5.2). The distributions of the variables PRED and FLOPRD were found to be nearly normal. The distributions of GRCV, ZERODAY, FLOFRQ, FLODUR, and FLOINT were skewed to the right and that of PROP was skewed to the left. GRCV, ZERODAY, FLOFRQ, FLODUR, and FLOINT were therefore transformed by taking natural logarithms - to, for example, ln(GRCV) - and PROP was transformed to ln(2-PROP). PRED and FLOPRD were not transformed. After transformation the distributions of all the variables were nearly normal. The transformed values of the variables were used as input to the SVDD program.

The technique does not require the input variables (columns) to be normally distributed. However, if the input variables are far from normal with several outliers, then there is a danger that the outliers will dominate the calculations and exert too much influence on the results. Outliers that are still outliers after transformation can be made into 'supplementary points' in which case they are excluded from the calculations but included in the biplots. Any suspect stations or variables that appear to be exerting too much influence on the calculations can also be made 'supplementary'. Failure to normalise the data can also result in the bulk of the points representing the stations being compressed in to a small (usually central) part of the biplots.

The program was instructed to standardise the variables to the same mean and standard deviation. This is standard procedure so as to weight each variable approximately equally in the analysis. The same data set (204 stations) was used as was used for the cluster and discriminant analysis method (see Section 11.5.2).

11.6.2 RESULTS

11.6.2.1 Seasonal flow regions

In the correspondence analysis of the monthly percentage data, the first axis explained approximately 70% of the inertia, the second axis approximately 10%, and the third axis approximately 5%. The other 9 axes explained the remaining 15% of the inertia. Seven axes were needed to explain 95% of the inertia. Only the biplot of Axis 1 versus Axis 2 (Figure 11.6) was used in grouping the stations.

Axis 1 contrasted stations with low percentages for the months January to March and high percentages for June to September with stations with high percentages for January to March and low percentages for June to September. Axis 2 contrasted stations with low percentages

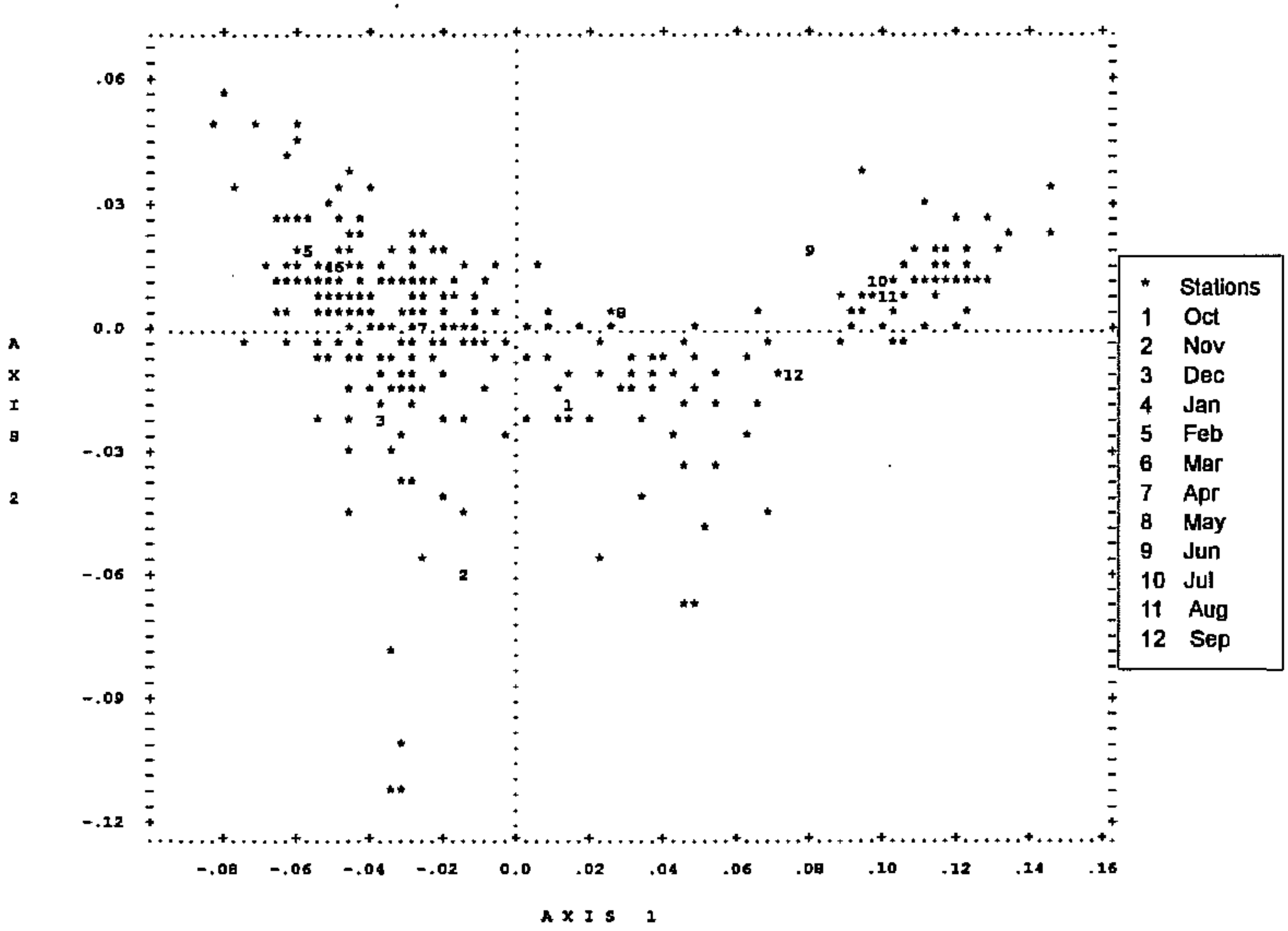


Figure 11.6 METHOD TWO: Biplot of the first two axes resulting from correspondence analysis of the matrix of monthly percentages of annual flow, showing stations and months. Each asterisk represents one or more stations. The numbers indicate the months of the water year

for November and December and high percentages for February with stations with high percentages for November and December and low percentages for February. In Figure 11.6 the points for January, February and March lie very close together and the points for July and August lie very close together. These months are the core months for summer high flow and winter high flow respectively. December and April are transitional months for summer high flow and June and September for winter high flow.

Stations in the upper left quadrant of the biplot in Figure 11.6 would tend to have maximum flow in January, February or March whereas stations in the lower left quadrant would tend to have maximum flow in November or December. Stations in the far right of the upper right quadrant would tend to have maximum flow in June, July or August whereas stations in the lower right quadrant would tend to have maximum flows in September or October.

The separation along Axis 1 between stations with essentially summer high flows (on the left) and those with essentially winter high flows (on the right) was exploited in the process of demarcating groups. The stations were divided into groups according mainly to their coordinates on Axis 1 but also taking their coordinates on Axis 2 into consideration. These groups were plotted, each with a different numeric symbol, on a map of South Africa. Some of the groups as demarcated on the biplot plotted more or less as groups on the map, especially in the western, southern, and eastern Cape. Regional boundaries were drawn on the map and points within each region plotted with the same symbol on the biplot. The points for the western Cape, southern Cape, and eastern Cape regions plotted in reasonably cohesive groups on the biplot. After a little trial and error in manipulating the (geographical) boundaries of the regions, a provisional division of the country into four regions was made; the western Cape (region 1), the southern Cape (region 2), the eastern Cape (region 3) and the rest of South Africa (region X).

Despite the fact that region X covered by far the largest geographical area, the points representing the stations in this region covered an area comparable to that of each one of the other three regions on the correspondence analysis biplot. No way could be found to split region X into smaller geographic regions which did not overlap each other considerably on the correspondence analysis biplot. It was felt that it might be practically useful to divide this large region into smaller units. It was therefore decided to split region X, more or less arbitrarily, mainly on the basis of aggregations of DWAF primary drainage regions. Four regions were chosen: southern Natal and most of Transkei (region 4), northern Natal, Swaziland and eastern Transvaal (region 5), north-west Transvaal (region 6), and the Orange-Vaal catchment (excluding a small area in the south-west (region 7). These regions are shown, along with regions 1 to 3, on a map in Figure 11.7 and on biplots of Axis 1 versus Axis 2 in Figures 11.8 and 11.9. In Figure 11.9 it can be seen that region 4 is more homogeneous than regions 5, 6 and 7. In Figures 11.8 and 11.9 the separation of the points representing regions 1 and 2 is quite remarkable. Boundaries between regions were chosen to follow primary, secondary or tertiary drainage region boundaries - see Table 11.5.

Figure 11.10 is a graph of the means of the monthly percentage flows for the stations in each region. Table 11.6 gives the means, standard deviations and standard errors of the means of the monthly percentages for the stations in each region. It can be seen from Figure 11.10 and Table 11.6 that, although the flow patterns for regions 4 to 7 are very similar, there are some noteworthy differences especially in October and November. (These differences were not tested for statistical significance.)

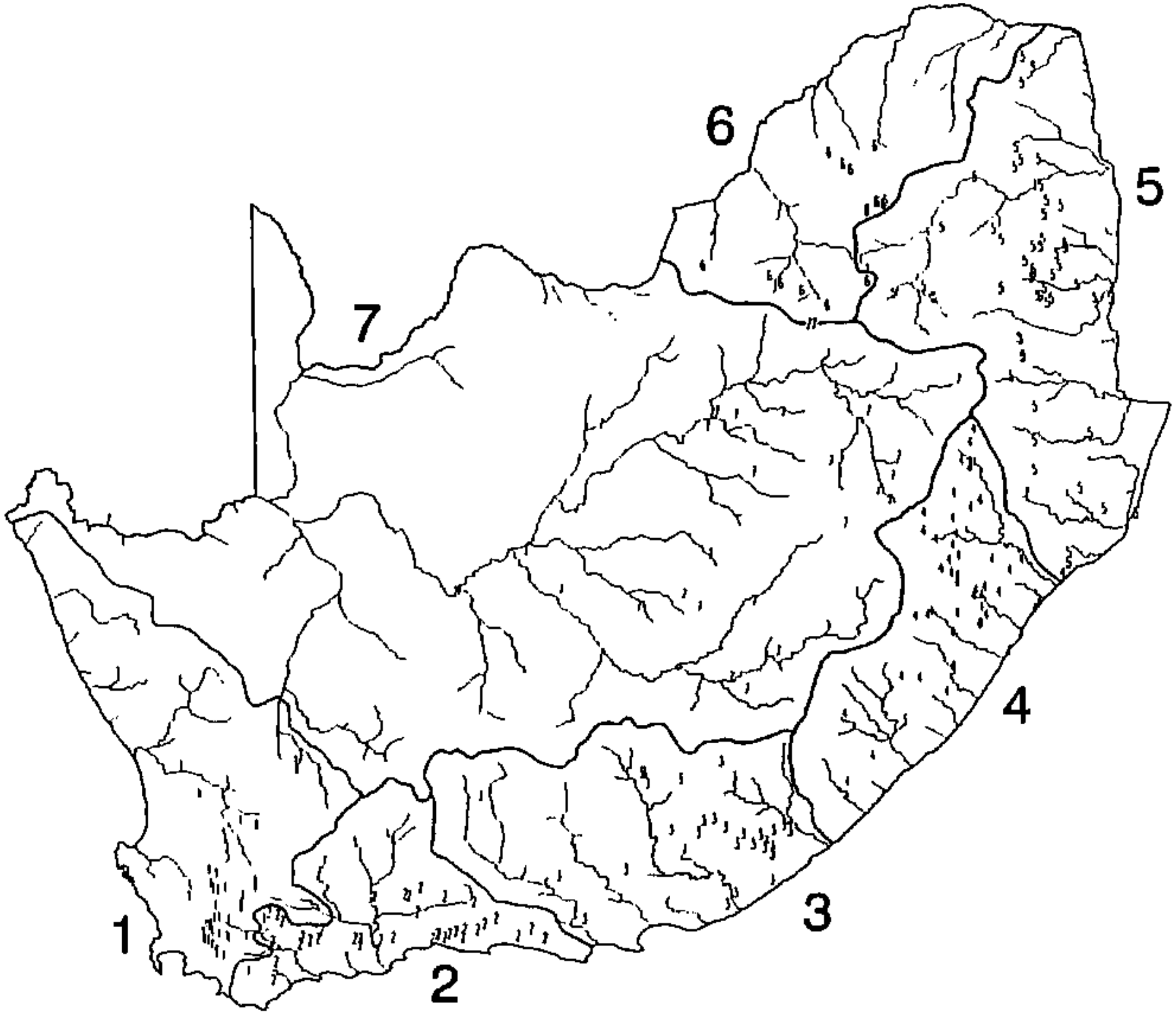


Figure 11.7 METHOD TWO: Map showing the locations of the stations used and the division of South Africa, Swaziland and Lesotho into seven regions based on correspondence analysis of monthly percentages of annual flow

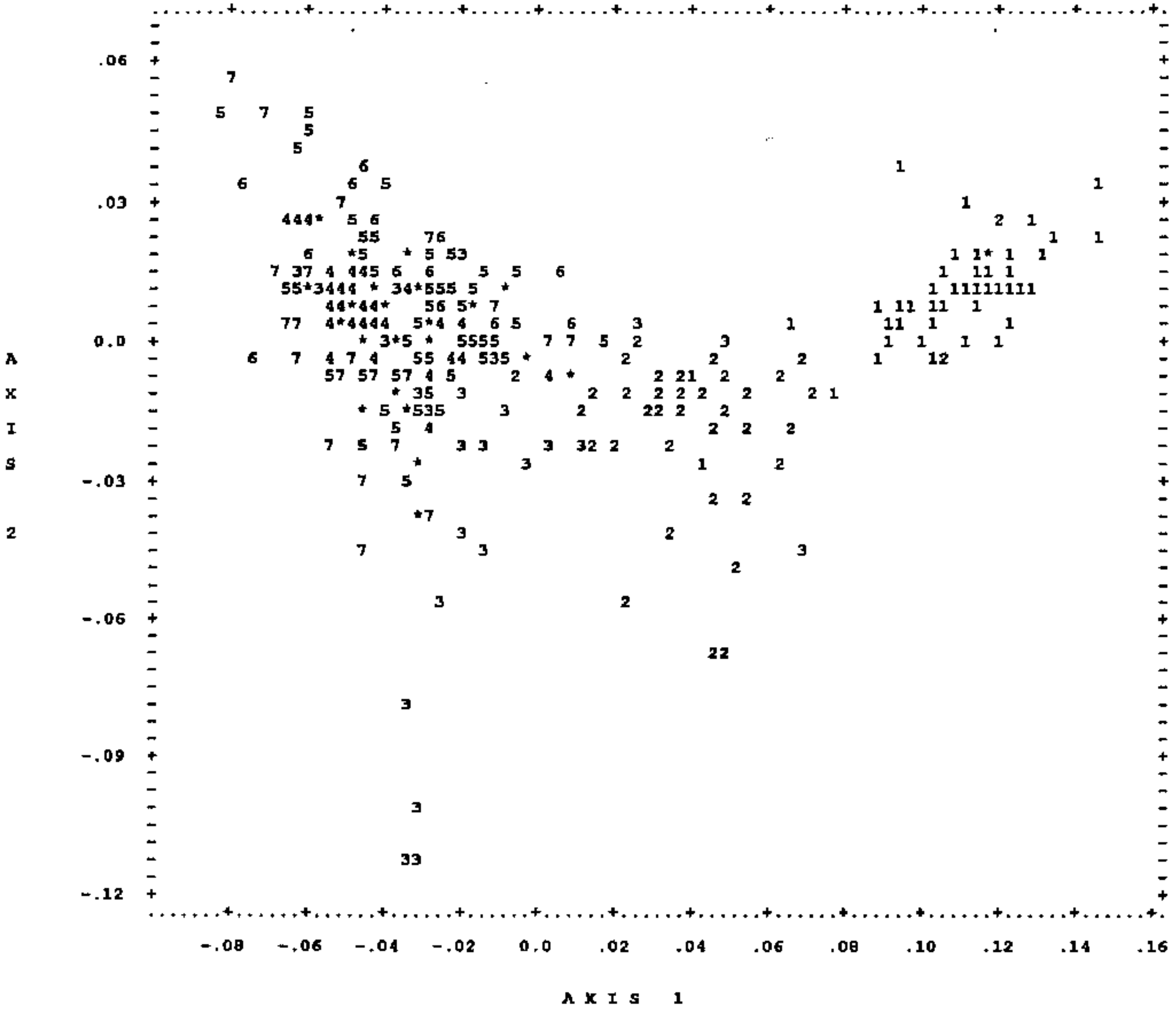


Figure 11.8 METHOD TWO: Biplot of the first two axes resulting from correspondence analysis of the matrix of monthly percentages of annual flow, showing stations in each of seven geographic regions. The numbers indicate the regions, and the asterices indicate coincidences of stations from different regions

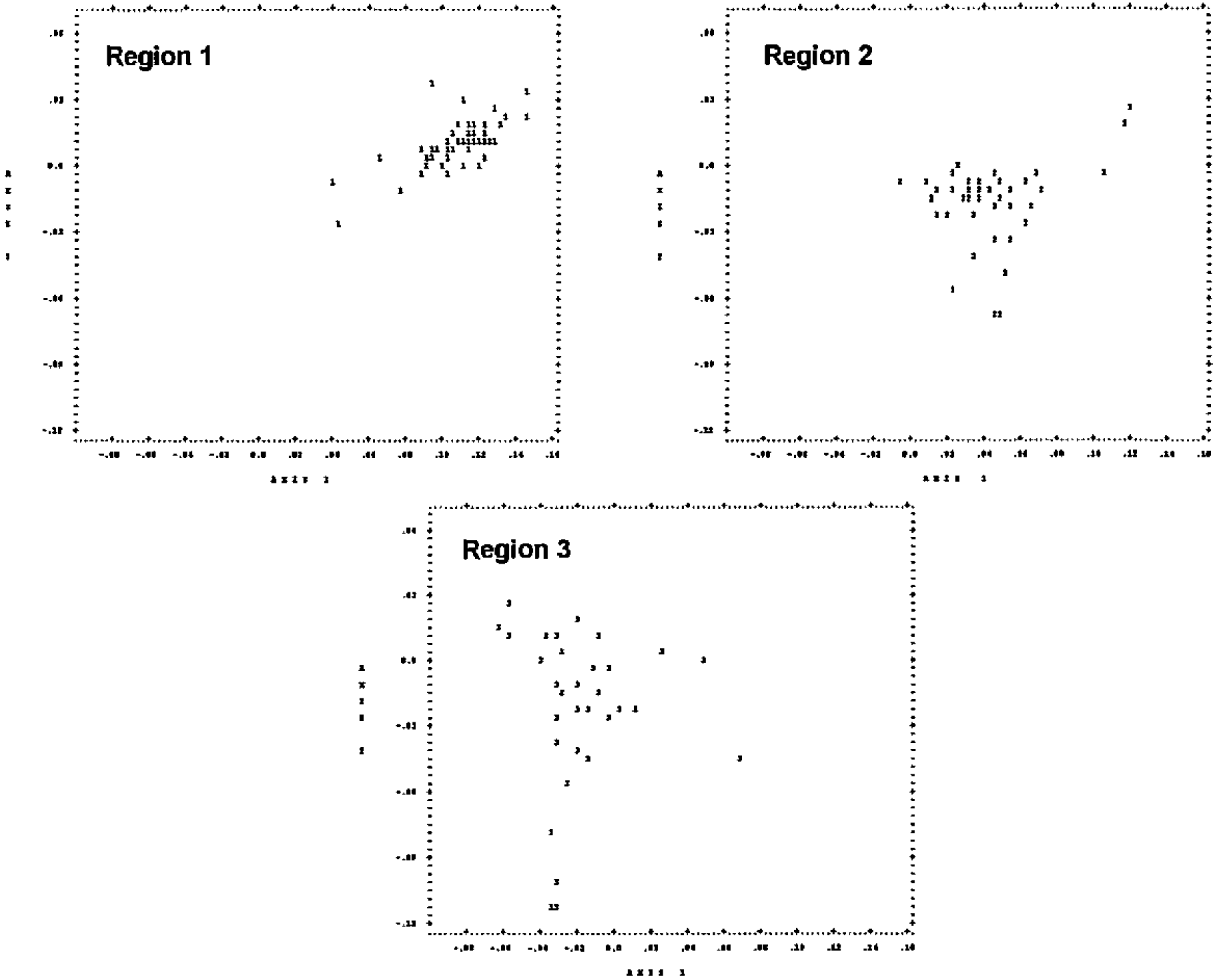


Figure 11.9 METHOD TWO: Biplot of the first two axes resulting from correspondence analysis of the matrix of monthly percentages of annual flow, showing stations in each of seven geographic regions separately

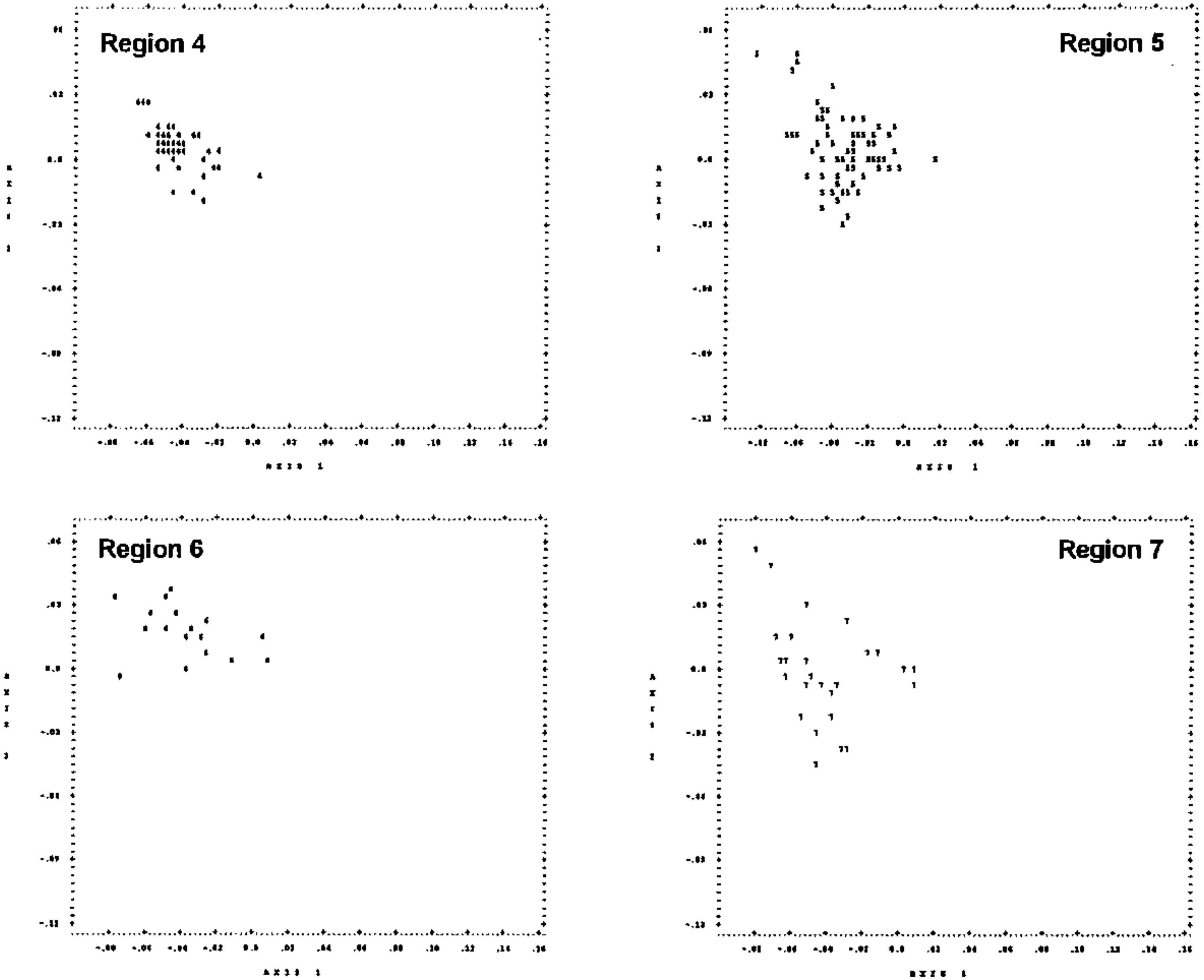


Figure 11.9 continued

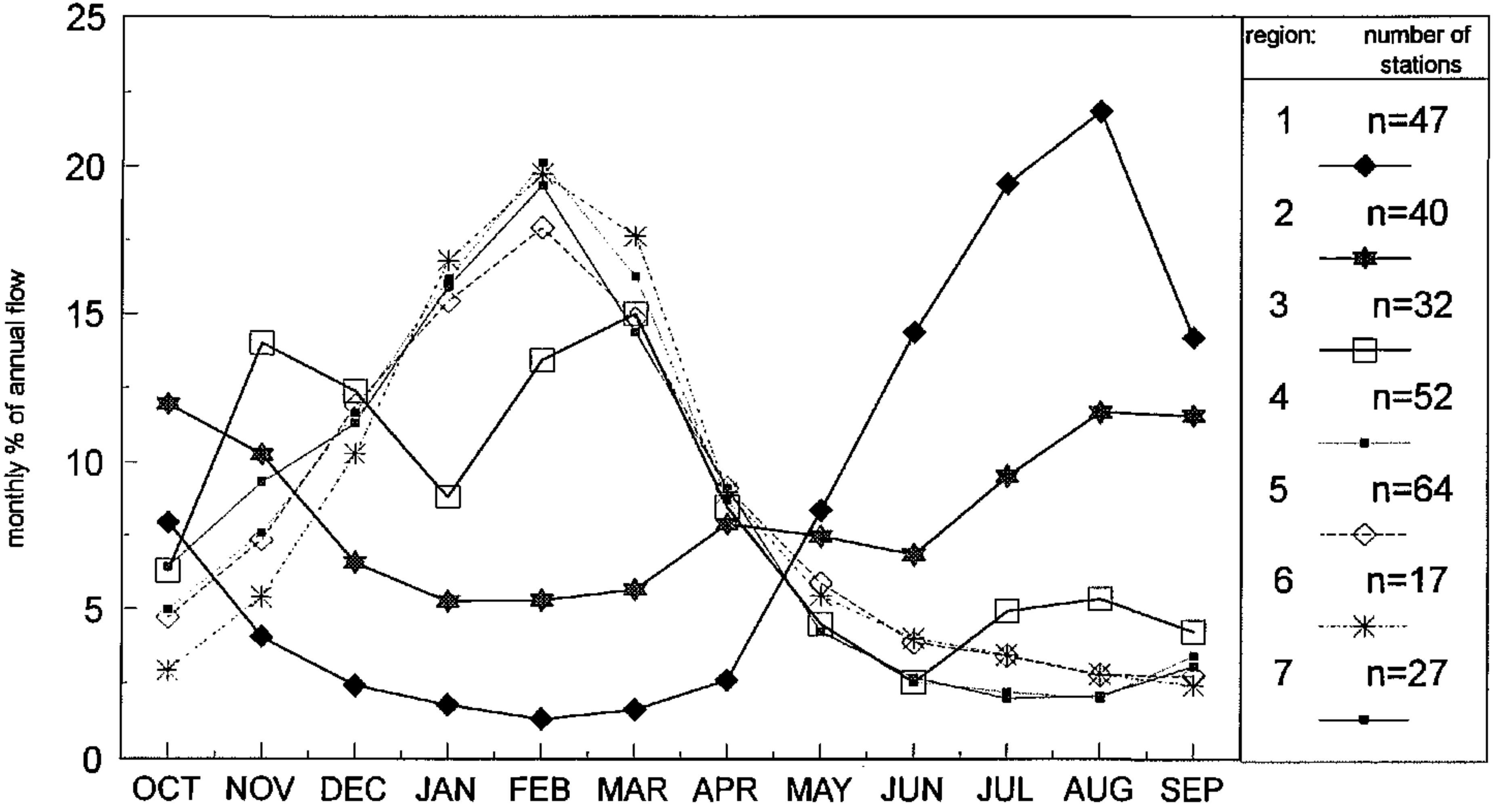


Figure 11.10 **METHOD TWO: Average monthly flow patterns of stations in seven geographic regions based on correspondence analysis of monthly percentages of annual flow**

Table 11.5 METHOD TWO: The allocation of DWAF drainage regions to seven flow regions based on correspondence analysis of monthly percentages of annual flow

REGION	DRAINAGE REGIONS
1 western Cape	D510 D520 D560 D580 E all F all G100 G200 G300 G400 H100 H200 H400 H600 J120
2 southern Cape	G500 H300 H500 H700 H800 H900 J except J120 K all L810 L820
3 eastern Cape	L except L810 L820 M all N all P all Q all R all S all
4 Transkei/ southern Natal	T all U all V all
5 northern Natal/ eastern Transvaal	A900 B all W all X all
6 north-western Transvaal	A except A900
7 Orange-Vaal catchment	C all D except D510 D520 D560 D580

Table 11.6 METHOD TWO: Means, standard deviations and standard errors of the means of the monthly percentages of annual flow for the stations in each of seven geographic regions

GROUP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	n	
1	**7.93**	**4.06**	**2.44**	**1.80**	**1.33**	**1.64**	**2.62**	**8.36**	**14.38**	**19.42**	**21.84**	**14.18**	47	mean
western Cape	2.45	2.24	1.58	1.79	1.45	1.78	1.72	3.11	3.76	4.04	4.34	4.12		std.dev.
	0.36	0.33	0.23	0.26	0.21	0.26	0.25	0.45	0.55	0.59	0.63	0.60		s.e.m.
2	**11.96**	**10.26**	**6.68**	**5.25**	**5.30**	**5.66**	**7.89**	**7.47**	**6.84**	**9.63**	**11.69**	**11.67**	40	
southern Cape	3.90	3.88	2.23	2.42	2.95	3.27	2.68	2.36	4.04	6.10	3.24	2.97		
	0.62	0.61	0.35	0.38	0.47	0.52	0.42	0.37	0.64	0.97	0.51	0.47		
3	**6.28**	**14.01**	**12.39**	**8.83**	**13.44**	**15.01**	**8.48**	**4.60**	**2.65**	**4.93**	**5.35**	**4.24**	32	
eastern Cape	2.47	9.76	6.02	3.93	6.93	6.99	4.25	2.99	2.06	5.34	5.43	2.30		
	0.44	1.73	1.06	0.70	1.23	1.24	0.75	0.53	0.36	0.94	0.96	0.41		
4	**4.96**	**7.69**	**11.67**	**16.20**	**20.14**	**16.28**	**8.73**	**4.26**	**2.66**	**2.21**	**2.01**	**3.42**	52	
Transkei/ southern Natal	1.95	1.67	2.14	2.98	4.58	3.03	2.22	1.86	1.27	1.09	0.99	2.02		
	0.27	0.23	0.30	0.41	0.64	0.42	0.31	0.26	0.18	0.15	0.14	0.26		
5	**4.70**	**7.34**	**11.91**	**16.43**	**17.94**	**14.85**	**9.13**	**5.88**	**3.87**	**3.43**	**2.78**	**2.76**	64	
northern Natal/ eastern Transvaal	2.86	2.91	3.91	5.25	4.96	3.61	2.60	1.97	1.64	1.59	1.44	1.27		
	0.36	0.36	0.49	0.66	0.62	0.45	0.33	0.25	0.21	0.20	0.18	0.16		
6	**2.93**	**5.40**	**10.29**	**16.82**	**19.75**	**17.66**	**8.98**	**5.46**	**4.01**	**3.46**	**2.62**	**2.44**	17	
north-western Transvaal	2.00	2.25	4.65	5.36	5.59	4.81	2.53	2.53	2.18	2.16	1.93	1.73		
	0.49	0.55	1.13	1.30	1.36	1.17	0.61	0.61	0.53	0.53	0.47	0.42		
7	**6.42**	**9.32**	**11.33**	**16.94**	**19.37**	**14.38**	**9.12**	**4.26**	**2.71**	**2.01**	**2.09**	**3.07**	27	
Orange-Vaal catchment	3.27	4.57	5.50	6.85	7.18	6.25	4.15	2.79	2.65	2.04	2.22	2.06		
	0.63	0.88	1.06	1.32	1.38	1.20	0.80	0.54	0.51	0.39	0.43	0.40		
4-7	**4.89**	**7.65**	**11.56**	**16.92**	**19.09**	**15.53**	**8.98**	**5.03**	**3.26**	**2.79**	**2.42**	**2.88**	160	
	2.73	3.04	3.86	4.96	5.39	4.23	2.78	2.27	1.91	1.72	1.57	1.75		
	0.22	0.24	0.31	0.39	0.43	0.33	0.22	0.18	0.15	0.14	0.12	0.14		

11.6.2.2 Flow types

In the covariance biplot analysis of the flow characteristics, the first axis explained only 30% of the inertia, the second axis 26%, the third axis 17%, the fourth axis 12% and the fifth axis 8%. Four axes were needed to explain 85% of the inertia and six to explain 95%. The technique failed to concentrate the information in only a few dimensions because of the low correlations between the eight (transformed) variables. The highest correlation coefficients were for GRCV versus ZERODAY (0.89), FLOINT versus FLOFRQ (-0.81 - but these two variables are inversely correlated by definition), PRED versus PROP (-0.57) and FLOINT versus FLODUR (-0.48). Only four other correlations - that is, altogether 8 out of 28 - were significant at the P=0.01 level. On the Axis 1 versus Axis 2 biplot (Figure 11.11) the points for GRCV and ZERODAY plotted very close together because of the high positive correlation between these two variables. On this biplot the points for FLOINT and FLOFRQ plotted more or less diagonally on opposite sides of the origin because of the high negative correlation between these two variables. Similarly the points for PRED and PROP plotted more or less diagonally opposite each other as did the points for FLOINT and FLODUR. None of the first four axes could be simply interpreted in terms of only two or three variables.

The positions of the points for ZERODAY and GRCV on Figure 11.11 imply that stations with high values of ZERODAY and GRCV would tend to plot towards the bottom right on this plot, stations with low ZERODAY and GRCV towards the top left. Similarly stations with high FLOFRQ would tend to plot towards the top right.

The demarcation of groups was complicated by the attempt to incorporate information from more than two axes. Initially the stations were divided into trial groups A to E as shown in Figure 11.12. The main criterion used was the coordinate on Axis 1 of the points representing the stations, but groups B and D were chosen so as to include most of the stations whose representative points lay far off Axis 1. These groups were then plotted on biplots of all combinations of axes 3, 4 and 5. An interesting feature was then noticed on the Axis 3 versus Axis 4 biplot (Figure 11.13). There was a narrow strip running diagonally across the plot, from top left to bottom centre, in which very few of the points representing the stations were plotted. Some of the trial groups tended to plot either to the left or to the right of this diagonal line. A number of points, mainly from trial group C, plotted away from the main body of points, towards the top right of the plot.

The trial groups were then abandoned and, instead, the stations were split into two using the diagonal line on the Axis 3 versus Axis 4 biplot (Figure 11.13) as a boundary. A separate biplot of Axis 1 versus Axis 2 was produced for the stations on each side of this boundary line (Figures 11.14 and 11.15).

On Figure 11.14, the Axis 1 versus Axis 2 biplot for the points to the right of the diagonal line, the stations were clearly split into the two groups around which envelopes have been drawn. Each of these two groups was then split into two groups of roughly equal size, labelled F and G, J and K respectively, as shown. The two new groups (F and G) at the top left of the biplot and the two new groups (J and K) at the bottom right of the biplot were then plotted separately (Figures 11.16 and 11.17) on biplots of Axis 3 versus Axis 4. In both cases the groups overlapped in this plane - the separation into two made on the Axis 1 - Axis 2 plane did not carry over on to the Axis 3 - Axis 4 plane.

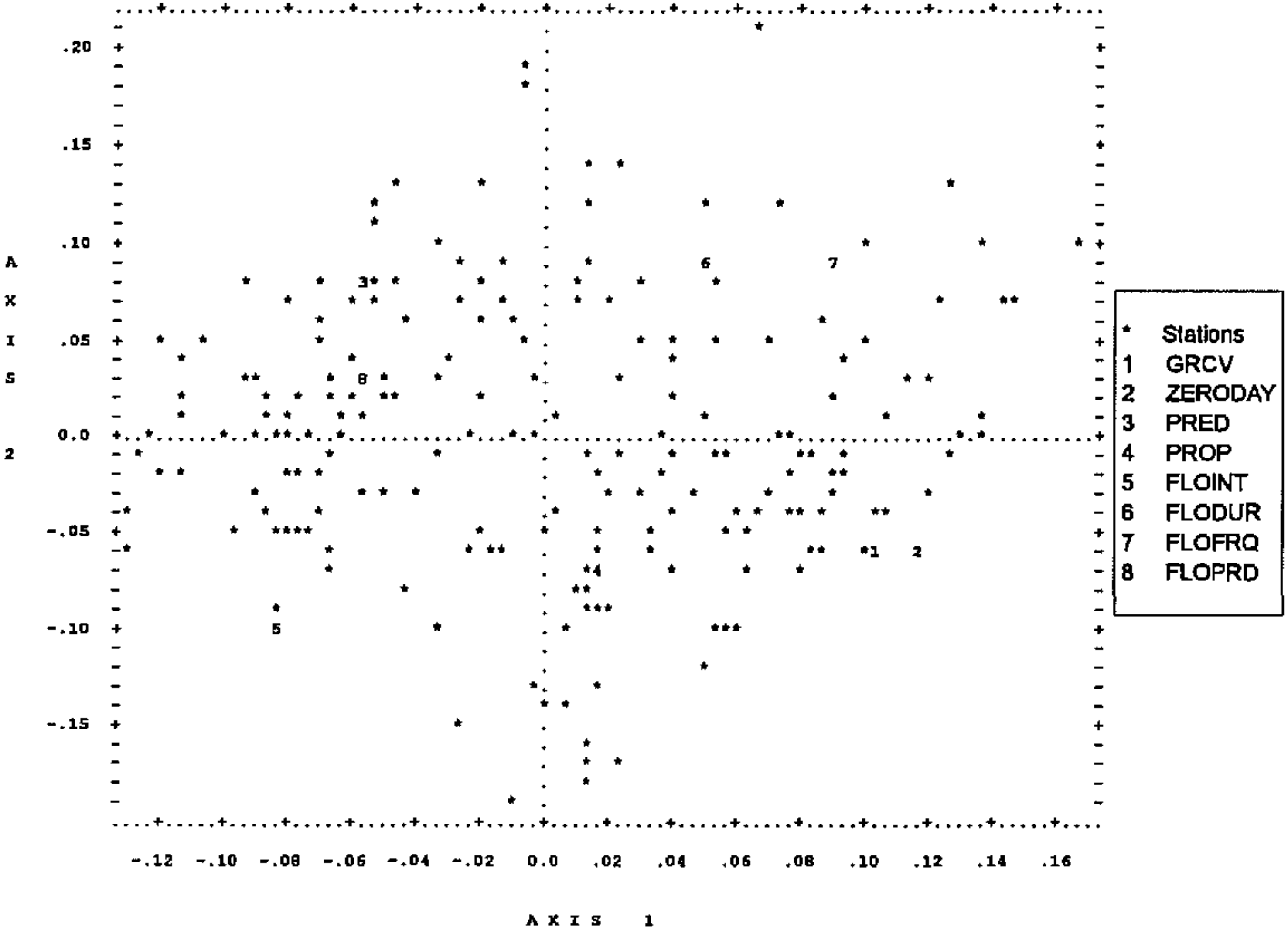


Figure 11.11 METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing stations and variables. The numbers indicate the variables

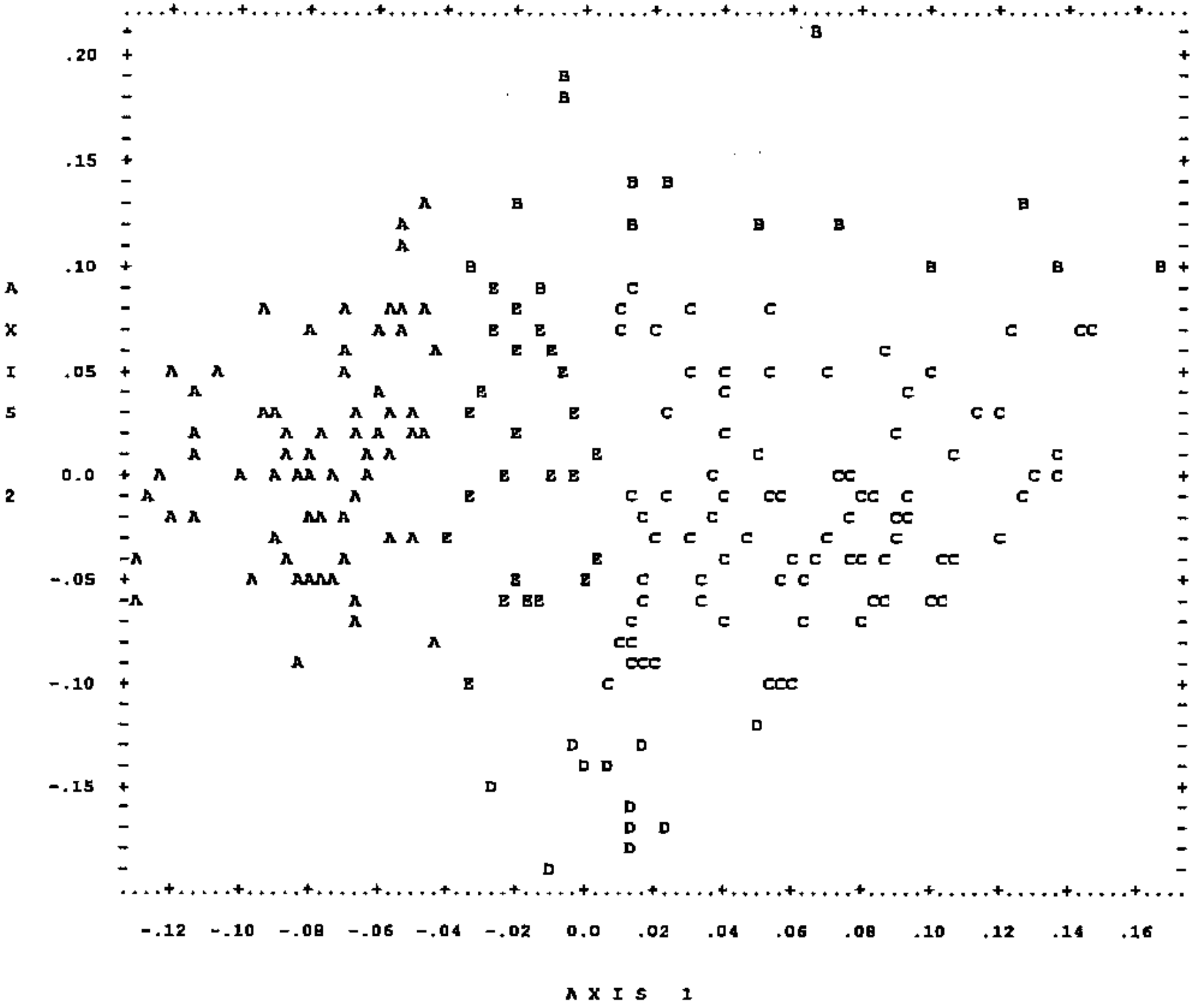


Figure 11.12 METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing stations divided into trial groups A to E

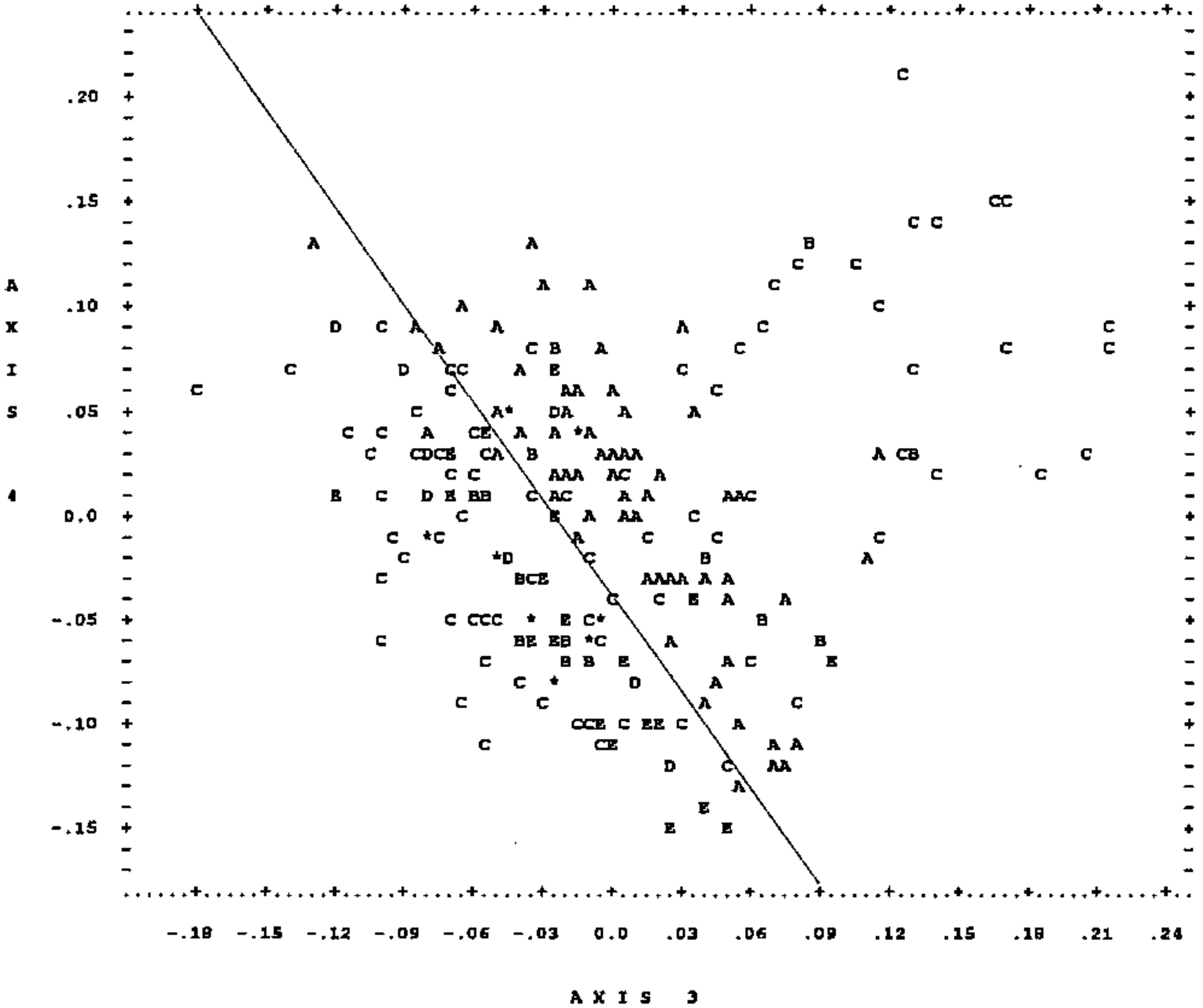


Figure 11.13 METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, with the stations labelled according to membership of trial groups A to E. Asterices indicate coincidences of stations from different regions. The diagonal line indicates an apparent gap in the stations (see text)

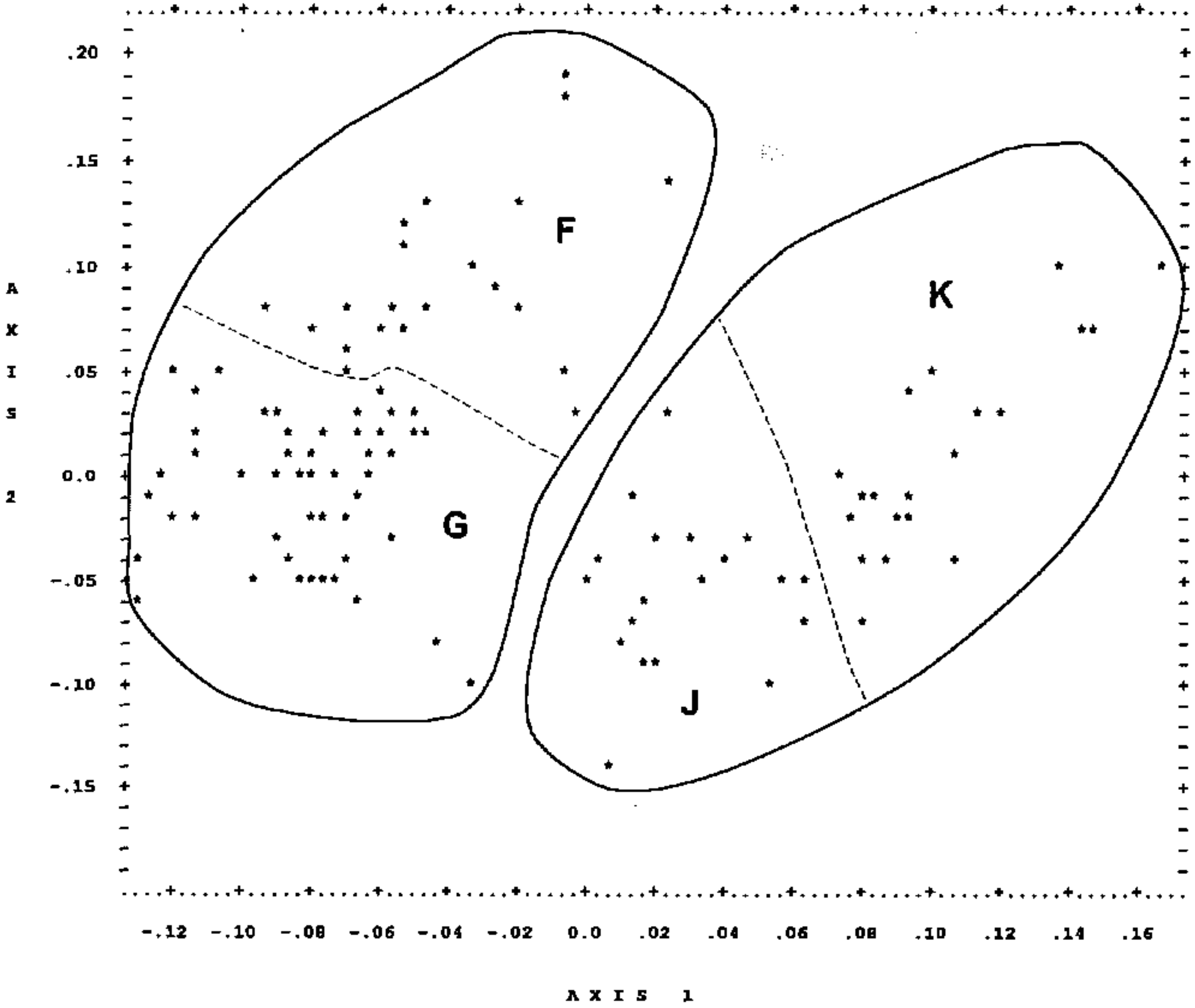


Figure 11.14 METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing only the stations to the right of the diagonal line in Figure 11.13. The envelopes indicate groups into which the stations were split (see text)

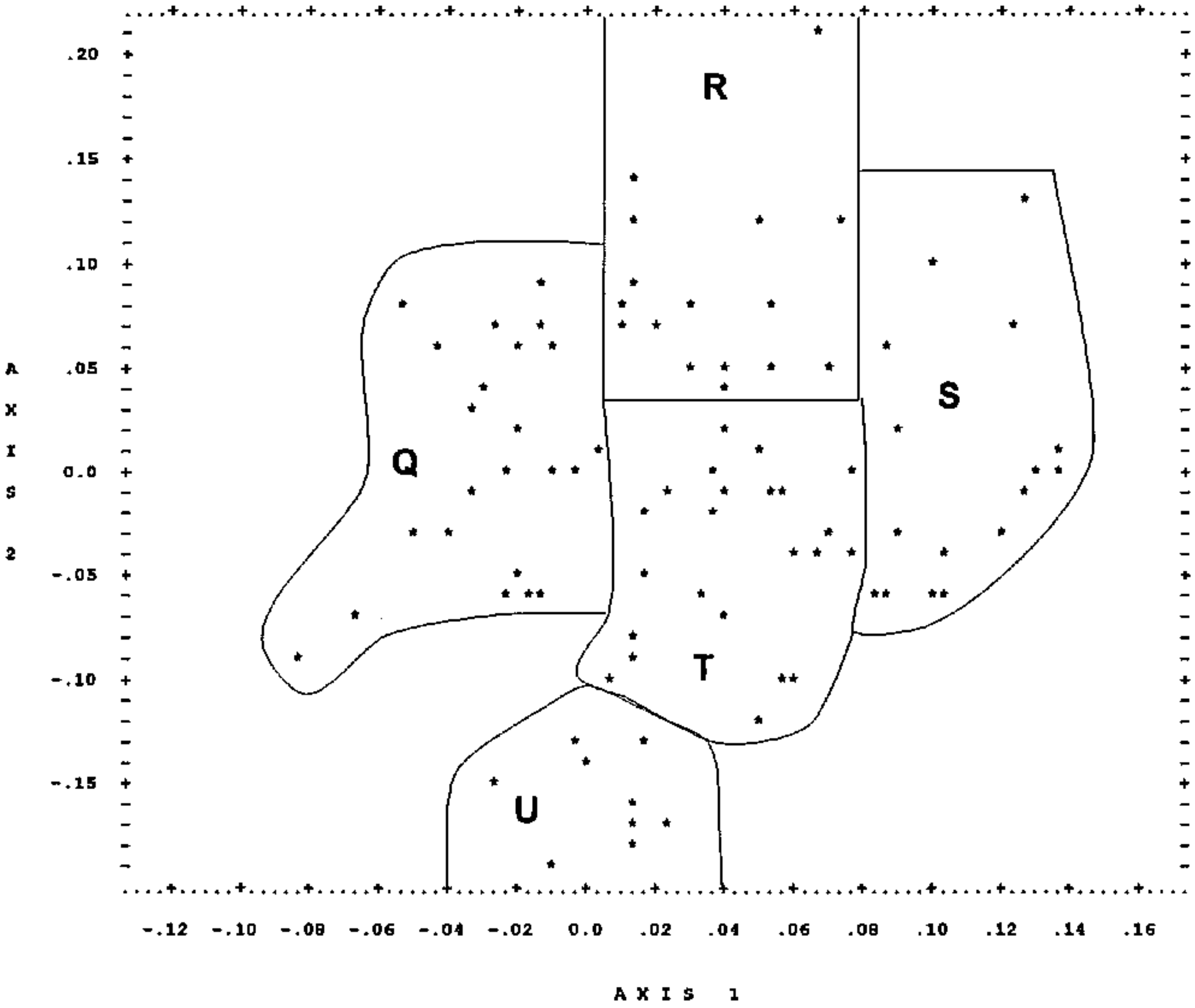


Figure 11.15 METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing only the stations to the left of the diagonal line in Figure 11.13. Envelopes indicate groups into which the stations were split (see text)

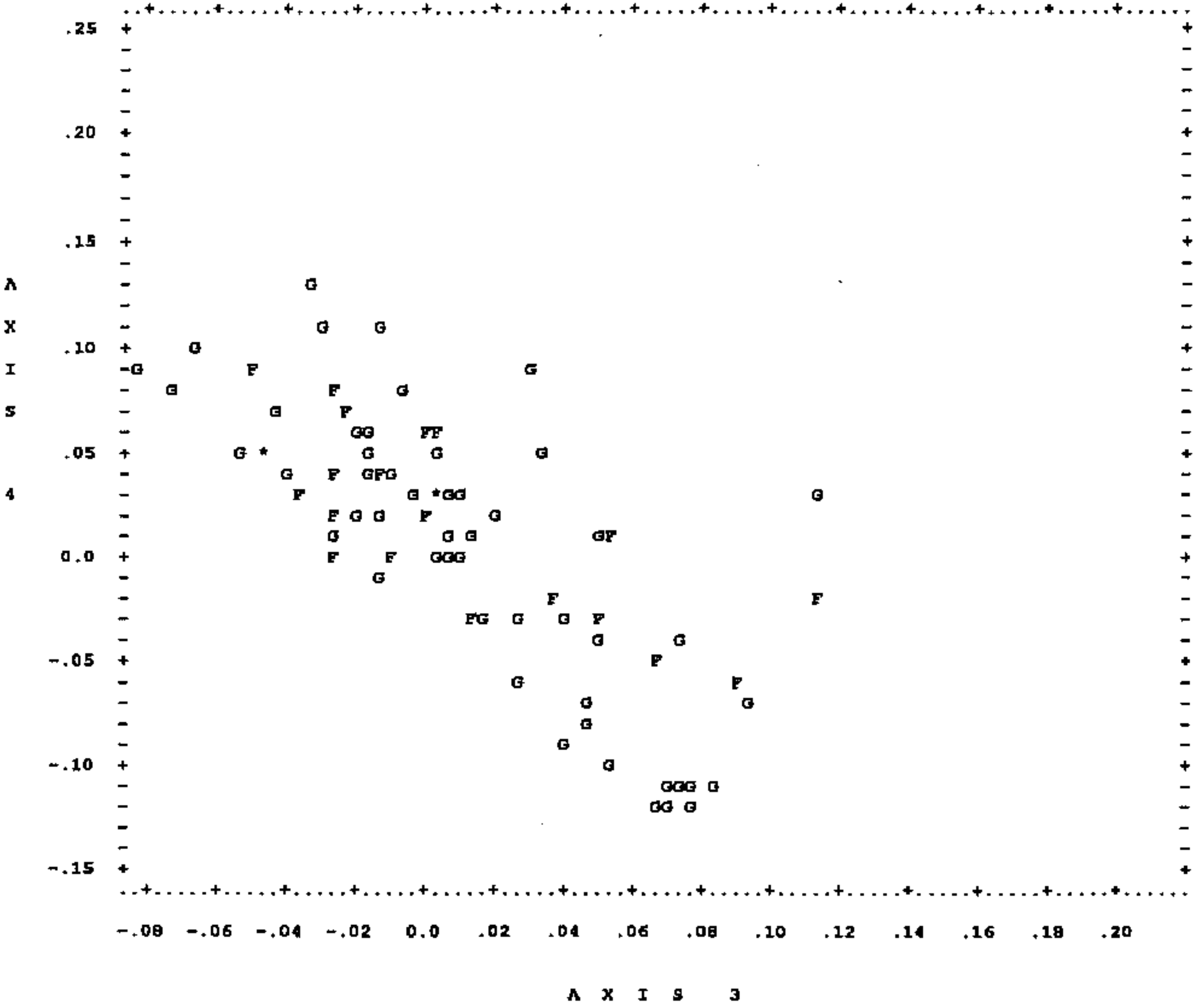


Figure 11.16 METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing only the stations in groups F and G as demarcated on Figure 11.14. Asterices indicate coincidences of stations from different groups

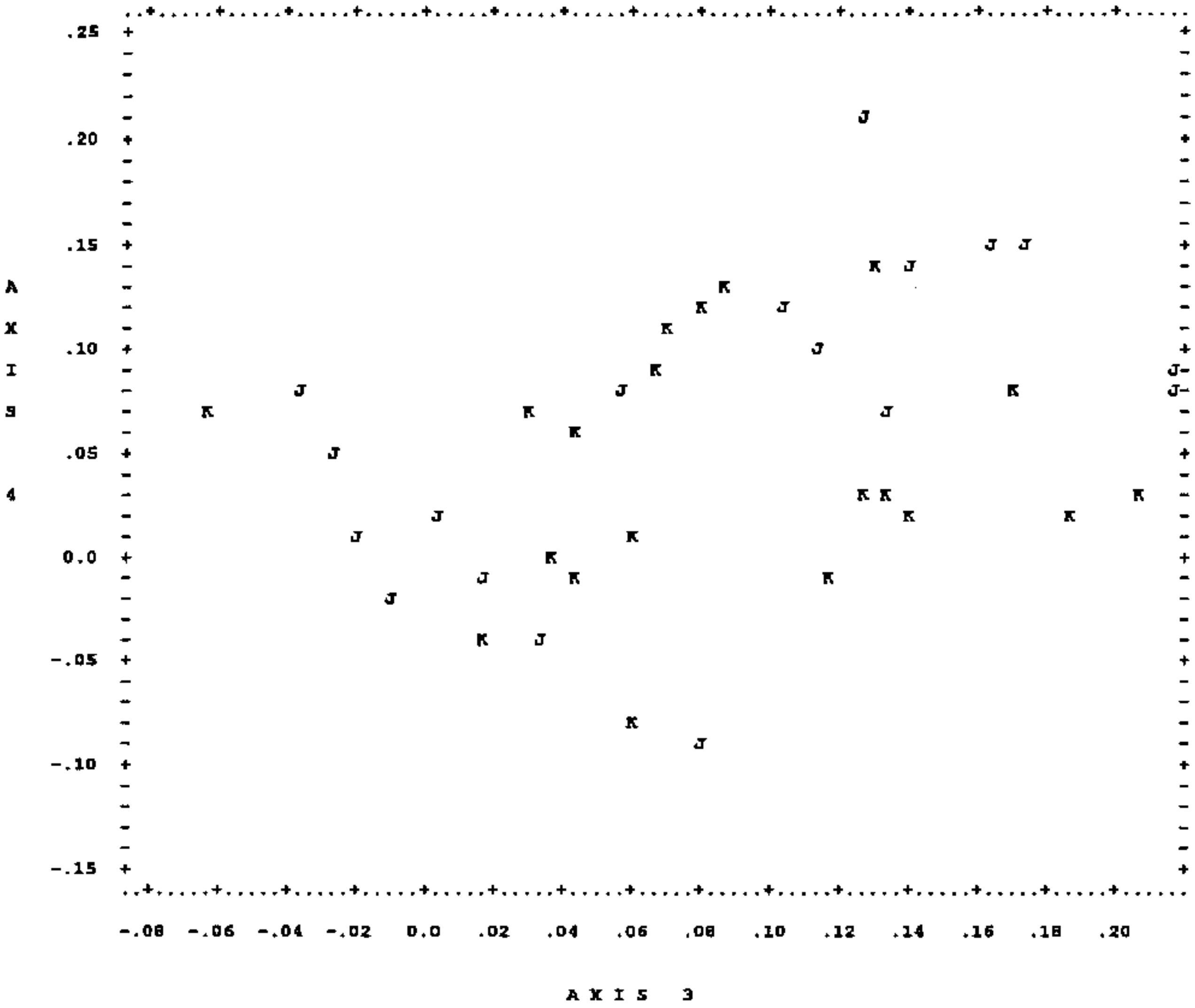


Figure 11.17 METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing only the stations in groups J and K as demarcated on Figure 11.14

On Figure 11.15, the Axis 1 versus Axis 2 biplot for the points to the left of the diagonal line in Figure 11.13, the points for the stations did not divide in any obvious way. They were arbitrarily split into five groups - Q,R,S,T and U - as shown, based largely on their coordinates on the two axes. These groups were plotted on a biplot of Axis 3 versus Axis 4 (Figure 11.18). No separation between the groups was evident on this plot - the separation into two made on the Axis 1 - Axis 2 plane did not carry over on to the Axis 3 - Axis 4 plane.

It was then noticed that the stations in the two groups at the top left in Figure 11.14 (groups F and G) and in the two groups at the top left of Figure 11.15 (groups Q and R) were almost all on apparently perennial rivers. The distribution of ZERODAY was examined. It was found that there were 81 stations with ZERODAY less than 0.50, 10 with ZERODAY between 0.50 and 0.99, 6 between 1.00 and 1.49, 5 between 1.50 and 1.99, 3 between 2.00 and 2.49 and none between 2.50 and 2.99. Between 3.00 and about 30 there was an apparently random scattering of stations. An arbitrary decision was made to define perennial stations as those with ZERODAY less than 3.0. This decision had to be changed later (see below).

Perennial stations classified in predominantly non-perennial groups and non-perennial stations classified in predominantly perennial groups were then transferred to the most appropriate - based on their coordinates on Axis 1 and Axis 2 - perennial or non-perennial group respectively. For example, a non-perennial station in the largely perennial group Q would have been transferred to the largely non-perennial group T. After these changes there were thus four perennial groups (the former F, G, Q and R) and five non-perennial groups (the former J, K, S, T and U). The two groups - J and K, as revised - at the bottom right of Figure 11.14 were then found to consist mainly of stations with high ZERODAY (mostly above 180). The three groups - S,T and U, as revised - at the bottom right of Figure 11.15 all consisted exclusively of stations with ZERODAY less than 180.

It then seemed to be appropriate to 'tidy up' the almost complete split that had occurred between non-perennial stations with ZERODAY between 3 and 180 and those with ZERODAY above 180. Only a few stations had ZERODAY close to 180, so it was arbitrarily decided to enforce a split at ZERODAY equals 180. This required that 16 stations with ZERODAY less than 180 be transferred from the groups J and K on Figure 11.14 to one of the groups S,T or U on Figure 11.15. However these stations did not fit well into the groups on Figure 11.15 because they lay to the right of the diagonal line on Figure 11.13, the Axis 3 versus Axis 4 biplot, whereas groups S,T and U lay to the left. They were therefore formed into a separate group.

It was then noticed that several stations on major rivers which would ordinarily be considered perennial - for example, the Orange River at Aliwal North - had not been classified as perennial. After a further examination of the data for the stations with ZERODAY between 3.0 and 20.0, it was decided to redefine perennial stations as those with ZERODAY less than 10.0. No major rivers which would normally flow all the year round were then classified as non-perennial. Fourteen stations were reclassified into the already-established four perennial groups as a result of this change.

The aforegoing description of the procedure by which the groups were derived has been simplified. As a result it might be thought that the process was straightforward and that the course of action to be taken at each stage was obvious. In reality the procedure was not

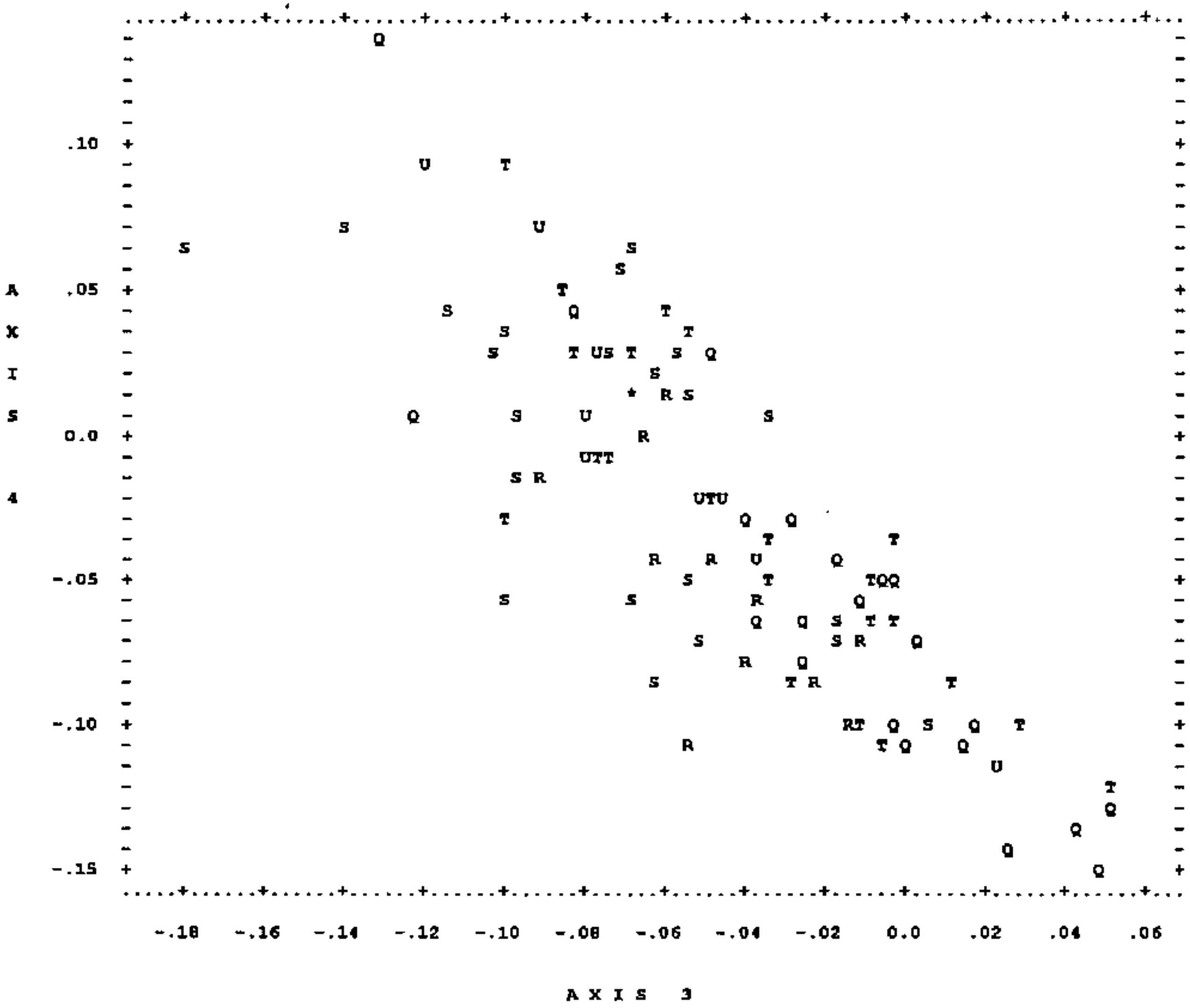


Figure 11.18 METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing only the stations in groups Q, R, S, T and U as demarcated on Figure 11.15. Asterices indicate coincidences of stations from different groups

straightforward and the course of action at any stage was not obvious. Alternative courses might have been taken and produced similar or very different results.

There were ultimately ten groups - four perennial groups, four non-perennial groups with ZERODAY between 3 and 180 and two non-perennial groups with ZERODAY greater than 180. Axis 1 versus Axis 2 and Axis 3 versus Axis 4 biplots for these three sets of groups, hereafter called supergroups, are shown separately in Figures 11.19 to 11.24.

Derivation of the terms quasi-perennial-seasonal and extreme-seasonal flow

It was not obvious how to name the non-perennial supergroup with ZERODAY less than 180 and the non-perennial supergroup with ZERODAY greater than 180 so as to adequately characterise them and emphasise the difference between them. The label 'quasi-perennial-seasonal' was chosen for the non-perennial supergroup with ZERODAY less than 180 after an analysis, using a sample of 100 stations. For each of the ten flow-type groups, a sample of ten stations was taken for this analysis. The sample was biased to include for each group, if possible, at least one station from each of the seven geographic regions demarcated on the basis of monthly flow patterns (Figure 11.7). For each of the stations, the number of days of zero flow in each of the last ten years of the record used in deriving the values of the variables describing the flow characteristics was recorded. There were thus 100 values of the number of days of zero flow per year for each of the ten groups. Where there were not ten stations available for a group, more than ten years were sampled from each of the available stations so as to give 100 values for the group. These 100 values were then arranged in ascending order and various percentiles determined. The n'th lowest of the 100 values for a group was taken to be the n'th percentile for that group. Table 11.7 shows various percentiles for the ten groups. For example, in the sample of 100 values of the number of days of zero flow per year for flow-type group 9, the 5'th lowest value was 55. The 5'th percentile for group 9 is therefore shown as 55 in Table 11.7. For the same group the entry 365 for the 95'th percentile implies that at least six of the values in the sample of 100 values of the number of days of zero flow per year were greater than or equal to 365. That is, there were years in which there was effectively no flow. In fact, five of the ten stations in the sample for this group had 365 or 366 days of zero flow in one or more of the years for which values were sampled. Flow-type group 2 illustrates the othet extreme. For this group 96 of the 100 values of number of days of zero flow per year were 0 or 1, hence the entry 1 for the 95'th percentile for group 2. A surprising number of years had exactly one day of zero flow and these single days should probably be regarded as errors.

Groups 0, 1 and 2 clearly consist of stations on perennial rivers - in over 90% of the years sampled there were no days, or exactly one day, of zero flow. For group 3 the 90th percentile is 9 days. This group contains a few stations at which flow stopped for short periods in some years but where, on the whole, flow was perennial during the years sampled. The analysis of number of days of zero flow therefore supports the labelling of groups 0, 1, 2 and 3 as 'perennial'.

The 25th percentile was 0 or 1 day for each of groups 4, 5, 6 and 7 implying that, during at least a quarter of the years sampled for each of these four groups, flow was essentially perennial. However the 75th percentiles for these four groups varied from

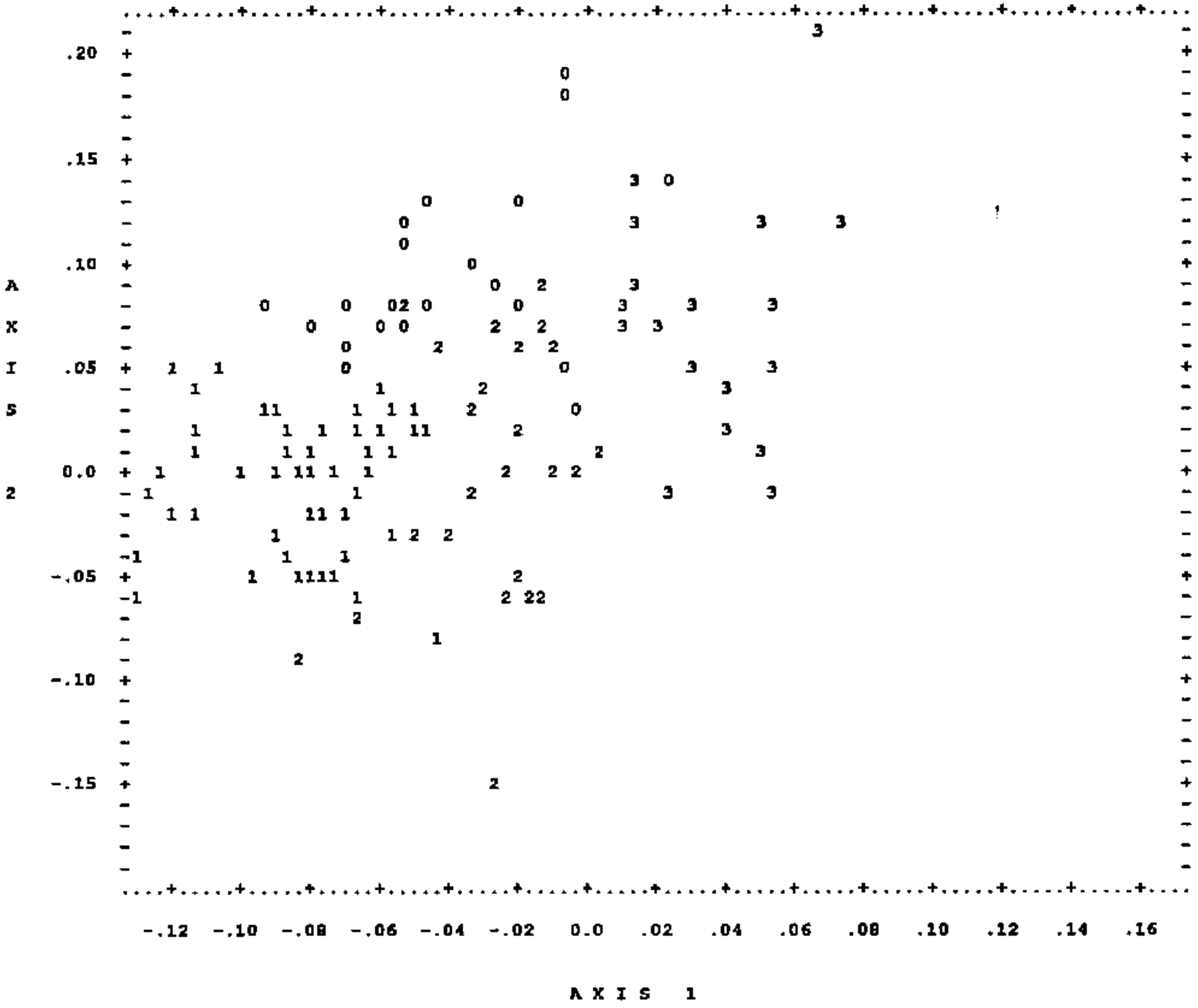


Figure 11.19 **METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing four groups of stations with perennial flow**

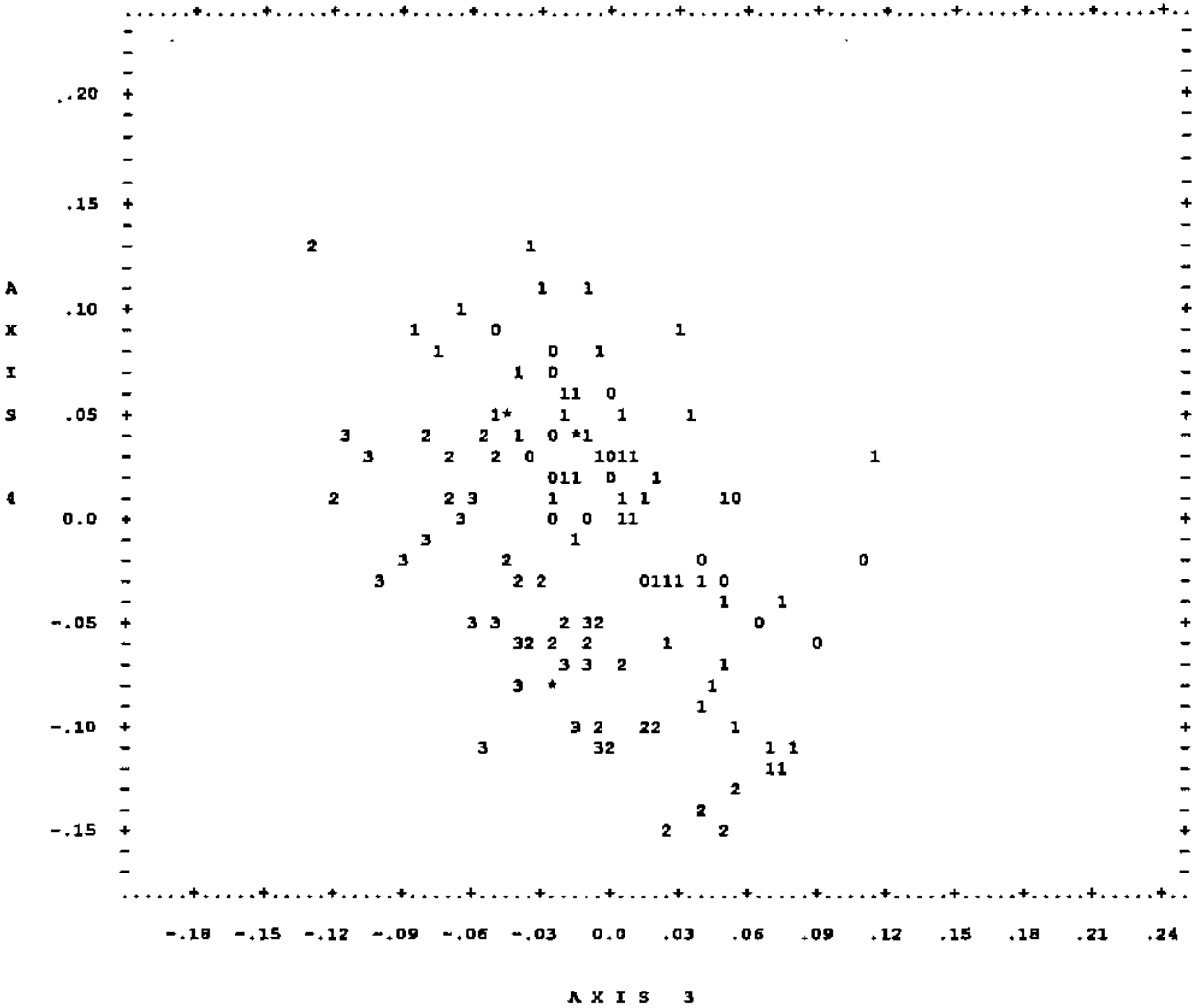


Figure 11.20 METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing four groups of stations with perennial flow. Asterices indicate coincidences of stations from different groups

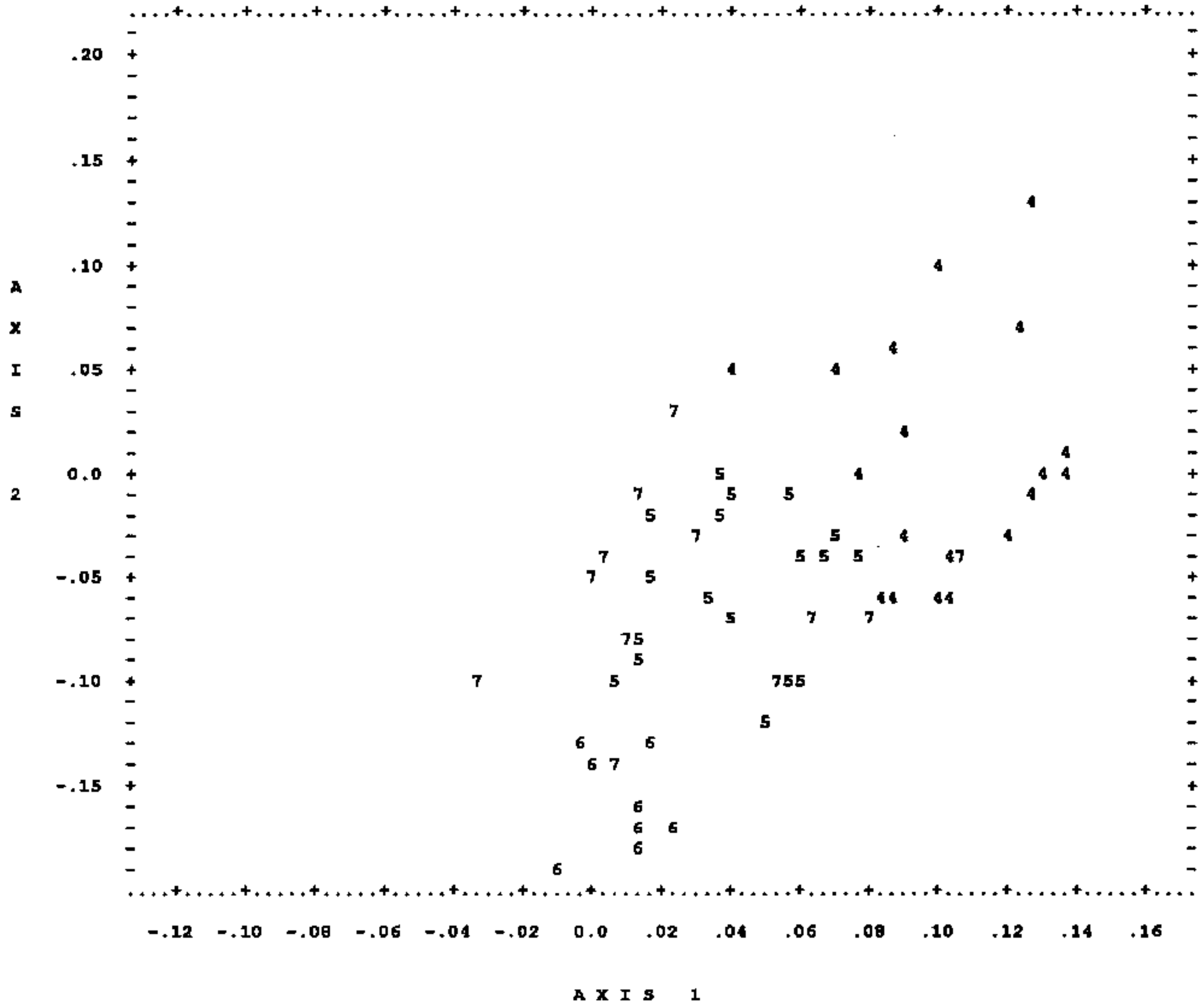


Figure 11.21 METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing four groups of stations with quasi-perennial-seasonal flow

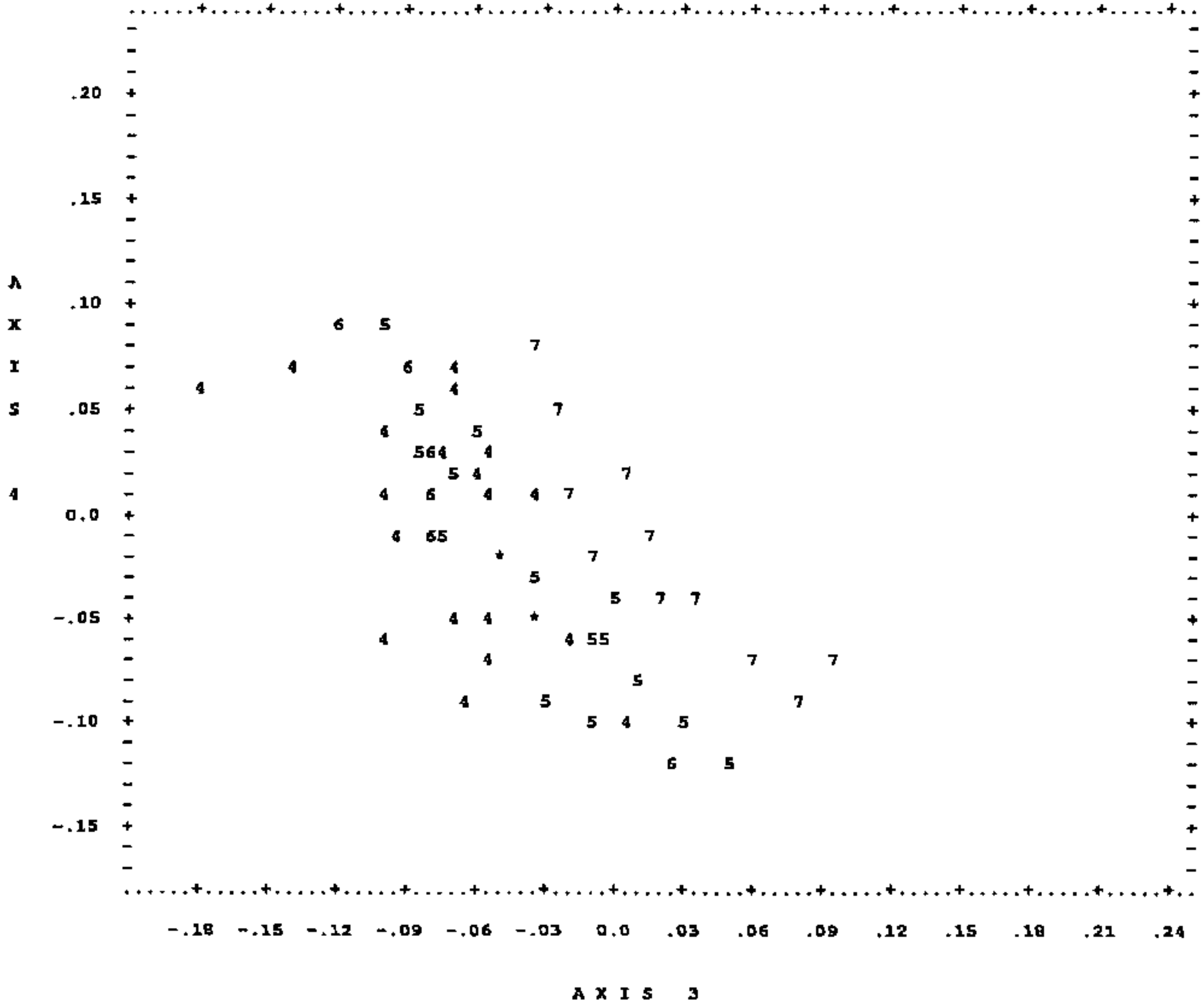


Figure 11.22 METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing four groups of stations with quasi-perennial-seasonal flow. Asterices indicate coincidences of stations from different groups

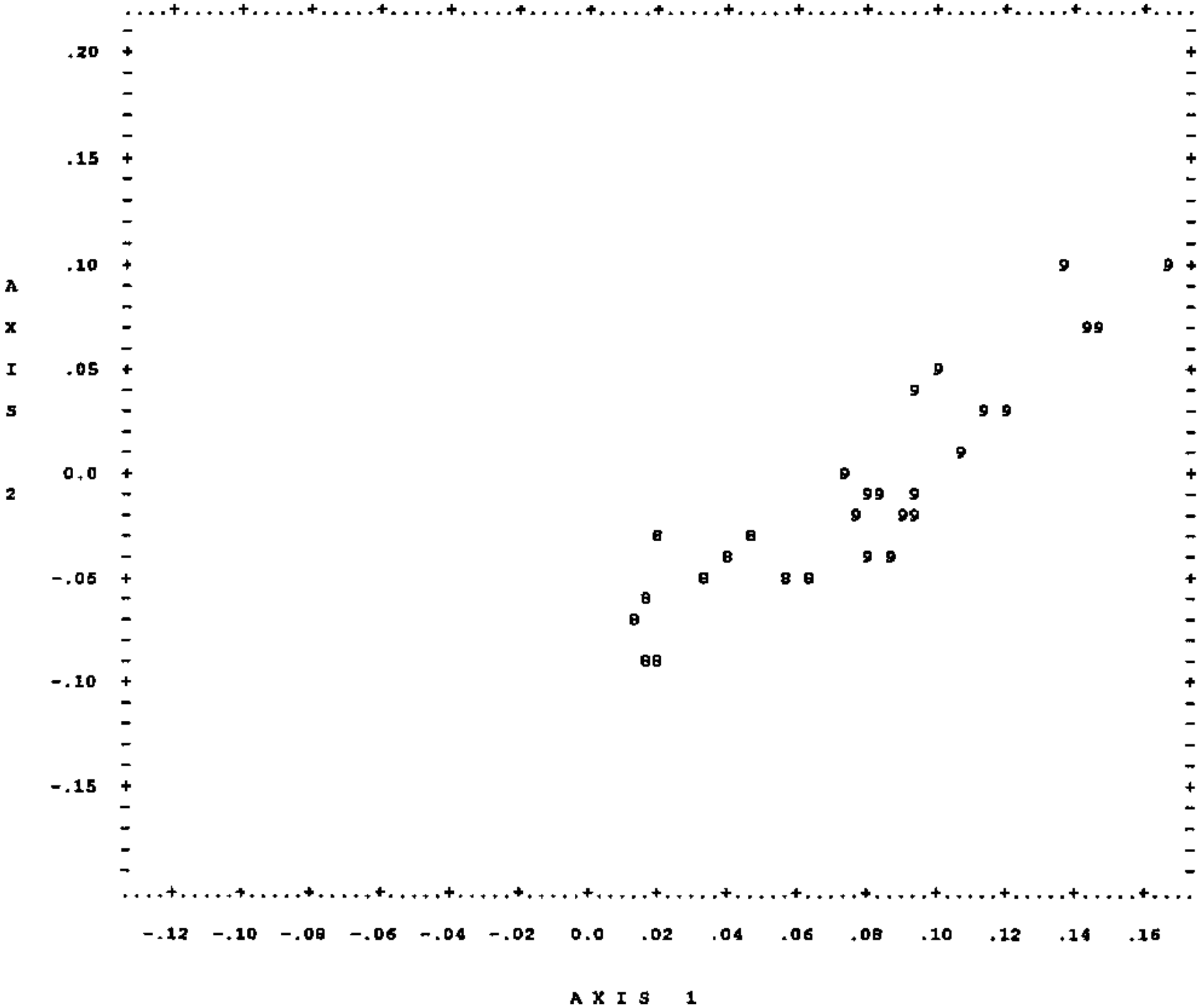


Figure 11.23 METHOD TWO: Biplot of the first two axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing two groups of stations with extreme-seasonal flow

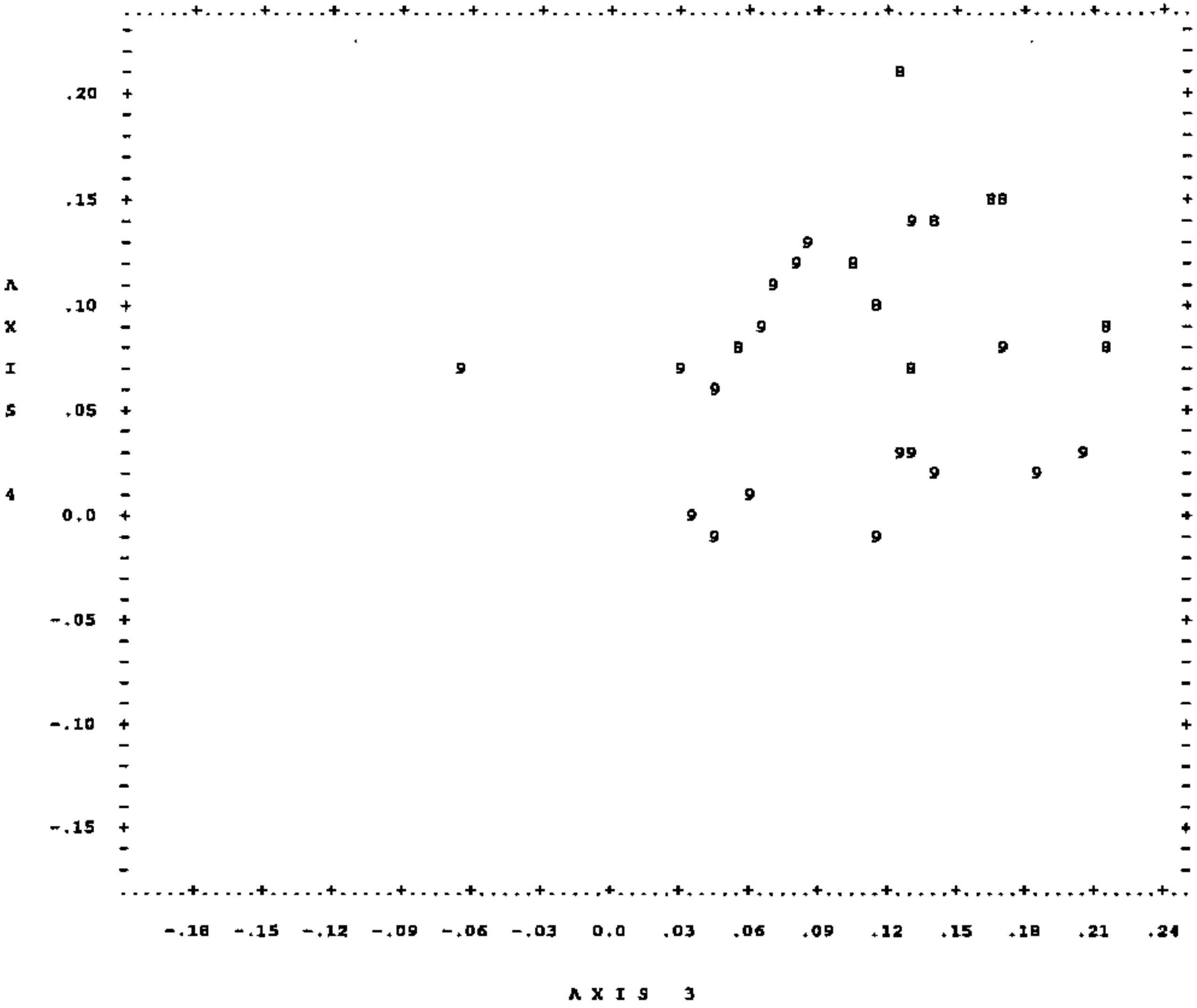


Figure 11.24 **METHOD TWO: Biplot of the third and fourth axes resulting from covariance biplot analysis of eight variables describing flow characteristics, showing two groups of stations with extreme-seasonal flow**

Table 11.7 METHOD TWO: Analysis of the number of days of zero flow per year for a sample consisting of 100 years of data taken from each of ten flow types. The entry for the n'th percentile for a flow type is the n'th lowest of the 100 values of the number of days of zero flow for the 100 years sampled for that flow type (see text)

percentile:	5	10	25	33	50	75	90	95
flow type groups:	number of days of zero flow per year							
0	0	0	0	0	0	1	1	2
1	0	0	0	0	0	1	1	4
2	0	0	0	0	0	1	1	1
3	0	0	0	0	0	1	9	17
4	0	0	1	2	26	119	217	307
5	0	0	0	1	7	59	159	188
6	0	1	1	8	35	117	152	167
7	0	0	0	1	6	88	188	286
8	61	223	279	301	333	347	354	356
9	55	129	249	272	310	350	360	365

59 to 119 days implying that at least a quarter of the years in each of these groups had zero flow for two months or longer. Furthermore, ten per cent of the years in two of these groups had zero flow for over six months. It was felt that these groups could not be labelled 'seasonal' as this name would not reflect the frequent perennial flows. These groups should perhaps be called 'quasi-perennial-seasonal'. It was also noted that there was a small number of stations, spread across these quasi-perennial-seasonal groups, which had no years with nought or one day of zero flow in the sample and, therefore, ought not to be labelled quasi-perennial. These stations possibly are truly seasonal, but it was not verified that the periods of zero flow occurred at the same season in all the years sampled for these few stations. Despite the problem posed by these few stations, groups 4, 5, 6 and 7 - non-perennial groups with ZERODAY less than 180 - were labelled 'quasi-perennial-seasonal'.

For each of groups 8 and 9, half of the years in the sample had zero flow for more than ten months and there were only a few years with less than two months of zero flow. Some of the stations in group 9 did not record any flow in some years. These groups have been labelled 'extreme-seasonal'. Some of the stations in groups 8 and 9 could probably be labelled 'episodic' but this aspect of the flow pattern was not examined in detail. For some of these stations, the word 'seasonal' may be inappropriate. An analysis was made of the monthly percentages of flow for the stations in each of groups 8 and 9, separately for each of the seven flow regions as shown in Figure 11.7. The flow patterns for the stations in these groups approximated the seasonal patterns for their respective regions as shown in Figure 11.10 with the exception of the six group 8 and 9 stations in region 3 (eastern Cape) some of which had a high percentage of flow in July, August or September. The five group 9 stations in region 2 (southern Cape), which does not have a large seasonal variation in flow, had their periods of high flow scattered throughout the year. The variability of the seasonal pattern of flow for these stations was not tested but it is probable that it is high. There are no group 8 stations in region 2. So the label 'seasonal' does not fit well on the group 8 and 9 stations in regions 2 and 3. Groups 8 and 9 - non-perennial groups with ZERODAY greater than 180 - have nevertheless been labelled 'extreme-seasonal'.

The final groups were then compared in various ways. Figure 11.25 shows the locations of the stations and how many of each group fell into each of the seven seasonal flow regions derived in Section 11.6.2.1. It was immediately obvious that stations in certain of the groups were concentrated in certain regions. Group 0, a perennial group, is absent from the western, southern and eastern Cape regions. Group 4, a quasi-perennial-seasonal group, is particularly common in the north-west Transvaal. Group 6, another quasi-perennial-seasonal group, occurs only in the western and southern Cape. Neither of the extreme-seasonal groups occurs in the southern Natal/Transkei region.

For each of the original (untransformed) eight variables, separate (side by side) histograms were plotted for each of the ten groups. Figure 11.26 shows these histograms for the variable PRED. It was noticed that there was, for most of the variables, considerable overlap of the values between groups. Means, standard deviations and standard errors of the means for the eight variables used in the classification into groups as well as for GRMEAN, SPMEAN and AREA (catchment area) are given in Table 11.8. The letters H, M and L in the table are the result of a simple classification of each group for each variable as High(H), Medium(M) or Low(L) based only on the mean and standard error of the mean of the values of each variable

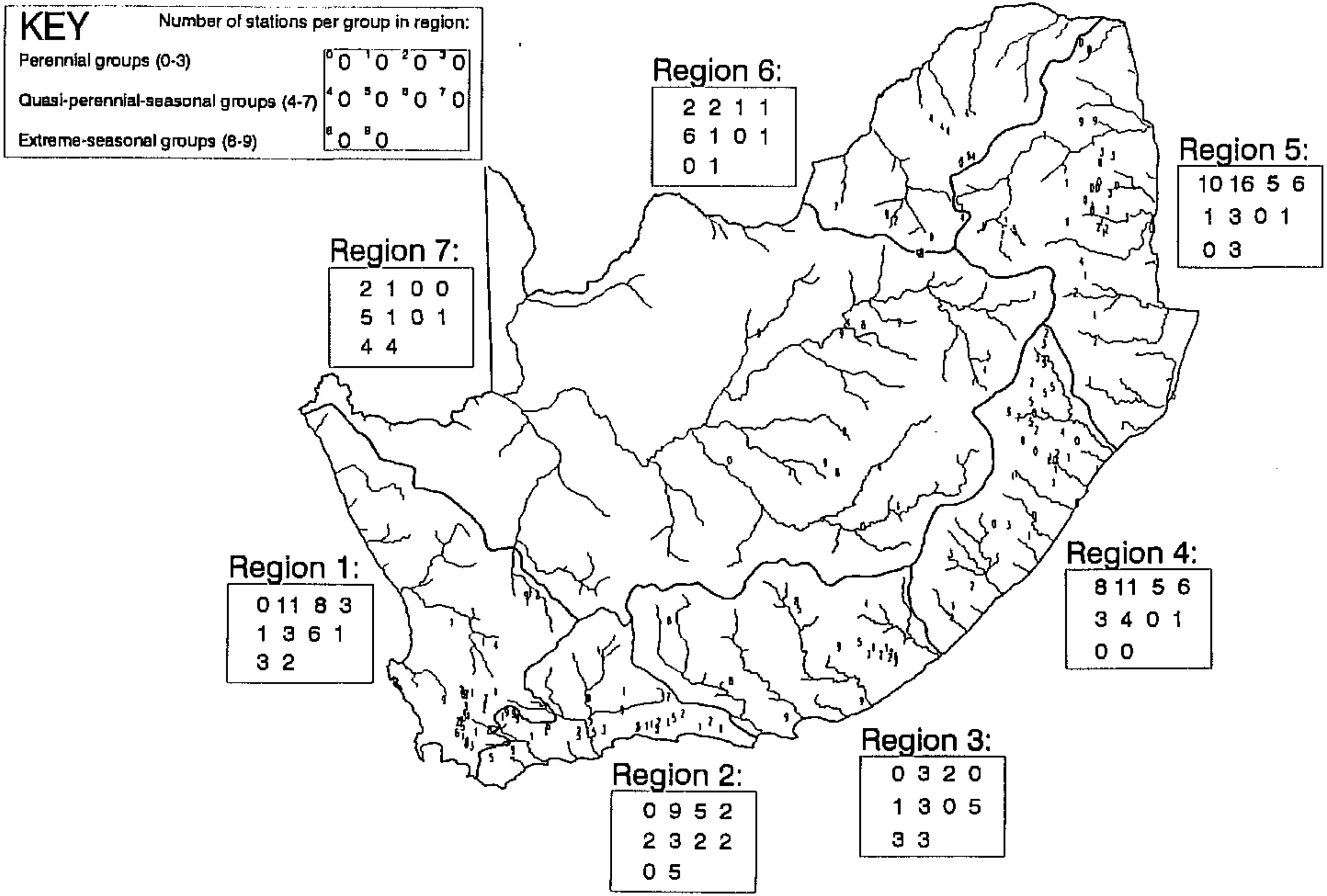


Figure 11.25 **METHOD TWO: Map showing the locations of the stations in the ten flow type groups and the number of stations of each type in each of the seven regions demarcated after correspondence analysis of the monthly distribution of flow**

```
                                                                       G R O U P

              0           1           2           3           4           5           6           7           8           9
              +...........+...........+...........+...........+...........+...........+...........+...........+...........+...........+
     1.000)   ****        *
     0.960)   *                                                                                               *
     0.920)                                                                                                   **          ***
     0.880)                                                                                                   **
     0.840)               *                       *                                                           *           **
     0.800)   M**         ****                                                                                M           **
     0.760)   *****       ***                     *                                                                       *
     0.720)   ****        *********   **                                                                      *           **
     0.680)   **          ******      ***         *                                                           *           N
     0.640)   *           M*****      ***         **
P    0.600)   *           *********** ***         ***                                     *                               *
     0.560)   *           ********    M*          M                                       *                               ***
R    0.520)               ***         **          *           *                           *           *           *
     0.480)                           ****        **          **          ****            *                       *
E    0.440)               *           ***         *                       *               *                       *
     0.400)                           ***         *****       **          *           *           N
D    0.360)                           *                       **          ***         **          **                      *
     0.320)                                                   *           M*          *           **
     0.280)                                                   M*          ***         M*          *
     0.240)                                                   **          *                       **
     0.200)                                                   *****       ***
     0.160)                                                   **                      **
     0.120)
     0.080)
     0.040)
     0.000)
              +...........+...........+...........+...........+...........+...........+...........+...........+...........+...........+

MEAN          0.782       0.656       0.543       0.547       0.296       0.339       0.288       0.390       0.815       0.684
STD.DEV.      0.131       0.099       0.111       0.136       0.121       0.098       0.088       0.117       0.133       0.178
S. E. M.      0.028       0.014       0.022       0.032       0.028       0.023       0.031       0.034       0.042       0.042
MAXIMUM       1.000       0.999       0.720       0.842       0.533       0.474       0.409       0.590       0.967       0.926
MINIMUM       0.570       0.450       0.362       0.389       0.145       0.199       0.146       0.230       0.530       0.342
STATIONS         22          53          26          18          19          18           8          12          10          18

              EACH ASTERISK REPRESENTS ONE STATION
              LEGEND FOR GROUP MEANS:       M - MEAN COINCIDES WITH AN ASTERISK
                                            N - MEAN DOES NOT COINCIDE WITH ANY ASTERISK
```

Figure 11.26 METHOD TWO: Histograms of PRED for the ten flow-type groups

Table 11.8 **METHOD TWO: Means, standard deviations and standard errors of the means of eleven variables for the stations in each of ten flow type groups. Where possible the group means of the eight variables used in grouping the stations have been classified as H (high), M (medium) or L (low)**

SUPERGROUPS		PERENNIAL				QUASI-PERENNIAL-SEASONAL				EXTREME SEASONAL	
	GROUP	0	1	2	3	4	5	6	7	8	9
VARIABLE	**NUMBER OF STATIONS**	22	53	26	18	19	18	8	12	10	18
GRCV	MEAN STD.DEV. S. E. M.	0.11 0.04 0.01 L	0.15 0.05 0.01 L	0.22 0.10 0.02 L	0.21 0.07 0.02 L	0.71 0.42 0.10 M	0.49 0.21 0.05 M	0.62 0.09 0.03 M	0.66 0.43 0.12 M	4.02 2.01 0.64 H	2.82 1.50 0.35 H
ZERODAY	MEAN STD.DEV. S. E. M.	1.18 2.23 0.47 L	0.58 0.99 0.14 L	1.29 2.26 0.44 L	2.85 3.07 0.72 L	71.48 46.28 10.62 M	45.86 39.52 9.31 M	55.10 25.14 8.89 M	70.21 55.39 15.99 M	305.02 45.21 14.30 H	266.58 55.06 12.98 H
FLODUR	MEAN STD.DEV. S. E. M.	4.83 2.62 0.56 H	2.17 1.02 0.14 M	1.77 0.55 0.11 L	4.00 3.30 0.78 H	4.80 3.21 0.74 H	1.92 0.51 0.12 L	1.38 0.24 0.08 L	2.18 0.70 0.20 M	1.58 0.27 0.09 L	5.39 4.08 0.96 H
PROP	MEAN STD.DEV. S. E. M.	0.91 0.06 0.01 H	0.87 0.09 0.01 H	0.80 0.15 0.03 H	0.80 0.09 0.02 H	0.72 0.11 0.03 M	0.74 0.13 0.03 M	0.49 0.16 0.06 L	0.84 0.08 0.02 H	0.96 0.04 0.01 H	0.93 0.09 0.02 H
FLOINT	MEAN STD.DEV. S. E. M.	66.79 62.32 13.29 M	276.84 139.74 19.19 H	117.06 110.97 21.76 M	24.00 10.28 2.42 L	32.45 21.60 4.96 L	113.83 73.92 17.42 M	391.62 67.64 23.91 H	216.67 156.60 45.21 H	234.65 133.25 42.14 H	54.69 37.97 8.95 M
PRED	MEAN STD.DEV. S. E. M.	0.78 0.13 0.03 H	0.66 0.10 0.01 M	0.54 0.11 0.02 M	0.55 0.14 0.03 M	0.30 0.12 0.03 L	0.34 0.10 0.02 L	0.29 0.09 0.03 L	0.39 0.12 0.03 L	0.81 0.13 0.04 H	0.68 0.18 0.04 M
FLOFRQ	MEAN STD.DEV. S. E. M.	1.36 0.52 0.11 M	0.88 0.21 0.03 L	1.35 0.43 0.08 M	2.32 0.65 0.15 H	2.07 0.66 0.15 H	1.34 0.30 0.07 M	0.73 0.16 0.06 L	1.12 0.26 0.08 M	0.96 0.15 0.05 L	1.66 0.38 0.09 M
FLOPRD	MEAN STD.DEV. S. E. M.	0.69 0.13 0.03 -	0.67 0.16 0.02 -	0.58 0.15 0.03 -	0.59 0.11 0.03 -	0.59 0.15 0.03 -	0.55 0.13 0.03 -	0.53 0.13 0.05 -	0.52 0.14 0.04 -	0.62 0.12 0.04 -	0.51 0.13 0.03 -
GRMEAN	MEAN STD.DEV. S. E. M.	8.32 2.01 0.43	6.83 1.58 0.22	5.95 1.73 0.34	6.78 1.39 0.33	4.40 2.00 0.46	4.94 1.45 0.34	3.46 1.15 0.41	4.61 2.24 0.65	0.89 0.81 0.26	1.55 0.90 0.21
SPMEAN	MEAN STD.DEV. S. E. M.	0.05 0.08 0.02	0.14 0.26 0.04	0.37 0.60 0.12	0.04 0.04 0.01	0.04 0.05 0.01	0.08 0.20 0.05	1.00 1.22 0.43	0.05 0.09 0.02	0.03 0.04 0.01	0.005 0.010 0.002
AREA	MEAN STD.DEV. S. E. M.	7162 21099 4498	1656 5579 766	249 337 66	579 633 149	1420 3073 705	554 936 221	15 14 5	1018 1649 476	2471 3371 1066	1327 2493 588

for each group. Each group could then be characterised uniquely in terms of the H, M and L classifications for only a few variables. In particular, a characterisation based on the H, M and L classification of the variables ZERODAY, FLOFRQ and FLODUR characterised the groups uniquely.

Figures 11.27 (perennial stations), 11.28 (quasi-perennial-seasonal stations) and 11.29 (extreme-seasonal stations) were plotted to explore the idea that grouping the stations using only the three variables ZERODAY, FLOFRQ and FLODUR might yield groups similar to those already demarcated. Although the groups demarcated using all eight variables have rather peculiar boundaries on Figures 11.27 to 11.29, not very many stations plot within the boundary of another group. A simple grouping of stations based on the perennial/quasi-perennial-seasonal/extreme-seasonal split and on straight line boundaries parallel to the axes in each of the three plots of FLOFRQ versus FLODUR could have produced broadly similar groups. It is interesting to note where group 7 plots on Figure 11.28 and on Figures 11.21 and 11.22. It either overlaps group 5 or is adjacent to it. The distribution of the two groups across the country is similar (Figure 11.25). The only variable in Table 11.8 for which the difference between the means for the two groups is of any consequence is PROP. The two groups could possibly be combined.

Three variables not used in the classification were included in Table 11.8 to show that the demarcated groups have some meaning in terms of other variables. Not surprisingly the four groups of perennial rivers have higher mean values of GRMEAN than the four groups of quasi-perennial-seasonal rivers which, in turn, have far higher mean values of GRMEAN than the two groups of extreme-seasonal rivers. Group 6 has by far the highest SPMEAN. This occurs because three of the stations in this small group have very high values of SPMEAN (above 1.0) and the other five all have moderately high values (above 0.1). Groups 1 and 2 each contain a small number of stations with very high SPMEAN but these two groups are both dominated by a much larger number of stations with low SPMEAN. Group 9 has very low SPMEAN. The means of AREA for each group tend to be dominated by a few large catchments. Groups 2, 3 and 5 do not contain any large catchments hence their small mean AREAs. Group 6 consists only of very small catchments, the largest being 36 square kilometres.

11.6.2.3 Discussion of flow types

The basic separation of stations into perennial, quasi-perennial-seasonal and extreme-seasonal supergroups needs to be refined by moving stations which have never been gauged as flowing all year - that is, never with 0 or 1 day of zero flow in a water year - from the quasi-perennial-seasonal supergroup to the extreme-seasonal supergroup or to a (new) seasonal supergroup. These stations could probably be allocated to one or other of the two extreme-seasonal groups without difficulty, thereby making these two groups less extreme. The extreme-seasonal supergroup would then need to be renamed. If the stations were formed into a separate seasonal supergroup, this supergroup would contain very few stations compared with the other supergroups. The reason for the small number of truly seasonal stations is not known, but it may be due to the siting of the gauging weirs used in this study close to the sources of rivers.

As has been suggested above, the number of quasi-perennial-seasonal groups could possibly be reduced to three by combining groups 5 and 7. The number of groups formed could also be increased by splitting some of the groups - especially the larger perennial ones - into two,

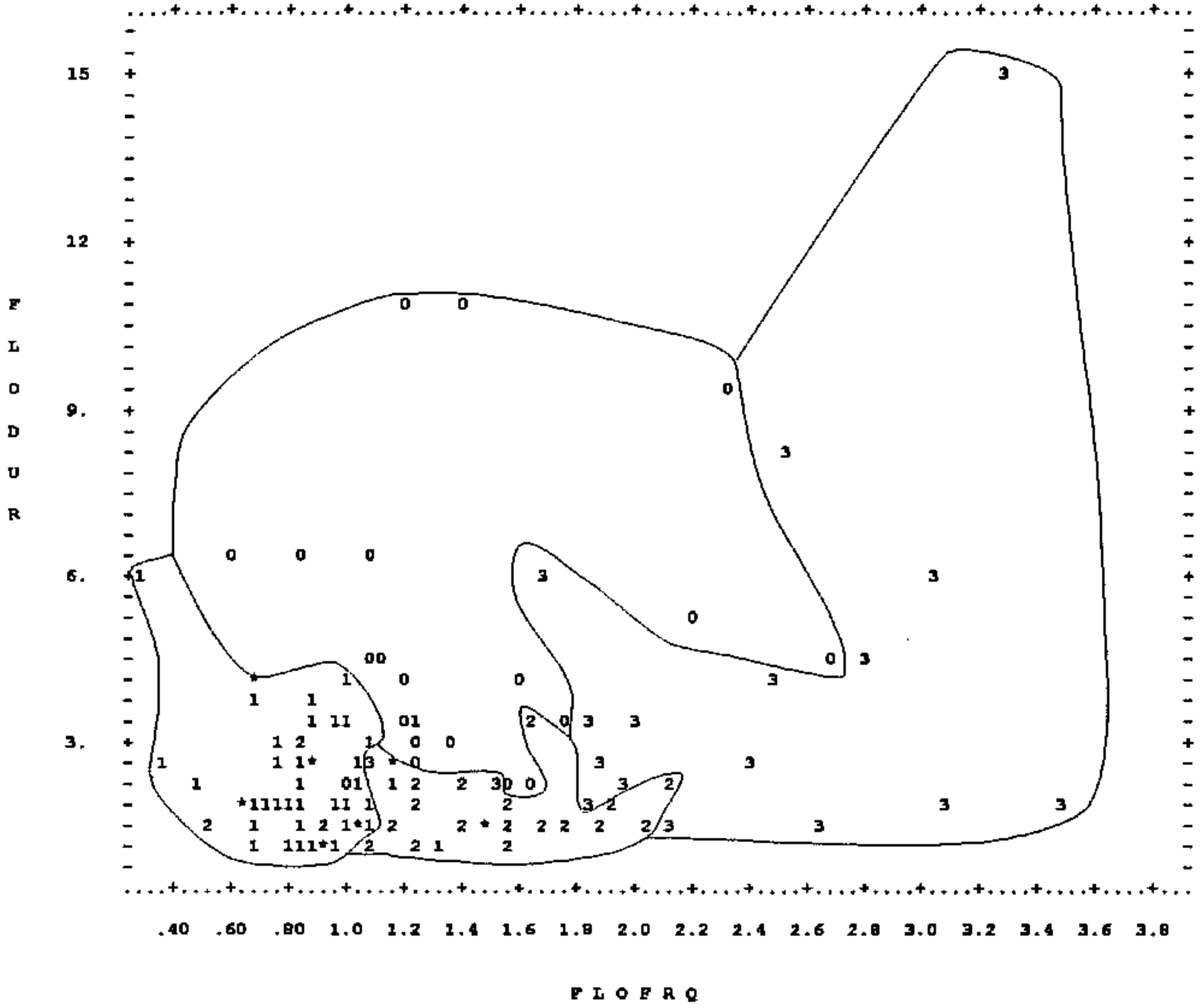


Figure 11.27 METHOD TWO: Plot of FLODUR (flood duration in days) versus FLOFRQ (flood frequency per year) for the stations in the perennial groups. The numbers indicate the groups demarcated using all eight variables as described in the text, with their approximate boundaries indicated by the envelopes. The asterices indicate coincidences of stations from different groups

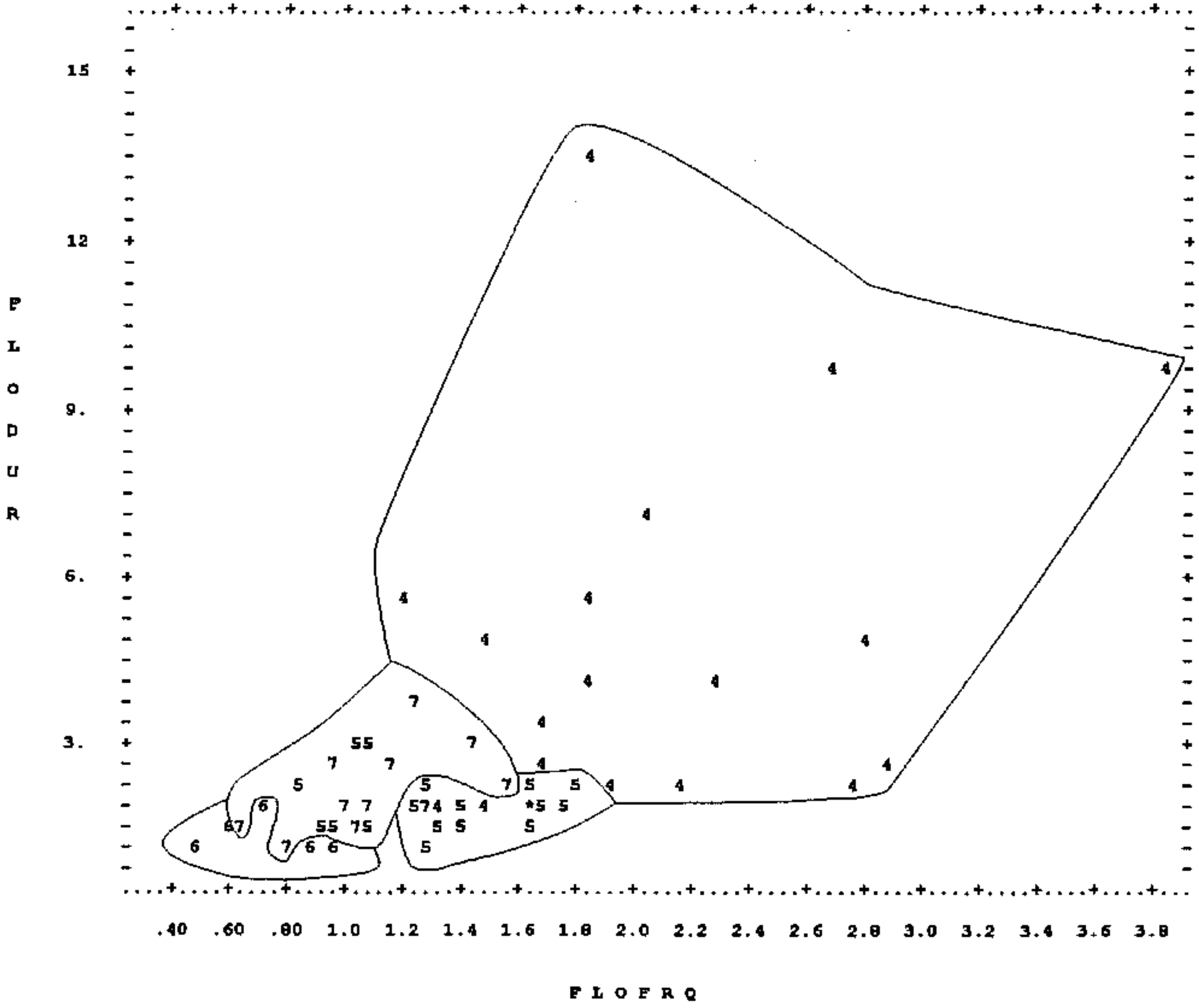


Figure 11.28 METHOD TWO: Plot of FLODUR (flood duration in days) versus FLOFRQ (flood frequency per year) for the stations in the quasi-perennial-seasonal groups. The numbers indicate the groups demarcated using all eight variables as described in the text, with their approximate boundaries indicated by the envelopes. The asterices indicate coincidences of stations from different groups

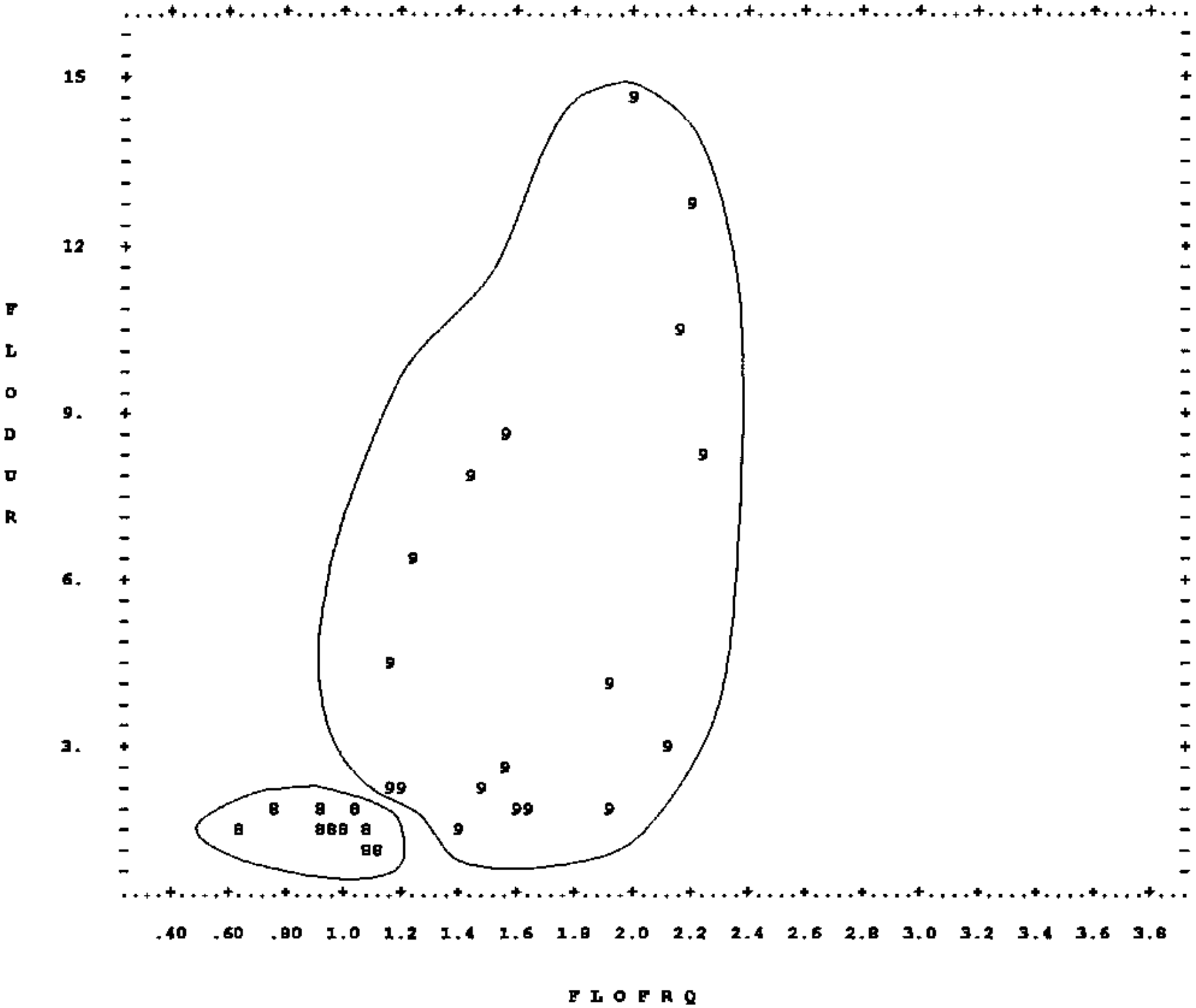


Figure 11.29 METHOD TWO: Plot of FLODUR (flood duration in days) versus FLOFRQ (flood frequency per year) for the stations in the extreme-seasonal groups. The numbers indicate the groups demarcated using all eight variables as described in the text, with their approximate boundaries indicated by the envelopes

based on the positions of the stations on the plot of Axis 3 versus Axis 4 (Figure 11.20, 11.22 or 11.24). It might have been better to have formed the groups using only the Axis 1 versus Axis 2 biplot for each supergroup and then using the Axis 3 versus Axis 4 biplots in this way to split groups where appropriate.

It must be asked whether the separation into groups by this technique is very sensitive to changes in the variables used. Some preliminary experiments were done using different combinations of the same eight variables and using untransformed variables. While around eight to ten groups would always have been formed, the groups would have differed considerably from those formed above. The decision to attempt to equalise the influence of the various variables, by transforming those whose distributions were far from normal, probably had a major impact on the final groups.

The covariance biplot technique, being of an exploratory nature, did not offer guidance on how many groups to form and did not attempt to prove any differences between groups to be statistically significant. The number of groups formed depended mostly on the researcher's intuition! Due to the nature of the data, the values for the variables for each station probably depend heavily on the choice of years of the record which were used. If the stations were to be divided into too many groups, these groups would certainly not be stable when a different choice of years was made. The robustness of the groups formed could be assessed by separating the usable record for each station into two halves and performing the covariance biplot analysis separately on the data for each half. In each analysis the stations on the Axis 1 versus Axis 2 biplots could be plotted for each supergroup using the group numbers allocated in the original analysis based on the full record. The robustness of the grouping could then be assessed visually.

A two-stage classification process could also be tried. First the stations could be separated into perennial, quasi-perennial-seasonal, seasonal and extreme-seasonal supergroups using the distribution of yearly number of zero days for each station and definitions of perennial, quasi-perennial-seasonal, seasonal and extreme-seasonal flow expressed in terms of the percentage of years of record which have less or more than various numbers of days of zero flow. Then each of the three supergroups would be analysed separately using the covariance biplot technique on the seven variables left after excluding ZERODAY. It is possible that different variables would dominate the subdivision of the different supergroups into groups.

Many of the distributions involved in this work are probably highly skewed. The distributions of the duration of floods, of the yearly values of the number of days of zero flow and of the number of floods in a year should be examined for each of a sample of stations. Should many prove to be highly skewed then variables FLODUR, ZERODAY and FLOFRQ should be redefined using medians rather than means and the grouping process repeated. The definition of flood could also be changed (Section 11.7.2). Despite the equal weighting of all the variables, FLODUR and FLOFRQ turned out to be critical variables in separating groups within each supergroup. Changing the definition of these two variables might have a major effect on the groups formed using this technique.

11.6.3 CONCLUSIONS

The exploratory nature of the method facilitated understanding of the data. The flexibility inherent in the approach used allowed the researcher to make choices based on his judgement.

Due to the exploratory nature of the method and the fact that groups are not formed on the basis of fixed algorithms, the results are subjective. Another researcher could make different choices and arrive at considerably different results.

The fact that no attempt is made to prove that there are statistically significant differences between the groups demarcated should not be seen as a disadvantage. For any of the variables, the range of values within a group may be quite broad and overlap the ranges of values of the variable for other groups, but this should not be seen as a problem either. It is the separation between groups when all the variables are considered simultaneously that is important. The way the method allowed this separation to be seen on two-dimensional plots was found to be extremely helpful.

Overall the results were promising and suggest that it may be worthwhile to use the method in similar situations.

11.7 PROBLEMS WITH DATA AND VARIABLES

11.7.1 SEASONAL FLOW PATTERNS

For the analyses of seasonal flow patterns as little as five years of data were used compared to other regionalisation studies which had minimum numbers of years ranging from five to 17 (Haines *et al.* 1988; Hughes 1987; Jowett & Duncan 1990; Poff & Ward 1989). Haines *et al.* (1988), in their global classification of rivers using monthly percentages of annual flow, used a minimum of eight years of data. It had been thought that even in a five year record, the same monthly *proportions* of flow would be reasonably well reflected in all years, dry or wet. However, in later work on the Lephalala River (Transvaal), it was noted that flow during dry years was almost completely muted, so that monthly proportions of flow were very different to those in wet years (DWAF 1992b). If this should be true for other rivers, those with short records covering a large proportion of dry years may be inappropriately grouped. The problem could be solved by analysing the seasonal patterns of flow using only data from years identified as being "wet" and "normal", if such records were available.

In addition to this another possible bias was introduced in the derivation of the monthly percentages of annual flow. All the years of data for a particular month were added together and divided by the total flow, and thus all years were not equally weighted. Equal weight can be given to each year by obtaining the twelve monthly percentages of annual flow for *each* of the usable years in the record and then taking the mean percentage for each month over all the years.

Group 4 of Method One contains only four stations, each of which has only five or six years of record. The stations occur in an area where aseasonal large floods occur approximately every five years (K. Rowntree, Rhodes University, pers. comm.). Such a flood pattern may unduly affect the average monthly flow pattern of the group. For these reasons, it is not certain whether or not Group 4 of Method One represents a true seasonal group or whether the stations are aberrant outliers.

11.7.2 FLOW CHARACTERISTICS

In the initial data transformation to natural logarithms, years with missing data were removed. Thus, not all years were necessarily contiguous. This could create a problem in relation to FLOINT, the interval between floods, as the years on either or one side of a missing section may have been more dry or wet than normal, giving a misleading value for that particular interval between floods. However, this would be unlikely to occur frequently, or to always influence the interval by only shortening or lengthening it. As the median interval between floods was used rather than the mean, any bias in this regard was reduced. However, it is felt that the variable FLOINT should not be used in its present form, as it combines intra- and inter-annual intervals between floods (Poff & Ward 1989). A useful indicator of the 'flashiness' of a river would be the mean or median intra-annual interval between floods.

Flows of a two-year return period can be approximated by the mean of the annual maximum flows for normally distributed maxima (see Section 11.3.2), and this was used to define the flood threshold level for each river. Poff & Ward (1989) referred to a more accurate method, where the annual maxima were plotted on probability paper and the 50% exceedance probability determined from this. Both that study and this used the mean annual maximum as a substitute. The results from plotting the 50% exceedance probability and the values obtained from the mean annual maxima were compared for a few stations. This indicated that the mean annual maxima were a reasonable substitute, but any in-depth study of return periods would obviously require a more accurate measure for defining floods.

The method used to define the flood threshold is important as it is used to derive all the variables describing floods. For example, a few very dry years in the period of record will negatively bias the mean, which will lead to overestimation of the flood frequency. The high number of events counted as floods as a result of the definition used here should not be seen as a problem. A higher skew, producing a higher 'flood frequency' is, in itself, a characteristic of the river and the groups formed reflect this characteristic. A possible improvement would be to use the median rather than the mean of the annual maxima. Both Hughes (1987) and Jowett & Duncan (1990) use specific mean annual discharge, together with other variables, in their attempts to regionalise Tasmanian and New Zealand rivers respectively. This is an index of catchment flood response and may be useful in future analyses of South African rivers. Clarity is needed as to what flood definition would be most useful and a separate analysis of flood patterns in an ecological context could perhaps be undertaken.

The skewness of the distribution of the annual maxima could be further exacerbated by weirs that are overtopped in floods. The peak magnitude of large floods may be unrecorded, or recorded at the maximum level of the weir, thus causing underestimation of maximum flows, and increasing the tendency towards a negative skewing of the data. The extent to which overtopping occurs is not known, but could have a profound effect on the variables derived from the estimated flood threshold level. In addition, flow gauges frequently record zero flow where very low flows occur, influencing ZERODAY.

Similarly, other variables had skewed distributions, and improved values may be obtained for ZERODAY, FLODUR, FLOFRQ, and FLOINT by using medians rather than means.

Through some experimentation in both methods it was found that the flow-type groups formed were sensitive to the subset of variables chosen and the transformations made to them, and that although the number of groups formed would not have differed greatly from that obtained here the composition and character of the groups could change substantially.

11.8 COMPARISON OF THE TWO METHODS

Direct comparison of the groups of gauging stations formed using the two methods of cluster and discriminant analysis (Method One) and correspondence analysis-covariance biplots (Method Two) is difficult, due to the different aims of the two methods. The aim of Method One was to group and characterise rivers using variables and techniques applied elsewhere, while the aim of Method Two was to form geographical boundaries. Method Two used techniques not used before, which allowed boundaries to be formed by the decisions of the researcher rather than by the software programs used.

Method One produced results that are reproducible, while Method Two required interpretation and subjective decisions at many stages (Section 11.6.2.2 and 11.6.2.3), and so its results could differ from researcher to researcher. However, once the groups formed by Method Two have been externally validated, they might be more directly useful to other studies than those formed by Method One. This is because Method Two defined seven geographical regions from the seasonal analysis as opposed to the three broad regions produced by Method One. Also, in the analysis of flow types, Method Two produced distinct supergroups, based on perenniality of flow, within which further divisions were created, while the groups formed by Method One were not exclusive with regards to degree of perenniality.

11.8.1 SEASONAL FLOW PATTERNS

Each of the methods produced seven groups with different seasonal flow patterns, and these are somewhat comparable (Table 11.9). Both Methods identified the western Cape winter peak flow group and the aseasonal/early spring group as occurring within fairly distinct geographical regions, and both indicated that there was a mosaic of summer rainfall regimes with no clear geographic boundaries. Method Two, because of its iterative approach, then created regions within this summer-rainfall area, which were based on subcatchment boundaries and somewhat similar flow patterns.

Thus, stations within the summer-rainfall area were split into different groups by the two Methods. Method Two split them into geographical groups, thereby losing some definition on the timing of peak flows, while Method One split them into groups with differently-timed peak flows, which had no clear regional definition.

Method Two highlighted a region (Region 3) in the eastern Cape (Figure 11.7) which appeared to be different to any group revealed by Method One. Region 3 contained all the summer-rainfall groups identified by Method One, but mainly the moderate late summer group (Group 7). The four stations of Group 4 (Method One), characterised by extreme November peaks, were all included in Region 3 and may be the reason for the elevated mean November monthly flow of this region (Figures 11.2 and 11.10). Some support for the formation of a separate region in the eastern Cape was given by the fact that when more than 10 groups were formed by Method One, a separate group appeared approximately in this area.

Table 11.9 The separation of seasonal groups formed by cluster and discriminant analysis (Method One) into those formed by correspondence analysis (Method Two)

Cluster analysis groups:	1	2	3	4	5	6	7	
Correspondence analysis groups:								Total n:
1	0	**44**	**3**	0	0	0	0	47
2	0	**3**	**36**	0	0	0	**1**	40
3	0	0	**4**	**4**	**3**	**5**	**15**	31
4	**1**	0	0	0	**4**	**33**	**14**	52
5	**4**	0	**1**	0	**11**	**18**	**30**	64
6	**2**	0	0	0	0	**8**	**7**	17
7	**4**	0	0	0	**7**	**5**	**11**	27
Total n:	11	47	44	4	25	69	78	278

The two sets of results complement each other. Where regional boundaries are required, Method Two will prove useful, while the distinct groups revealed in Method One provide information on timing and magnitude of flows which is lost in Method Two where the summer peak flow regions (Regions 4,5,6,7) may be regarded as having similar flow patterns (Figures 11.2. and 11.10). It must be noted that, in order to maximise the number of stations and the number of years of record available for analysis, all available years were used and do not necessarily coincide. It may be that, because of this and the method of deriving the monthly percentages, stations lying fairly close together geographically appear to have peak flows in different months, whereas if the same years were used and a different method used to derive the monthly percentages of flow, these differences may lessen or disappear (see Section 11.7.1).

It is felt that a reworking of the same database for the analysis of seasonal flow patterns, using the same basic techniques or other methods is unlikely to yield significant changes, but that changes could be made to the way the database and variables are constructed (Section 11.7.1).

11.8.2 FLOW TYPES

The analysis of flow types using both methods produced results which were less obviously useful than those from the seasonal analyses. The groups resulting from the two methods are very different (Table 11.10) and are not easily comparable because of the different methods used. There are at least three probable reasons for this:

- The BMDP-KM algorithm (Method One) creates groups by splitting based on the (single) variable with the most variance at each split whereas the covariance biplot method uses all the variables simultaneously.
- In Method Two, subjective decisions were made on the boundaries between groups.
- Six of the variables were transformed in Method Two to make their distributions more closely normal while no transformations were made for Method One.

Method One produced eight groups, with different combinations of variables dominating the formation of each group. The groups were homogeneous with respect to the more dominant variables for each group (Section 11.5.2.2) and thus each group could be described in terms of a subset of variables. Method Two created three supergroups, within which a total of ten subgroups were formed, by associating stations grouped naturally on the first four axes of the covariance biplots. The supergroups classified the station's flow as perennial, quasi-perennial-seasonal or extreme-seasonal. Within each supergroup, the subgroups could be uniquely described in terms of FLODUR and FLOFRQ (Table 11.8). The success, in Method Two, of the plots of FLOFRQ and FLODUR (Figures 11.27, -11.28 and 11.29) in illustrating the groups, suggests that groups could be formed using only these two variables within the three supergroups. However other characteristics would be lost. Although FLODUR was of the more important variables in Method One, both PROP and PRED were more influential than FLOFRQ. Similarly, different classifications using different combinations of the variables derived, fewer variables or other variables are possible, but attempting these should depend on perceived user needs (Section 11.9).

Table 11.10 The separation of flow-type groups formed by cluster and discriminant analysis (Method One) into those formed by covariance biplots (Method Two)

Cluster analysis groups:	A	B	C	D	E	F	G	H	
Covariance biplot groups:									Total n:
0	0	3	12	0	7	0	0	0	22
1	0	0	35	3	1	2	0	12	53
2	0	0	2	4	10	0	2	8	26
3	0	2	0	0	11	0	4	1	18
4	0	3	0	0	0	0	16	0	19
5	0	0	0	3	0	0	9	6	18
6	0	0	0	7	0	0	0	1	8
7	0	0	1	1	1	1	3	5	12
8	9	0	1	0	0	0	0	0	10
9	9	5	0	0	0	0	4	0	18
Total n:	18	13	51	18	30	3	38	33	204

A visual comparison of the means and standard deviations for the groups formed by Method Two (Table 11.8) and of the histograms of each variable by group (for example Figure 11.26), revealed that there was wide variation within groups on almost all variables except ZERODAY. There was thus, in general, less homogeneity of each variable within the groups of Method Two than for those of Method One but there were some outliers in the groups formed by Method One.

Irrespective of the method used, the variables derived and the groups formed provide a comprehensive characterisation of the flow at the stations, that could be useful for a variety of other purposes.

11.9 SUMMARY AND RECOMMENDATIONS

Research was carried out to investigate whether the daily flow data held by DWAF could be used to group the rivers of South Africa, either into geographic regions or into non-contiguous groups. Using daily flow data, two fundamentally different methods were used to group gauging stations. Each method was used to group stations with similar distribution of flow over the months of the water year (hereafter referred to as seasonal flow patterns) and, separately, to group stations with similar flow characteristics excluding the seasonal patterns.

Method One used cluster analysis and discriminant analysis to determine the groups, whereas Method Two used correspondence analysis and covariance biplots. In Method One the researcher had little flexibility and the results are therefore objective and repeatable. Computer programs used fixed algorithms to form the groups although the researcher had to decide on the number of groups. Method Two is an exploratory technique and the researcher had much more flexibility. The researcher divided the stations into regions and supergroups when the data suggested this even when the divisions were not sufficiently clear-cut to be found by any algorithm. The researcher was able to be guided by other considerations including aspects of the data - such as latitude, longitude and perenniality - not specifically included as variables in the data set being analysed at the time. Thus the results of Method Two are subjective and not necessarily repeatable by another researcher. The groupings of the stations produced by the two methods differed considerably, particularly in the case of the grouping by (non-seasonal) flow characteristics. Probable reasons for this are given in Section 11.8.

During the course of the research it became apparent that some aspects of the work could be done differently in any future such exercise. These include:

- calculating the monthly percentage of annual flow for the stations so as to weight each year equally (Section 11.7.1)
- paying more attention to the effects on the groupings, both by seasonal flow patterns and by flow type, of the inclusion of different years and, particularly, different proportions of wet and dry years in the data used for the various stations (Section 11.7.1)
- defining floods differently (Section 11.7.2)

- using medians rather than means to define some of the variables describing flow characteristics (Section 11.7.2)
- forming the groups by a two-stage process in which the stations are first split into a small number of regions (for example winter peak flow, spring/aseasonal peak flow, summer peak flow) or flow types (for example perennial, quasi-perennial seasonal, true seasonal, extreme seasonal, non-seasonal episodic) and then further split, if justified, into sub-regions or sub-groups by analysing each region or group separately.

It is felt that the work reported here was worthwhile both in that it produced groupings that should be useful to the research community and in that the present researchers gained useful experience of grouping techniques.

It is not clear whether further research in this area is justified at present. Possibly, it would be best to wait for a few years before assessing the usefulness of the groupings to other researchers. By that time shortcomings in the present groupings might be apparent and it might be obvious on which aspects selected from those listed above, or others, further research effort should be concentrated.

12. THE BUILDING BLOCK METHODOLOGY

12.1 INTRODUCTION

When the need to undertake instream flow assessments (IFAs) in South Africa was first identified in the late 1980s, the communication gap between, on the one hand, the water managers and engineers working on the water-resource developments and, on the other hand, the river scientists who had to determine suitable modified flow regimes, was enormous. The two sets of disciplines had rarely worked together, had little understanding of each others' work, and had no common language. Most of the scientists had not studied river flow *per se*, and could not relate their knowledge to the new kinds of questions being asked by the managers. Many of the managers and engineers had a poor understanding of ecological concepts and the fact that there was no one amount of water that was the "right" flow for a regulated river.

The managers and engineers needed an approach to IFAs that was not based directly on species-based concepts, for these will remain obscure to most of them for many years (A. Görgens, Ninham Shand (Cape Town), pers. comm.). On the other hand, the ecologists required hydrological and hydraulic data that related to conditions actually experienced by the riverine biota; such data were likely to be at a different level of resolution than those usually used by hydrologists. During the early years of liaison between such widely different disciplines many lessons were learnt in workshop sessions and discussion groups, and a new untested methodology - the Building Block Methodology - was first applied in 1992 and has since been developed further. In this Chapter, the origins of the Building Block Methodology are explained, and its essential details and some lessons learnt from applying it are described. References to other local approaches to instream flow assessments are given in Chapter Two.

12.2 LIMITATIONS ON INSTREAM FLOW ASSESSMENTS IN SOUTH AFRICA

At an early stage it was apparent that established, complex methodologies for IFAs, such as the Instream Flow Incremental Methodology, would be inappropriate for large-scale use in South Africa because they are based on the availability of generous amounts of time, expertise, finances and biological data. All of these criteria are likely to be limiting in South Africa, and it was clear that local methodologies for IFAs needed to be developed. These needed to combine aspects of established international approaches with local expertise and ideas that reflected the limitations and requirements apparent here.

The multidisciplinary approach to IFAs being developed within the Kruger National Park (KNP) Rivers Research Programme is designed to eventually provide guidelines and methodologies that can be used countrywide; however, no such aid is presently available. Meanwhile, plans for water-resource developments are proceeding for several rivers in other parts of the country, and determinations of their instream flow requirements (IFRs) are needed as a matter of urgency. In response to this situation, new local methodologies are being developed that provide at least a first estimate of the flow needs of the rivers of concern, for use in project planning. One such methodology, called the "Building Block Methodology", has developed from the earlier "Cape Town" and "Skukuza" approaches (King & O'Keeffe 1989; Bruwer 1991), and it is hoped that with refinement it can be used to provide IFAs at a number of levels of resolution, depending on time, data and finances. Use of the prototype during 1992/3 (Section 12.3) highlighted the requirement for new kinds of hydrological information as well as critical gaps in scientific knowledge, and allowed further development of the methodology. Although it is by no means the only possible route to follow in an IFA, the hydrological data that it requires are probably much the same as are needed for other approaches. Both the methodology and the new kinds of information it requires are explained below.

12.3 THE CONCEPTUAL BASIS OF THE BUILDING BLOCK METHODOLOGY

The conceptual basis of the methodology was initiated before and during meetings with Australian colleagues (King *et al.* 1991; Arthington *et al.* 1992; King *et al.* in press), and further developed during practical applications in IFA workshops convened by the Environment Studies sub-directorate of DWAF (Lephalala River, DWAF 1992b; Berg River, DWAF 1993a, 1993b).

In the methodology it is assumed that the species associated with a river can cope with baseflow conditions that naturally occur in it often, and may be reliant on higher flow conditions that occur in it at certain times (e.g. specific floods). It is further assumed, though largely untested as yet by scientific studies, that identifying such flow conditions and ensuring that they are incorporated as part of a modified flow regime will allow some semblance of the natural biota to be maintained. Finally, it is also assumed that certain kinds of flow influence channel geomorphology more than others, and that incorporating such flows into the modified flow regime will aid maintenance of the natural channel structure. Thus, the final modified flow regime is envisaged as encompassing a skeleton framework of commonly-occurring low flows, interspersed with selected higher flows each of which adheres to natural limits of magnitude, duration and timing and performs certain functions.

The methodology, then, is a combined hydrological, ecological and geomorphological approach which uses those features of a river's natural flow regime that are perceived to be ecologically or geomorphologically important, to create a modified flow regime designed to maintain the river at some pre-determined status. Pre-determination of the future required status of the river is discussed in Section 12.5.

The methodology does not take into account the water requirements of any other users, but simply states the case for the river; negotiations with other user-groups form a later phase of the whole decision-making process.

It is stressed that because the methodology recognises and caters for the urgency with which IFRs are required by water managers, it relies almost entirely on present, usually inadequate, scientific knowledge. It is therefore a prerequisite of the use of the methodology that allowance be made within the water-resource project budget for either pre-development research, so that the accuracy of the IFR can be refined, and/or post-development monitoring of the river, so that the success of the IFA can be assessed.

12.4 THE PRACTICAL BASIS OF THE BUILDING BLOCK METHODOLOGY

Accepting that some of the river's flow will be taken for offstream use, the methodology focuses thought on which parts of the flow regime are most important for the riverine ecosystem and thus should **not** be taken for offstream use. To do this, the natural flow regime is first dissected into its fundamental flow components: at this stage, these components are seen as the seasonal base- or low flows, the intra-wet season small increases in flow, or freshes, and the small and medium floods. It is felt that large floods cannot be stopped by most dams and hence cannot be managed, and so can be ignored. The flood terms "small", "medium" and "large" will have different magnitudes in different rivers; however, similarly named floods would be expected to perform similar functions in different sized rivers.

Using the hydrological record, each flow component is assessed by river scientists, to determine how much of the flow it represents can be removed for offstream users without threatening the required future status of the river ecosystem. The essential part of the component remains, as a building block that will be incorporated into the modified flow regime. The blocks of flow are added one by one to a blank graph of discharge (Y-axis) versus calendar months (X-axis), with each addition being described in terms of four criteria: magnitude, timing, duration and frequency (Figure 12.1).

It is known to some extent that each block of flow performs an identifiable function(s) in rivers (see references in King *et al.* in press), and is important for a different reason. For instance, the low flows maintain the basic ephemeral or perennial nature of the river and, through their different magnitudes in the dry and wet seasons, create fundamentally different seasonal conditions. Intra-wet season freshes, *inter alia*, stimulate spawning in serial-spawning fish species, flush out poor quality water and mobilise sandy sediments, creating the flow variability that seems to be such an important feature of rivers in arid areas. Floods re-set a wide spectrum of conditions in the river, synchronising activities as varied as upstream migration of fish and germination of riparian seedlings, as well as maintaining the basic channel form. As specific motivation must be provided regarding the importance and function of each block of flow added, they must be selected by a multidisciplinary team consisting of those with specialist knowledge of the river or of some aspect of the functioning of rivers.

In combination, the chosen blocks of flow represent a modified annual flow regime that incorporates the flow features considered most important for maintaining the river system at the pre-determined status. The volume of water encompassed within this modified regime is used to "block book" water for the river in the project planning phase of the development, on the understanding that some re-allocation of water within the flow blocks may become necessary as knowledge increases. As the percentage of mean annual runoff (MAR) represented by each block of flow can be calculated, scenarios can be created linking more or less MAR (through the addition, removal, expansion or contraction of flow blocks) with the likely consequences for the river. Similar scenarios can be created where the MAR is not altered, but flow is shifted around between seasons.

12.5 THE TRIPLE CHALLENGE IDENTIFIED BY THE BUILDING BLOCK METHODOLOGY

Three main problems became apparent at an early stage of those DWAF workshops on IFAs where the Building Block Methodology was used. The first of these centred on the fact that the amount of flow required for maintenance of a river depends on the long-term management objective for that river: more flow will be required to maintain a river in a pristine condition than in an "acceptable" condition, and this in turn will be more than is required for merely producing irrigation flows or carrying away waste waters. The first challenge, then, is for policy makers, water managers and river scientists to formulate procedures that will allow both those involved in IFA workshops, and those making the final decisions on water allocations after the workshops, to determine the required future status of any particular river. As an interim measure, the specialists involved in a recent workshop identified what they considered to be a **realistic** future status for the river under consideration, determined the IFR to maintain the river at that status, and then identified the alternative flow patterns that could occur once potential or actual offstream users are also catered for. These alternative flow patterns were linked with the likely consequences for the river, and can be presented along with the initially-identified recommended future flow pattern, to aid the decision-maker in assessing the merits of different scenarios. At this stage, there is no clarity on what should guide the decision maker in the final choice of scenario, but presumably this will be done through some kind of activity involving public participation or interested parties.

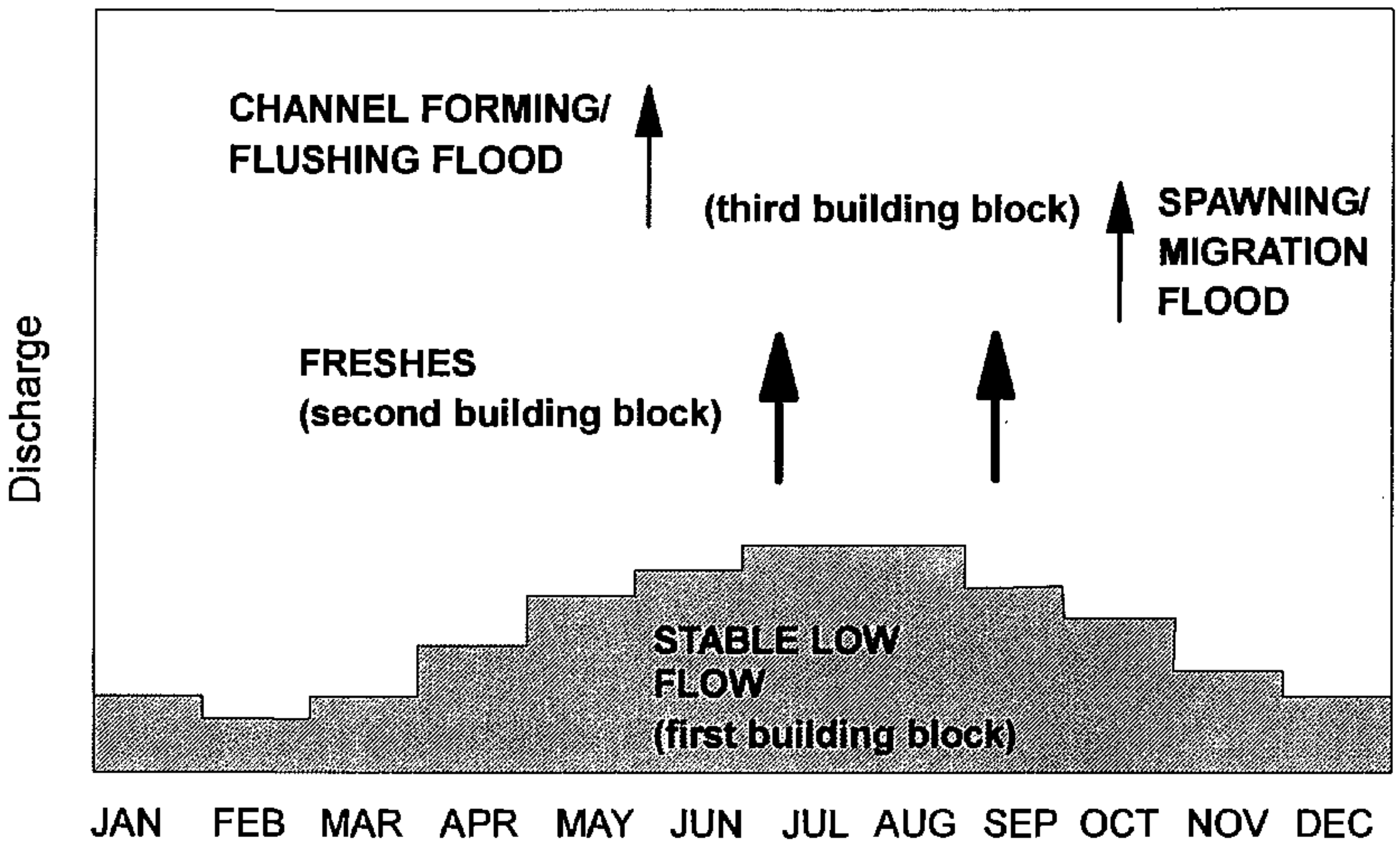


Figure 12.1 An hypothetical modified flow regime created using the Building Block Methodology

The second challenge is for river scientists to identify the characteristics of the blocks of flow to be included in a modified flow regime for any one river. With relatively little flow-related research occurring in the country until very recently, much reliance has had to be placed on the general knowledge of such scientists. Workshops and research projects presently being funded by, among others, the Water Research Commission (WRC) are designed to develop this information base and identify the most urgent research needs, while the KNP Rivers Research Programme should ultimately produce more in-depth answers and guidance.

The third challenge is for hydrologists to produce the kind of hydrological data that river scientists need for IFAs. In the early days of liaison between the two sets of disciplines, hydrologists produced the standard hydrological analyses used in water-resource developments, namely, flow sequences of total monthly runoff for past, present and future conditions, with and without the proposed development. The hydrologists often felt that the scientists did not seem to use this wealth of data, but the scientists were discovering that the data were not necessarily helpful. It became obvious that at least part of the problem was that much of the data was not being presented in a form that could be used by scientists in IFAs. Additionally, some of the provided data were not needed, while some required data were missing.

To address this problem, teams of engineers, hydrologists, water managers and river scientists began to determine the kinds and formats of hydrological data required as input to the methodology. This process is still in the developmental stage, and the types of data perceived as necessary may change, as may the procedure followed for using them. Nevertheless, development of the methodology is in itself an excellent way for different disciplines to learn a common language, and considerable progress in understanding has been made. In the following Section, details of the methodology, and the kinds of hydrological data presently seen as necessary for use in it, are given. It is assumed, for simplicity, that the proposed water-resource development is a dam, and that the methodology is being used to formulate operating rules for flow releases from the dam.

12.6 USE OF THE HYDROLOGICAL RECORD TO PROVIDE INFORMATION FOR THE BUILDING BLOCK METHODOLOGY

Ideally, long-term data on natural, daily flow should be available for the IFA. Long-term data are seen as necessary because they provide comprehensive information on the timing, magnitude, frequency and duration of flow conditions that occur **often** in the river - that is, conditions that the natural biota of the river is adapted to cope with.

Data on natural flow are considered necessary because the natural flow regime is one of the driving forces sculpturing both the river channel and the character of its biological communities. Maintaining something resembling the natural flow pattern in a regulated river reduces the likelihood of costly ecological repercussions. However, there may be cases where a modified flow regime has been established for so long that the river channel and biota have adjusted to some new status, and consideration of the natural flow regime may no longer be appropriate; for simplicity here, only the natural flow regime is considered.

Daily flow data are considered necessary because these come closest to describing the instantaneous flow that the riverine biota experiences and reacts to. To explain further, a figure for monthly average flow (the finest level of resolution in most hydrological analyses for water management purposes) could represent a similar flow each day of the month, or 29 days of dry river bed and a flood, or any variation in between. In terms of total yield these may produce the same amount of water, but they represent widely different conditions for riverine species; an understanding of these conditions is essential when undertaking an IFA.

In the following Sections, use of the long-term, natural, daily flow data to build a modified flow regime, and some suggestions of what to do when such data are unavailable, are addressed. The building blocks of flow, and the hydrological data required to describe them, were identified by several river scientists during a series of workshops dealing with actual water-resource developments needing preliminary answers on IFRs. The subsequent hydrological computations and summaries were produced by DWAF's consulting hydrologists. The procedures described below, and the specialist contributors involved, are detailed in DWAF (1992b, 1993a, 1993b).

12.6.1 THE FIRST BUILDING BLOCK - THE STABLE LOW FLOW

Month by month, and using as many years of data as possible, the lowest flow that occurs often (i.e. the stable low flow) is identified. The twelve monthly values so derived form the first building block that will contribute to the modified flow regime (Figure 12.1).

Several approaches have been used to derive each monthly value, including identifying some value related to the seven-day running mean (such as the average of the five lowest values), or a percentile (e.g., 75th or 80th) from the monthly flow duration curves. When daily flow data are not available it may be possible to use daily data from a nearby suitable gauge to convert simulated monthly values for the river of concern into approximate daily values. Alternatively, using several nearby gauges, monthly conversion factors may be derived that relate monthly average flows to stable low flows and these then used to determine stable low-flow values for each month for the river of concern from simulated data on monthly averages. WRC-funded research continues in order to increase understanding of the merits of each of these kinds of derived low-flow values.

12.6.2 THE SECOND BUILDING BLOCK - THE INTRA-WET SEASON FRESHES

Small short-lived increases in flow, or freshes, may occur throughout the year but are probably most abundant in the wet season; the absolute magnitude of these flows may be less important than their magnitude relative to the preceding low flow. Such freshes are tentatively identified as being two to five times the preceding stable low flow, but this is an area needing research. Freshes of this magnitude provide essential flow variability, initiate scouring and cleansing of the river bed (Biggs & Close 1989), dilute poor-quality waters and may trigger spawning in some fish species. Information on the occurrence, magnitude, duration, time to peak and recession time of these freshes, and particularly on the average daily flow at the peak, would enable river scientists to select those deemed most essential for inclusion in a modified flow regime. A summary of the average number, average peak size, and range of numbers and sizes, of such events per calendar month would be very useful for this purpose.

12.6.3 THE THIRD BUILDING BLOCK - THE FLOODS

Determining the requirement for floods has presented the most difficulty when rebuilding a modified flow regime, because almost no research on this topic has been done in South Africa, and the world literature is presently unassessed but appears to be sparse. Deliberations at the workshops produced the following tentative guidelines, which should be seen as a first attempt, and by no means a final statement, on how the flood requirement of a river could be determined or what it should be.

It was noted that substantial scouring of bed materials, and initiation of bed movement, may occur at flows as low as five times the preceding low flow (Biggs & Close 1989), while floods at specific times may trigger or synchronise a wide range of biological responses from the river ecosystem (King *et al.* in press). Any flows greater than those considered to be freshes may thus be selected by scientists for inclusion in the third building block. Several different floods, of specific timing and magnitude, may be included, each being considered important for a different ecological or geomorphological reason.

In the south-western Cape, for instance, several river ecologists have identified the need for flushing flows at the beginning of winter, to "re-set" the river to winter conditions; fish biologists have also identified a need for migratory or spawning floods for fish in spring. Additionally, fluvial geomorphologists have stated the need for substantial flows to maintain the fundamental shape of the channel; they recognise the one-in-one-year or one-in-two-year floods as probably important channel-forming floods (Figure 12.1). It is acknowledged that research aimed at refining understanding of the role of different types of floods is urgently needed.

At present, to aid the compilation of a modified flow regime containing such flood features, similar hydrological data to that for freshes are seen as necessary for all high-flow events. The information should include summary details of specific categories of flood, which will have to be identified by the river scientists, and should include the magnitude of the one-in-one-year and the one-in-two-year events.

12.6.4 GROUND TRUTHING

Up to this point in the methodology, the procedure is an office exercise, drawing on the analytical skills of hydrologists and the general (or relevant specific) knowledge of scientists. However, as each river has a different flow regime and channel shape, and may have special features to be protected, it is essential that some kinds of ground-truthing activities be incorporated into the IFA.

Such activities could take many forms, depending on the time and finances available and the importance of the river, and represent another topic badly in need of research. Clearly, however, there should be included some procedure for initially identifying key river reaches. An example of such a reach would be one where flow is most likely to cease first along an entire river, during extreme low flow conditions. For each of the key reaches, and at known flows, several determinations should then probably be made; variables to be measured could include the wetted perimeter, proportion of channel inundated, stage-discharge relationship, or similar information (see DWAF 1992b for a check list of procedures).

Because of the necessity for river-specific fine-tuning of the IFA, resource managers should **not** apply the pattern of flows determined for one river to another without input from local river scientists.

12.7 CONCLUSION

The Building Block Methodology is a quick approach to IFAs that relies on current knowledge and understanding of river ecosystem functioning. It can be used to provide a first estimate of the amount of water required as an IFR. As such, it can provide much needed early protection for a river, an aspect that may otherwise remain unconsidered in development plans. It should never be seen as the final answer to the IFR of a river unless supported by further research and/or monitoring, which should preferably be provided for within the budget of the water-resource development.

It will possibly be less satisfactory in providing for ecological components reacting to groundwater regimes, such as the riparian vegetation, than for those reacting to surface flow. Additionally, it does not address the issue of changes in the flow of sediments in dammed rivers, though this is clearly of major concern (Dr R.T. Milhous pers. comm.; W. Ellery, Geology Department, University of the Witwatersrand, pers. comm.).

As the methodology is still in the developmental stage, it is not yet clear if the flow components and required hydrological data that have been identified as important so far, are the only ones needed, or even the right ones. The importance, function and definition of the different flow components need to be researched, data requirements are likely to need further refinement, and short-cuts or other procedures not yet apparent may need to be devised. Research and monitoring, budgetted for in to the project costs, would be an obvious way to ensure refinement of the methodology and gradual improvement in the quality of its output.

The Building Block Methodology has been offered to the community in a prototype condition (King & Tharme 1993) because water-resource managers are searching for some early guidance on the amount of water needed for maintaining river systems. Acknowledging that it is still in the developmental stage, it is hoped that the managers and scientists needing such a tool will be willing to test it, criticise it and, ultimately, help to improve it. Meanwhile, research on some of the topics mentioned above has commenced (1993 to 1995) in the WRC project "The effects of different magnitude flows on South African riverine systems".

13. PROJECT SUMMARY AND RECOMMENDATIONS FOR FUTURE WORK

The Instream Flow Incremental Methodology (IFIM) is difficult and time-consuming to learn because it incorporates concepts and skills from a wide range of disciplines. It is also difficult to apply because in places it is vague, non-pragmatic or still largely conceptual. Its most-used component, the model PHABSIM II, is complex and difficult to master. Finally, and probably most importantly IFIM, in its present state of development, does not allow compilation of a comprehensive modified flow regime for a regulated river in the way required by the South African Department of Water Affairs and Forestry (DWAF). For all of these reasons, it would be an unrealistic objective to attempt to train large numbers of South African river scientists in its use.

At the same time, it would be unwise to ignore the wealth of information contained in the IFIM manuals and related papers, and the years of experience available among the specialists who developed IFIM. This is especially so as the fledgling Kruger National Park Rivers Research Programme (KNPRRP) is now basically, although not by design, following something very similar to the IFIM approach. Many of South Africa's most experienced river scientists and water managers are joining forces to collaborate in this, the largest and most comprehensive research programme on river management ever undertaken in this country. Looking elsewhere, a few large river studies, similar to the KNPRRP, are also underway in the United States of America. One of these, at least, seems to be following the classic trend of producing abundant interesting and high-quality research, the results of which water managers either cannot or will not use. This is a situation that the KNPRRP participants will wish to avoid. There thus seems to be considerable scope for a networking exercise that is designed to share knowledge of the strengths and weaknesses of these various comprehensive endeavors that all have the overall objective of guiding sustainable development of a river's water resources.

As a result of limitations of time, finances and data, however, the fate of most South African rivers involved in water-resource developments presently rests with the ROIP-IFA process. ROIP is the Afrikaans acronym for Relevant Environmental Impact Prognosis, and IFA stands for Instream Flow Assessment. Both activities are carried out by the Environment Studies sub-directorate of DWAF, as parts of the in-house environmental impact assessment carried out on all the Department's proposed water-resource developments. ROIPs follow standard guidelines for Integrated Environmental Management, incorporating scoping and screening exercises of all potential impacts of proposed developments. As one of the most detrimental effects of a development such as a dam is likely to be flow changes in the downstream river, an IFA workshop, to determine an ecologically acceptable modified flow regime for the dammed river, has become a routine sequence to a ROIP for such proposed developments.

In an IFA workshop, DWAF brings together consulting hydrologists and teams of river scientists who have either specialist knowledge of the river of concern, or of some aspect of river functioning, to produce a first estimate of the required modified flow regime for the river.

This estimate is presently being determined using the Building Block Methodology (see Chapter Twelve), and is based on the best available knowledge. It is more than likely that this best available knowledge will consist of general information on the catchment, simulated hydrological data at the level of resolution of monthly average flows, an assessment of the conservation status of the stretch of river of concern based on a recent helicopter survey, perhaps some information on channel morphology, and a generalised feeling among the scientists who know the river of what parts of its flow-regime are most important and should be the priorities for retention. There might be some knowledge of the composition and distribution of the riverine biota, but usually there will be nothing specific known of the life-cycle or flow-related requirements of any of the species, nor will there be the time or finances to collect such data. These are the common realities of making recommendations regarding modified flow regimes in South Africa at present.

The IFIM/KNPRRP and ROIP-IFA activities are at opposite ends of the spectrum of instream-flow related work in this country. ROIP-IFAs rely on present knowledge and understanding, and any related research will be short-term and limited to that needed to provide specific information for the workshop. Yet these activities are completely relevant to the KNPRRP, because they can provide detailed information on research topics that urgently need addressing. The KNPRRP, on the other hand, should produce the kinds of in-depth understanding of riverine functioning that the ROIP-IFA process is not designed to produce and, in doing so, provide a vital source of knowledge and data that can be used to improve the IFA results. The ultimate objective for all involved in, or wishing to collaborate with, the KNPRRP and the ROIP-IFA activities should be to use these twin strengths to produce methodologies for sustainable management of South African rivers that are both based on good science and entirely relevant to managing water resources in a developing and dry country. The following recommendations for future work are designed to further this objective.

- Strengthen the links between South Africa and those developing IFIM. Forge new links with those running the large river-study programmes in the United States of America. Encourage networking, to facilitate the exchange of information on the successes and weaknesses of the various methodologies and programmes. In particular, search for tested and satisfactory simulation models working at fine resolutions, for such aspects as sediment transport, hydrology, temperature and water quality. In this regard, further investigations of the use of PHABSIM II, including house-keeping of the model to make it more user-friendly, would be very useful.

- Broaden and strengthen the links with Australian river scientists. Since the visit of twelve South African water specialists to Australia in 1991, there has been a growth in contact and in visitors in both directions. Water managers and river scientists in both countries recognise that the two countries have similar river systems and face similar management problems. Exchanges of knowledge and expertise are already taking place. A next logical step would be collaboration on joint research programmes, which would be designed to develop, test and execute methodologies aimed at aiding sustainable development of rivers in arid countries.

- Initiate links with relevant scientists in other southern African countries. It is vital that knowledge and expertise start to flow freely throughout the sub-continent.

- Assessment of the various methodologies for IFAs currently used or available in South Africa should be made by the national scientific community, and recommendations made regarding which should be used in any specific circumstance.

- Initiate research to investigate possible links between hydrological statistics commonly used and easily computed by hydrologists, and ecologically meaningful flows. Identify the different-magnitude flows that are ecologically meaningful and develop definitions for them. At the moment ecologists use hydrological definitions, such as baseflow, two-year return flow and so on, which may have no particular ecological significance.

- Initiate research on the impact on the riverine biota of abnormally low and abnormally high low-flows. Two present trends in South Africa are pertinent here: abstraction of river water to the point of changing perennial rivers to seasonal ones in the dry season, which results in abnormally low low-flows; and damming of flood waters for downstream release for irrigation purposes in the dry season, which can results in abnormally high low-flows and even the seasonal reversal of the natural flow regime.

- Initiate research on the requirements for floods in regulated rivers. At the moment, attempts are made in the IFA workshops to include these in the recommended modified flow regime, but there is little understanding of the functions of different-sized floods, and which might be most or least important.

- Initiate the gradual creation of a library of "habitat suitability curves". These curves describe the conditions that a riverine species most often occurs in, and which therefore are assumed to constitute its "most preferred habitat". At the Freshwater Research Unit at the University of Cape Town, data bases have been begun which detail, for either water-quality, or flow-related variables, or both, the conditions in which species were collected. It is now routine procedure within the Unit to collect all possible habitat-related data whenever biological collections are made, and thereby to continually refine the knowledge of the most preferred habitat of any species. It would be extremely useful if this could become practice in other centres of river research.

- Encourage development of extant hydrological models to produce simulated daily flow data. Continually assess during their development if the level of resolution of the daily flow data is acceptable for ecological purposes.

- Bearing in mind the South African reality of recommending modified flow regimes for rivers with limited biological data but large water-supply problems, a realistic interim management option might be to manage river flow at the biotope level (that is, the level of the riffle, pool and so on), on the assumption that if the biotope is in an acceptable condition the species will look after themselves. The biotope is also a good common meeting point for research from different disciplines. The hydraulics modeller and geomorphologist could study, and simulate conditions, down to the level of the biotope, with little need for biological data. On the other hand, the ecologist could undertake studies of biological responses up to the level of the biotope. These studies could be designed to answer questions raised by the predictions of the physical modellers, such as, what would be the consequences if the wetted area of all riffles is reduced by 50%, or their water depth by 90%. It is therefore recommended that the potential for inter-disciplinary work at the level of the biotope be explored.

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GLOSSARY

The following definitions of terms have been compiled from a combination of sources. Although the general definitions for several of these terms have been taken from Bovee (1982), frequent inconsistencies in the usage of terminology in IFIM have necessitated their modification or adaptation for the purposes of this report. In some instances, the misuse of terms, including incorrect synonymies, has resulted in the authors of this report redefining terms more explicitly for the purposes of clarity. Further discussion of some of these terms takes place in Chapter Three.

Biotope

An homogeneous environment which satisfies the habitat requirements of a biotic community. It thereby recognises the integration of those physical, chemical and biological features which define the habitats of the individual species within the community. In this study, only some of the physical aspects of biotopes (e.g., depth, substrate and velocity) have been addressed.

Catchment equilibrium

A situation where dynamic changes in catchment processes influencing hydrological, chemical, thermal and sedimentological yields to a river are about some longer-term steady state.

Critical reach

A critical reach is a section of river which contains a type of biotope (or microhabitat) that is essential for the completion of one or more life stages of the target species, but which is under-represented or absent in the representative reaches. See **representative reach**.

Habitat

An environment which integrates the physical, chemical and biological features required by a particular species. In IFIM, the term habitat is used more loosely to define any area of river channel which provides a suitable physical environment for the existence of a species and its various life stages, or assemblages or communities of species. For the purposes of IFIM, this physical habitat is divided into two broad categories, namely **macrohabitat** and **microhabitat**. In this report, these two terms have been used when referring specifically to IFIM, acknowledging that microhabitat can be viewed as similar to the physical aspects of a biotope. See **biotope**. When macrohabitat and microhabitat are combined in IFIM, the result is termed total habitat.

Hydraulic control

A physical feature of the river channel which causes a change in the stage-discharge relationship or in the slope of the water surface.

Macrohabitat

This is an IFIM term which represents sections of a river that are different in terms of habitat at a macro-scale and thus influence species distribution ranges. Zones of macrohabitat are defined by marked longitudinal changes in water quality, temperature and channel geomorphology, which altogether are called macrohabitat variables. The species is also responding to habitat at the micro-scale, but macrohabitat delimits the length of river that is potentially habitable for it, if microhabitat is available. In other words, macrohabitat is defined by variables that change upstream and downstream, while **microhabitat** refers to those physical variables that change across a channel cross-section.

Microhabitat

This is an IFIM term, which is more correctly called physical microhabitat, but has often been abbreviated to microhabitat in this report. It comprises two basic components in IFIM, namely relatively rigid structural physical characteristics of the channel and variable hydraulic conditions. The physical structure of the channel is described by variables such as channel geometry, overhead or instream cover and bed particle size. The hydraulic conditions include water depth and velocity, which change as a function of discharge. Physical microhabitat is therefore defined as a complex array of combinations of depths, velocities and structural characteristics which change with discharge. Both sets of variables are measured at a number of point locations in the river, each of which reflects the habitat of an individual of a species or the biotope of an entire community.

Normalisation

A procedure employed in the construction of microhabitat suitability index curves, whereby calculated values of relative suitability of a microhabitat variable are converted to values between zero (zero suitability) and one (maximum suitability).

Preference

A suitability index curve for a particular species and microhabitat variable can be used to represent the conditions that are "most preferred" by the species, on the basis of comparing what microhabitat is utilised by the species with what is actually available to it in the river. In some texts, preference is used synonymously with **suitability**.

Representative reach

Within a **river zone**, there are a number of representative reaches which are similar to one another in having the full range of biotopes (habitats) such as riffles, runs and other geomorphological features. According to the the cyclical repetition of channel features along a river, each representative reach should be about as long as 10 to 14 times the average channel width. From these reaches only one need be selected within each zone, because they are theoretically similar, to be the representative reach within which a site is established to measure microhabitat conditions. For each zone along the river, there will therefore be a representative reach. See **critical reach**.

River segment

A series of very similar reaches having a common channel morphology and flow regime, but not necessarily the same water quality, temperature, or species composition. However, segment boundaries supposedly also occur wherever the flow regime changes significantly, and **subsegment** boundaries wherever channel morphology changes significantly. As segments and subsegments are poorly distinguished in the literature on IFIM, both are encompassed here in the term segment. For the purposes of this report and for simplicity, the term **river zone** is used instead of segment. Wadeson's segments are termed major zones (see Chapter Five, Sections 5.3.3.4 and 5.4)

River zone

Defined for the purposes of this report as being equivalent to a river segment. Major river zones are equivalent to Wadeson's segments.

Study site

A location on a stream where some characteristic of habitat is measured.

Subsegment

Where more gradual changes in slope or channel pattern occur within a segment. That is, a transition zone between two well-defined channel types. See **segment**.

Substrate

In order to be consistent with the majority of the literature on IFIM, the term substrate(s) was used instead of substratum (substrata) to represent channel bed materials.

Suitability

Suitability is an IFIM term used in connection with suitability index curves to represent the relative degree of suitability of a particular microhabitat variable for the target species on a scale of zero to one. It is used to describe either microhabitat utilisation or preference, a fact that is often not clarified in the literature.

Target biota

For an instream flow assessment using IFIM, the objective is to determine changes in the amount of physical habitat, for a pre-selected target component of the biota such as a fish species or a community of benthic macroinvertebrates, with changes in discharge. The assumption is made that the flow requirements of the chosen target biota will adequately represent the instream flow requirements of the riverine ecosystem. The choice of a target component of the biota is dictated by the study objectives.

Smoothing

Prodedure used to reduce the magnitude of effects associated with random sampling ("random noise"), such as outliers. It is applied to suitability index curves to accentuate and hereby define the general trend of the data.

Interpolation

Procedure used to eliminate irregularities (usually small-scale) in the trend of the data when **smoothing** is not considered necessary. For suitability index curves, if data values increase, then decrease, and then increase again for consecutive microhabitat class intervals, the values for the irregular classes are interpolated from a straight line joining those values deemed acceptable on either side. This is based on the assumption that suitability values for microhabitat would generally exhibit monotonic increases or decreases. Cases of possible multi-modality would require careful assessment before applying this technique.

Appendix 5.1 Department of Water Affairs and Forestry principal hydrological gauging stations for the Olifants River system (E drainage region) (modified from DWA 1990b)

GAUGING STATION NUMBER	SITE LOCATION	LATITUDE	LONGITUDE	CATCHMENT AREA (km2)	STARTING DATE OF OBSERVATIONS AS ELEMENT	STARTING DATE OF AUTOMATIC RECORDING	END DATE OF OBSERVATIONS / RECORDING FOR STATION
E1H001	Olifants River (Langkloof)	32°02'50"	18°49'26"	2659	1910.10.**	-	1941.**.**
E1H005	Olifants River (Keerom)	32°51'10"	19°05'04"	532	1938.01.**	-	1943.01.31
E1H006	Jan Dissels River	32°12'44"	18°56'11"	160	1971.03.06	1971.03.06	-
E1H011	Olifants River (Clanwilliam Dam, Andriesgrond)	32°11'05"	18°52'30"	2033	1969.09.17	1969.09.17	-
E2H002	Doring River (Elands Drift, Aspoort)	32°30'10"	19°32'09"	6903	1923.03.12	1960.02.**	-
E2H003	Doring River (Melkboom)	31°51'37"	19°41'15"	24044	1927.04.09	1960.02.**	-
E2H011	Doring River (Melkboom, Doorn Bridge)	31°51'77"	18°41'15"	24044	1927.04.09	-	-

Appendix 5.2 Monthly average discharge data simulated for the Olifants River Systems Analysis (from NSI), for Grootfontein and the inflow to Clanwilliam Dam, with and without the proposed Rosendaal Dam

5.2.1 Naturalised monthly average discharges for Grootfontein
5.2.2 Present monthly average discharges for Grootfontein, without Rosendaal Dam
5.2.3 Present monthly average discharges for Grootfontein, with Rosendaal Dam
5.2.4 Future monthly average discharges for Grootfontein, without Rosendaal Dam
5.2.5 Future monthly average discharges for Grootfontein, with Rosendaal Dam
5.2.6 Naturalised monthly average discharges for the inflow to Clanwilliam Dam
5.2.7 Present monthly average discharges for the inflow to Clanwilliam Dam, without Rosendaal Dam
5.2.8 Present monthly average discharges for the inflow to Clanwilliam Dam, with Rosendaal Dam
5.2.9 Future monthly average discharges for the inflow to Clanwilliam Dam, without Rosendaal Dam
5.2.10 Future monthly average discharges for the inflow to Clanwilliam Dam, with Rosendaal Dam

Data provided by NSI - Ninham Shand Consulting Engineers, Cape Town

Appendix 5.2.1 Naturalised monthly average discharges for Grootfontein

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	2.281	1.003	0.848	0.642	1.303	0.418	1.150	0.228	66.605	26.994	13.754	4.811	9.977
2	1921	1.344	0.231	1.213	1.232	0.385	0.459	1.404	1.725	20.729	4.585	23.697	2.627	4.990
3	1922	0.907	0.336	0.071	0.284	0.111	0.258	1.879	8.460	29.892	9.468	9.274	3.681	5.386
4	1923	1.471	0.883	0.213	0.105	0.147	0.396	0.613	0.373	16.632	5.190	21.700	4.140	4.340
5	1924	3.252	1.825	0.078	0.146	0.234	0.153	0.131	1.430	60.617	18.811	3.058	1.740	7.594
6	1925	6.399	1.921	0.168	0.123	0.754	0.101	0.201	6.933	2.164	14.718	6.310	2.805	3.590
7	1926	7.191	1.200	0.056	0.164	0.864	0.075	0.945	2.516	4.456	2.169	14.468	3.457	3.154
8	1927	0.736	2.434	0.470	0.317	0.102	0.474	0.062	0.157	19.456	4.465	6.840	4.035	3.285
9	1928	1.131	1.381	0.276	0.041	0.166	0.228	2.697	5.391	7.160	16.211	6.937	3.164	3.760
10	1929	0.795	0.266	0.848	0.273	0.303	0.273	0.370	1.206	1.323	3.678	3.420	11.184	1.993
11	1930	2.072	1.875	0.179	0.041	0.246	0.157	2.141	4.693	2.419	4.141	25.101	6.292	4.152
12	1931	2.445	0.181	0.381	0.343	4.380	0.179	0.170	6.847	15.756	11.197	5.081	5.143	4.331
13	1932	1.449	0.297	0.258	0.183	0.615	0.433	0.073	2.259	19.549	27.102	5.948	3.279	5.147
14	1933	1.792	0.370	0.922	0.175	0.406	0.948	0.120	2.449	5.169	5.899	4.786	7.639	2.556
15	1934	5.287	2.153	0.078	0.052	0.172	0.545	1.640	5.182	7.924	6.989	15.057	4.259	4.143
16	1935	1.023	0.563	0.097	0.605	0.180	0.362	0.147	2.315	0.729	5.402	13.153	10.548	2.847
17	1936	1.968	0.652	1.900	0.093	0.107	0.429	0.926	3.834	18.225	22.771	5.249	2.160	4.869
18	1937	1.157	0.093	0.351	0.900	0.287	0.138	2.222	7.172	4.329	4.671	7.841	6.316	2.973
19	1938	2.628	0.760	0.437	0.041	0.430	0.134	0.984	4.689	2.550	2.595	8.221	4.294	2.330
20	1939	0.865	0.448	0.202	0.127	0.188	0.872	3.094	1.116	12.319	3.902	1.736	3.002	2.278
21	1940	1.247	1.362	0.325	0.758	0.176	0.082	3.484	17.682	29.132	12.582	11.287	16.547	7.895
22	1941	5.130	0.725	0.317	0.052	0.102	0.101	0.174	5.496	43.507	5.492	14.479	2.731	6.516
23	1942	2.016	0.177	0.545	0.750	1.016	0.571	0.517	0.485	3.573	20.863	23.159	6.073	5.035
24	1943	1.654	1.674	0.071	0.243	0.107	0.511	0.745	5.813	28.619	4.372	21.057	5.035	5.833
25	1944	1.693	0.941	0.848	0.026	0.086	0.161	1.474	15.252	32.126	23.928	15.741	2.141	7.929
26	1945	1.990	0.355	0.220	0.049	0.111	0.351	0.934	0.933	2.323	2.927	4.245	21.053	2.944
27	1946	2.431	0.282	0.310	0.019	0.086	0.747	0.235	2.218	1.636	24.630	5.078	2.469	3.393
28	1947	2.520	0.490	0.123	0.045	0.467	0.732	1.651	5.817	5.401	15.939	2.763	8.846	3.753
29	1948	2.636	0.806	0.329	0.168	0.090	0.119	1.644	1.617	4.028	6.593	12.302	5.795	3.032
30	1949	2.882	6.570	0.444	0.056	0.086	0.198	7.010	1.045	1.987	26.635	2.229	9.807	4.933
31	1950	2.684	2.701	1.042	0.601	0.090	0.067	0.201	0.967	27.600	10.786	9.543	4.128	5.032
32	1951	2.651	3.052	0.116	0.056	0.483	0.317	0.684	5.186	3.939	7.351	18.821	5.150	4.017
33	1952	1.587	4.564	0.370	0.022	0.430	0.179	17.226	13.501	4.425	24.395	14.079	2.029	6.948
34	1953	0.698	1.447	1.725	0.097	0.524	0.538	4.051	30.612	8.584	43.384	23.014	4.005	10.019
35	1954	2.363	0.421	0.952	0.015	2.638	0.321	1.620	0.455	14.622	21.195	39.751	4.834	7.491
36	1955	6.631	2.056	0.601	0.314	0.201	0.441	0.204	3.125	19.633	16.185	10.700	2.716	5.262
37	1956	1.184	0.093	0.930	0.097	3.015	0.638	0.482	13.721	30.903	21.965	16.103	3.812	7.769
38	1957	10.107	0.810	0.086	0.034	1.106	0.336	0.694	8.718	10.405	2.199	9.349	3.160	3.940
39	1958	1.664	0.521	0.037	0.078	0.463	0.329	1.462	31.302	3.627	1.990	9.390	3.256	4.567
40	1959	4.361	0.313	0.754	0.034	0.197	0.627	1.362	5.668	8.792	2.565	2.106	1.339	2.353
41	1960	0.644	0.181	1.386	0.433	0.250	0.392	1.377	1.788	9.772	5.869	7.363	11.593	3.435
42	1961	1.254	0.081	0.056	0.172	0.246	0.411	2.076	1.090	31.979	10.529	20.206	5.513	6.137
43	1962	12.343	1.956	0.149	0.228	0.139	0.082	0.262	0.310	6.547	10.043	40.412	4.016	6.456
44	1963	0.997	1.740	1.165	0.022	1.106	0.119	0.660	1.557	15.463	6.418	10.297	4.533	3.671
45	1964	1.591	1.235	0.022	0.385	0.936	2.487	2.404	4.126	2.415	2.263	3.595	1.782	1.944
46	1965	1.142	0.224	0.874	0.015	0.066	2.177	1.088	0.706	3.596	17.253	5.070	3.198	2.891
47	1966	0.523	0.116	0.149	0.273	0.295	0.146	2.234	2.468	29.163	6.448	4.962	3.252	4.149
48	1967	1.908	1.235	0.037	0.149	0.045	0.190	2.631	12.683	11.833	13.168	9.147	1.698	4.597
49	1968	8.807	0.671	0.235	0.317	0.242	0.190	1.941	0.366	1.439	1.307	3.271	6.134	2.085
50	1969	6.948	0.529	0.026	0.011	0.328	0.022	0.050	4.622	21.497	15.905	13.053	6.173	5.790
51	1970	1.714	0.266	0.213	0.075	0.098	0.388	0.123	1.084	1.740	20.299	12.623	1.682	3.408
52	1971	0.426	0.116	0.078	0.482	0.188	0.260	2.191	7.404	8.125	6.097	3.132	3.341	2.665
53	1972	1.042	0.062	1.661	0.011	0.586	0.627	0.081	0.877	0.640	24.601	4.816	4.672	3.348
54	1973	1.591	0.231	0.937	0.045	0.561	0.254	0.147	6.687	26.420	8.938	12.817	6.107	5.400
55	1974	1.546	1.177	0.280	0.355	0.213	0.220	2.901	24.152	3.673	7.176	10.484	1.543	4.532
56	1975	3.588	0.374	0.090	0.276	0.193	0.361	3.125	1.124	34.463	14.606	4.126	2.002	5.352
57	1976	1.210	4.171	6.463	0.579	0.647	0.248	5.081	34.405	34.263	30.261	27.808	4.047	12.526
58	1977	1.172	0.841	0.665	0.508	0.184	0.829	1.242	1.620	0.687	0.366	5.666	6.296	1.676
59	1978	1.217	0.363	3.058	0.336	0.783	0.097	0.177	3.405	16.611	7.441	5.122	5.077	3.805
60	1979	2.819	0.343	0.037	0.653	0.442	0.108	0.775	5.739	10.891	2.630	8.710	2.110	2.968
61	1980	1.613	5.868	1.034	1.561	0.107	0.526	0.660	0.373	1.858	18.037	25.411	12.620	5.871
62	1981	1.765	0.594	0.205	0.698	0.139	1.385	5.096	2.188	5.482	6.041	2.936	1.057	2.300
63	1982	2.158	0.428	0.922	0.119	1.876	0.773	0.444	25.411	20.671	17.671	3.752	4.556	6.601
64	1983	1.202	0.305	0.194	0.015	0.127	0.967	1.671	36.003	3.468	8.117	4.409	20.143	6.432
65	1984	11.906	0.637	2.479	2.214	0.848	6.330	2.948	5.175	16.223	21.509	15.767	6.262	7.926
66	1985	1.337	0.992	1.844	0.019	0.156	0.804	0.432	1.841	13.831	7.504	20.322	4.012	4.461
67	1986	1.128	0.505	0.007	0.433	0.115	0.011	1.198	13.250	17.589	10.252	10.947	6.393	5.176
68	1987	0.862	0.054	0.368	0.153	0.008	0.907	3.148	2.076	13.441	4.533	10.271	5.860	3.476
69	1988	1.120	0.297	0.534	0.414	0.516	3.084	2.677	2.546	7.184	16.439	32.094	23.819	7.603
70	1989	3.144	1.327	0.142	0.351	0.262	0.765	2.180	23.790	17.701	29.208	4.223	1.061	7.079
71	1990	0.564	0.509	0.564	0.889	0.004	0.157	0.170	3.118	31.370	44.542	6.078	16.786	8.757
AVERAGE		2.589	1.088	0.636	0.304	0.487	0.587	1.662	6.628	14.436	12.573	11.488	5.592	4.861

Appendix 5.2.2 Present monthly average discharges for Grootfontein, without Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	2.076	0.857	0.799	0.605	1.200	0.396	1.057	0.220	60.168	27.247	13.850	4.568	9.411
2	1921	1.072	0.182	1.101	1.079	0.373	0.433	1.304	1.591	17.932	4.230	21.134	2.307	4.412
3	1922	0.754	0.289	0.067	0.258	0.111	0.254	1.667	7.497	25.725	8.925	8.892	3.242	4.810
4	1923	1.247	0.741	0.194	0.101	0.143	0.381	0.571	0.355	14.051	4.895	19.362	3.825	3.839
5	1924	2.891	1.671	0.063	0.134	0.229	0.149	0.116	1.355	52.288	19.074	2.941	1.508	6.842
6	1925	5.767	1.678	0.142	0.119	0.713	0.101	0.193	6.157	2.091	13.045	5.851	2.546	3.236
7	1926	6.157	1.061	0.041	0.153	0.815	0.075	0.887	2.326	4.140	2.072	12.914	3.152	2.837
8	1927	0.631	2.172	0.444	0.295	0.102	0.448	0.058	0.157	15.953	4.208	6.575	3.816	2.898
9	1928	0.963	1.292	0.261	0.041	0.164	0.217	2.492	4.981	8.620	14.389	6.095	2.809	3.385
10	1929	0.631	0.224	0.784	0.250	0.279	0.261	0.355	1.172	1.292	3.491	3.241	9.533	1.793
11	1930	1.833	1.736	0.168	0.041	0.234	0.153	1.925	4.174	2.292	3.827	21.733	5.879	3.700
12	1931	2.121	0.123	0.351	0.325	3.597	0.169	0.166	6.082	14.282	10.107	4.495	4.501	3.852
13	1932	1.217	0.243	0.243	0.175	0.594	0.411	0.073	1.968	16.759	24.759	5.684	2.957	4.616
14	1933	1.583	0.309	0.859	0.157	0.393	0.896	0.112	2.207	4.807	5.548	4.450	6.574	2.332
15	1934	4.521	1.914	0.060	0.049	0.160	0.508	1.481	4.708	7.369	6.429	13.280	3.765	3.714
16	1935	0.836	0.467	0.086	0.564	0.176	0.343	0.139	2.065	0.675	4.842	11.537	9.815	2.646
17	1936	1.740	0.583	1.691	0.082	0.107	0.399	0.849	3.454	15.936	20.727	4.939	1.856	4.391
18	1937	0.867	0.054	0.325	0.806	0.279	0.134	1.944	6.228	4.055	4.335	7.045	5.587	2.662
19	1938	2.363	0.683	0.407	0.037	0.397	0.131	0.914	4.114	2.419	2.431	7.445	3.870	2.115
20	1939	0.538	0.401	0.183	0.119	0.176	0.653	2.743	1.038	10.868	3.614	1.538	2.666	2.036
21	1940	1.116	1.246	0.306	0.665	0.168	0.078	3.075	14.860	26.308	12.072	10.705	15.690	7.195
22	1941	4.820	0.563	0.287	0.045	0.102	0.097	0.174	4.678	37.982	5.470	14.581	2.388	5.912
23	1942	1.755	0.123	0.523	0.694	0.951	0.523	0.490	0.437	3.144	18.141	21.424	5.634	4.537
24	1943	1.310	1.454	0.052	0.231	0.107	0.485	0.679	4.842	24.910	4.192	19.839	4.739	5.246
25	1944	1.602	0.791	0.795	0.022	0.066	0.157	1.343	12.754	28.844	22.471	15.774	1.729	7.240
26	1945	1.673	0.270	0.202	0.045	0.107	0.332	0.876	0.862	2.195	2.800	3.980	18.052	2.605
27	1946	2.151	0.224	0.291	0.019	0.066	0.683	0.228	1.994	1.559	21.110	4.630	2.168	2.970
28	1947	2.244	0.432	0.119	0.041	0.438	0.624	1.497	5.156	5.008	13.956	2.445	8.446	3.384
29	1948	2.292	0.721	0.306	0.164	0.090	0.116	1.506	1.505	3.688	6.112	11.119	5.139	2.749
30	1949	2.464	5.467	0.392	0.052	0.086	0.190	5.733	1.004	1.867	23.302	2.028	9.529	4.361
31	1950	2.352	2.245	0.967	0.545	0.090	0.067	0.193	0.877	22.936	10.400	9.219	3.826	4.479
32	1951	2.304	2.685	0.093	0.049	0.463	0.302	0.633	4.320	3.630	6.396	17.116	4.702	3.588
33	1952	1.292	3.966	0.325	0.019	0.414	0.175	14.244	12.008	4.269	22.595	13.366	1.617	6.236
34	1953	0.465	1.258	1.602	0.086	0.516	0.519	3.549	25.748	8.377	42.471	23.200	3.696	9.414
35	1954	2.005	0.313	0.885	0.011	2.323	0.302	1.520	0.433	12.674	18.675	38.461	4.550	6.903
36	1955	6.232	1.775	0.541	0.291	0.188	0.426	0.201	2.744	17.060	14.614	10.213	2.330	4.745
37	1956	1.012	0.054	0.889	0.093	2.638	0.601	0.444	11.764	26.742	21.050	16.215	3.497	7.110
38	1957	9.810	0.644	0.067	0.026	1.041	0.329	0.656	7.740	9.541	2.020	8.468	2.870	3.622
39	1958	1.493	0.459	0.034	0.075	0.434	0.306	1.250	26.008	3.426	1.855	8.936	2.990	3.986
40	1959	3.933	0.243	0.708	0.030	0.193	0.582	1.285	5.093	7.975	2.360	1.912	1.198	2.134
41	1960	0.777	0.158	1.296	0.403	0.246	0.381	1.296	1.658	8.819	5.482	6.653	9.833	3.093
42	1961	1.042	0.042	0.049	0.161	0.229	0.370	1.863	0.997	26.634	10.269	19.372	4.996	5.510
43	1962	11.437	1.686	0.116	0.217	0.139	0.078	0.255	0.302	5.822	9.259	35.348	3.634	5.764
44	1963	0.821	1.547	1.072	0.019	1.061	0.116	0.613	1.441	13.364	5.826	9.339	4.286	3.291
45	1964	1.359	1.065	0.011	0.366	0.832	2.218	2.222	3.749	2.265	2.106	3.312	1.617	1.767
46	1965	0.993	0.193	0.926	0.015	0.061	1.968	1.030	0.653	3.164	15.267	4.626	2.801	2.670
47	1966	0.392	0.085	0.142	0.269	0.291	0.142	2.025	2.319	24.572	6.183	4.801	2.977	3.668
48	1967	1.635	1.111	0.030	0.142	0.041	0.190	2.411	11.092	10.849	11.574	8.687	1.377	4.127
49	1968	8.035	0.552	0.217	0.306	0.234	0.183	1.767	0.351	1.335	1.236	2.998	5.660	1.914
50	1969	6.060	0.455	0.019	0.011	0.320	0.022	0.050	4.144	16.564	14.629	12.556	5.690	5.238
51	1970	1.426	0.197	0.198	0.071	0.098	0.382	0.120	1.001	1.578	17.602	11.300	1.416	3.009
52	1971	0.332	0.089	0.071	0.452	0.180	0.265	1.948	6.564	7.527	5.511	2.819	2.994	2.404
53	1972	0.896	0.035	1.531	0.007	0.569	0.597	0.077	0.821	0.613	20.699	4.320	4.207	2.900
54	1973	1.381	0.181	0.870	0.041	0.549	0.243	0.135	5.739	23.056	6.099	11.795	5.619	4.814
55	1974	1.281	0.999	0.246	0.336	0.205	0.213	2.658	20.255	3.438	6.474	10.104	1.285	4.006
56	1975	3.136	0.309	0.078	0.261	0.180	0.373	2.774	1.057	28.830	14.205	3.911	1.717	4.730
57	1976	1.016	3.434	5.582	0.538	0.615	0.239	4.579	28.773	33.939	30.555	28.037	3.734	11.841
58	1977	0.907	0.748	0.624	0.489	0.160	0.780	1.173	1.557	0.652	0.347	4.816	5.760	1.505
59	1976	1.068	0.332	2.826	0.314	0.709	0.090	0.170	3.069	16.273	6.769	4.674	4.549	3.403
60	1979	2.490	0.282	0.030	0.605	0.422	0.105	0.737	5.098	9.950	2.632	7.829	1.867	2.681
61	1980	1.426	4.811	0.911	1.318	0.098	0.497	0.625	0.358	1.748	15.560	22.643	12.266	5.232
62	1981	1.464	0.505	0.194	0.635	0.135	1.232	4.286	2.053	4.958	5.593	2.546	0.910	2.050
63	1982	1.908	0.382	0.877	0.116	1.692	0.709	0.428	20.803	19.514	16.857	3.427	4.156	5.935
64	1983	0.982	0.239	0.179	0.015	0.123	0.829	1.543	29.884	3.330	7.844	4.204	19.883	5.792
65	1984	11.622	0.471	2.151	1.994	0.770	6.967	2.670	4.742	14.498	19.862	15.886	6.077	7.373
66	1985	1.038	0.883	1.695	0.011	0.147	0.840	0.409	1.729	12.087	6.788	18.309	3.659	3.992
67	1968	0.922	0.440	0.000	0.418	0.107	0.007	1.073	11.346	15.584	9.888	10.444	5.903	4.700
68	1987	0.620	0.012	0.340	0.149	0.008	0.810	2.716	1.956	11.937	4.144	9.058	5.189	3.081
69	1988	0.896	0.239	0.508	0.403	0.483	2.684	2.357	2.348	6.188	14.408	28.169	23.288	6.884
70	1989	2.651	1.150	0.119	0.332	0.238	0.736	1.867	20.288	16.064	28.928	4.152	0.741	6.502
71	1990	0.441	0.448	0.526	0.846	0.004	0.149	0.150	2.849	26.427	43.213	6.044	16.869	6.195
AVERAGE		2.289	0.912	0.579	0.260	0.447	0.532	1.474	5.714	12.753	11.666	10.687	5.135	4.394

Appendix 5.2.3 Present monthly average discharges for Grootfontein, with Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	1.997	0.945	0.747	2.094	1.065	0.748	0.918	0.209	57.976	27.419	13.910	4.552	9.371
2	1921	0.967	0.192	2.300	0.836	1.611	2.320	1.181	1.393	15.571	3.577	19.726	2.216	4.339
3	1922	0.683	0.308	2.352	2.796	2.636	2.402	1.350	6.620	22.218	7.206	6.403	3.021	4.844
4	1923	1.148	0.602	2.001	3.005	3.004	2.417	0.894	0.325	11.721	4.070	17.003	3.376	4.138
5	1924	2.270	1.601	0.817	2.908	2.697	2.249	1.222	1.273	45.070	14.446	2.414	1.397	6.496
6	1925	4.734	1.424	1.221	3.035	2.698	2.189	1.164	5.552	1.979	10.887	5.335	2.392	3.593
7	1926	5.048	0.957	1.684	3.080	2.578	2.062	0.802	2.106	3.750	1.927	11.201	2.917	3.192
8	1927	0.582	1.910	1.112	2.675	0.102	0.448	0.058	0.157	12.357	3.472	5.369	3.295	2.628
9	1928	0.806	1.307	2.346	3.162	0.706	0.217	2.338	4.659	5.787	11.620	4.783	2.554	3.398
10	1929	0.549	0.300	2.042	2.632	1.846	0.261	0.355	1.161	1.269	3.323	2.998	6.628	1.946
11	1930	1.594	1.659	1.407	2.152	0.234	0.153	1.640	3.491	2.087	3.222	18.746	4.591	3.449
12	1931	1.893	0.108	2.378	2.699	2.421	0.153	0.951	5.477	13.040	8.412	3.696	3.461	3.727
13	1932	1.090	0.227	2.438	3.001	2.541	0.411	0.073	1.508	13.920	18.634	4.510	2.527	4.253
14	1933	1.466	0.282	1.411	2.430	2.484	0.825	0.230	1.897	4.406	4.816	4.017	4.626	2.407
15	1934	3.446	1.709	0.056	2.882	2.902	2.114	1.242	4.241	6.636	5.201	11.338	3.414	3.777
16	1935	0.750	0.367	1.669	2.277	2.230	1.864	0.127	1.721	0.567	3.790	9.017	6.281	2.565
17	1936	1.579	0.536	2.643	1.852	2.611	2.088	0.725	2.981	13.090	15.647	4.178	1.748	4.153
18	1937	0.844	0.046	0.366	0.665	2.500	1.360	1.532	4.966	3.704	3.625	5.742	4.151	2.459
19	1938	2.207	0.640	2.774	2.703	2.754	1.920	0.814	3.368	2.211	2.188	5.903	3.387	2.580
20	1939	0.455	1.866	2.860	1.837	0.176	0.653	2.288	0.911	9.498	3.170	1.340	2.276	2.275
21	1940	1.001	1.134	1.404	2.503	0.168	0.078	2.565	11.940	21.157	9.319	7.930	14.908	6.181
22	1941	4.573	0.498	0.425	0.683	1.050	0.093	1.156	3.558	35.767	5.471	14.623	2.312	5.842
23	1942	1.669	0.108	3.028	1.445	2.603	1.043	0.446	0.351	2.820	14.436	19.713	5.627	4.479
24	1943	1.221	1.321	0.937	2.901	2.668	1.916	0.571	3.394	19.888	3.831	18.832	4.745	5.189
25	1944	1.500	0.652	0.747	2.023	2.029	2.211	1.183	10.129	25.208	22.600	15.865	1.642	7.187
26	1945	1.598	0.228	2.061	1.807	0.329	2.013	0.787	0.747	2.052	2.647	3.655	14.502	2.702
27	1946	1.938	0.197	1.518	2.337	2.291	1.786	0.212	1.684	1.443	17.706	3.868	1.921	3.104
28	1947	2.009	0.397	1.265	2.886	3.135	1.812	1.265	4.387	4.217	11.305	2.229	4.869	3.323
29	1948	2.009	0.687	1.938	2.964	2.341	1.834	1.319	1.337	3.221	4.913	9.711	4.144	3.048
30	1949	2.042	4.174	0.803	2.277	2.631	1.883	3.939	0.937	1.713	18.668	1.826	5.243	3.855
31	1950	2.053	1.613	0.892	3.237	2.255	0.067	1.137	0.728	18.723	7.374	8.243	3.801	4.168
32	1951	2.228	2.569	0.090	2.247	2.332	1.789	0.590	3.252	3.021	5.096	14.253	4.681	3.530
33	1952	1.187	3.869	0.967	2.329	2.806	1.920	11.636	9.550	3.643	20.644	13.430	1.526	6.178
34	1953	0.394	1.129	1.799	1.553	2.591	1.857	2.940	20.910	8.427	42.707	23.321	3.663	9.382
35	1954	1.914	0.266	0.806	0.832	1.917	0.276	1.416	0.399	11.595	18.797	38.695	4.514	6.848
36	1955	6.208	1.632	0.497	0.261	0.837	0.535	0.193	2.218	16.245	14.692	10.247	2.269	4.677
37	1956	0.948	0.050	1.680	1.986	2.143	0.549	0.378	10.301	25.313	21.181	16.263	3.463	7.057
38	1957	9.802	0.596	0.067	1.206	1.177	0.314	0.602	7.060	8.221	1.882	8.430	2.813	3.537
39	1958	1.396	0.413	1.068	2.049	1.091	0.419	0.965	21.920	3.385	1.816	8.997	2.951	3.915
40	1959	3.885	0.212	0.646	1.635	0.841	0.990	1.200	4.499	6.385	2.173	1.729	1.069	2.114
41	1960	0.728	0.582	2.363	1.945	1.181	1.039	1.204	1.471	6.117	4.618	5.496	7.724	3.038
42	1961	0.946	0.039	1.292	2.012	1.857	1.524	1.570	0.829	21.752	7.997	19.528	4.947	5.365
43	1962	11.475	1.537	0.108	0.855	1.165	0.695	0.243	0.267	5.104	7.799	34.732	3.573	5.698
44	1963	0.750	1.365	0.967	1.411	1.419	0.434	0.532	1.281	11.138	5.634	9.418	4.272	3.220
45	1964	1.263	0.934	0.821	1.852	2.222	1.897	2.029	3.286	2.045	1.915	2.968	1.431	1.889
46	1965	0.803	0.168	1.460	1.501	1.697	2.084	0.949	0.568	2.635	12.608	4.256	2.442	2.616
47	1966	0.321	0.497	1.695	1.702	2.123	1.476	1.771	2.151	20.297	4.421	3.558	2.596	3.531
48	1967	1.366	1.007	0.056	0.433	0.599	0.187	2.199	10.084	9.205	11.342	8.734	1.288	3.805
49	1968	8.063	0.490	2.778	3.043	2.771	2.170	1.547	0.332	1.188	1.120	2.595	5.027	2.596
50	1969	4.753	0.405	0.608	1.038	1.259	0.677	0.050	3.704	15.563	11.839	8.789	4.985	4.487
51	1970	1.296	0.165	0.187	0.474	1.138	1.226	0.112	0.911	1.416	14.583	11.248	1.333	2.878
52	1971	0.308	0.077	0.250	0.582	0.168	0.239	1.613	5.682	7.498	5.542	2.798	2.962	2.318
53	1972	0.788	0.551	1.661	2.441	2.767	0.617	0.073	0.738	0.571	17.518	3.420	3.735	2.926
54	1973	1.502	0.150	0.780	2.650	2.988	2.178	0.334	4.615	20.482	6.418	8.397	5.607	4.668
55	1974	1.224	0.891	0.224	0.310	1.366	2.118	2.438	17.428	3.129	6.219	10.176	1.201	3.934
56	1975	3.087	0.274	0.075	1.396	0.160	1.300	2.330	0.952	26.505	14.297	3.904	1.656	4.662
57	1976	0.928	3.440	5.475	0.497	0.569	0.224	4.240	28.857	34.112	30.755	28.174	3.697	11.836
58	1977	0.796	0.714	0.582	0.470	0.276	0.709	1.080	1.493	0.602	0.329	4.112	5.768	1.413
59	1978	0.954	0.316	2.748	0.455	1.742	0.307	0.158	2.707	14.532	6.806	4.671	4.532	3.322
60	1979	2.409	0.258	0.145	0.612	2.668	1.763	0.675	4.424	8.665	2.445	6.605	1.728	2.699
61	1980	1.273	3.827	0.765	0.942	0.194	0.452	0.579	0.336	1.632	15.381	22.738	12.349	5.080
62	1981	1.361	0.475	0.190	0.538	0.131	0.993	3.791	2.028	5.009	5.613	2.527	0.827	1.965
63	1982	1.843	0.340	0.836	0.713	2.173	0.609	0.589	19.051	19.648	16.963	3.413	4.137	5.884
64	1983	0.877	0.201	0.164	1.829	1.964	1.614	1.362	25.121	3.302	7.699	4.195	20.009	5.736
65	1984	11.615	0.432	1.665	1.830	0.656	6.907	2.635	4.751	14.589	19.992	15.970	6.071	7.341
66	1985	0.948	0.645	1.587	1.560	1.841	1.901	0.370	1.624	10.367	5.176	16.981	3.627	3.919
67	1986	0.814	0.401	1.318	2.232	1.759	1.293	0.968	9.341	12.566	8.320	10.497	5.893	4.635
68	1987	0.553	0.008	0.310	1.814	1.652	1.651	2.296	1.615	10.448	3.633	7.519	4.479	3.011
69	1988	0.803	0.216	0.485	2.117	2.144	2.158	2.025	2.065	5.224	12.536	28.317	23.344	6.811
70	1989	2.572	1.061	0.631	1.657	2.078	2.114	1.524	17.488	13.654	29.062	4.148	0.653	6.443
71	1990	0.411	1.133	2.218	2.863	1.792	1.591	0.778	2.587	22.415	38.681	6.036	16.918	8.142
AVERAGE		2.120	0.867	1.294	1.854	1.746	1.329	1.359	4.946	11.309	10.445	9.936	4.623	4.336

Appendix 5.2.4 Future monthly average discharges for Grootfontein, without Rosendaal Dam

Appendix

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	2.076	0.957	0.789	0.605	1.200	0.396	1.057	0.220	60.168	27.247	13.850	4.568	9.411
2	1921	1.072	0.162	1.101	1.079	0.373	0.433	1.304	1.591	17.932	4.230	21.134	2.307	4.412
3	1922	0.754	0.289	0.067	0.258	0.111	0.254	1.667	7.497	25.725	8.925	8.892	3.242	4.810
4	1923	1.247	0.741	0.194	0.101	0.143	0.381	0.571	0.355	14.051	4.895	19.362	3.825	3.839
5	1924	2.891	1.671	0.063	0.134	0.229	0.149	0.116	1.355	52.288	19.074	2.941	1.508	6.842
6	1925	5.767	1.678	0.142	0.119	0.713	0.101	0.193	6.157	2.091	13.045	5.851	2.546	3.236
7	1926	6.157	1.061	0.041	0.153	0.815	0.075	0.887	2.326	4.140	2.072	12.814	3.152	2.837
8	1927	0.631	2.172	0.444	0.295	0.102	0.448	0.058	0.157	15.953	4.208	6.575	3.816	2.898
9	1928	0.963	1.292	0.261	0.041	0.164	0.217	2.492	4.881	8.620	14.389	6.095	2.809	3.385
10	1929	0.631	0.224	0.764	0.250	0.279	0.261	0.355	1.172	1.292	3.491	3.241	9.533	1.793
11	1930	1.833	1.736	0.168	0.041	0.234	0.153	1.925	4.174	2.292	3.827	21.733	5.879	3.700
12	1931	2.121	0.123	0.351	0.325	3.597	0.168	0.166	6.082	14.282	10.107	4.495	4.501	3.852
13	1932	1.217	0.243	0.243	0.175	0.594	0.411	0.073	1.968	16.759	24.759	5.684	2.957	4.616
14	1933	1.583	0.309	0.859	0.157	0.393	0.896	0.112	2.207	4.807	5.548	4.450	6.574	2.332
15	1934	4.521	1.914	0.060	0.049	0.160	0.508	1.481	4.708	7.369	6.429	13.280	3.765	3.714
16	1935	0.836	0.467	0.086	0.564	0.176	0.343	0.139	2.065	0.675	4.842	11.537	9.815	2.646
17	1936	1.740	0.583	1.691	0.082	0.107	0.399	0.849	3.454	15.937	20.727	4.939	1.856	4.391
18	1937	0.967	0.054	0.325	0.806	0.279	0.134	1.944	6.228	4.055	4.335	7.045	5.587	2.662
19	1938	2.363	0.683	0.407	0.037	0.397	0.131	0.914	4.114	2.419	2.431	7.445	3.870	2.115
20	1939	0.538	0.401	0.183	0.119	0.176	0.853	2.743	1.038	10.868	3.614	1.538	2.868	2.036
21	1940	1.116	1.246	0.306	0.665	0.168	0.078	3.075	14.860	26.306	12.072	10.705	15.690	7.195
22	1941	4.620	0.563	0.287	0.045	0.102	0.097	0.174	4.678	37.982	5.470	14.581	2.388	5.912
23	1942	1.755	0.123	0.523	0.694	0.951	0.523	0.490	0.437	3.144	18.141	21.424	5.634	4.537
24	1943	1.310	1.454	0.052	0.231	0.107	0.485	0.679	4.842	24.910	4.192	19.839	4.739	5.246
25	1944	1.602	0.791	0.795	0.022	0.066	0.157	1.343	12.754	28.844	22.471	15.774	1.729	7.240
26	1945	1.673	0.270	0.202	0.045	0.107	0.332	0.676	0.862	2.195	2.800	3.980	18.052	2.605
27	1946	2.151	0.224	0.291	0.019	0.088	0.683	0.228	1.994	1.559	21.110	4.630	2.168	2.970
28	1947	2.244	0.432	0.119	0.041	0.438	0.624	1.497	5.156	5.008	13.956	2.445	8.446	3.384
29	1948	2.292	0.721	0.306	0.164	0.090	0.116	1.505	1.505	3.688	6.112	11.119	5.139	2.749
30	1949	2.464	5.467	0.392	0.052	0.086	0.190	5.733	1.004	1.867	23.302	2.028	9.529	4.361
31	1950	2.352	2.245	0.967	0.545	0.090	0.067	0.193	0.877	22.936	10.400	9.219	3.826	4.479
32	1951	2.304	2.685	0.093	0.049	0.463	0.302	0.633	4.320	3.630	6.396	17.116	4.702	3.568
33	1952	1.292	3.966	0.325	0.019	0.414	0.175	14.244	12.008	4.269	22.595	13.366	1.617	6.236
34	1953	0.485	1.258	1.602	0.086	0.516	0.518	3.549	25.748	8.377	42.471	23.200	3.696	9.414
35	1954	2.005	0.312	0.885	0.011	2.323	0.302	1.520	0.433	12.674	16.675	38.461	4.550	6.903
36	1955	6.232	1.775	0.541	0.291	0.188	0.426	0.201	2.744	17.060	14.614	10.213	2.330	4.745
37	1956	1.012	0.054	0.889	0.093	2.638	0.601	0.444	11.764	26.742	21.050	16.215	3.497	7.110
38	1957	9.810	0.644	0.067	0.026	1.041	0.329	0.656	7.740	9.541	2.020	8.468	2.870	3.622
39	1958	1.493	0.459	0.034	0.075	0.434	0.306	1.250	26.008	3.426	1.855	8.936	2.990	3.986
40	1959	3.933	0.243	0.708	0.030	0.193	0.582	1.285	5.093	7.975	2.360	1.912	1.196	2.134
41	1960	0.777	0.158	1.296	0.403	0.246	0.381	1.296	1.658	8.819	5.492	6.653	9.833	3.093
42	1961	1.042	0.042	0.049	0.161	0.229	0.370	1.863	0.997	26.634	10.269	19.372	4.996	5.510
43	1962	11.437	1.686	0.116	0.217	0.139	0.078	0.255	0.302	5.822	9.259	35.348	3.834	5.764
44	1963	0.821	1.547	1.072	0.019	1.061	0.116	0.613	1.441	13.364	5.826	9.339	4.286	3.291
45	1964	1.359	1.065	0.011	0.366	0.832	2.216	2.222	3.749	2.265	2.106	3.312	1.617	1.767
46	1965	0.893	0.183	0.926	0.015	0.061	1.968	1.030	0.653	3.164	15.267	4.626	2.801	2.670
47	1966	0.392	0.085	0.142	0.269	0.291	0.142	2.025	2.319	24.572	6.183	4.801	2.977	3.668
48	1967	1.635	1.111	0.030	0.142	0.041	0.190	2.411	11.092	10.849	11.574	8.687	1.377	4.127
49	1968	8.035	0.552	0.217	0.306	0.234	0.183	1.767	0.351	1.335	1.236	2.998	5.660	1.914
50	1969	6.060	0.455	0.019	0.011	0.320	0.022	0.050	4.144	18.584	14.629	12.556	5.690	5.238
51	1970	1.426	0.197	0.198	0.071	0.096	0.362	0.120	1.001	1.578	17.802	11.300	1.416	3.009
52	1971	0.332	0.089	0.071	0.452	0.180	0.265	1.948	6.584	7.527	5.511	2.819	2.994	2.404
53	1972	0.896	0.035	1.531	0.007	0.569	0.597	0.077	0.621	0.613	20.699	4.320	4.207	2.900
54	1973	1.381	0.181	0.870	0.041	0.549	0.243	0.135	5.739	23.056	8.099	11.795	5.819	4.814
55	1974	1.281	0.899	0.246	0.336	0.205	0.213	2.658	20.255	3.437	6.474	10.104	1.285	4.006
56	1975	3.136	0.309	0.078	0.261	0.180	0.373	2.774	1.057	28.830	14.205	3.911	1.717	4.730
57	1976	1.016	3.434	5.582	0.538	0.615	0.239	4.579	28.773	33.939	30.555	28.037	3.734	11.841
58	1977	0.907	0.748	0.624	0.489	0.160	0.780	1.173	1.557	0.652	0.347	4.816	5.760	1.505
59	1978	1.066	0.332	2.826	0.314	0.709	0.090	0.170	3.069	16.273	6.769	4.674	4.549	3.403
60	1979	2.490	0.282	0.030	0.605	0.422	0.105	0.737	5.096	9.950	2.632	7.829	1.867	2.681
61	1980	1.426	4.811	0.911	1.318	0.098	0.497	0.625	0.358	1.748	15.580	22.643	12.266	5.232
62	1981	1.464	0.505	0.194	0.635	0.135	1.232	4.286	2.053	4.958	5.593	2.546	0.910	2.050
63	1982	1.908	0.362	0.877	0.116	1.692	0.709	0.428	20.803	19.514	16.857	3.427	4.156	5.935
64	1983	0.982	0.239	0.179	0.015	0.123	0.829	1.543	29.684	3.330	7.844	4.204	19.883	5.792
65	1984	11.622	0.471	2.151	1.994	0.770	6.967	2.670	4.742	14.498	19.862	15.886	6.077	7.373
66	1985	1.038	0.883	1.695	0.011	0.147	0.840	0.409	1.729	12.087	6.788	16.309	3.659	3.992
67	1986	0.922	0.440	0.000	0.416	0.107	0.007	1.073	11.346	15.584	9.888	10.444	5.903	4.700
68	1987	0.620	0.012	0.340	0.149	0.008	0.810	2.716	1.958	11.937	4.144	9.058	5.189	3.081
69	1988	0.898	0.239	0.508	0.403	0.483	2.684	2.357	2.348	6.168	14.408	26.169	23.268	6.864
70	1989	2.651	1.150	0.119	0.332	0.238	0.736	1.867	20.288	16.064	28.928	4.152	0.741	6.502
71	1990	0.441	0.446	0.526	0.648	0.004	0.149	0.150	2.649	26.427	43.213	6.044	16.869	8.195
AVERAGE		2.289	0.912	0.579	0.290	0.447	0.532	1.474	5.714	12.753	11.666	10.687	5.135	4.394

Appendix 5.2.5 Future monthly average discharges for Grootfontein, with Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	1.997	0.945	1.329	2.839	1.065	1.361	1.126	0.209	55.657	27.419	13.910	4.552	9.371
2	1921	0.967	0.846	3.092	1.573	2.394	2.933	1.249	1.393	15.571	3.577	17.096	2.195	4.416
3	1922	0.683	0.962	3.144	3.641	3.619	3.015	1.350	6.620	22.218	7.206	6.403	3.021	5.149
4	1923	1.146	0.602	2.793	3.850	3.016	0.381	0.571	0.325	11.721	4.070	17.003	3.376	4.079
5	1924	2.270	1.601	1.609	3.753	1.383	0.149	0.116	1.273	45.070	14.446	2.414	1.397	6.264
6	1925	4.734	1.424	2.013	3.880	3.681	2.802	1.481	5.552	1.979	10.887	5.335	2.392	3.870
7	1926	5.048	0.957	2.476	2.773	0.815	0.075	0.602	2.106	3.750	1.927	11.201	2.917	2.928
8	1927	0.582	1.910	1.904	1.711	0.102	0.448	0.058	0.157	12.357	3.472	5.369	3.295	2.613
9	1928	0.806	1.961	3.140	2.283	0.164	0.217	2.336	4.659	5.787	11.920	4.783	2.554	3.403
10	1929	0.549	0.954	2.834	2.702	0.279	0.261	0.355	1.161	1.269	3.323	2.998	6.628	1.951
11	1930	1.594	1.659	2.199	1.375	0.234	0.153	1.640	3.491	2.087	3.222	18.746	4.591	3.450
12	1931	1.893	0.108	3.170	3.437	2.421	0.153	1.244	5.477	13.040	8.412	3.696	3.461	3.881
13	1932	1.090	0.881	3.230	1.741	0.594	0.411	0.073	1.508	13.920	18.634	4.510	2.527	4.117
14	1933	1.486	0.262	2.203	3.275	3.247	1.167	0.547	1.897	4.406	4.816	4.017	4.626	2.662
15	1934	3.446	1.709	0.056	3.727	3.685	0.801	1.242	4.241	6.636	5.201	11.339	3.414	3.798
16	1935	0.750	0.367	2.461	3.019	0.176	0.343	0.139	1.721	0.587	3.790	9.017	6.281	2.409
17	1936	1.579	0.536	3.435	2.697	3.270	0.399	0.725	2.991	13.090	15.647	4.178	1.748	4.200
18	1937	0.844	0.117	1.158	0.665	3.283	1.973	1.532	4.966	3.704	3.625	5.742	4.151	2.645
19	1938	2.207	1.286	3.566	3.548	1.781	0.131	0.914	3.388	2.211	2.188	5.903	3.387	2.553
20	1939	0.455	2.520	1.282	0.119	0.176	0.653	2.288	0.911	9.498	3.170	1.340	2.276	2.049
21	1940	1.001	1.355	2.196	1.519	0.168	0.078	2.585	11.940	21.157	9.319	7.930	14.806	6.183
22	1941	4.573	0.498	1.217	1.528	1.833	0.308	1.473	3.558	32.807	5.471	14.623	2.312	5.843
23	1942	1.669	0.108	3.820	2.290	3.386	1.656	0.448	0.351	2.820	14.438	16.749	5.627	4.479
24	1943	1.221	1.321	1.729	3.746	3.451	2.529	0.821	3.384	19.888	3.831	15.610	4.745	5.167
25	1944	1.500	0.652	0.747	2.868	2.812	2.824	1.500	10.129	22.626	22.600	15.865	1.642	7.186
26	1945	1.598	0.228	2.853	2.652	1.112	2.626	0.787	0.747	2.052	2.647	3.655	14.502	2.953
27	1946	1.938	0.197	2.308	3.182	3.074	2.301	0.228	1.684	1.443	17.708	3.868	1.921	3.349
28	1947	2.009	0.397	2.057	2.891	0.438	0.624	1.265	4.387	4.217	11.305	2.229	4.869	3.081
29	1848	2.009	0.687	2.730	3.809	2.163	0.116	1.319	1.337	3.221	4.913	9.711	4.144	3.027
30	1949	2.042	4.174	1.595	3.122	1.710	0.190	3.939	0.937	1.713	18.668	1.826	5.243	3.779
31	1950	2.053	1.613	0.892	4.082	3.038	0.067	1.454	0.728	18.723	7.374	6.754	3.252	4.155
32	1951	2.009	2.357	0.090	3.092	3.115	2.402	0.728	3.252	3.021	5.096	12.780	3.954	3.505
33	1952	1.146	3.499	1.759	3.174	3.591	2.533	11.638	9.550	3.843	17.693	13.408	1.526	6.143
34	1953	0.394	1.129	2.591	2.398	3.374	2.470	2.940	20.426	6.157	42.417	23.321	3.663	9.381
35	1954	1.914	0.266	0.606	1.677	1.917	0.276	1.416	0.399	11.512	16.040	38.695	4.514	6.649
36	1955	6.208	1.632	0.497	0.647	1.620	1.148	0.193	2.218	14.518	14.659	10.247	2.269	4.677
37	1956	0.948	0.050	2.472	2.831	2.143	1.066	0.378	10.301	23.099	21.181	16.283	3.463	7.058
38	1957	9.802	0.598	0.165	2.051	1.960	0.651	0.602	7.060	8.221	1.882	7.997	2.666	3.657
39	1958	1.359	0.413	1.860	2.894	1.874	1.032	0.965	21.920	3.098	1.699	6.993	2.585	3.929
40	1959	3.323	0.212	0.646	2.480	1.624	1.603	1.200	4.499	6.385	2.173	1.729	1.069	2.250
41	1960	0.728	1.236	3.155	2.790	1.964	1.652	1.338	1.471	8.117	4.618	5.496	7.724	3.354
42	1961	0.948	0.039	2.084	2.857	2.640	0.367	1.570	0.829	21.752	7.736	13.023	4.668	4.871
43	1962	11.014	1.537	0.108	1.700	1.948	1.308	0.243	0.287	5.104	7.799	32.562	3.573	5.659
44	1963	0.750	1.365	1.169	2.256	2.202	1.047	0.532	1.281	11.138	4.506	8.183	4.272	3.221
45	1964	1.263	0.934	1.613	2.697	3.005	1.966	2.029	3.286	2.045	1.915	2.968	1.431	2.094
46	1965	0.803	0.541	2.252	2.346	2.480	2.697	0.949	0.568	2.635	12.608	4.256	2.442	2.898
47	1966	0.321	1.151	2.487	2.547	1.190	0.142	1.771	2.151	20.297	4.421	3.558	2.596	3.539
48	1967	1.366	1.007	0.848	1.278	1.382	0.424	2.199	10.084	9.205	9.487	6.281	1.269	3.758
49	1968	5.668	0.490	3.570	3.888	3.554	2.783	1.547	0.332	1.188	1.120	2.595	5.027	2.646
50	1969	4.753	0.405	1.400	1.883	0.569	0.022	0.050	3.704	15.563	11.839	8.769	4.965	4.517
51	1970	1.296	0.165	0.736	1.319	1.919	1.639	0.112	0.911	1.416	14.583	9.629	1.292	2.968
52	1971	0.306	0.530	1.042	1.427	0.338	0.248	1.613	5.682	6.370	4.421	2.557	2.681	2.277
53	1972	0.788	1.205	2.453	3.286	3.550	1.230	0.073	0.736	0.571	17.518	3.420	3.735	3.231
54	1973	1.908	0.150	0.780	3.495	2.990	0.243	0.135	4.615	20.482	6.418	8.397	4.271	4.482
55	1974	1.075	0.891	0.534	0.310	2.149	2.731	2.438	17.428	3.129	4.973	6.840	1.165	3.669
56	1975	2.718	0.274	0.586	2.241	0.936	1.913	2.330	0.952	23.754	13.253	3.904	1.656	4.543
57	1976	0.928	3.440	5.475	0.497	0.569	0.375	4.240	28.704	34.112	30.755	28.174	3.697	11.835
58	1977	0.796	0.714	0.582	0.470	1.059	1.290	1.080	1.493	0.602	0.329	4.055	4.672	1.428
59	1978	0.948	0.316	3.051	1.300	2.525	0.920	0.158	2.707	13.993	5.485	4.211	4.210	3.310
60	1979	2.409	0.258	0.937	1.457	3.451	2.376	0.675	4.424	8.665	2.445	6.605	1.728	2.950
61	1980	1.273	3.827	0.765	1.375	0.977	0.452	0.579	0.336	1.632	12.746	21.401	12.349	4.841
62	1981	1.361	0.475	0.190	0.538	0.227	1.271	3.414	2.026	5.009	5.613	2.527	0.827	1.965
63	1982	1.843	0.340	1.628	1.558	2.956	1.219	0.906	16.980	18.419	16.963	3.413	4.137	5.884
64	1983	0.877	0.201	0.860	2.674	2.767	2.227	1.600	24.242	2.998	6.143	4.195	20.009	5.735
65	1984	11.615	0.432	1.865	1.930	1.071	6.528	2.635	4.751	14.588	19.992	15.970	6.071	7.341
66	1985	0.948	0.645	1.587	2.405	2.824	2.514	0.370	1.624	10.367	5.176	14.809	3.827	3.919
67	1986	0.814	0.401	2.110	3.077	2.542	1.806	0.968	9.341	12.566	7.523	8.329	5.893	4.634
68	1987	0.553	0.008	0.310	2.659	2.435	2.264	2.296	1.615	10.448	3.633	7.519	4.479	3.195
69	1988	0.803	0.216	1.038	2.962	2.927	2.507	2.025	2.065	5.224	12.175	24.092	23.344	6.631
70	1989	2.572	1.061	1.423	2.502	2.861	2.727	1.524	17.488	13.090	26.825	4.146	0.653	6.441
71	1990	0.411	1.767	3.010	3.708	2.575	2.204	1.095	2.587	22.415	34.758	6.036	16.918	6.141
AVERAGE		2.066	0.976	1.825	2.408	2.031	1.348	1.383	4.888	11.013	10.106	9.341	4.550	4.344

Appendix 5.2.6 – Naturalised monthly average discharges for the inflow to Clanwilliam Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	8.449	5.127	3.502	1.934	5.547	2.165	1.659	1.034	172.415	89.598	30.873	13.403	27.924
2	1921	5.731	2.677	2.106	3.890	1.934	0.635	1.790	3.902	54.730	21.322	48.249	20.212	13.957
3	1922	4.122	2.666	0.911	0.874	0.434	0.351	3.761	33.606	86.941	31.638	15.733	10.895	16.003
4	1923	6.187	3.935	1.404	0.485	0.303	0.474	1.038	0.941	35.081	15.901	46.263	22.145	11.214
5	1924	8.162	7.647	2.453	0.624	0.696	0.399	0.228	3.987	169.907	81.317	14.382	6.046	24.601
6	1925	12.381	8.191	2.139	0.474	1.016	0.407	0.355	25.336	11.127	18.145	15.222	7.562	8.605
7	1926	17.372	6.665	1.564	0.470	1.446	0.508	2.438	5.765	7.940	5.593	27.804	14.155	7.853
8	1927	3.782	5.725	2.550	1.001	0.410	0.747	0.340	0.358	38.604	16.991	12.235	9.336	7.681
9	1928	4.144	2.712	1.120	0.265	0.234	0.329	11.539	23.350	24.622	35.468	20.542	12.535	11.475
10	1929	6.235	2.604	1.997	1.027	0.846	0.657	0.837	3.801	3.399	7.728	8.862	37.631	6.292
11	1930	14.975	5.054	1.964	0.418	0.373	0.329	6.632	14.624	7.033	7.314	56.004	30.918	12.222
12	1931	11.451	4.236	1.195	1.030	12.021	3.894	0.536	29.204	48.349	25.202	10.685	11.204	13.229
13	1932	6.515	2.708	1.012	0.568	0.832	1.221	0.498	5.514	56.497	62.022	23.477	7.913	14.133
14	1933	6.608	3.391	2.703	1.131	1.102	2.890	1.208	8.677	11.929	9.711	9.334	11.231	5.850
15	1934	10.951	20.255	6.556	0.556	0.430	0.926	4.209	14.393	15.162	15.076	37.963	25.640	12.729
16	1935	7.336	5.664	1.620	1.714	1.110	0.993	1.412	2.647	5.324	12.806	32.930	32.782	8.893
17	1936	4.361	4.055	2.449	1.628	0.656	0.836	3.221	13.243	48.611	50.403	23.111	10.871	13.668
18	1937	5.417	3.268	3.177	4.958	0.946	1.273	2.458	20.217	6.752	8.550	19.303	29.623	8.886
19	1938	12.466	2.766	0.855	0.724	0.836	0.709	1.671	14.546	4.437	4.182	20.945	9.363	6.182
20	1939	2.626	1.219	0.534	0.269	0.365	0.633	4.900	10.320	19.676	10.379	9.633	9.367	5.869
21	1940	3.405	3.299	2.113	1.240	1.258	0.986	5.440	41.820	74.460	36.776	67.951	103.044	28.469
22	1941	15.834	5.679	3.084	2.755	2.212	2.901	0.336	6.732	111.111	15.382	23.522	13.598	16.867
23	1942	7.176	3.989	0.709	2.692	1.573	2.024	2.222	2.207	6.906	45.923	69.444	10.926	13.145
24	1943	11.936	8.962	2.326	0.728	0.598	1.090	1.559	11.130	43.210	55.630	33.565	21.038	16.067
25	1944	15.786	7.342	5.111	1.389	1.217	0.444	1.609	25.769	88.349	91.846	79.525	12.762	27.795
26	1945	12.444	5.594	1.352	1.628	2.942	0.833	4.221	5.724	7.913	9.259	22.177	57.149	10.911
27	1946	8.598	4.711	1.986	1.068	0.955	1.456	1.628	8.143	6.906	53.013	23.634	16.300	10.809
28	1947	9.158	5.856	2.050	0.545	0.492	1.415	2.638	9.898	19.444	35.316	16.174	36.350	11.662
29	1948	14.505	4.973	1.583	0.590	0.910	0.780	2.269	5.384	10.687	11.275	36.025	23.542	9.430
30	1949	9.323	22.608	2.834	1.165	0.615	0.810	7.770	3.767	4.475	54.854	10.249	11.084	10.865
31	1950	19.082	5.602	5.074	0.750	0.996	5.279	0.382	6.119	37.450	60.842	29.521	26.863	16.602
32	1951	10.223	14.228	4.107	1.195	1.311	1.023	1.570	10.850	7.620	14.221	72.764	33.125	14.454
33	1952	16.551	5.471	2.595	1.079	0.783	0.754	27.801	27.042	14.745	44.366	63.071	17.654	18.649
34	1953	5.656	6.941	3.118	1.930	1.094	1.176	5.313	62.328	34.857	105.903	55.570	30.006	26.422
35	1954	13.038	6.370	7.557	2.589	8.293	3.237	4.221	3.917	20.081	70.120	92.454	30.586	21.889
36	1955	21.431	14.657	7.841	3.698	2.524	2.401	2.627	7.008	27.126	44.751	45.158	17.226	16.502
37	1956	6.627	3.989	2.442	1.497	7.379	2.881	3.283	14.804	82.438	75.329	60.439	28.738	24.203
38	1957	26.045	8.113	3.905	2.214	3.089	2.793	2.720	11.421	16.019	7.288	10.125	17.650	9.308
39	1958	7.284	5.575	2.162	1.415	2.532	2.404	2.816	82.388	36.987	12.104	30.567	11.590	14.917
40	1959	6.806	8.669	4.447	1.765	2.516	2.132	3.908	14.031	34.815	7.329	4.917	5.436	8.051
41	1960	4.607	2.238	2.195	1.874	2.229	1.848	1.674	5.570	41.813	9.401	18.616	36.838	10.698
42	1961	8.154	3.337	1.956	1.546	1.549	1.381	3.503	3.155	62.816	26.471	58.871	22.207	16.283
43	1962	30.317	8.976	4.447	2.759	2.135	1.882	2.488	2.849	8.144	20.994	123.376	17.006	19.012
44	1963	7.953	7.014	3.980	1.997	2.847	2.180	2.743	4.940	24.282	11.682	17.611	13.202	8.373
45	1964	7.176	7.002	2.393	1.919	1.876	3.629	6.894	9.636	7.747	7.280	20.957	8.719	7.136
46	1965	7.071	2.975	2.707	1.900	1.526	2.587	4.024	2.472	6.948	35.783	14.509	11.597	7.905
47	1966	3.663	2.257	1.647	1.958	1.332	1.165	2.481	2.950	83.407	16.719	22.454	17.542	13.074
48	1967	9.241	5.397	3.174	3.103	2.608	2.875	4.201	23.970	19.919	36.645	34.360	13.194	13.331
49	1968	20.942	4.938	0.650	0.661	0.631	0.515	2.593	2.789	4.745	6.971	7.982	15.112	5.736
50	1969	12.851	4.275	2.610	2.360	2.229	1.841	1.605	5.063	22.542	27.860	32.210	20.093	11.354
51	1970	8.849	4.410	3.461	2.987	2.122	1.658	1.782	3.495	3.360	29.876	20.191	8.237	7.610
52	1971	4.596	2.878	3.020	3.286	3.794	3.140	2.365	11.694	12.257	6.657	14.572	10.436	6.574
53	1972	4.133	2.149	3.192	0.956	0.979	2.505	1.890	2.348	2.836	33.619	9.883	16.678	6.834
54	1973	1.781	6.466	5.007	0.780	0.733	0.571	1.130	6.933	39.271	24.791	103.958	48.283	20.079
55	1974	2.998	6.613	3.730	14.483	2.008	0.597	4.190	38.011	9.147	15.016	16.674	12.052	10.551
56	1975	8.341	6.512	3.487	2.268	3.200	1.576	18.410	4.600	80.289	74.612	26.157	14.626	20.363
57	1976	6.332	8.063	8.139	6.549	4.466	2.979	5.575	77.983	76.906	93.089	74.489	19.117	32.231
58	1977	14.165	7.103	7.650	4.848	3.048	2.647	3.700	4.872	3.611	2.587	13.172	21.238	7.403
59	1978	10.712	4.857	3.991	3.267	2.200	2.285	1.767	4.099	27.404	14.710	19.411	10.899	8.823
60	1979	17.596	6.103	3.084	3.427	0.934	0.840	2.558	6.866	14.417	8.841	13.075	7.747	7.164
61	1980	5.152	15.374	10.652	4.417	3.073	3.200	2.041	2.513	4.552	26.842	67.298	48.603	16.395
62	1981	9.494	5.459	4.708	4.693	3.855	3.222	7.454	7.034	9.564	15.401	15.558	5.185	7.672
63	1982	9.763	4.086	3.278	2.793	2.864	2.662	1.173	26.824	49.001	64.337	15.800	16.613	16.674
64	1983	7.631	4.460	3.498	1.572	1.303	1.848	1.705	59.857	7.855	41.960	18.309	43.287	16.240
65	1984	29.977	5.945	7.911	5.873	3.720	13.452	8.036	14.408	41.766	45.419	49.765	16.123	20.350
66	1985	8.412	4.784	4.518	1.844	1.475	1.497	3.268	5.302	18.337	25.235	56.440	20.154	12.700
67	1986	7.826	5.282	1.882	1.587	1.516	1.213	2.326	15.812	23.831	27.095	26.027	21.798	11.402
68	1987	11.787	5.388	4.495	1.725	1.516	1.751	6.061	5.981	26.420	17.611	15.091	30.965	10.731
69	1988	9.999	5.401	3.460	1.884	1.532	3.685	5.147	6.836	14.016	23.327	44.833	51.146	14.302
70	1989	11.996	5.988	2.700	2.080	1.344	1.146	4.028	27.569	19.853	111.272	37.254	9.508	19.805
71	1990	4.073	2.014	1.538	1.411	1.373	1.060	0.710	4.346	37.257	85.152	47.338	45.864	19.457
AVERAGE		9.971	5.957	3.203	2.095	1.955	1.840	3.560	13.754	32.657	33.385	33.615	21.290	13.670

Appendix 5.2.7 Present monthly average discharges for the inflow to Clanwilliam Dam, without Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	6.661	2.566	0.400	0.000	2.413	0.000	0.355	0.631	165.978	69.852	30.964	12.377	25.983
2	1921	3.875	0.093	0.000	0.485	0.000	0.000	0.479	3.371	51.933	20.968	45.682	18.109	12.195
3	1922	2.386	0.105	0.000	0.000	0.000	0.000	2.358	32.247	82.774	31.095	15.347	9.674	14.677
4	1923	4.380	1.277	0.000	0.000	0.000	0.000	0.000	0.526	32.500	15.606	43.921	21.048	9.972
5	1924	6.218	4.977	0.000	0.000	0.000	0.000	0.000	3.517	161.578	81.481	14.261	5.031	23.046
6	1925	10.165	5.433	0.000	0.000	0.000	0.000	0.000	24.163	11.053	16.473	14.759	6.520	7.454
7	1926	14.755	6.011	0.000	0.000	0.000	0.000	1.169	5.178	7.623	5.496	26.247	13.067	6.675
8	1927	2.095	2.948	0.000	0.000	0.000	0.000	0.000	0.000	35.301	16.734	11.966	8.334	6.440
9	1928	2.393	0.108	0.000	0.000	0.000	0.000	10.124	22.543	24.082	33.666	19.696	11.398	10.400
10	1929	4.488	0.047	0.000	0.000	0.000	0.000	0.000	3.371	3.368	7.542	8.699	35.197	5.217
11	1930	13.153	2.400	0.000	0.000	0.000	0.000	5.205	13.709	6.906	7.000	52.632	29.722	10.974
12	1931	9.543	1.663	0.000	0.000	8.206	1.508	0.000	28.043	46.675	24.111	10.095	9.779	11.646
13	1932	4.701	0.139	0.000	0.000	0.000	0.000	0.000	4.827	53.708	59.680	23.209	6.808	12.626
14	1933	4.816	0.814	0.000	0.000	0.000	0.463	0.000	8.038	11.547	9.360	8.994	9.383	4.474
15	1934	8.602	17.500	3.483	0.000	0.000	0.000	2.840	13.523	14.606	14.516	36.182	24.364	11.348
16	1935	5.567	3.052	0.000	0.000	0.000	0.000	0.193	2.001	5.270	12.246	31.309	31.266	7.606
17	1936	2.550	1.470	0.000	0.000	0.000	0.000	1.933	12.466	46.323	48.359	22.798	9.584	12.185
18	1937	3.644	0.714	0.097	1.613	0.000	0.000	0.969	18.877	6.478	8.214	18.503	28.311	7.320
19	1938	10.618	0.174	0.000	0.000	0.000	0.000	0.390	13.575	4.306	4.017	20.165	8.156	5.176
20	1939	1.116	0.000	0.000	0.000	0.000	0.000	3.338	8.845	18.225	10.092	8.431	8.249	5.036
21	1940	1.691	0.668	0.000	0.000	0.000	0.000	3.820	38.601	71.634	36.265	67.385	101.404	26.796
22	1941	13.741	3.002	0.000	0.000	0.000	0.522	0.000	5.518	105.566	15.360	23.619	12.469	14.930
23	1942	5.332	1.420	0.000	0.000	0.000	0.000	0.984	1.762	6.478	43.201	67.706	9.705	11.542
24	1943	10.010	6.227	0.000	0.000	0.000	0.000	0.282	9.763	39.501	55.450	32.343	19.959	14.548
25	1944	13.911	4.676	2.005	0.000	0.000	0.000	0.267	22.675	85.067	90.389	79.555	11.567	26.059
26	1945	10.544	2.994	0.000	0.000	0.000	0.000	2.952	5.257	7.785	9.132	21.908	53.364	9.487
27	1946	6.735	2.138	0.000	0.000	0.000	0.000	0.409	7.523	6.629	49.492	23.181	15.216	8.398
28	1947	7.299	3.284	0.000	0.000	0.000	0.000	1.470	6.841	19.051	33.333	15.852	35.167	10.388
29	1948	12.578	2.373	0.000	0.000	0.000	0.000	0.919	4.876	10.347	10.794	34.838	22.103	8.290
30	1949	7.322	18.990	0.000	0.000	0.000	0.000	5.282	3.330	4.356	51.521	10.044	10.023	9.304
31	1950	17.167	2.632	1.945	0.000	0.000	2.904	0.000	5.834	32.785	60.456	29.193	25.779	14.982
32	1951	8.292	11.347	1.031	0.000	0.000	0.000	0.328	9.588	7.311	13.265	71.054	31.893	12.941
33	1952	14.673	2.358	0.000	0.000	0.000	0.000	23.608	25.154	14.590	42.568	62.353	16.459	16.968
34	1953	3.881	4.237	0.000	0.000	0.000	0.000	3.600	57.069	34.651	104.890	55.753	28.916	24.679
35	1954	11.096	3.747	4.436	0.000	2.846	0.843	2.909	3.498	18.133	67.600	91.160	29.520	19.850
36	1955	19.448	11.860	4.727	0.623	0.000	0.011	1.412	6.231	24.552	43.179	44.666	16.057	14.516
37	1956	4.672	1.436	0.000	0.000	3.970	0.268	2.034	12.451	78.277	74.414	60.547	27.840	22.239
38	1957	24.165	5.433	0.833	0.000	0.000	0.410	1.470	10.047	15.154	7.109	9.240	16.578	7.570
39	1958	5.511	2.998	0.000	0.000	0.000	0.007	1.393	56.698	36.767	11.969	30.109	10.540	13.100
40	1959	4.796	6.085	1.344	0.000	0.000	0.000	2.620	13.060	33.997	7.124	4.719	4.510	6.512
41	1960	2.957	0.000	0.000	0.000	0.000	0.000	0.382	5.044	40.860	8.024	17.902	34.393	9.177
42	1961	6.358	0.784	0.000	0.000	0.000	0.000	2.080	2.666	57.471	26.211	58.033	20.906	14.589
43	1962	27.827	6.193	1.359	0.000	0.000	0.000	1.270	2.445	7.419	20.210	118.308	15.841	15.965
44	1963	6.184	4.306	0.833	0.000	0.000	0.000	1.486	4.428	22.184	11.092	16.649	12.172	6.624
45	1964	5.361	4.318	0.000	0.000	0.000	0.985	5.502	8.863	7.596	7.124	20.669	7.770	5.718
46	1965	5.339	0.429	0.000	0.000	0.000	0.003	2.755	2.023	8.516	33.796	14.060	10.417	6.339
47	1966	1.849	0.000	0.000	0.000	0.000	0.000	1.061	2.404	78.816	16.455	22.289	16.484	11.572
48	1967	7.385	2.759	0.112	0.000	0.000	0.500	2.770	21.983	18.935	35.051	33.896	12.091	11.399
49	1968	18.586	2.304	0.000	0.000	0.000	0.000	1.208	2.378	4.641	6.900	7.706	13.854	4.827
50	1969	10.379	1.686	0.000	0.000	0.000	0.000	0.394	4.169	19.630	26.584	31.709	18.627	9.513
51	1970	6.978	1.825	0.392	0.000	0.000	0.000	0.568	3.035	3.198	27.378	18.864	7.188	5.857
52	1871	2.920	0.336	0.000	0.004	0.754	0.750	0.911	10.457	11.659	8.071	14.255	9.306	4.807
53	1972	2.404	0.000	0.008	0.000	0.000	0.100	0.676	1.896	2.809	29.917	9.382	15.430	5.263
54	1973	0.000	3.901	1.686	0.000	0.000	0.000	0.000	5.589	35.907	23.952	102.931	47.012	18.534
55	1974	1.150	3.920	0.642	11.212	0.000	0.000	2.736	33.718	8.912	14.315	16.291	11.011	8.746
56	1975	6.306	3.932	0.422	0.000	0.155	0.000	16.848	4.137	74.636	74.211	25.939	13.557	18.385
57	1976	4.555	4.811	4.204	3.256	1.401	0.597	3.862	71.958	76.581	93.383	74.714	18.021	30.035
58	1977	12.317	4.495	4.555	1.576	0.012	0.224	2.419	4.413	3.576	2.569	12.317	19.919	5.721
59	1978	8.979	2.311	0.706	0.000	0.000	0.000	0.548	3.367	25.066	14.038	18.959	9.567	6.989
60	1979	15.685	3.527	0.022	0.127	0.000	0.000	1.308	5.828	13.476	8.843	12.190	6.721	5.663
61	1980	3.383	11.802	7.475	0.922	0.033	0.795	0.795	2.102	4.444	26.385	64.526	47.266	14.246
62	1981	7.590	2.855	1.643	1.378	0.819	0.694	5.433	6.504	9.039	14.953	15.263	4.256	5.912
63	1982	7.930	1.524	0.179	0.000	0.000	0.224	0.000	21.621	47.844	63.523	15.471	15.429	14.569
64	1983	5.828	1.879	0.429	0.000	0.000	0.000	0.367	53.341	7.717	41.707	18.100	42.244	14.422
65	1964	28.110	3.264	4.529	2.401	0.610	9.714	6.547	13.579	40.062	43.771	49.880	15.155	18.288
66	1985	6.530	2.161	1.314	0.000	0.000	0.000	2.034	4.794	16.593	24.518	54.424	19.018	11.042
67	1986	6.037	2.701	0.000	0.000	0.000	0.000	0.992	13.512	21.826	26.730	25.520	20.525	9.876
68	1987	9.981	2.828	1.415	0.000	0.000	0.000	4.418	5.466	24.915	17.223	13.874	29.510	9.134
69	1988	6.191	2.828	0.400	0.000	0.000	0.911	3.615	6.242	13.021	21.296	40.804	49.811	12.305
70	1989	9.920	3.295	0.000	0.000	0.000	0.000	2.504	23.671	18.217	110.992	37.179	8.403	18.069
71	1990	2.367	0.000	0.000	0.000	0.000	0.000	0.000	3.681	32.315	83.823	47.300	45.184	18.006
AVERAGE		8.088	3.329	0.744	0.332	0.300	0.316	2.262	12.444	30.974	32.478	32.811	20.050	12.076

Appendix 5.2.8 Present monthly average discharges for the inflow to Clanwilliam Dam, with Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	6.581	2.554	0.347	0.134	2.278	0.120	0.216	0.620	163.786	90.024	31.025	12.361	25.608
2	1921	3.771	0.123	0.138	0.243	0.128	0.120	0.355	3.173	49.572	20.314	44.274	19.017	11.799
3	1922	2.315	0.123	0.138	0.134	0.128	0.120	2.041	31.369	79.267	29.376	12.858	9.452	13.951
4	1923	4.279	1.139	0.138	0.134	0.126	0.120	0.107	0.496	30.170	14.781	41.562	20.598	9.503
5	1924	5.597	4.908	0.138	0.134	0.126	0.120	0.107	3.435	154.360	76.853	13.734	4.919	21.992
6	1925	9.133	5.178	0.138	0.134	0.128	0.120	0.107	23.559	10.941	14.315	14.243	6.366	7.097
7	1926	13.646	5.907	0.138	0.134	0.128	0.120	1.085	4.958	7.234	5.350	24.533	12.832	6.381
8	1927	2.046	2.686	0.138	0.106	0.000	0.000	0.000	0.000	31.705	15.998	10.760	7.613	5.932
9	1928	2.236	0.123	0.138	0.134	0.000	0.000	9.970	22.222	23.248	31.097	18.384	11.142	9.952
10	1929	4.406	0.123	0.138	0.134	0.000	0.000	0.000	3.360	3.345	7.374	8.456	32.292	4.963
11	1930	12.914	2.323	0.136	0.000	0.000	0.000	4.919	13.026	6.701	6.396	49.645	28.434	10.450
12	1931	9.315	1.648	0.138	0.134	7.030	1.493	0.107	27.438	45.633	22.416	9.296	8.739	11.114
13	1932	4.574	0.123	0.138	0.134	0.000	0.000	0.000	4.368	50.868	53.554	22.035	6.377	11.910
14	1933	4.719	0.787	0.138	0.134	0.128	0.392	0.107	7.728	11.146	8.628	8.561	7.435	4.181
15	1934	7.527	17.296	3.480	0.134	0.128	0.120	2.601	13.056	13.673	13.288	34.240	24.013	10.854
16	1935	5.481	2.952	0.138	0.134	0.128	0.120	0.182	1.657	5.162	11.193	28.789	27.732	7.002
17	1936	2.390	1.424	0.138	0.134	0.128	0.120	1.810	12.003	43.476	43.280	22.035	9.475	11.423
18	1937	3.521	0.706	0.138	1.471	0.128	0.120	0.556	17.615	6.127	7.504	17.200	26.875	6.862
19	1938	10.462	0.132	0.138	0.134	0.128	0.120	0.290	12.828	4.097	3.775	18.623	7.674	4.922
20	1939	1.034	0.123	0.138	0.000	0.000	0.000	2.882	9.718	16.856	9.648	9.233	7.859	4.804
21	1940	1.576	0.556	0.138	0.000	0.000	0.000	3.330	35.682	66.485	33.513	64.591	100.620	25.545
22	1941	13.694	2.936	0.136	0.134	0.128	0.519	0.107	4.398	103.371	15.361	23.662	12.393	14.683
23	1942	5.246	1.405	0.138	0.134	0.126	0.120	0.942	1.676	6.154	39.497	65.994	9.697	11.079
24	1943	9.920	6.094	0.138	0.134	0.128	0.120	0.174	8.314	34.479	55.089	31.336	19.965	13.913
25	1944	13.809	4.537	1.958	0.134	0.128	0.120	0.107	20.251	81.431	90.517	79.645	11.481	25.543
26	1945	10.469	2.952	0.138	0.134	0.128	0.120	2.863	5.141	7.643	8.979	21.584	49.815	9.159
27	1946	6.523	2.111	0.138	0.134	0.128	0.120	0.394	7.213	6.713	46.091	22.420	14.969	9.010
28	1947	7.064	3.249	0.138	0.134	0.128	0.120	1.239	8.072	18.260	30.682	15.636	31.590	9.722
29	1948	12.295	2.338	0.138	0.134	0.128	0.120	0.733	4.708	9.880	9.595	33.430	21.107	7.935
30	1949	6.900	17.697	0.138	0.134	0.128	0.120	3.488	3.263	4.201	46.886	9.841	5.737	8.277
31	1950	16.868	1.989	1.871	0.134	0.128	2.904	0.107	5.484	28.573	57.430	28.218	25.753	14.228
32	1951	6.216	11.231	1.027	0.134	0.128	0.120	0.286	8.520	6.701	11.966	68.192	31.873	12.457
33	1952	14.588	2.261	0.138	0.134	0.128	0.120	21.000	22.696	14.163	40.615	62.418	16.368	16.369
34	1953	3.769	4.108	0.138	0.134	0.128	0.120	2.990	52.230	34.701	105.226	55.874	28.883	24.275
35	1954	11.005	3.700	4.357	0.134	2.540	0.817	2.805	3.465	17.055	67.722	91.394	28.483	19.737
36	1955	19.424	11.717	4.682	0.594	0.128	0.120	1.405	5.705	23.737	43.258	44.701	15.996	14.407
37	1956	4.809	1.432	0.138	0.134	3.474	0.216	1.968	10.988	76.849	74.545	60.615	27.607	21.881
38	1957	24.158	5.386	0.833	0.134	0.128	0.395	1.416	9.367	13.835	6.971	9.203	16.521	7.396
39	1958	5.413	2.952	0.138	0.134	0.128	0.120	1.108	52.610	38.745	11.931	30.170	10.501	12.755
40	1959	4.747	6.054	1.284	0.134	0.128	0.120	2.535	12.466	32.407	6.937	4.536	4.383	6.302
41	1960	2.908	0.123	0.138	0.134	0.128	0.120	0.290	4.857	40.158	8.150	16.745	32.164	8.791
42	1961	6.265	0.760	0.138	0.134	0.128	0.120	1.787	2.498	52.568	23.939	58.169	20.858	14.001
43	1962	27.865	6.044	1.352	0.134	0.128	0.120	1.258	2.430	6.701	18.750	117.692	15.780	16.744
44	1963	8.123	4.124	0.728	0.134	0.128	0.120	1.405	4.267	19.958	10.898	16.728	12.158	6.412
45	1964	5.265	4.186	0.138	0.134	0.128	0.664	5.309	8.400	7.377	6.933	20.325	7.585	5.572
46	1965	5.149	0.402	0.138	0.134	0.128	0.120	2.674	1.937	5.988	31.138	13.691	10.058	6.020
47	1966	1.878	0.123	0.138	0.134	0.128	0.120	0.807	2.236	74.541	14.692	21.046	16.104	10.947
48	1967	7.116	2.655	0.138	0.134	0.128	0.496	2.558	20.975	17.292	34.819	33.943	12.002	11.130
49	1968	18.614	2.242	0.138	0.134	0.128	0.120	0.988	2.359	4.495	6.784	7.303	13.222	4.739
50	1969	9.073	1.636	0.138	0.134	0.128	0.120	0.394	3.748	16.609	23.794	27.842	18.102	8.540
51	1970	6.847	1.814	0.381	0.134	0.128	0.120	0.560	2.946	3.036	24.160	18.811	7.105	5.570
52	1971	2.894	0.325	0.138	0.134	0.741	0.724	0.575	9.576	11.630	6.102	14.234	9.274	4.717
53	1972	2.296	0.123	0.138	0.134	0.128	0.120	0.672	1.811	2.766	26.736	8.482	14.958	4.902
54	1973	0.109	3.670	1.796	0.134	0.128	0.120	0.107	4.465	33.333	22.271	99.533	47.000	17.835
55	1974	1.094	3.812	0.620	11.186	0.128	0.120	2.516	30.891	8.603	14.059	16.362	10.927	8.443
56	1975	6.256	3.897	0.418	0.134	0.135	0.120	16.405	4.032	72.311	74.303	25.932	13.497	18.163
57	1976	4.467	4.818	4.097	3.215	1.356	0.582	3.523	72.039	76.755	93.584	74.851	17.983	30.030
58	1977	12.206	4.460	4.514	1.557	0.128	0.153	2.327	4.349	3.526	2.550	11.613	19.926	5.629
59	1976	8.865	2.296	0.627	0.134	0.128	0.120	0.537	3.005	23.324	14.075	18.956	9.571	6.830
60	1979	15.604	3.504	0.138	0.134	0.128	0.120	1.247	5.156	12.191	8.457	10.965	6.582	5.386
61	1980	3.230	10.818	7.329	0.546	0.128	0.750	0.749	2.079	4.329	26.186	64.621	47.349	14.094
62	1981	7.488	2.825	1.639	1.281	0.815	0.455	4.938	6.479	9.090	14.973	15.244	4.172	5.826
63	1982	7.865	1.482	0.138	0.134	0.128	0.123	0.107	18.868	47.977	63.629	15.457	15.411	14.446
64	1983	5.724	1.841	0.414	0.134	0.128	0.120	0.186	48.579	7.689	41.762	18.091	42.370	14.033
65	1984	28.102	3.228	4.244	2.237	0.496	9.654	6.513	13.588	40.153	43.902	49.963	15.149	18.255
66	1985	6.440	2.122	1.206	0.134	0.128	0.120	1.995	4.689	14.873	22.909	53.095	18.986	10.648
67	1986	5.929	2.662	0.138	0.134	0.128	0.120	0.888	11.507	18.808	25.162	25.573	20.515	9.350
68	1987	9.894	2.825	1.385	0.134	0.128	0.120	3.997	5.324	23.426	16.711	12.335	28.800	8.756
69	1988	8.096	2.805	0.377	0.134	0.128	0.384	3.284	5.959	12.056	19.425	41.052	49.887	12.000
70	1989	9.641	3.206	0.138	0.134	0.128	0.120	2.161	20.870	15.607	111.126	37.173	8.315	17.659
71	1990	2.337	0.123	0.138	0.134	0.128	0.120	0.107	3.420	28.302	79.291	47.291	45.213	17.332
AVERAGE		7.919	3.243	0.807	0.425	0.365	0.371	2.075	11.679	29.530	31.257	32.059	19.538	11.669

Appendix 5.2.9 Future monthly average discharges for the inflow to Clanwilliam Dam, without Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	6.255	1.912	0.000	0.000	1.630	0.000	0.038	0.527	165.976	89.852	30.964	12.176	25.749
2	1921	3.469	0.000	0.000	0.000	0.000	0.000	0.162	3.267	51.833	20.968	45.682	18.908	12.060
3	1922	1.980	0.000	0.000	0.000	0.000	0.000	2.041	32.143	82.774	31.095	15.347	9.473	14.582
4	1923	3.974	0.623	0.000	0.000	0.000	0.000	0.000	0.422	32.500	15.606	43.921	20.847	9.858
5	1924	5.812	4.323	0.000	0.000	0.000	0.000	0.000	3.413	161.576	81.481	14.261	4.830	22.932
6	1925	9.759	4.779	0.000	0.000	0.000	0.000	0.000	24.059	11.053	16.473	14.759	6.319	7.340
7	1926	14.349	5.357	0.000	0.000	0.000	0.000	0.852	5.074	7.623	5.496	26.247	12.866	6.536
8	1927	1.689	2.294	0.000	0.000	0.000	0.000	0.000	0.000	35.301	16.734	11.966	8.133	6.335
9	1928	1.987	0.000	0.000	0.000	0.000	0.000	9.807	22.439	24.082	33.666	19.696	11.197	10.305
10	1929	4.082	0.000	0.000	0.000	0.000	0.000	0.000	3.267	3.368	7.542	8.699	34.996	5.153
11	1930	12.747	1.746	0.000	0.000	0.000	0.000	4.888	13.605	6.906	7.000	52.632	29.521	10.835
12	1931	9.137	1.009	0.000	0.000	7.423	0.895	0.000	27.939	46.875	24.111	10.095	9.578	11.420
13	1932	4.295	0.000	0.000	0.000	0.000	0.000	0.000	4.723	53.708	59.680	23.209	6.607	12.754
14	1933	4.410	0.160	0.000	0.000	0.000	0.000	0.000	7.934	11.547	9.360	8.994	9.182	4.321
15	1934	8.196	16.846	2.691	0.000	0.000	0.000	2.523	13.419	14.606	14.516	36.182	24.163	11.141
16	1935	5.161	2.398	0.000	0.000	0.000	0.000	0.000	1.897	5.270	12.246	31.309	31.065	7.477
17	1936	2.144	0.816	0.000	0.000	0.000	0.000	1.616	12.362	46.323	48.359	22.796	9.383	12.046
18	1937	3.238	0.060	0.000	0.768	0.000	0.000	0.652	18.773	6.478	8.214	18.503	28.110	7.100
19	1938	10.212	0.000	0.000	0.000	0.000	0.000	0.073	13.471	4.306	4.017	20.165	7.965	5.076
20	1939	0.710	0.000	0.000	0.000	0.000	0.000	3.021	9.741	18.225	10.092	9.431	8.048	4.950
21	1940	1.285	0.014	0.000	0.000	0.000	0.000	3.503	38.497	71.634	36.265	67.365	101.203	26.657
22	1941	13.335	2.348	0.000	0.000	0.000	0.000	0.000	5.414	105.586	15.360	23.619	12.268	14.773
23	1942	4.926	0.766	0.000	0.000	0.000	0.000	0.667	1.658	6.478	43.201	67.706	9.504	11.402
24	1943	9.604	5.573	0.000	0.000	0.000	0.000	0.000	9.659	39.501	55.450	32.343	19.758	14.411
25	1944	13.505	4.022	1.213	0.000	0.000	0.000	0.000	22.771	85.067	90.389	79.555	11.366	25.857
26	1945	10.138	2.340	0.000	0.000	0.000	0.000	2.635	5.153	7.785	9.132	21.908	53.163	9.347
27	1946	6.329	1.484	0.000	0.000	0.000	0.000	0.092	7.419	6.829	49.492	23.181	15.015	9.259
28	1947	6.893	2.630	0.000	0.000	0.000	0.000	1.153	8.737	19.051	33.333	15.852	34.966	10.249
29	1948	12.172	1.719	0.000	0.000	0.000	0.000	0.602	4.772	10.347	10.794	34.838	21.902	8.150
30	1949	6.916	18.336	0.000	0.000	0.000	0.000	4.965	3.226	4.356	51.521	10.044	9.822	9.164
31	1950	16.761	1.976	1.153	0.000	0.000	2.291	0.000	5.530	32.785	60.456	29.193	25.578	14.749
32	1951	7.886	10.693	0.239	0.000	0.000	0.000	0.011	9.484	7.311	13.265	71.054	31.692	12.734
33	1952	14.267	1.704	0.000	0.000	0.000	0.000	23.291	25.050	14.590	42.566	62.353	16.258	16.828
34	1953	3.455	3.583	0.000	0.000	0.000	0.000	3.283	56.965	34.651	104.990	55.753	28.715	24.539
35	1954	10.690	3.093	3.644	0.000	2.163	0.230	2.592	3.394	18.133	67.600	91.160	29.319	19.530
36	1955	19.042	11.206	3.935	0.000	0.000	0.000	1.095	6.127	24.552	43.179	44.666	15.856	14.255
37	1956	4.466	0.782	0.000	0.000	3.187	0.000	1.717	12.347	78.277	74.414	60.547	27.439	22.016
38	1957	23.759	4.779	0.041	0.000	0.000	0.000	1.153	9.943	15.154	7.109	9.240	16.377	7.329
39	1958	5.105	2.344	0.000	0.000	0.000	0.000	1.076	56.594	36.787	11.969	30.109	10.339	12.959
40	1959	4.390	5.431	0.552	0.000	0.000	0.000	2.303	12.956	33.997	7.124	4.719	4.309	6.306
41	1960	2.551	0.000	0.000	0.000	0.000	0.000	0.065	4.940	40.860	9.024	17.902	34.192	9.091
42	1961	5.952	0.130	0.000	0.000	0.000	0.000	1.763	2.562	57.471	26.211	58.033	20.705	14.449
43	1962	27.421	5.539	0.567	0.000	0.000	0.000	0.953	2.341	7.419	20.210	118.308	15.640	16.758
44	1963	5.788	3.652	0.041	0.000	0.000	0.000	1.169	4.324	22.184	11.092	16.649	11.971	6.417
45	1964	4.855	3.664	0.000	0.000	0.000	0.372	5.185	8.759	7.596	7.124	20.669	7.569	5.527
46	1965	4.933	0.000	0.000	0.000	0.000	0.000	2.438	1.919	6.516	33.796	14.060	10.216	6.218
47	1966	1.543	0.000	0.000	0.000	0.000	0.000	0.744	2.300	78.816	16.455	22.289	16.283	11.467
48	1967	6.979	2.105	0.000	0.000	0.000	0.000	2.453	21.879	16.935	35.051	33.896	11.890	11.207
49	1968	18.180	1.650	0.000	0.000	0.000	0.000	0.891	2.274	4.641	6.900	7.706	13.653	4.687
50	1968	9.973	1.032	0.000	0.000	0.000	0.000	0.077	4.085	19.630	26.584	31.709	18.626	9.374
51	1970	6.572	1.171	0.000	0.000	0.000	0.000	0.251	2.931	3.198	27.378	18.864	6.987	5.685
52	1971	2.514	0.000	0.000	0.000	0.000	0.137	0.594	10.353	11.659	6.071	14.255	9.105	4.583
53	1972	1.998	0.000	0.000	0.000	0.000	0.000	0.359	1.792	2.809	29.917	9.382	15.229	5.168
54	1973	0.000	3.247	1.094	0.000	0.000	0.000	0.000	5.485	35.907	23.952	102.931	46.811	18.368
55	1974	0.744	3.266	0.000	10.367	0.000	0.000	2.419	33.614	8.912	14.315	16.291	10.810	8.480
56	1975	5.900	3.276	0.000	0.000	0.000	0.000	16.531	4.033	74.636	74.211	25.938	13.356	18.197
57	1976	4.149	4.157	3.412	2.411	0.618	0.000	3.545	71.852	76.581	93.383	74.714	17.820	29.646
58	1977	11.911	3.841	3.763	0.731	0.000	0.000	2.102	4.309	3.576	2.569	12.317	19.718	5.423
59	1978	8.573	1.657	0.000	0.000	0.000	0.000	0.231	3.263	25.066	14.038	18.959	9.386	6.790
60	1979	15.279	2.873	0.000	0.000	0.000	0.000	0.991	5.724	13.476	8.643	12.190	6.520	5.510
61	1980	2.977	11.148	6.663	0.077	0.000	0.182	0.478	1.998	4.444	26.385	64.526	47.065	13.913
62	1981	7.184	2.201	0.851	0.533	0.036	0.081	5.116	6.400	9.039	14.953	15.263	4.055	5.521
63	1982	7.524	0.870	0.000	0.000	0.000	0.000	0.000	21.517	47.844	63.523	15.471	15.228	14.421
64	1983	5.422	1.225	0.000	0.000	0.000	0.000	0.050	53.237	7.717	41.707	18.100	42.043	14.246
65	1984	27.704	2.610	3.737	1.556	0.000	9.101	6.230	13.475	40.062	43.771	49.880	14.954	17.910
66	1985	6.124	1.507	0.522	0.000	0.000	0.000	1.717	4.690	16.593	24.518	54.424	18.817	10.835
67	1986	5.631	2.047	0.000	0.000	0.000	0.000	0.675	13.408	21.826	26.730	25.520	20.324	9.736
68	1987	9.555	2.174	0.623	0.000	0.000	0.000	4.101	5.362	24.915	17.223	13.874	29.309	8.927
69	1988	7.765	2.174	0.000	0.000	0.000	0.298	3.298	6.136	13.021	21.296	40.904	48.610	12.080
70	1989	9.514	2.641	0.000	0.000	0.000	0.000	2.187	23.567	18.217	110.992	37.179	8.202	17.950
71	1990	1.961	0.000	0.000	0.000	0.000	0.000	0.000	3.577	32.315	83.623	47.300	44.963	17.946
AVERAGE		7.688	2.775	0.490	0.232	0.212	0.191	2.006	12.342	30.974	32.478	32.811	19.649	11.902

Appendix 5.2:10—Future monthly average discharges for the inflow to Clanwilliam Dam, with Rosendaal Dam

RECORD	YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
1	1920	6.175	1.900	0.138	0.134	1.495	0.120	0.107	0.516	161.467	90.024	31.025	12.160	25.416
2	1921	3.365	0.123	0.138	0.134	0.128	0.120	0.107	3.069	49.572	20.314	41.644	18.796	11.482
3	1922	1.909	0.123	0.138	0.134	0.128	0.120	1.724	31.265	79.267	29.376	12.858	9.251	13.866
4	1923	3.873	0.485	0.138	0.134	0.000	0.000	0.000	0.392	30.170	14.781	41.562	20.397	9.360
5	1924	5.191	4.254	0.138	0.134	0.000	0.000	0.000	3.331	154.360	76.853	13.734	4.718	21.850
6	1925	8.727	4.524	0.138	0.134	0.128	0.120	0.107	23.455	10.941	14.315	14.243	6.165	6.984
7	1926	13.240	5.253	0.138	0.000	0.000	0.000	0.768	4.854	7.234	5.350	24.533	12.631	6.210
8	1927	1.640	2.032	0.136	0.000	0.000	0.000	0.000	0.000	31.705	15.998	10.760	7.612	5.816
9	1928	1.830	0.123	0.138	0.000	0.000	0.000	9.653	22.118	23.248	31.097	18.384	10.941	9.855
10	1929	4.000	0.123	0.138	0.000	0.000	0.000	0.000	3.256	3.345	7.374	8.456	32.081	4.892
11	1930	12.508	1.669	0.138	0.000	0.000	0.000	4.602	12.922	8.701	6.396	49.645	28.233	10.311
12	1931	8.909	0.894	0.138	0.027	6.247	0.880	0.083	27.334	45.633	22.416	9.296	8.538	10.877
13	1932	4.168	0.123	0.138	0.000	0.000	0.000	0.000	4.264	50.868	53.554	22.035	6.176	11.838
14	1933	4.313	0.133	0.138	0.134	0.128	0.120	0.107	7.624	11.146	8.628	8.561	7.234	4.045
15	1934	7.121	16.842	2.688	0.134	0.128	0.000	2.284	12.952	13.873	13.288	34.240	23.812	10.637
16	1935	5.075	2.298	0.138	0.031	0.000	0.000	0.000	1.553	5.182	11.193	28.789	27.531	6.844
17	1936	1.984	0.770	0.138	0.134	0.004	0.000	1.493	11.899	43.476	43.280	22.035	9.274	11.264
18	1937	3.115	0.123	0.138	0.626	0.128	0.120	0.239	17.511	6.127	7.504	17.200	26.674	6.656
19	1938	10.056	0.123	0.138	0.134	0.000	0.000	0.073	12.724	4.097	3.775	18.623	7.473	4.824
20	1939	0.628	0.123	0.000	0.000	0.000	0.000	2.565	9.614	16.856	9.648	9.233	7.658	4.708
21	1940	1.170	0.123	0.136	0.000	0.000	0.000	3.013	35.578	66.485	33.513	64.591	100.419	25.423
22	1941	13.288	2.282	0.138	0.134	0.128	0.120	0.107	4.294	100.411	15.361	23.662	12.182	14.292
23	1942	4.840	0.751	0.136	0.134	0.128	0.120	0.625	1.572	6.154	39.497	63.030	9.496	10.688
24	1943	9.514	5.440	0.138	0.134	0.128	0.120	0.107	8.210	34.479	55.089	28.114	19.764	13.520
25	1944	13.403	3.863	1.164	0.134	0.128	0.120	0.107	20.147	78.849	90.517	79.645	11.280	25.151
26	1945	10.063	2.298	0.138	0.134	0.128	0.120	2.546	5.037	7.643	8.979	21.584	49.614	9.019
27	1946	6.117	1.457	0.138	0.134	0.128	0.023	0.092	7.109	6.713	46.091	22.420	14.768	8.884
28	1947	6.656	2.595	0.138	0.000	0.000	0.000	0.922	7.968	18.260	30.682	15.636	31.389	9.551
29	1948	11.889	1.684	0.138	0.134	0.000	0.000	0.416	4.604	9.880	9.595	33.430	20.906	7.776
30	1949	6.494	17.043	0.138	0.134	0.000	0.000	3.171	3.159	4.201	46.886	9.841	5.536	8.117
31	1950	16.462	1.345	1.079	0.134	0.128	2.291	0.107	5.380	28.573	57.430	26.728	25.004	13.824
32	1951	7.591	10.365	0.235	0.134	0.128	0.120	0.107	8.416	6.701	11.966	66.719	30.945	12.040
33	1952	14.121	1.237	0.138	0.134	0.128	0.120	20.683	22.592	14.163	37.664	62.396	16.167	15.943
34	1953	3.363	3.454	0.138	0.134	0.128	0.120	2.673	51.643	32.431	104.936	55.874	28.682	23.883
35	1954	10.599	3.046	3.565	0.134	1.757	0.204	2.488	3.361	16.971	66.964	91.394	29.282	19.346
36	1955	19.018	11.063	3.890	0.134	0.128	0.120	1.088	5.601	22.010	43.224	44.701	15.795	14.017
37	1956	4.403	0.778	0.138	0.134	2.691	0.120	1.651	10.884	74.634	74.545	60.615	27.406	21.591
38	1957	23.752	4.732	0.138	0.134	0.128	0.120	1.099	9.263	13.835	6.871	8.770	16.173	7.125
39	1958	4.970	2.298	0.138	0.134	0.128	0.120	0.791	52.506	36.458	11.813	28.166	8.934	12.379
40	1959	3.779	5.400	0.492	0.134	0.128	0.120	2.218	12.362	32.407	6.937	4.536	4.182	6.048
41	1960	2.502	0.123	0.138	0.134	0.128	0.120	0.107	4.753	40.158	8.150	16.745	31.883	8.716
42	1961	5.859	0.126	0.138	0.134	0.128	0.000	1.470	2.394	52.589	23.678	51.684	20.378	13.254
43	1962	26.998	5.390	0.560	0.134	0.128	0.120	0.941	2.326	8.701	18.750	115.522	15.579	16.314
44	1963	5.717	3.470	0.138	0.134	0.128	0.120	1.088	4.163	19.958	9.771	15.493	11.957	6.022
45	1964	4.859	3.532	0.138	0.134	0.128	0.120	4.992	8.296	7.377	6.933	20.325	7.384	5.386
46	1965	4.743	0.123	0.138	0.134	0.128	0.120	2.357	1.633	5.988	31.138	13.691	9.857	5.911
47	1966	1.472	0.123	0.138	0.134	0.000	0.000	0.490	2.132	74.541	14.692	21.046	15.903	10.841
48	1967	6.710	2.001	0.138	0.134	0.128	0.120	2.241	20.871	17.292	32.964	31.500	11.782	10.592
49	1968	15.813	1.586	0.138	0.134	0.128	0.120	0.671	2.255	4.495	6.784	7.303	13.021	4.396
50	1969	8.667	0.982	0.138	0.134	0.000	0.000	0.077	3.644	16.609	23.794	27.942	17.901	8.380
51	1970	6.441	1.160	0.138	0.134	0.128	0.120	0.243	2.842	3.036	24.160	17.193	6.863	5.269
52	1971	2.488	0.123	0.138	0.134	0.128	0.120	0.258	9.472	10.502	4.981	13.993	8.792	4.285
53	1972	1.890	0.123	0.138	0.134	0.128	0.120	0.355	1.707	2.766	26.736	8.482	14.757	4.616
54	1973	0.109	3.216	1.004	0.134	0.000	0.000	0.000	4.361	33.333	22.271	99.533	45.463	17.550
55	1974	0.539	3.158	0.138	10.341	0.128	0.120	2.199	30.767	8.603	12.814	13.026	10.890	7.786
56	1975	5.482	3.243	0.138	0.134	0.128	0.120	16.088	3.928	69.560	73.259	25.932	13.296	17.654
57	1976	4.061	4.164	3.305	2.370	0.573	0.120	3.206	71.782	76.755	93.584	74.851	17.782	29.639
58	1977	11.800	3.606	3.722	0.712	0.128	0.120	2.010	4.245	3.526	2.550	11.555	18.630	5.253
59	1978	8.454	1.642	0.138	0.134	0.128	0.120	0.220	2.901	22.785	12.754	18.496	9.047	6.427
60	1979	15.198	2.850	0.138	0.134	0.128	0.120	0.830	5.052	12.191	8.457	10.965	6.381	5.246
61	1980	2.824	10.164	6.537	0.134	0.128	0.137	0.432	1.975	4.329	23.551	63.284	47.148	13.463
62	1981	7.082	2.171	0.847	0.436	0.128	0.120	4.243	6.375	9.090	14.973	15.244	3.871	5.435
63	1982	7.459	0.828	0.138	0.134	0.128	0.120	0.107	17.694	46.748	63.629	15.457	15.210	14.056
64	1983	5.318	1.187	0.136	0.134	0.128	0.120	0.107	47.596	7.384	40.006	18.091	42.169	13.641
65	1984	27.696	2.572	3.452	1.392	0.128	8.663	6.196	13.484	40.153	43.902	49.963	14.948	17.864
66	1985	6.034	1.468	0.414	0.134	0.128	0.120	1.678	4.565	14.873	22.909	50.924	18.785	10.257
67	1986	5.523	2.008	0.138	0.134	0.128	0.120	0.571	11.403	18.808	24.365	23.405	20.314	8.959
68	1987	9.488	2.171	0.593	0.134	0.128	0.120	3.680	5.220	23.426	16.711	12.335	28.599	8.549
69	1988	7.692	2.151	0.138	0.134	0.128	0.120	2.967	5.855	12.056	19.064	36.827	49.686	11.428
70	1989	9.435	2.552	0.138	0.134	0.128	0.120	1.644	20.766	15.243	108.689	37.173	8.114	17.268
71	1990	1.931	0.123	0.138	0.134	0.128	0.120	0.107	3.316	28.302	75.368	47.291	45.012	16.940
AVERAGE		7.459	2.698	0.577	0.326	0.265	0.246	1.828	11.526	29.235	30.918	31.464	19.263	11.379

Appendix 5.3 Methods of collection and analysis of water quality data

Field measurements

Temperature, pH, turbidity and conductivity were measured on site, while dissolved oxygen was not measured as it was considered too variable over time to produce a meaningful instantaneous measure. Temperature was measured using a mercury thermometer, accurate to ± 0.5 °C. Twenty-four hour ranges in temperature were recorded at PHABSIM II sites using a minimum/maximum thermometer. pH was measured with a Crison Portable 506 field pH meter accurate to 0.01 pH units. A relative index of turbidity was obtained using a Secchi disc. Conductivity was measured with a Crison Conductimeter Portable 523 field meter, with built-in temperature compensation of 25 °C. The meter is accurate to 0.1 mS cm^{-1} (accuracy > ± 0.3%; reproducibility > 0.2%). Conductivity values were recorded as µS cm^{-1} and then converted to mS m^{-1}.

Water for laboratory analyses of nutrients, cations and anions was pre-filtered through an 80 µ m-mesh sieve to remove large particulate matter, and then filtered through pre-combusted and pre-weighed Whatman GF/F glass microfibre filters able to trap particles down to a size of 0.7 mm. A measured volume of water, approximately 1 *l*, was filtered in a similar way for laboratory analysis of total dissolved solids (TDS), and the filter paper was used for analysis of total suspended solids (TSS). All filtered water, except that for analysis of ammonia, was bottled in polythene containers 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 ammonia were stored in HCl-washed glass vials within polythene containers. All water samples were kept frozen while in the field and in the laboratory until they were defrosted for analysis.

Laboratory analyses

TSS

Each GF/F filter of known pre-filtration dry mass, through which a known volume of water had been filtered in the field, was dried at 60 °C for 48 h and then reweighed. The filter was weighed using a Mettler AE 100 laboratory balance with a readability and reproducibility of 0.1 mg. The difference in dry mass pre- and post-filtration in relation to the volume of water filtered constituted a measure of TSS in mg l^{-1}. Three to five control filters were subjected to transportation and handling procedures in the field similar to those of the sample filters, and then had 1 *l* of double-distilled water filtered through them on return to the laboratory. The differences in mass measured for the control filters were averaged and applied to the sample filters as a correction factor, to correct for losses in mass as a result of field procedures and the removal of soluble residues from the filters. This procedure was found to be essential for the filters of water from the upper reaches of the river, to prevent low TSS values from being masked by larger differences in mass due to filter wearing.

The organic fraction of the TSS was calculated as a percentage for the sample filters, using the difference in mass before and after combustion of the dried filter at 450 °C for 4 h.

Appendix 5.3 continued

TDS

A known volume of water filtered in the field (on average 1 *l*), was evaporated at 60 °C from preweighed lightweight glass beakers. Once all the water had evaporated, the beakers were reweighed and the difference in mass represented the TDS, expressed relative to the volume of water as concentration in mg l^{-1}. Masses were measured using a Sartorius precision laboratory balance accurate to 1 mg.

Total alkalinity (TA) and phenolphthalein alkalinity (PA)

Both measures of alkalinity were determined using the titrimetric method of Golterman *et al.* (1978). A 0.005M HCl solution was first standardised using a standardised (with oxalic acid) NaOH solution. This HCl was then used in titration to both phenolphthalein indicator and mixed indicator endpoints. Three replicate titrations were performed for each water sample. TA and PA were calculated as explained in Golterman *et al.* (1978) and expressed as mEq l^{-1} $HCO3^-$ (bicarbonate). The precision of this method is estimated at 2% at TA = 1 mmol l^{-1}, and 2-10% at TA = 1-0.1 mmol l^{-1} (Golterman *et al.* 1978).

Chloride (Cl^-) and sulphate ($SO4^{2-}$)

The anions Cl^- and $SO4^{2-}$ were determined by R. Watkins, Department of Geology, University of Cape Town, using the technique of high-performance ion chromatography as described in Haddad & Jackson (1990). The Dionex Ion Chromatograph of the Department of Geology, equipped with a conductivity detector and an automated computer-linked output facility, was used for the analysis. The anions were separated on the HPIC-AS4A anion exchange separator column with a carbonate/bicarbonate buffer eluent. Detection is by conductivity with chemical eluent suppression. Results were given in mg l^{-1} and were converted to mmol l^{-1}.

Chloride was also analysed using a method of titration described in Golterman *et al.* (1978), and the results obtained by this method were very similar to those of the HPIC method. A 0.2 M HNO_3 solution was added to each of three replicate water samples. These were then titrated with a 0.01M $Hg(NO_3)_2$ solution, standardised against NaCl, to Diphenylcarbazone-bromphenol blue mixed indicator endpoint. The precision of the method is estimated as 0.5 mg l^{-1} between 0 and 50 mg l^{-1}.

Cations

The cations Na^{2+}, K^+, Ca^{2+} and Mg^{2+} were analysed using the technique of atomic absorption flame spectrophotometry, with a VARIAN Spectra AA-30 by L. Harrower, Department of Chemical Engineering, University of Cape Town. Mg^{2+} analysis required an air-acetyl gas mixture and there were no additions. The detection limit was 0.2 ppm, with an accuracy range for the results of 5-20 ppm. An air-acetyl gas mixture was used for the analysis of Na^{2+}. The detection limit was 0.05 ppm and the range of accuracy 0.5-2 ppm. KCl was added to give 2000 ppm in all solutions. Ca^{2+} required a NO_2-acetyl gas mixture, and the addition of KCl to give 5000 ppm in all solutions. The detection limit for this element was 0.05 ppm and the accuracy range from 1-4 ppm. K^+ was analysed using an air-acetyl gas mixture, and required the addition of $CsNO_3$ to give 1000 ppm in all solutions. The detection limit of this analysis was 0.05 ppm and the accuracy range 0.5-2 ppm. Where additions were required, they were to suppress partial ionisation of the element in the flame. Detection limits were calculated from the actual absorbance readings, but a figure of 0.1 ppm could be

Appendix 5.3 continued

considered an acceptable minimum (L. Harrower, Department of Chemical Engineering, University of Cape Town, pers. comm.).

Water samples were analysed for the metals Fe and Cu by L. Harrower, Department of Chemical Engineering, University of Cape Town, using atomic absorption flame spectrophotometry, with a VARIAN Spectra AA-30 and air-acetyl gas mixture. No additions were made. The accuracy range of Cu was 2-8 ppm and that of Fe 2.5-10 ppm.

Detection limits were 0.1 ppm in both cases. However, the concentrations of both metals were below these detection limits.

Reactive silicon (SiO_2-Si)
Reactive silicon was determined using a TECHNICON AutoAnalyser II, by CSIR technicians at CSIR, EMATEK, Stellenbosch. The method employed is a standard CSIR procedure, and is outlined in Windt (1993). Results were expressed as mg l^{-1} and were converted to µmol l^{-1}.

Nutrients
Nitrates (NO_3-N), nitrites (NO_2-N), phosphates (PO_4-P) and ammonia (NH_4-N) were determined using a TECHNICON AutoAnalyser II (AAII), by CSIR technicians at CSIR, EMATEK, Stellenbosch. The principles of the methods employed are outlined in Mostert (1983). The methods themselves have been highly modified from those of Mostert to improve detection limits (H. Henning, CSIR, Stellenbosch, pers. comm.). These modified standard CSIR methods are described in Windt (1993). Results were expressed as either mg l^{-1} or mmol l^{-1} of the nutrient atom, i.e. NO3-N, NO2-N, PO4-P and NH4-N, and were converted to µmol l^{-1}. For nitrates and nitrites, the detection limit is 1 µg l^{-1}. For ammonia, the detection limit is 10 µg l^{-1}, and for phosphates, 1 µg l^{-1} (Windt 1993).

Appendix 5.4 Summary of water quality data for all mainstream sites on the Olifants River for all field trips

SEASON	SITE	DATE	CONDUCTIVITY mS/m	pH pH UNITS	NO3-N umol/l	NO2-N umol/l
WINTER	GROOTFONTEIN	25.07.90	4.50	6.80	12.71	<<0.36
WINTER	KRIEDOUWKRANS	29.07.90	10.40	7.50	21.26	<<0.36
WINTER	KLAWER	24.07.90	16.20	6.90	6.57	<<0.36
EARLY SPRING	VISGAT	23.09.90	4.80	6.00	12.28	<<0.36
EARLY SPRING	GROOTFONTEIN	25.09.90	4.70	5.80	5.06	<<0.36
EARLY SPRING	TWEEFONTEIN	26.09.90	6.40	6.10	5.17	<<0.36
EARLY SPRING	KRIEDOUWKRANS	27.09.90	10.30	6.00	14.51	<<0.36
EARLY SPRING	CLANWILLIAM	27.09.90	8.50	6.40	16.11	<<0.36
EARLY SPRING	LANGKLOOF	28.09.90	14.40	5.90	16.05	<<0.36
EARLY SPRING	BULSHOEK	28.09.90	17.80	6.30	16.29	<<0.36
EARLY SPRING	ZYPHERFONTEIN	01.10.90			12.67	<<0.36
EARLY SPRING	KLAWER	03.10.90	68.30	6.90	7.71	<<0.36
EARLY SPRING	BOTHA'S FARM	03.10.90	117.70	7.10	11.93	0.50
SPRING	VISGAT	24.11.90	3.00	6.50	3.85	<<0.36
SPRING	GROOTFONTEIN	12.11.90	3.50	5.80	<<0.36	<<0.36
SPRING	TWEEFONTEIN	23.11.90	5.00	6.40	<<0.36	<<0.36
SPRING	KRIEDOUWKRANS	16.11.90	11.20	5.50	10.16	<<0.36
SPRING	CLANWILLIAM	22.11.90	9.10	6.40	10.93	<<0.36
SPRING	LANGKLOOF	22.11.90	13.60	6.80	11.95	<<0.36
SPRING	BULSHOEK	21.11.90	13.40	6.70	7.71	<<0.36
SPRING	ZYPHERFONTEIN	21.11.90	22.00	6.70	4.07	<<0.36
SPRING	KLAWER	20.11.90	108.60	6.90	0.57	<<0.36
SPRING	BOTHA'S FARM	20.11.90	175.30	6.90	9.86	0.64
SUMMER	SOURCE	20.03.91	6.60	6.00	71.34	0.25
SUMMER	VISGAT	20.03.91	2.50	6.00	2.85	0.08
SUMMER	BOSCHKLOOF	19.03.91	2.90	6.50	0.43	<<0.07
SUMMER	GROOTFONTEIN	25.02.91	3.70	6.10	0.29	0.08
SUMMER	TWEEFONTEIN	08.03.91	5.00	6.90	5.50	<<0.07
SUMMER	KRIEDOUWKRANS	01.03.91	18.60	6.40	34.02	0.14
SUMMER	CLANWILLIAM	03.03.91	11.50	6.50	2.79	<<0.07
SUMMER	LANGKLOOF	03.03.91	14.90	6.70	4.86	0.08
SUMMER	BULSHOEK	07.03.91	15.10	6.40	1.07	0.08
SUMMER	ZYPHERFONTEIN	07.03.91	16.10	6.40	<<0.07	<<0.07
SUMMER	KLAWER	04.03.91	110.60	8.00	0.36	0.14
SUMMER	BOTHA'S FARM	06.03.91	199.10	7.40	12.79	0.67
AUTUMN	VISGAT	22.05.91	4.50	7.90	4.88	<<0.07
AUTUMN	GROOTFONTEIN	17.05.91	4.60	7.50	0.07	0.07
AUTUMN	TWEEFONTEIN	16.05.91	5.40	5.90	0.36	0.08
AUTUMN	KRIEDOUWKRANS	19.05.91	12.20	6.50	12.71	0.10
AUTUMN	CLANWILLIAM	19.05.91	32.40	6.30	40.62	0.41
AUTUMN	LANGKLOOF	20.05.91	69.30	6.50	51.64	0.33
AUTUMN	BULSHOEK	20.05.91	24.00	6.40	9.07	0.12
AUTUMN	ZYPHERFONTEIN	20.05.91	21.90	6.60	3.06	<<0.07
AUTUMN	KLAWER	21.05.91	116.80	6.80	1.14	0.17
AUTUMN	BOTHA'S FARM	21.05.91	169.00	7.20	10.64	0.43
EARLY SPRING	GROOTFONTEIN	15.10.91	4.10	4.90		
EARLY SPRING	KRIEDOUWKRANS	08.10.91	6.40	6.50		
EARLY SPRING	KLAWER	10.10.91	24.50	6.50		

Appendix 5.4 continued

SEASON	SITE	DATE	NH4-N umol/l	PO4-P umol/l	TDS mg/l	TSS mg/l
WINTER	GROOTFONTEIN	25.07.90	1.00	0.32	36.6	2.8
WINTER	KRIEDOUWKRANS	29.07.90	2.29	0.48	73.8	5.4
WINTER	KLAWER	24.07.90	7.43	1.45	112.9	13.1
EARLY SPRING	VISGAT	23.09.90	1.79	<<0.03	45.3	0.2
EARLY SPRING	GROOTFONTEIN	25.09.90	1.50	<<0.03	44.3	0.4
EARLY SPRING	TWEEFONTEIN	26.09.90	2.00	<<0.03	44.3	0.4
EARLY SPRING	KRIEDOUWKRANS	27.09.90	1.64	<<0.03	66.5	3.4
EARLY SPRING	CLANWILLIAM	27.09.90	3.50	<<0.03	56.6	0.5
EARLY SPRING	LANGKLOOF	28.09.90	1.71	<<0.03	93.1	1.3
EARLY SPRING	BULSHOEK	28.09.90	3.14	<<0.03	112.2	1.3
EARLY SPRING	ZYPHERFONTEIN	01.10.90	3.79	<<0.03	91.1	2.0
EARLY SPRING	KLAWER	03.10.90	2.43	<<0.03	369.6	8.0
EARLY SPRING	BOTHA'S FARM	03.10.90	3.21	<<0.03	523.5	18.2
SPRING	VISGAT	24.11.90	1.79	<<0.03	22.8	0.6
SPRING	GROOTFONTEIN	12.11.90	4.86	1.94	17.7	1.7
SPRING	TWEEFONTEIN	23.11.90	1.93	<<0.03	25.5	1.1
SPRING	KRIEDOUWKRANS	16.11.90	2.29	<<0.03	66.4	2.8
SPRING	CLANWILLIAM	22.11.90	4.00	<<0.03	59.7	1.3
SPRING	LANGKLOOF	22.11.90	3.07	<<0.03	71.4	1.7
SPRING	BULSHOEK	21.11.90	3.79	0.97	72.2	2.4
SPRING	ZYPHERFONTEIN	21.11.90	2.86	<<0.03	72.2	1.5
SPRING	KLAWER	20.11.90	1.57	<<0.03	591.5	3.3
SPRING	BOTHA'S FARM	20.11.90	3.64	<<0.03	1080.7	6.4
SUMMER	SOURCE	20.03.91	5.07	0.94	47.9	0.9
SUMMER	VISGAT	20.03.91	4.36	0.94	22.8	0.3
SUMMER	BOSCHKLOOF	19.03.91	5.79	1.29	20.6	0.7
SUMMER	GROOTFONTEIN	25.02.91	3.50	0.94	27.1	0.7
SUMMER	TWEEFONTEIN	08.03.91	4.00	1.19	31.7	1.0
SUMMER	KRIEDOUWKRANS	01.03.91	5.43	1.10	116.0	0.8
SUMMER	CLANWILLIAM	03.03.91	5.79	0.97	43.1	1.0
SUMMER	LANGKLOOF	03.03.91	5.00	1.29	87.7	1.4
SUMMER	BULSHOEK	07.03.91	4.00	1.32	89.8	1.2
SUMMER	ZYPHERFONTEIN	07.03.91	3.71	0.94	87.5	1.2
SUMMER	KLAWER	04.03.91	2.71	0.77	631.5	2.0
SUMMER	BOTHA'S FARM	06.03.91	1.86	0.87	1144.3	6.5
AUTUMN	VISGAT	22.05.91	1.86	0.94	31.6	1.9
AUTUMN	GROOTFONTEIN	17.05.91	1.71	1.74	28.2	0.9
AUTUMN	TWEEFONTEIN	18.05.91	3.36	1.00	33.2	0.7
AUTUMN	KRIEDOUWKRANS	19.05.91	2.86	1.48	64.5	1.9
AUTUMN	CLANWILLIAM	19.05.91	5.14	1.39	188.4	2.5
AUTUMN	LANGKLOOF	20.05.91	6.14	1.00	409.5	2.1
AUTUMN	BULSHOEK	20.05.91	4.29	1.48	141.0	1.3
AUTUMN	ZYPHERFONTEIN	20.05.91	3.07	1.32	147.8	4.1
AUTUMN	KLAWER	21.05.91	2.29	1.29	661.7	2.0
AUTUMN	BOTHA'S FARM	21.05.91	3.21	1.29	1193.0	4.0
EARLY SPRING	GROOTFONTEIN	15.10.91				
EARLY SPRING	KRIEDOUWKRANS	08.10.91				
EARLY SPRING	KLAWER	10.10.91				

Appendix 5.4 continued

SEASON	SITE	DATE	% ORGANICS IN TSS %	TURBIDITY SECCHI DISC m	SiO2-Si umol/l	PHENOLPHTHALEIN ALKALINITY mEq/l
WINTER	GROOTFONTEIN	25.07.90	1.40	clear		0.000
WINTER	KRIEDOUWKRANS	29.07.90	1.29	0.62		0.000
WINTER	KLAWER	24.07.90	1.82	0.45		0.000
EARLY SPRING	VISGAT	23.09.90	1.10	clear		0.000
EARLY SPRING	GROOTFONTEIN	25.09.90	1.10	clear		0.000
EARLY SPRING	TWEEFONTEIN	26.09.90	0.77	clear		0.000
EARLY SPRING	KRIEDOUWKRANS	27.09.90	0.93	clear		0.000
EARLY SPRING	CLANWILLIAM	27.09.90	1.74	clear		0.000
EARLY SPRING	LANGKLOOF	28.09.90	1.09	clear		0.000
EARLY SPRING	BULSHOEK	28.09.90	1.20	clear		0.000
EARLY SPRING	ZYPHERFONTEIN	01.10.90	1.39			0.000
EARLY SPRING	KLAWER	03.10.90	2.16	0.80		0.143
EARLY SPRING	BOTHA'S FARM	03.10.90	1.61	0.60		0.000
SPRING	VISGAT	24.11.90	0.39	clear		0.000
SPRING	GROOTFONTEIN	12.11.90	1.15	clear		0.000
SPRING	TWEEFONTEIN	23.11.90	0.55	clear		0.000
SPRING	KRIEDOUWKRANS	16.11.90	0.68	clear		0.000
SPRING	CLANWILLIAM	22.11.90	0.54	clear		0.000
SPRING	LANGKLOOF	22.11.90	0.62	clear		0.000
SPRING	BULSHOEK	21.11.90	2.15	clear		0.000
SPRING	ZYPHERFONTEIN	21.11.90	1.06	1.25		0.000
SPRING	KLAWER	20.11.90	1.00	clear		0.315
SPRING	BOTHA'S FARM	20.11.90	1.20	0.75		0.455
SUMMER	SOURCE	20.03.91	2.34	clear	7.05	0.000
SUMMER	VISGAT	20.03.91	1.45	clear	3.10	0.000
SUMMER	BOSCHKLOOF	19.03.91	2.53	clear	7.05	0.000
SUMMER	GROOTFONTEIN	25.02.91	1.59	clear	6.19	0.000
SUMMER	TWEEFONTEIN	08.03.91	1.59	clear	6.19	0.000
SUMMER	KRIEDOUWKRANS	01.03.91	1.45	clear	24.20	0.000
SUMMER	CLANWILLIAM	03.03.91	2.45	clear	4.77	0.000
SUMMER	LANGKLOOF	03.03.91	2.53	clear	8.29	0.000
SUMMER	BULSHOEK	07.03.91	1.98	clear	21.32	0.000
SUMMER	ZYPHERFONTEIN	07.03.91	2.59	0.80	8.29	0.000
SUMMER	KLAWER	04.03.91	1.74	clear	64.95	0.179
SUMMER	BOTHA'S FARM	06.03.91	2.47	0.80	84.41	0.260
AUTUMN	VISGAT	22.05.91	1.60	clear	7.44	0.000
AUTUMN	GROOTFONTEIN	17.05.91	1.61	clear	6.01	0.000
AUTUMN	TWEEFONTEIN	18.05.91	1.29	clear	6.83	0.000
AUTUMN	KRIEDOUWKRANS	19.05.91	1.75	clear	8.47	0.000
AUTUMN	CLANWILLIAM	19.05.91	2.14	clear	22.78	0.000
AUTUMN	LANGKLOOF	20.05.91	2.17	clear	21.10	0.000
AUTUMN	BULSHOEK	20.05.91	1.99	clear	7.86	0.000
AUTUMN	ZYPHERFONTEIN	20.05.91	2.11	clear	17.19	0.000
AUTUMN	KLAWER	21.05.91	1.83	clear	54.84	0.078
AUTUMN	BOTHA'S FARM	21.05.91	1.83	clear	95.37	0.331
EARLY SPRING	GROOTFONTEIN	15.10.91				
EARLY SPRING	KRIEDOUWKRANS	08.10.91				
EARLY SPRING	KLAWER	10.10.91				

Appendix 5.4 continued

SEASON	SITE	DATE	TOTAL ALKALINITY mEq/l	Cl- mmol/l	SO42- mmol/l	Na+ mmol/l	K+ mmol/l
WINTER	GROOTFONTEIN	25.07.90	0.041	0.219	0.017	5.74	0.015
WINTER	KRIEDOUWKRANS	29.07.90	0.046	0.489	0.029	2.78	0.028
WINTER	KLAWER	24.07.90	0.219	0.816	0.072	3.48	0.384
EARLY SPRING	VISGAT	23.09.90	0.046	0.197	0.013	0.57	0.089
EARLY SPRING	GROOTFONTEIN	25.09.90	0.025	0.143	0.009	2.70	0.015
EARLY SPRING	TWEEFONTEIN	26.09.90	0.035	0.282	0.015	4.39	0.010
EARLY SPRING	KRIEDOUWKRANS	27.09.90	0.053	0.520	0.025	2.57	0.018
EARLY SPRING	CLANWILLIAM	27.09.90	0.028	0.458	0.027	1.87	0.020
EARLY SPRING	LANGKLOOF	28.09.90	0.037	0.610	0.049	2.78	0.025
EARLY SPRING	BULSHOEK	28.09.90	0.064	1.573	0.060	2.87	0.028
EARLY SPRING	ZYPHERFONTEIN	01.10.90	0.087	0.952	0.049	2.83	0.026
EARLY SPRING	KLAWER	03.10.90	0.819	2.376	0.354	5.87	0.061
EARLY SPRING	BOTHA'S FARM	03.10.90	1.362	2.653	0.448	5.22	0.051
SPRING	VISGAT	24.11.90	0.032	0.175	0.008	0.22	0.010
SPRING	GROOTFONTEIN	12.11.90	0.030	0.138	0.006	0.39	0.010
SPRING	TWEEFONTEIN	23.11.90	0.053	0.252	0.010	0.26	0.010
SPRING	KRIEDOUWKRANS	16.11.90	0.055	0.525	0.022	0.39	0.015
SPRING	CLANWILLIAM	22.11.90	0.058	0.435	0.023	0.35	0.015
SPRING	LANGKLOOF	22.11.90	0.053	0.554	0.034	0.61	0.015
SPRING	BULSHOEK	21.11.90	0.060	0.193	0.007	0.13	0.007
SPRING	ZYPHERFONTEIN	21.11.90	0.083	0.204	0.013	0.26	0.020
SPRING	KLAWER	20.11.90	0.934	2.596	0.439	4.78	0.064
SPRING	BOTHA'S FARM	20.11.90	1.589	6.073	1.259	6.96	0.064
SUMMER	SOURCE	20.03.91	0.106	0.260	0.012	0.30	0.020
SUMMER	VISGAT	20.03.91	0.012	0.142	0.006	0.43	0.020
SUMMER	BOSCHKLOOF	19.03.91	0.025	0.158	0.006	1.74	0.012
SUMMER	GROOTFONTEIN	25.02.91	0.025	0.184	0.006	3.04	0.012
SUMMER	TWEEFONTEIN	08.03.91	0.062	0.239	0.010	2.43	0.012
SUMMER	KRIEDOUWKRANS	01.03.91	0.131	0.847	0.041	3.22	0.046
SUMMER	CLANWILLIAM	03.03.91	0.104	0.644	0.030	1.83	0.023
SUMMER	LANGKLOOF	03.03.91	0.113	0.667	0.036	2.78	0.038
SUMMER	BULSHOEK	07.03.91	0.094	0.825	0.037	2.78	0.025
SUMMER	ZYPHERFONTEIN	07.03.91	0.106	0.918	0.033	2.78	0.023
SUMMER	KLAWER	04.03.91	1.265	4.492	0.740	7.81	0.061
SUMMER	BOTHA'S FARM	06.03.91	2.045	2.483	0.600	18.70	0.089
AUTUMN	VISGAT	22.05.91	0.028	0.219	0.011	0.26	0.012
AUTUMN	GROOTFONTEIN	17.05.91	0.023	0.188	0.008	5.74	0.023
AUTUMN	TWEEFONTEIN	18.05.91	0.055	0.244	0.013	2.52	0.012
AUTUMN	KRIEDOUWKRANS	19.05.91	0.083	0.551	0.025	0.30	0.015
AUTUMN	CLANWILLIAM	19.05.91	0.092	0.751	0.088	3.65	0.051
AUTUMN	LANGKLOOF	20.05.91	0.140	3.757	0.038	2.17	0.102
AUTUMN	BULSHOEK	20.05.91	0.124	0.975	0.053	3.39	0.041
AUTUMN	ZYPHERFONTEIN	20.05.91	0.127	1.294	0.072	3.04	0.038
AUTUMN	KLAWER	21.05.91	1.233	2.520	0.924	7.39	0.097
AUTUMN	BOTHA'S FARM	21.05.91	1.684	6.333	1.905	16.09	0.102
EARLY SPRING	GROOTFONTEIN	15.10.91				4.48	0.021
EARLY SPRING	KRIEDOUWKRANS	08.10.91				2.61	0.019
EARLY SPRING	KLAWER	10.10.91					

Appendix 5.4 continued

SEASON	SITE	DATE	Ca2+ mmol/l	Mg2+ mmol/l	Fe * mmol/l	Cu ** mmol/l
WINTER	GROOTFONTEIN	25.07.90	0.007	0.040	0	0
WINTER	KRIEDOUWKRANS	29.07.90	0.010	0.080	0	0
WINTER	KLAWER	24.07.90	0.007	0.140	0	0
EARLY SPRING	VISGAT	23.09.90	0.010	0.040	0	0
EARLY SPRING	GROOTFONTEIN	25.09.90	0.010	0.040	0	0
EARLY SPRING	TWEEFONTEIN	26.09.90	0.005	0.040	0	0
EARLY SPRING	KRIEDOUWKRANS	27.09.90	0.010	0.080	0	0
EARLY SPRING	CLANWILLIAM	27.09.90	0.010	0.080	0	0
EARLY SPRING	LANGKLOOF	28.09.90	0.010	0.080	0	0
EARLY SPRING	BULSHOEK	28.09.90	0.010	0.145	0	0
EARLY SPRING	ZYPHERFONTEIN	01.10.90	0.010	0.105	0	0
EARLY SPRING	KLAWER	03.10.90	0.050	0.615	0	0
EARLY SPRING	BOTHA'S FARM	03.10.90	0.090	0.410	0	0
SPRING	VISGAT	24.11.90	0.000	0.020	0	0
SPRING	GROOTFONTEIN	12.11.90	0.002	0.025	0	0
SPRING	TWEEFONTEIN	23.11.90	0.002	0.045	0	0
SPRING	KRIEDOUWKRANS	16.11.90	0.002	0.140	0	0
SPRING	CLANWILLIAM	22.11.90	0.002	0.075	0	0
SPRING	LANGKLOOF	22.11.90	0.002	0.080	0	0
SPRING	BULSHOEK	21.11.90	0.000	0.025	0	0
SPRING	ZYPHERFONTEIN	21.11.90	0.002	0.075	0	0
SPRING	KLAWER	20.11.90	0.035	0.575	0	0
SPRING	BOTHA'S FARM	20.11.90	0.040	0.945	0	0
SUMMER	SOURCE	20.03.91	0.002	0.060	0	0
SUMMER	VISGAT	20.03.91	0.010	0.040	0	0
SUMMER	BOSCHKLOOF	19.03.91	0.007	0.040	0	0
SUMMER	GROOTFONTEIN	25.02.91	0.002	0.040	0	0
SUMMER	TWEEFONTEIN	08.03.91	0.010	0.040	0	0
SUMMER	KRIEDOUWKRANS	01.03.91	0.090	0.165	0	0
SUMMER	CLANWILLIAM	03.03.91	0.010	0.080	0	0
SUMMER	LANGKLOOF	03.03.91	0.010	0.125	0	0
SUMMER	BULSHOEK	07.03.91	0.015	0.125	0	0
SUMMER	ZYPHERFONTEIN	07.03.91	0.010	0.125	0	0
SUMMER	KLAWER	04.03.91	0.087	0.615	0	0
SUMMER	BOTHA'S FARM	06.03.91	0.060	1.235	0	0
AUTUMN	VISGAT	22.05.91	0.002	0.025	0	0
AUTUMN	GROOTFONTEIN	17.05.91	0.002	0.040	0	0
AUTUMN	TWEEFONTEIN	18.05.91	0.010	0.040	0	0
AUTUMN	KRIEDOUWKRANS	19.05.91	0.002	0.040	0	0
AUTUMN	CLANWILLIAM	19.05.91	0.015	0.205	0	0
AUTUMN	LANGKLOOF	20.05.91	0.030	0.615	0	0
AUTUMN	BULSHOEK	20.05.91	0.010	0.205	0	0
AUTUMN	ZYPHERFONTEIN	20.05.91	0.015	0.206	0	0
AUTUMN	KLAWER	21.05.91	0.050	0.945	0	0
AUTUMN	BOTHA'S FARM	21.05.91	0.150	1.645	0	0
EARLY SPRING	GROOTFONTEIN	15.10.91	0.013	0.040	0	0
EARLY SPRING	KRIEDOUWKRANS	08.10.91	0.011	0.080	0	0
EARLY SPRING	KLAWER	10.10.91				0

* Fe concentrations were below detection limits

** Cu concentrations were below detection limits

Appendix 5.4 continued

SEASON	SITE	DATE	MINIMUM TEMPERATURE °C	MAXIMUM / INSTANTANEOUS TEMPERATURE °C
WINTER	GROOTFONTEIN	25.07.90	12.5	14.5
WINTER	KRIEDOUWKRANS	29.07.90	13.0	14.0
WINTER	KLAWER	24.07.90		12.0
EARLY SPRING	VISGAT	23.09.90		16.5
EARLY SPRING	GROOTFONTEIN	25.09.90		18.0
EARLY SPRING	TWEEFONTEIN	26.09.90	20.5	23.0
EARLY SPRING	KRIEDOUWKRANS	27.09.90	21.0	22.0
EARLY SPRING	CLANWILLIAM	27.09.90		18.0
EARLY SPRING	LANGKLOOF	28.09.90	17.0	21.5
EARLY SPRING	BULSHOEK	28.09.90		19.5
EARLY SPRING	ZYPHERFONTEIN	01.10.90		
EARLY SPRING	KLAWER	03.10.90	20.0	21.0
EARLY SPRING	BOTHA'S FARM	03.10.90		24.0
SPRING	VISGAT	24.11.90		15.5
SPRING	GROOTFONTEIN	12.11.90	15.0	23.0
SPRING	TWEEFONTEIN	23.11.90		22.0
SPRING	KRIEDOUWKRANS	16.11.90	21.0	24.0
SPRING	CLANWILLIAM	22.11.90		21.0
SPRING	LANGKLOOF	22.11.90		25.0
SPRING	BULSHOEK	21.11.90		23.0
SPRING	ZYPHERFONTEIN	21.11.90		23.0
SPRING	KLAWER	20.11.90	25.5	26.0
SPRING	BOTHA'S FARM	20.11.90		23.0
SUMMER	SOURCE	20.03.91		19.0
SUMMER	VISGAT	20.03.91		19.0
SUMMER	BOSCHKLOOF	19.03.91		23.0
SUMMER	GROOTFONTEIN	25.02.91	21.0	27.0
SUMMER	TWEEFONTEIN	08.03.91		29.5
SUMMER	KRIEDOUWKRANS	01.03.91		23.5
SUMMER	CLANWILLIAM	03.03.91		24.0
SUMMER	LANGKLOOF	03.03.91		26.5
SUMMER	BULSHOEK	07.03.91		24.5
SUMMER	ZYPHERFONTEIN	07.03.91		25.5
SUMMER	KLAWER	04.03.91		22.5
SUMMER	BOTHA'S FARM	06.03.91		22.0
AUTUMN	VISGAT	22.05.91		13.5
AUTUMN	GROOTFONTEIN	17.05.91		15.0
AUTUMN	TWEEFONTEIN	18.05.91		15.5
AUTUMN	KRIEDOUWKRANS	19.05.91		16.5
AUTUMN	CLANWILLIAM	19.05.91		18.0
AUTUMN	LANGKLOOF	20.05.91		16.0
AUTUMN	BULSHOEK	20.05.91		18.0
AUTUMN	ZYPHERFONTEIN	20.05.91		18.0
AUTUMN	KLAWER	21.05.91		12.5
AUTUMN	BOTHA'S FARM	21.05.91		16.0
EARLY SPRING	GROOTFONTEIN	15.10.91		13.0
EARLY SPRING	KRIEDOUWKRANS	08.10.91		17.0
EARLY SPRING	KLAWER	10.10.91		20.0

Appendix 5.5 Water quality profiles for all sampled water quality variables, based on site-specific seasonal data for the mainstream of the Olifants River

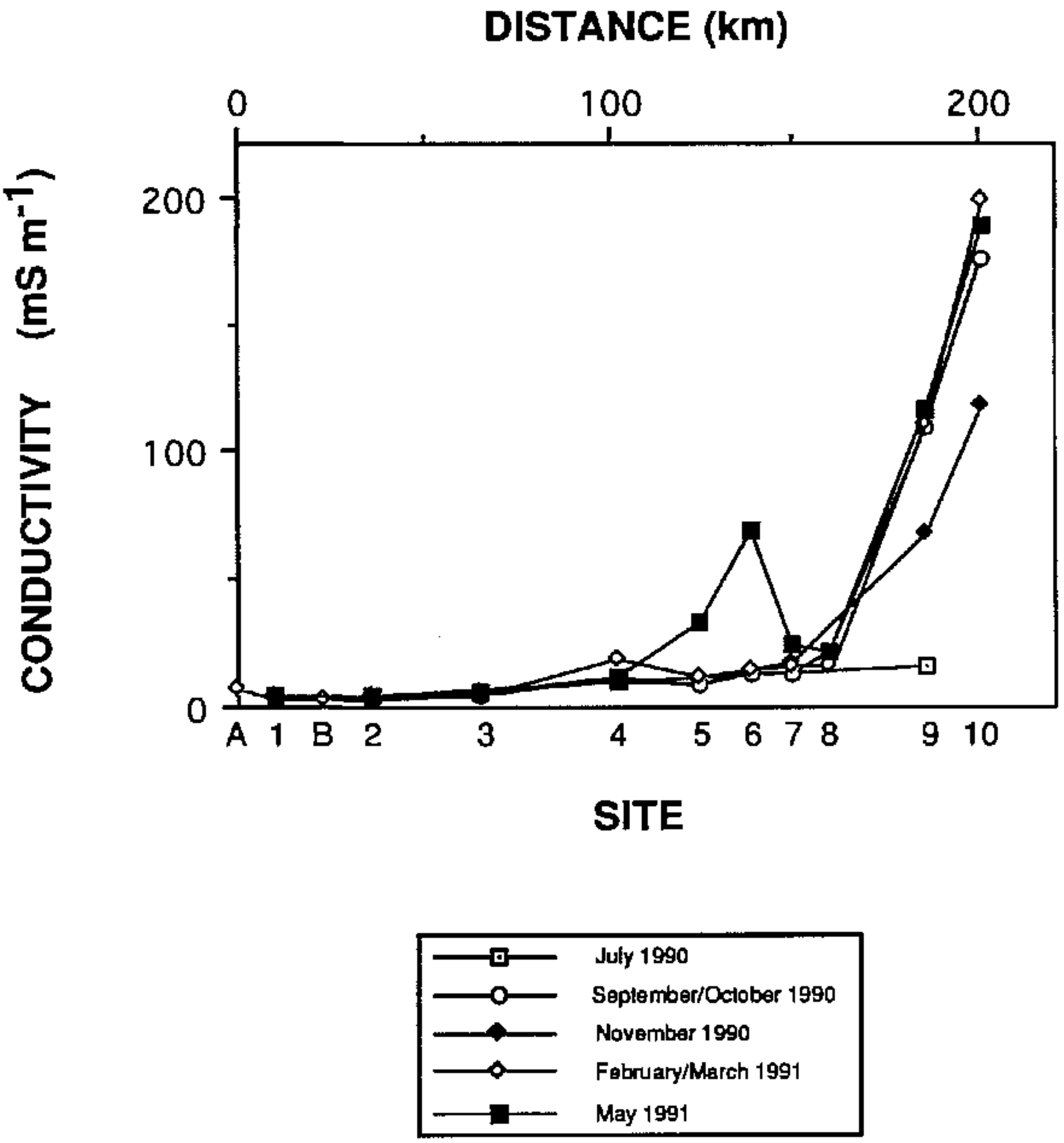
Sites are coded as for Table 4.1, and are shown in their actual locations along the river (distance in km).

The key to seasons pertains to both profiles per page.

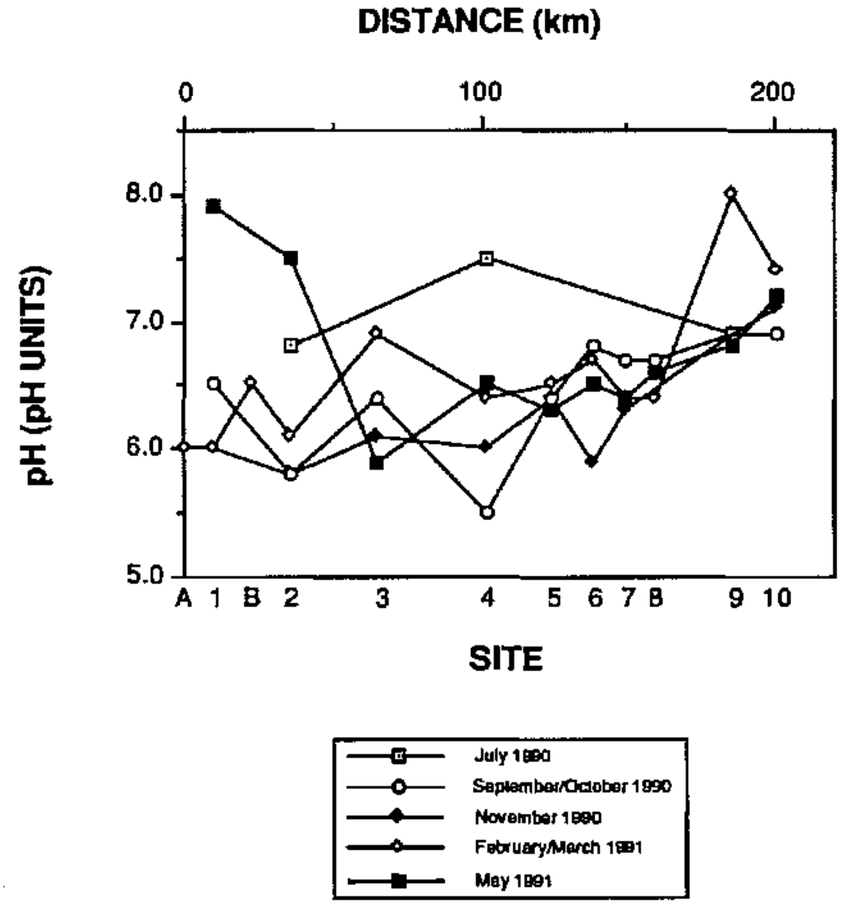
Profiles for chloride and ammonia are provided in the text as Figures 5.8 and 5.9 respectively.

5.5.1 Conductivity
5.5.2 pH
5.5.3 Nitrate
5.5.4 Nitrite
5.5.5 Soluble reactive phosphate
5.5.6 Total dissolved solids
5.5.7 Total suspended solids
5.5.8 Percentage organics in the total suspended solids
5.5.9 Reactive silicon
5.5.10 Phenolphthalein alkalinity
5.5.11 Total alkalinity
5.5.12 Sulphate
5.5.13 Sodium
5.5.14 Potassium
5.5.15 Calcium
5.5.16 Magnesium
5.5.17 Instantaneous temperature

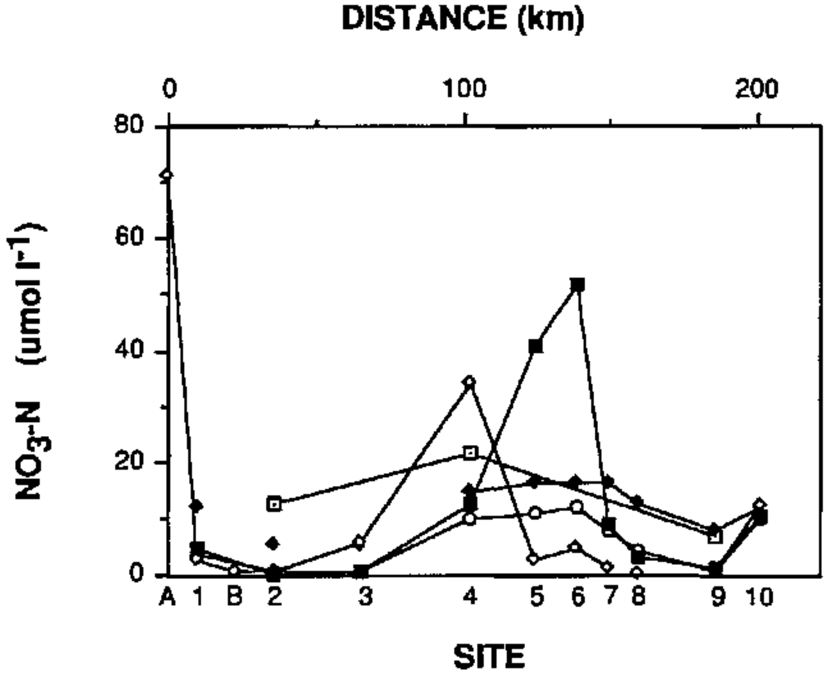
Appendix 5.5.1 Conductivity



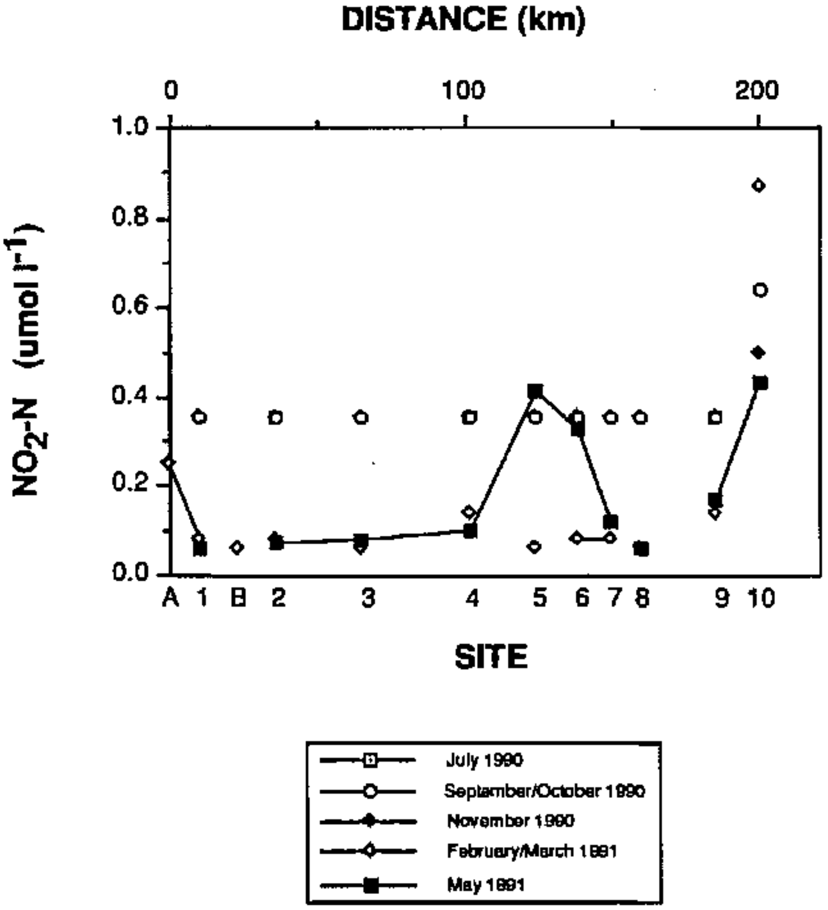
Appendix 5.5.2 pH



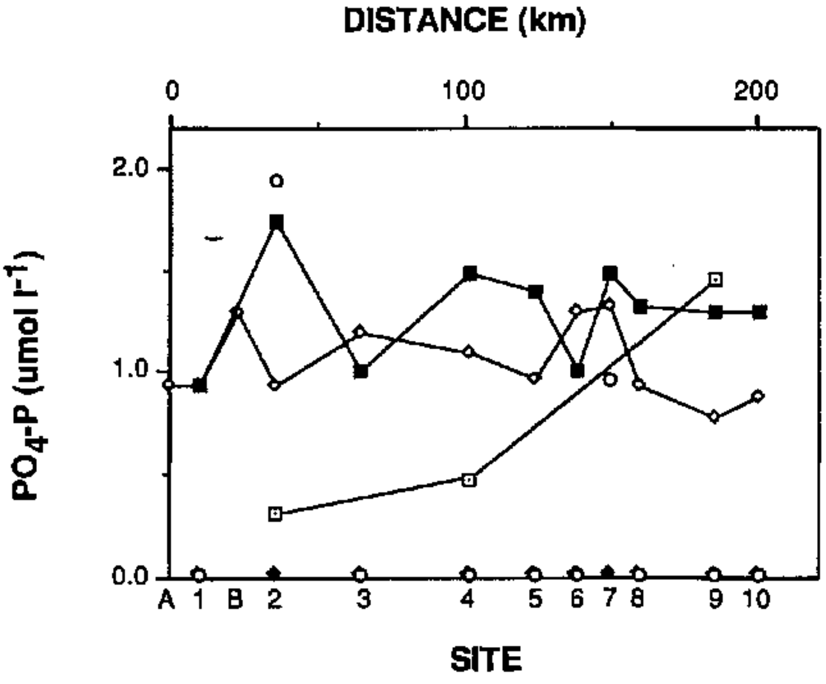
Appendix 5.5.3 Nitrate. Symbols not connected to one another represent nitrate values that are lower than the detection limits represented by these points



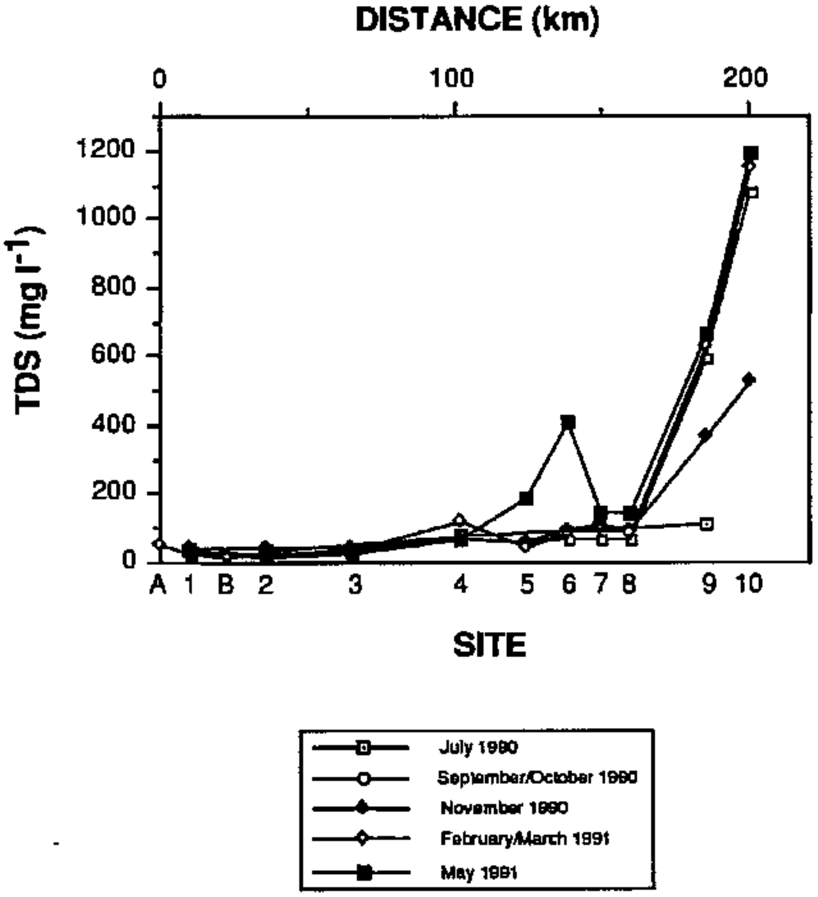
Appendix 5.5.4 **Nitrite. Symbols not connected to one another represent nitrite values that are lower than the detection limits represented by these points**



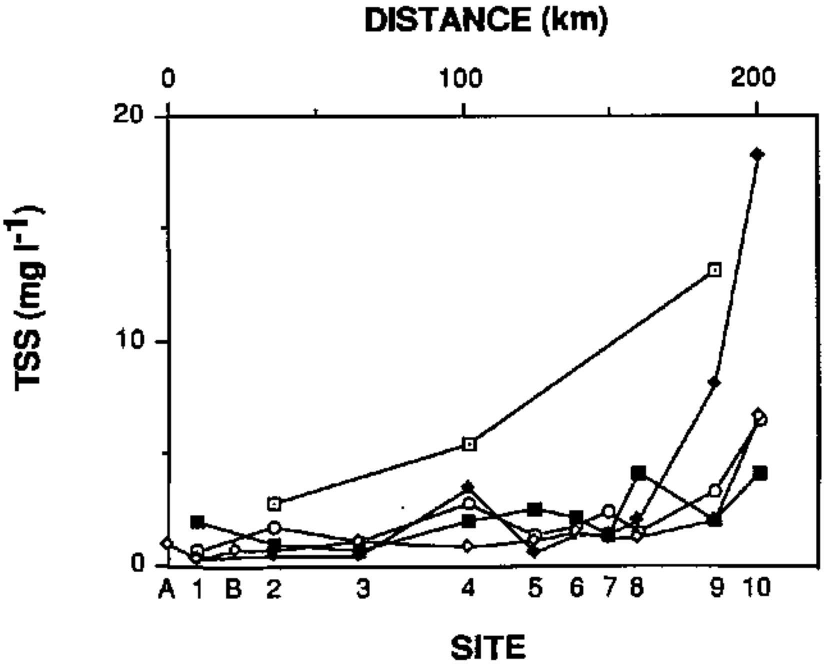
Appendix 5.5.5 **Soluble reactive phosphate. Symbols not connected to one another represent SRP values that are lower than the detection limits represented by these points**



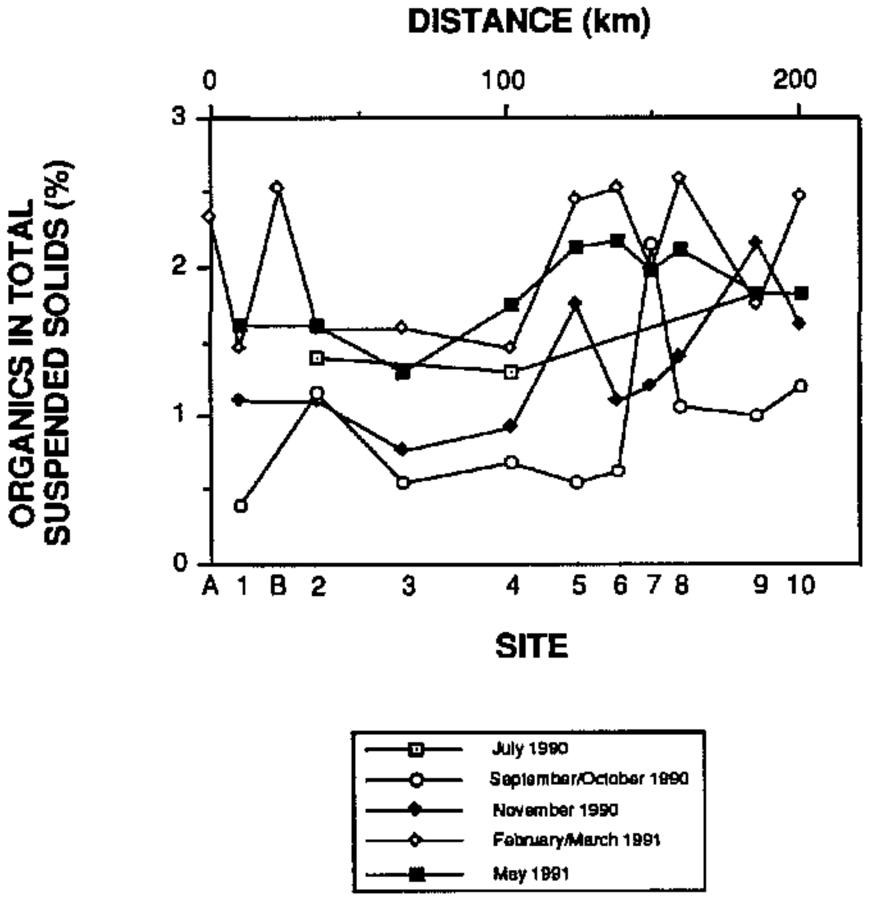
Appendix 5.5.6 Total dissolved solids



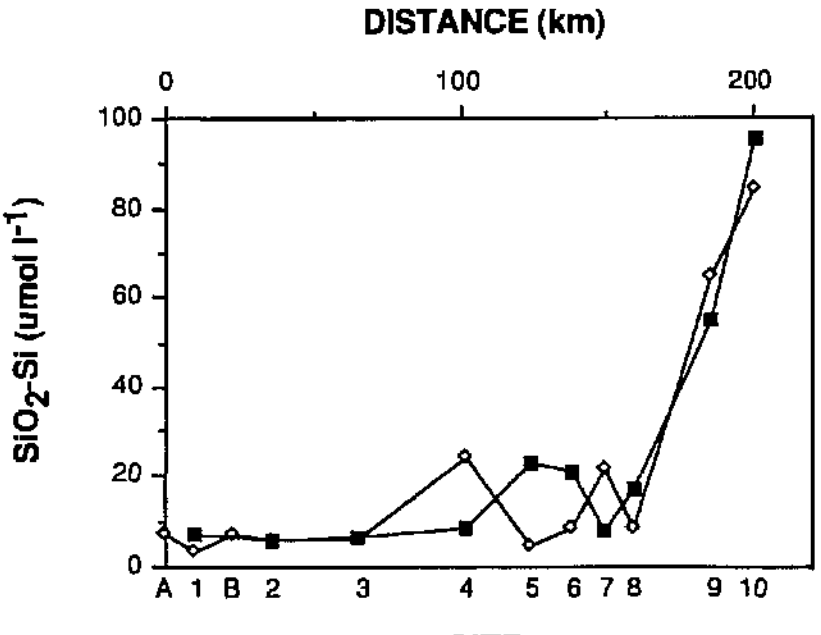
Appendix 5.5.7 Total suspended solids



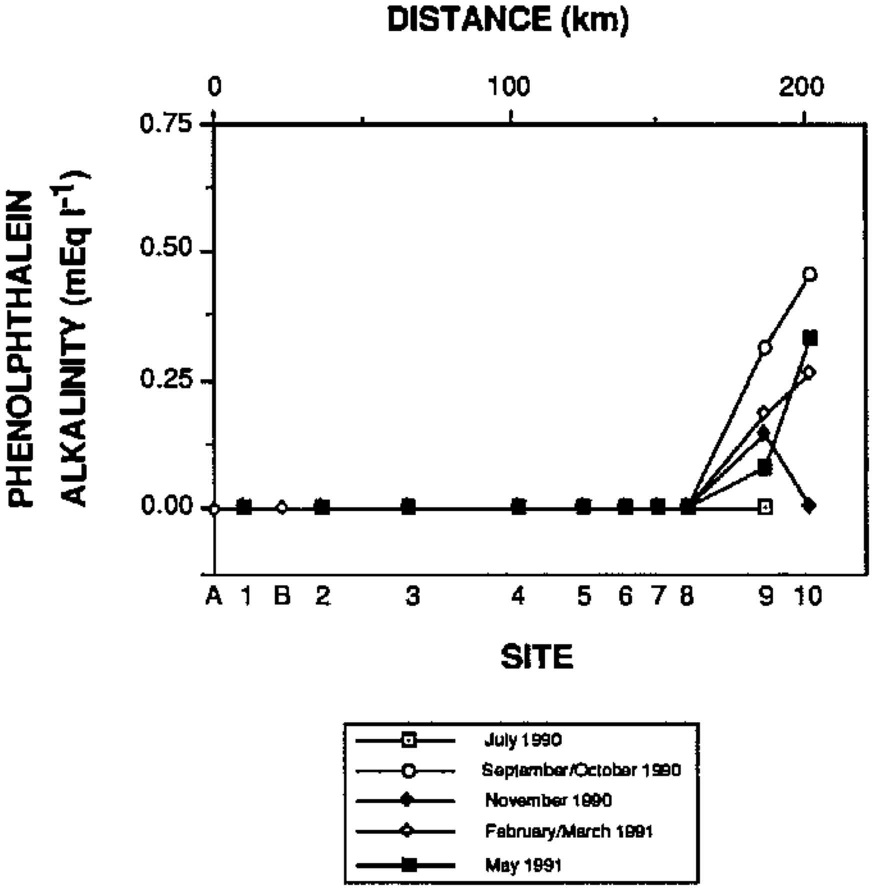
Appendix 5.5.8 Percentage organics in the total suspended solids



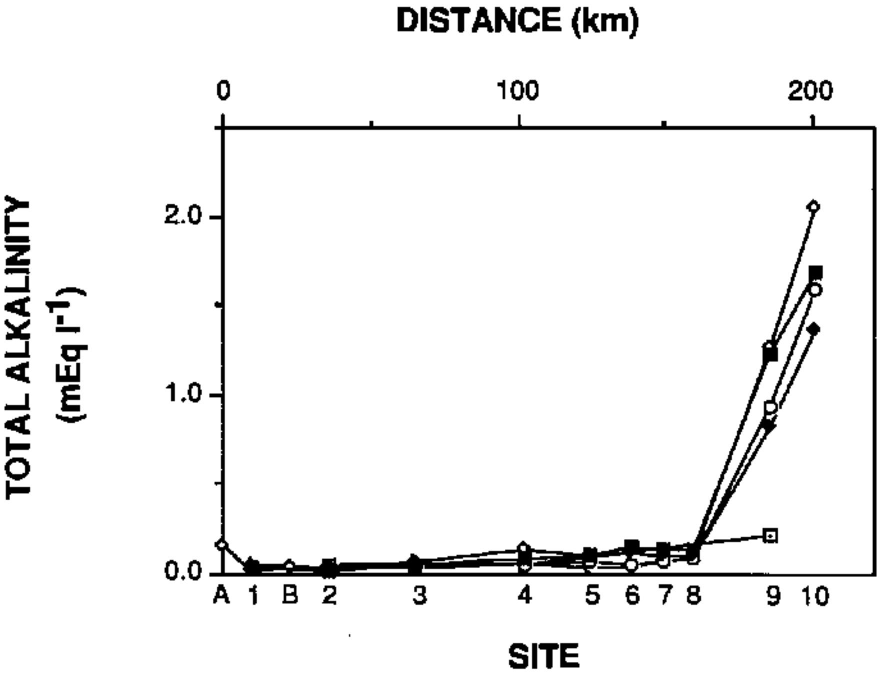
Appendix 5.5.9 Reactive silicon. This was only measured during summer and autumn



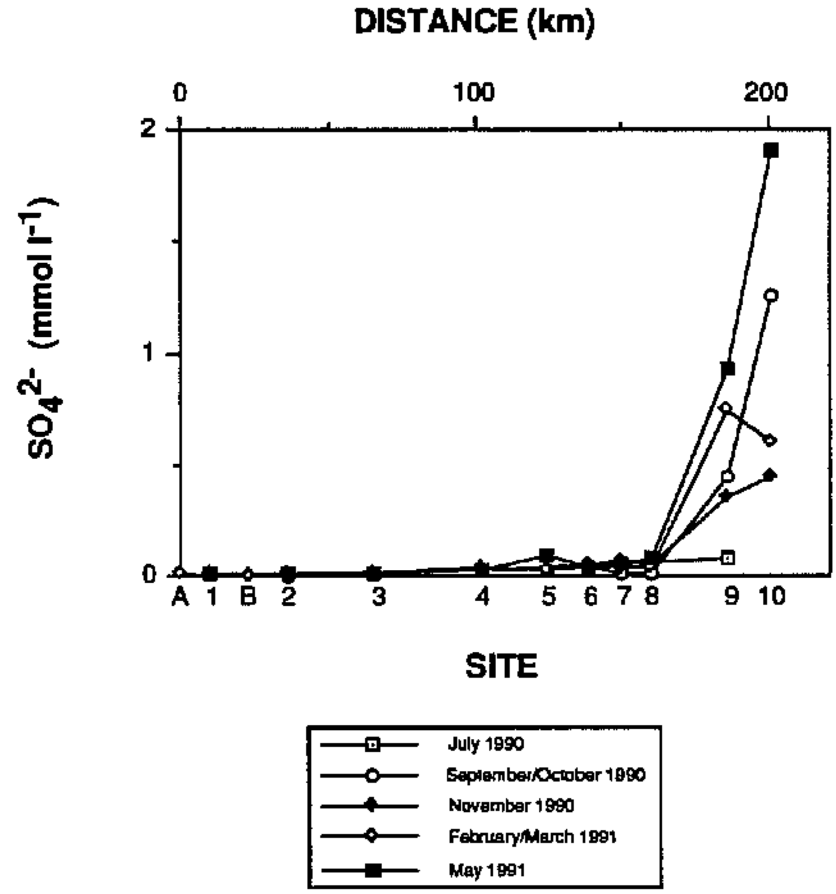
Appendix 5.5.10 Phenolphthalein alkalinity



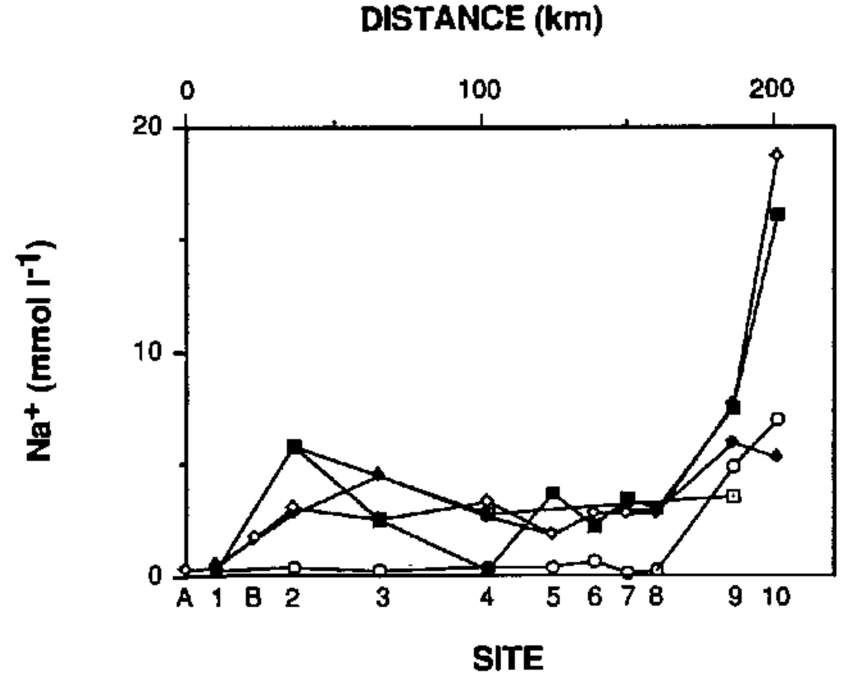
Appendix 5.5.11 Total alkalinity



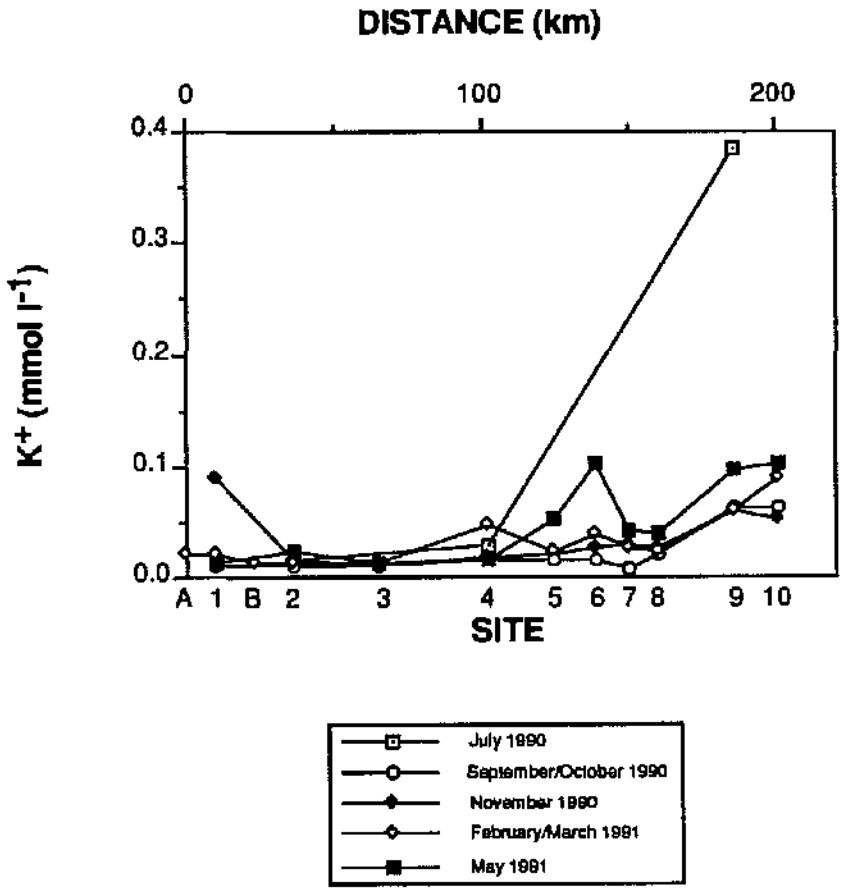
Appendix 5.5.12 Sulphate



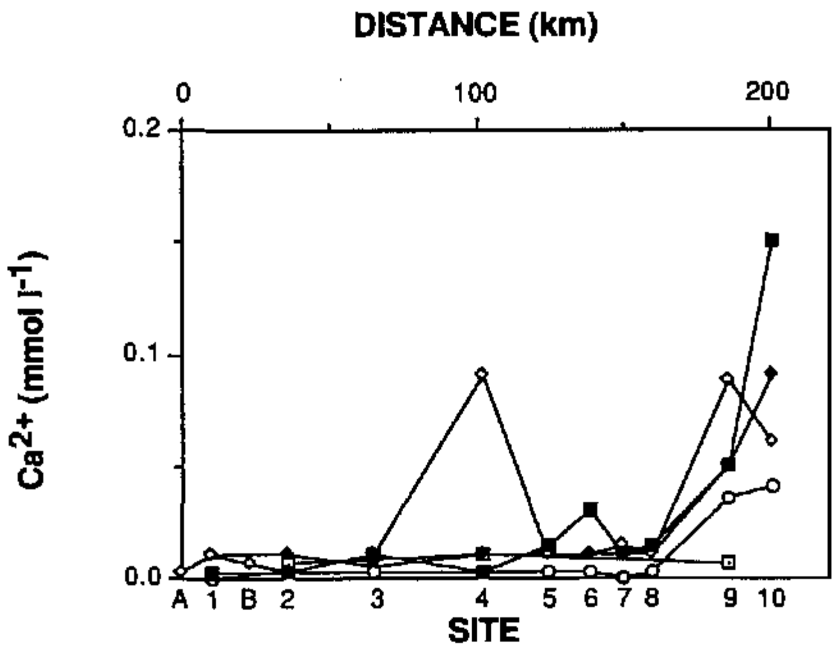
Appendix 5.5.13 Sodium



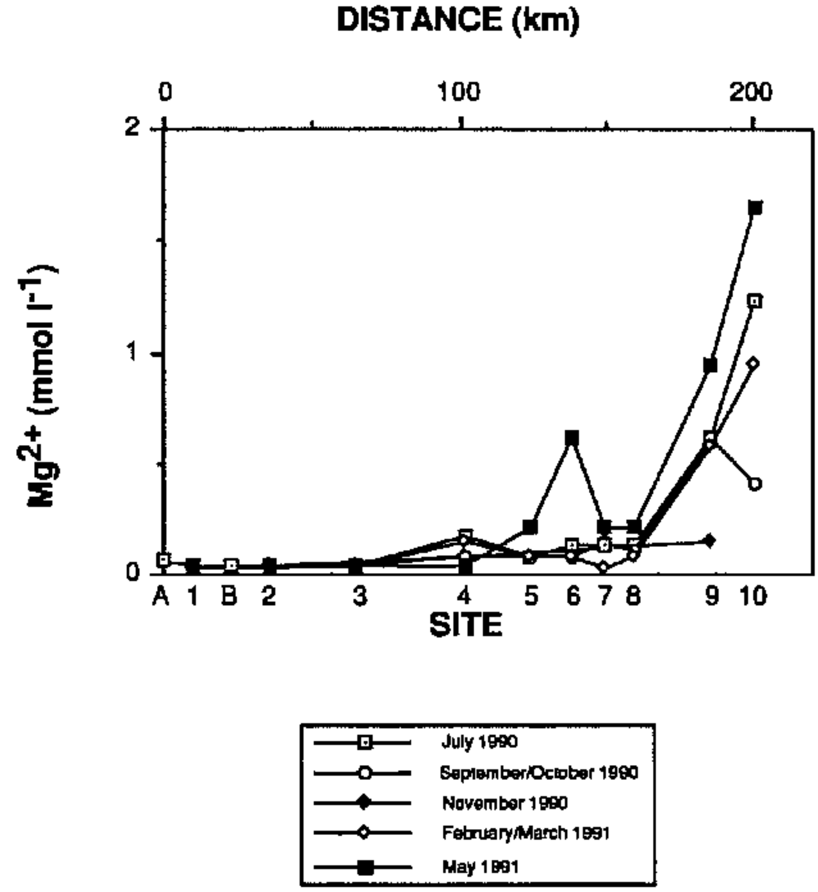
Appendix 5.5.14 Potassium



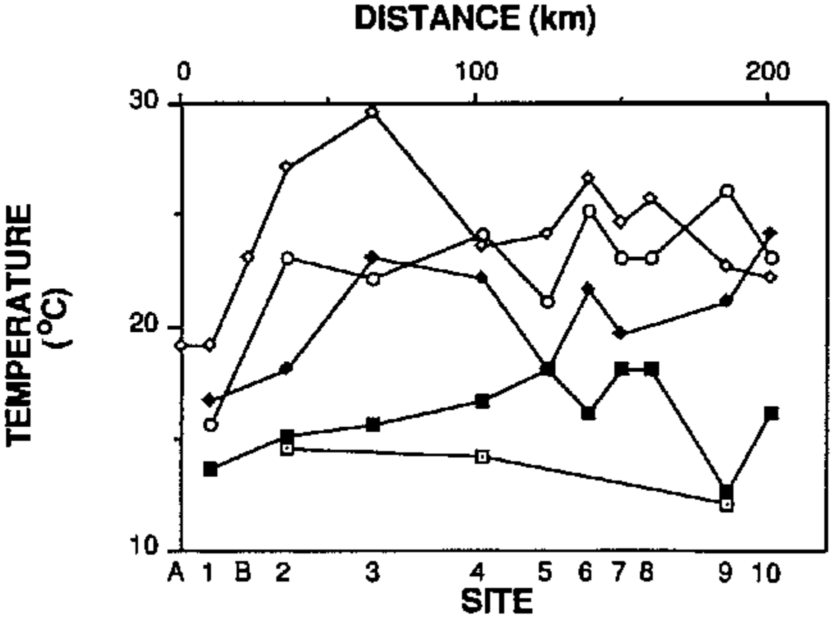
Appendix 5.5.15 Calcium



Appendix 5.5.16 Magnesium



Appendix 5.5.17 Instantaneous temperature



Appendix 5.6 Summary of water quality data for benthic macroinvertebrate and fish tributary sites on the Olifants River system, for all seasons and sites of interest

SEASON	SITE	DATE	CONDUCTIVITY mS/m	pH pH UNITS	NO3-N umol/l	NO2-N umol/l	NH4-N umol/l	PO4-P umol/l	TDS mg/l	TSS mg/l	ORGANICS IN TSS %	TURBIDITY SECCHI DISC m
AUTUMN	DORING R.	13.04.90	130.0									
WINTER	DORING R.	23.07.90	14.6	7.2	6.07	<<0.36	10.71	<<0.03	202.1	26.40	1.48	0.27
EARLY SPRING	DORING R.	02.10.90	32.5	6.6	<<0.36	<<0.36	2.07	<<0.03	164.8	1.50	0.78	Clear
SPRING	DORING R.	21.11.90	75.2	7.9	0.43	<<0.36	2.21	<<0.03	441.4	1.50	1.38	Clear
SUMMER	DORING R.	06.03.91	157.3	8.7	0.07	0.07	4.79	1.32	869.2	3.20	2.37	Clear
AUTUMN	DORING R.	20.05.91	187.5	8.2	0.07	0.07	2.71	1.19	1098.5	5.20	3.17	Clear
EARLY SPRING	RATEL R.	25.09.90	4.8	6.1	10.43	<<0.36	3.86	0.81	31.1	0.50	1.22	Clear
SPRING	RATEL R.	13.11.90	5.5	5.5	6.50	<<0.36	3.00	0.32	21.7	1.90	0.98	Clear
SUMMER	RATEL R.	28.02.91	5.0	6.1	0.79	<<0.07	3.50	0.97	43.0	0.80	2.46	Clear
AUTUMN	RATEL R.	16.05.91	6.0	5.7	0.64	<<0.07	4.93	1.65	36.4	0.58	1.92	Clear
AUTUMN	RATEL R.	17.05.91	5.4	4.6	1.86	<<0.07	2.50	1.48				Clear
AUTUMN	NOORDHOEK R.	14.04.90	3.1	6.1								Clear
EARLY SPRING	NOORDHOEK R.	26.09.90	3.4	4.5	<<0.36	<<0.36	4.36	<<0.03	19.0	0.70	0.77	Clear
SPRING	NOORDHOEK R.	23.11.90	3.1	6.0	<<0.36	<<0.36	2.21	<<0.03	19.4	0.40	0.39	Clear
SUMMER	NOORDHOEK R.	08.03.91	3.3	6.0	<<0.07	<<0.07	3.71	0.97	22.5	0.17	2.45	Clear
AUTUMN	NOORDHOEK R.	18.05.91	4.8	5.8	0.29	<<0.07	4.57	1.10	24.5	0.64	1.45	Clear
AUTUMN	KLAWER CANAL	21.05.91	28.6	8.2								Clear
AUTUMN	LUTZVILLE	21.05.91	397.0	8.2								Clear
SUMMER	RONDEGAT R.	26.01.92	2.9	5.3	0.41	0.09	1.82	0.33				Clear
SUMMER	DRIEHOEKS R.	30.01.92	1.7		0.01	0.09	1.32	0.35				Clear
SUMMER	THEE R.	25.01.92	6.0	6.9	0.41	0.09	4.19	0.29				Clear
SUMMER	BOSKLOOF R.	28.01.92	6.2	6.7	0.90	0.11	0.93	0.35				Clear
SUMMER	MIDDELDEUR R.	28.01.92	4.1		0.02	0.11	2.17	0.22				Clear

Appendix 5.6 continued

SEASON	SITE	DATE	SiO2-Si umol/l	PHENOLPHTHALEIN ALKALINITY mEq/l	TOTAL ALKALINITY mEq/l	Cl- mmol/l	SO42- mmol/l	Na+ mmol/l	K+ mmol/l	Ca2+ mmol/l	Mg2+ mmol/l	Fe mmol/l	Cu mmol/l	INSTANTANEOUS TEMPERATURE °C
AUTUMN	DORING R.	13.04.90												21.5
WINTER	DORING R.	23.07.90		0.000	0.219	0.678	0.068	2.70	0.051	0.020	0.165	0	0	11.5
EARLY SPRING	DORING R.	02.10.90		0.046	0.297	1.867	0.147	3.44	0.048	0.040	0.410	0	0	24.0
SPRING	DORING R.	21.11.90		0.177	0.708	1.802	0.151	2.17	0.064	0.025	0.245	0	0	24.0
SUMMER	DORING R.	06.03.91	22.14	0.101	0.704	8.305	0.367	13.91	0.243	0.090	1.235	0	0	25.5
AUTUMN	DORING R.	20.05.91	20.28	0.216	1.518	7.599	0.337	15.65	0.500	0.030	1.235	0	0	19.0
EARLY SPRING	RATEL R.	25.09.90		0.000	0.000	0.249	0.012	2.00	0.010	0.002	0.040	0	0	20.5
SPRING	RATEL R.	13.11.90		0.000	0.046	0.319	0.012	0.26	0.012	0.002	0.040	0	0	19.0
SUMMER	RATEL R.	28.02.91	6.19	0.000	0.030	0.359	0.006	2.09	0.007	0.015	0.040	0	0	26.5
AUTUMN	RATEL R.	16.05.91	6.83	0.000	0.028	0.356	0.011	0.70	0.007	0.010	0.040	0	0	18.5
AUTUMN	RATEL R.	17.05.91	4.56											18.0
AUTUMN	NOORDHOEK R.	14.04.90												18.0
EARLY SPRING	NOORDHOEK R.	26.09.90		0.000	0.000	0.079	0.006	1.96	0.010	0.002	0.040	0	0	21.0
SPRING	NOORDHOEK R.	23.11.90		0.000	0.000	0.165	0.004	0.26	0.007	0.000	0.015	0	0	20.0
SUMMER	NOORDHOEK R.	08.03.91	2.28	0.000	0.000	0.220	0.004	2.26	0.007	0.002	0.040	0	0	22.0
AUTUMN	NOORDHOEK R.	18.05.91	3.10	0.000	0.007	0.221	0.005	2.35	0.007	0.010	0.040	0	0	17.0
AUTUMN	KLAWER CANAL	21.05.91												17.0
AUTUMN	LUTZVILLE	21.05.91												16.5
SUMMER	RONDEGAT R.	26.01.92	52.30											24.0
SUMMER	DRIEHOEKS R.	30.01.92	63.51											22.4
SUMMER	THEE R.	25.01.92	97.13											28.0
SUMMER	BOSKLOOF R.	28.01.92	104.60											23.0
SUMMER	MIDDELDEUR R.	28.01.92	37.36											28.0

Appendix 6.1 Explanation of Wentworth substrate grade scale modifications for this study, as indicated in Table 6.2

The version of the Wentworth grade scale used by the Department of Geology, University of Cape Town, was modified in several ways for this study, as indicated in Table 6.2. Firstly, the descriptions for each substrate grade were changed to conform with descriptions already used in the field. For example, the Wentworth description of small boulder (column A of Table 6.2) was changed to large cobble (column B of Table 6.2), and very fine pebble (column A) to small gravel (column B). However, the substrate size classes themselves encompassed the same range of particle sizes as the Wentworth scale.

The following explanation refers to the modified substrate classes (columns B and C of Table 6.2). During the field survey trip, at each of the PHABSIM II sites, substrates were described by eye according to a simplified field guide. Later, at these sites, and at all other sites where benthic macroinvertebrates were collected, the sizes of a characteristic selection of the substrate were measured accurately (β axis in mm). Comparison of these measurements with corresponding field descriptions revealed that, during the field survey trip, the "large gravel" substrate class (column B) had commonly been misclassified as "small cobble". Consequently, in order that the substrate descriptions for the survey matched consistently with those for the sample microhabitat data, the large gravel class was grouped with small cobble (column C). Where substrates were recorded as small or medium gravel in the field, it was found that these descriptions adequately matched the actual size measurements (column B), so these classes were retained for this study.

For the purposes of PHABSIM II, the survey data and associated microhabitat data were coded differently for the fish and the benthic macroinvertebrates, in order to better reflect the different substrate requirements of these two groups. The specific codes used are discussed in Chapter Seven (see Table 7.5) for the fish and Chapter Eight (see Table 8.3) for the benthic macroinvertebrates. The principal difference pertaining to the specific categories, outlined in Table 6.2 column C, was that the bedrock and boulder classes were grouped together for the purposes of the benthic macroinvertebrate data, and were used as two separate substrate classes for the fish data.

All the sand and mud categories of the Wentworth scale (column A) were simply grouped as sand or mud (including silt) respectively in this study (column C). Settling column analyses of the sand fraction of the substrate were performed to determine proportions of the different categories of sand, but these data were not incorporated into this study.

Appendices 6.2 to 6.4 Raw cross-section data for the three PHABSIM II sites at Grootfontein, Kriedouwkrans and Klawer

Appendix 6.2 Grootfontein cross-sections

6.2.1 Cross-section 1
6.2.2 Cross-section 2
6.2.3 Cross-section 3
6.2.4 Cross-section 4
6.2.5 Cross-section 5
6.2.6 Cross-section 6
6.2.7 Cross-section 7

Appendix 6.3 Kriedouwkrans cross-sections

6.3.1 Cross-section 1
6.3.2 Cross-section 2
6.3.3 Cross-section 3
6.3.4 Cross-section 4
6.3.5 Cross-section 5

Appendix 6.4 Klawer cross-sections

6.4.1 Cross-section 1
6.4.2 Cross-section 2
6.4.3 Cross-section 3
6.4.4 Cross-section 4
6.4.5 Cross-section 5

PHABSIM II requires that values of 0.001 (/0.0001) are used as input to represent zero or near-zero velocities in the model. Hence, zero and near-zero velocities are recorded for the cross-sections as both 0.0001 m s^{-1} and 0.0001 ft s^{-1}.

Appendix 6.2.1

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 1 : Cross-section ID No. GR 000 (GR 000)

Reach length : 0.0 m 0.0 ft
Reach length = distance to next cross-section downstream
Reach length weight : 0.80
Reach length weight = upstream weighting factor
Slope : 0.00440
Stage of zero flow : 245.62 m 805.84 ft

Water Surface Elevation November : 246.72 m 809.45 ft
February : 246.46 m 808.60 ft
October : 246.96 m 810.24 ft

Calculated Discharge : November : 3.163 m3/s 111.685 ft3/s
February : 1.214 m3/s 42.877 ft3/s
October : 4.942 m3/s 174.530 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Depth Oct. (m)	Depth Oct. (ft)	Velocity Oct. (m/s)	Velocity Oct. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	251.92	826.51													34	13
2	13.56	44.49	247.10	810.69													34	43
3	18.80	61.68	246.98	810.30													52	21
4	31.11	102.07	247.76	812.86													34	43
5	48.96	160.63	247.10	810.70													34	43
6	60.06	197.05	246.39	808.37													34	43
7	61.18	200.72	246.32	808.14	0.17	0.56	0.0001	0.0001	0.12	0.39	0.0001	0.0001					24	33
8	62.44	204.86	248.39	808.37													24	33
9	66.21	217.22	246.92	810.10													11	21
10	70.90	232.61	247.39	811.65													34	33
11	73.89	242.40	247.25	811.19													52	11
12	75.07	246.29	246.71	809.42	0.14	0.46	0.0001	0.0001					0.38	1.25	-0.0001	-0.0001	52	21
13	76.41	250.69	246.05	807.25	0.60	1.97	0.0350	0.1148	0.36	1.18	0.0001	0.0001	0.53	1.74	-0.1090	-0.3576	54	41
14	77.42	254.00	246.00	807.09	0.72	2.36	0.0500	0.1640	0.49	1.61	0.0001	0.0001	0.92	3.02	-0.1690	-0.5545	44	31
15	78.40	257.22	245.86	806.63	0.76	2.49	0.0350	0.1148	0.57	1.87	0.0001	0.0001	1.05	3.44	-0.1090	-0.3576	34	33
16	79.17	259.74	245.77	806.33	0.90	2.95	0.0210	0.0689	0.63	2.07	0.0001	0.0001	1.10	3.61	0.0500	0.1640	34	43
17	80.78	265.03	245.84	806.56	0.86	2.82	0.0500	0.1640	0.65	2.13	0.0001	0.0001	1.09	3.58	0.1240	0.4068	14	43

Appendix 6.2.1 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 1 : Cross-section ID No. GR 000 (GR 000)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Depth Oct. (m)	Depth Oct. (ft)	Velocity Oct. (m/s)	Velocity Oct. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	81.68	267.98	246.62	809.12	0.05	0.16	0.0001	0.0001					0.86	2.82	0.4290	1.4075	11	41
19	82.14	269.49	246.94	810.17									0.86	2.82	0.4290	1.4075	44	41
20	82.24	269.82	246.94	810.17									0.12	0.39	0.5820	1.9094	44	41
21	82.34	270.14	246.94	810.17									0.12	0.39	0.5820	1.9094	44	41
22	82.41	270.37	245.99	807.05	0.77	2.53	0.1690	0.5545					0.13	0.43	0.5230	1.7159	14	43
23	83.47	273.85	246.06	807.28	0.73	2.40	0.2720	0.8924	0.36	1.18	0.0810	0.2657	0.94	3.08	0.6710	2.2014	24	43
24	84.56	277.43	246.07	807.32	0.62	2.03	0.2720	0.8924	0.38	1.25	0.2600	0.8530	0.90	2.95	0.7310	2.3983	24	43
25	85.87	281.73	246.00	807.09	0.78	2.56	0.3600	1.1811	0.41	1.35	0.3720	1.2205	0.85	2.79	0.8320	2.7297	34	43
26	86.96	285.30	245.97	806.99	0.74	2.43	0.4790	1.5715	0.45	1.48	0.6440	2.1129	0.89	2.92	0.6850	2.2474	34	43
27	88.25	289.53	245.91	806.79	0.76	2.49	0.3900	1.2795	0.52	1.71	0.4390	1.4403	0.90	2.95	0.4480	1.4698	24	43
28	89.31	293.01	245.95	806.92	0.82	2.69	0.3740	1.2270	0.51	1.67	0.2530	0.8301	0.83	2.72	0.3010	0.9875	24	43
29	91.56	300.39	245.83	806.53	0.88	2.89	0.2420	0.7940	0.62	2.03	0.0550	0.1804	1.18	3.87	0.1240	0.4068	54	31
30	92.52	303.54	245.80	806.43	0.89	2.92	0.1540	0.5052	0.61	2.00	0.0001	0.0001	1.30	4.27	0.0790	0.2592	54	31
31	94.42	309.78	245.69	806.07	1.04	3.41	0.0500	0.1640	0.68	2.23	0.0001	0.0001	1.35	4.43	0.0210	0.0689	34	33
32	96.48	316.54	245.85	805.94	1.08	3.54	0.0350	0.1148	0.90	2.95	0.0001	0.0001	1.30	4.27	0.0001	0.0001	14	33
33	98.21	322.21	245.76	806.30	1.13	3.71	0.0500	0.1640	0.74	2.43	0.0001	0.0001	1.40	4.59	0.0001	0.0001	14	33
34	100.48	329.66	245.62	805.84	0.93	3.05	0.0350	0.1148	0.54	1.77	0.0001	0.0001	1.12	3.67	0.0001	0.0001	11	41
35	102.08	334.91	248.09	807.38	0.34	1.12	0.0350	0.1148					0.17	0.56	0.0001	0.0001	11	41
36	102.57	336.52	246.73	809.46													11	41
37	103.79	340.52	247.15	810.86													11	21
38	109.44	359.06	247.36	811.55													11	41
39	116.01	380.61	246.68	815.88													11	21
40	125.66	412.27	248.68	815.88													11	21
41	125.76	412.60	248.69	815.91													11	11
42	125.86	412.93	248.68	815.88													11	11
43	137.69	451.74	248.49	815.26													11	11
44	146.56	480.84	248.48	815.22													11	11
45	157.04	515.22	246.27	814.53													11	11

Appendix 6.2.2

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 2 : Cross-section ID No. GR 276 (GR 906)

Reach length : 276.0 m 905.5 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.08

Reach length weight - upstream weighting factor

Slope : 0.00280

Stage of zero flow : 247.37 m 811.58 ft

Water Surface Elevation:
November : 247.93 m 813.40 ft
February : 247.82 m 813.10 ft
October : 248.10 m 814.00 ft

Calculated Discharge:
November : 3.352 m3/s 118.370 ft3/s
February : 1.397 m3/s 49.350 ft3/s
October : 9.416 m3/s 332.520 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	254.77	835.86									52	21
2	19.18	62.93	249.78	819.49									52	21
3	22.98	75.39	249.22	817.65									52	21
4	25.71	84.35	249.31	817.95									52	21
5	27.90	91.54	247.87	813.21	0.90	2.95	0.0001	0.0001					34	43
6	29.41	96.49	247.18	810.96	0.72	2.36	0.0001	0.0001	0.48	1.57	0.0001	0.0001	54	41
7	31.66	103.87	247.31	811.38	0.58	1.90	0.0001	0.0001	0.44	1.44	0.0001	0.0001	52	11
8	33.63	110.33	247.93	813.40	0.56	1.84	0.0001	0.0001					54	31
9	34.36	112.73	248.75	816.11									54	21
10	35.22	115.55	247.77	812.89	0.20	0.66	0.0001	0.0001					52	21
11	36.95	121.23	247.62	812.40	0.34	1.11	0.3460	1.1352	0.13	0.43	0.0880	0.2887	14	33
12	38.26	125.52	247.61	812.37	0.28	0.92	0.5970	1.9587	0.16	0.52	0.3330	1.0925	24	33
13	39.44	129.40	247.47	811.91	0.46	1.51	0.3310	1.0860	0.28	0.92	0.2070	0.6791	24	33
14	41.07	134.74	247.44	811.81	0.45	1.48	0.3900	1.2795	0.27	0.87	0.1940	0.6365	24	33
15	42.48	139.37	247.37	811.58	0.53	1.74	0.5670	1.8602	0.36	1.18	0.4520	1.4829	14	33
16	43.72	143.44	247.38	811.61	0.51	1.67	0.6560	2.1522	0.42	1.38	0.5250	1.7224	24	33
17	44.90	147.31	247.44	811.81	0.48	1.57	0.6710	2.2014	0.37	1.21	0.5450	1.7881	14	33

Appendix 6.2.2 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 2 : Cross-section ID No. GR 276 (GR 906)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	46.09	151.21	247.43	811.78	0.47	1.54	0.4480	1.4698	0.35	1.15	0.3790	1.2434	14	33
19	46.94	154.00	247.39	811.65	0.47	1.54	0.3900	1.2795	0.34	1.11	0.3990	1.3091	14	33
20	48.13	157.91	247.51	812.04	0.42	1.38	0.5970	1.9587	0.28	0.92	0.2870	0.9416	14	33
21	49.10	161.09	247.70	812.66	0.18	0.59	0.3740	1.2270	0.07	0.22	0.2320	0.7611	14	33
22	50.80	166.67	247.70	812.66	0.20	0.66	0.3460	1.1352	0.12	0.39	0.0001	0.0001	14	43
23	51.99	170.57	247.87	813.21	0.08	0.26	0.3160	1.0400					14	43
24	53.31	174.90	247.96	813.50									14	43
25	58.53	192.03	248.00	813.65									14	43
26	63.01	206.73	247.96	813.50									14	43
27	65.58	215.16	247.86	813.18	0.28	0.92	0.6710	2.2014					14	43
28	67.36	221.00	246.63	809.15	0.48	1.57	0.0360	0.1181	0.12	0.39	0.2470	0.8104	52	21
29	68.91	226.08	247.87	813.21	0.40	1.31	0.0790	0.2592					52	41
30	73.16	240.03	247.96	813.50									52	21
31	76.14	249.80	247.87	813.21									52	21
32	80.20	263.12	246.49	808.69	0.60	1.97	0.0001	0.0001	0.38	1.25	0.0001	0.0001	52	11
33	81.21	266.44	246.58	808.99	0.58	1.90	0.0650	0.2133	0.44	1.44	0.0001	0.0001	52	11
34	81.62	267.78	246.56	808.92	0.63	2.07	0.0650	0.2133	0.39	1.28	0.0001	0.0001	52	11
35	83.73	274.70	246.42	808.48	0.72	2.36	0.0650	0.2133	0.44	1.44	0.0001	0.0001	52	11
36	86.88	285.04	247.87	813.21	0.52	1.71	0.0001	0.0001					52	31
37	90.64	297.38	248.83	816.37									52	31
38	96.46	316.47	249.01	816.96									52	31
39	99.67	327.00	248.22	814.40									34	43
40	103.73	340.32	248.77	816.17									31	43
41	109.07	357.84	248.39	814.90									34	43
42	110.09	361.19	248.14	814.10									34	43
43	115.64	379.40	248.65	815.78									52	11
44	129.09	423.52	250.89	823.13									52	11
45	129.19	423.85	250.90	823.16									52	11

Appendix 6.2.3

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 3 : Cross-section ID No. GR 302 (GR 991)

Reach length : 26.00 m 85.30 ft
Reach length = distance to next cross-section downstream
Reach length weight : 0.91
Reach length weight = upstream weighting factor
Slope : 0.00070
Stage of zero flow : 247.37 m 811.58 ft

Water Surface Elevation:	November :	247.96 m	813.52 ft
	February :	247.80 m	812.99 ft
	October :	248.22 m	814.37 ft
Calculated Discharge:	November :	2.703 m3/s	95.448 ft3/s
	February :	0.810 m3/s	28.594 ft3/s
	October :	9.416 m3/s	332.523 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	252.09	827.07									35	43
2	13.12	43.04	249.38	818.18									35	43
3	20.86	68.44	248.28	814.57									35	43
4	22.45	73.65	248.38	814.90									35	43
5	23.29	76.41	247.99	813.60									35	43
6	24.89	81.66	247.60	812.34	0.36	1.18	0.050	0.164	0.30	0.98	0.0001	0.0001	14	33
7	26.57	87.17	247.27	811.25	0.63	2.07	0.079	0.259	0.63	2.07	0.0001	0.0001	52	11
8	27.66	90.75	246.96	810.24	0.96	3.15	0.095	0.312	0.88	2.89	0.0001	0.0001	54	31
9	29.43	96.56	246.80	809.71	1.10	3.61	0.109	0.358	1.20	3.94	0.0350	0.1146	24	33
10	30.51	100.10	246.64	809.19	1.16	3.81	0.124	0.407	1.10	3.61	0.0550	0.1804	24	33
11	31.89	104.63	246.73	809.46	1.24	4.07	0.139	0.456	1.10	3.61	0.0680	0.2231	24	33
12	33.34	109.38	246.69	809.35	1.22	4.00	0.139	0.456	1.04	3.41	0.0820	0.2690	24	33
13	35.30	115.81	246.84	809.64	1.10	3.61	0.169	0.554	0.84	2.76	0.0480	0.1575	24	33
14	36.95	121.23	246.85	809.88	1.05	3.44	0.154	0.505	0.92	3.01	0.0520	0.1706	24	33
15	38.46	126.18	246.92	810.10	0.98	3.22	0.124	0.407	0.86	2.82	0.0520	0.1706	24	33
16	39.91	130.94	247.10	810.70	1.00	3.28	0.139	0.456	0.88	2.89	0.0440	0.1444	34	33
17	41.57	136.38	247.17	810.93	0.90	2.95	0.139	0.456	0.70	2.30	0.0680	0.2231	24	33

Appendix 6.2.3 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 3 : Cross-section ID No. GR 302 (GR 991)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	42.89	140.72	247.14	810.83	0.81	2.66	0.095	0.312	0.66	2.17	0.0750	0.2461	24	33
19	44.19	144.98	247.09	810.66	0.73	2.40	0.124	0.407	0.70	2.30	0.0001	0.0001	24	33
20	45.38	148.88	247.13	810.79	0.80	2.62	0.095	0.312	0.68	2.23	0.0001	0.0001	24	33
21	46.51	152.59	247.20	811.02	0.78	2.56	0.079	0.259	0.62	2.03	0.0150	0.0492	34	33
22	47.40	155.51	247.27	811.25	0.65	2.13	0.079	0.259	0.50	1.64	0.0001	0.0001	34	33
23	48.98	160.70	247.88	813.25	0.12	0.39	0.065	0.213					52	11
24	50.33	165.12	248.57	815.52									11	41
25	51.53	169.06	248.19	814.27									52	41
26	53.14	174.34	248.12	814.04									11	41
27	56.59	185.66	248.01	813.68									52	41
28	59.38	194.82	247.99	813.60									52	41
29	63.11	207.05	248.43	815.06									52	41
30	67.60	221.78	248.20	814.30									52	11
31	68.69	225.36	249.90	819.88									52	11
32	72.34	237.34	247.99	813.60									52	11
33	77.20	253.28	247.99	813.60									52	41
34	80.73	264.86	248.01	813.68									52	41
35	82.91	272.01	248.32	814.70									11	41
36	85.71	281.20	249.19	817.55									52	11
37	89.03	292.09	248.35	814.80									52	11
38	93.26	305.97	248.05	813.81									52	41
39	95.17	312.24	247.99	813.60									11	11
40	98.42	322.90	248.31	814.67									11	11
41	100.46	329.59	247.99	813.60									52	21
42	101.10	331.69	248.19	814.27									52	11

Appendix 6.2.3 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 3 : Cross-section ID No. GR 302 (GR 991)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	102.96	337.80	247.91	813.35									34	33
44	103.83	340.65	247.80	812.99									34	33
45	104.92	344.23	247.84	813.12									52	41
46	107.25	351.87	249.05	817.09									11	21
47	109.31	358.63	249.50	818.57									11	21
48	121.92	400.00	251.42	824.87									11	21
49	122.02	400.33	251.43	824.90									11	21

Appendix 6.2.4

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 4 : Cross-section ID No. GR 517 (GR 1696)

Reach length : 215.0 m 705.4 ft
Reach length = distance to next cross-section downstream
Reach length weight : 0.50
Reach length weight = upstream weighting factor
Slope : 0.00480
Stage of zero flow : 247.37 m 811.58 ft

Water Surface Elevation:	November :	247.99 m	813.62 ft
	February :	247.82 m	813.06 ft
	October :	248.35 m	814.80 ft
Calculated Discharge:	November :	2.480 m3/s	87.577 ft3/s
	February :	1.127 m3/s	39.800 ft3/s
	October :	9.416 m3/s	332.523 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	251.82	826.18									11	21
2	14.71	48.26	249.61	818.93									11	21
3	17.50	57.41	249.13	817.36									52	11
4	19.09	62.63	248.79	816.24									52	21
5	20.34	66.73	247.98	813.58									52	21
6	20.59	67.55	247.97	813.55	0.65	2.13	0.0001	0.0001					11	11
7	22.55	73.98	246.93	810.14	1.08	3.54	0.0360	0.1181	0.82	2.69	0.0350	0.1148	52	33
8	23.87	73.31	246.87	809.94	1.14	3.74	0.0790	0.2592	0.97	3.18	0.0950	0.3117	34	33
9	24.57	80.61	246.92	810.10	1.10	3.61	0.2420	0.7940	0.94	3.08	0.1080	0.3543	34	33
10	25.88	84.91	247.01	810.40	1.02	3.35	0.2420	0.7940	0.85	2.79	0.1080	0.3543	24	43
11	26.75	87.76	247.05	810.53	0.92	3.02	0.1830	0.6004	0.76	2.49	0.0420	0.1378	24	33
12	27.92	91.60	247.13	810.79	0.86	2.82	0.2570	0.8432	0.68	2.23	0.0480	0.1575	24	43
13	28.49	93.47	247.24	811.15	0.73	2.40	0.2420	0.7940	0.86	2.17	0.0610	0.2001	24	33
14	29.20	95.80	247.25	811.19	0.71	2.33	0.1980	0.6496	0.55	1.80	0.1280	0.4199	34	43
15	29.78	97.70	247.29	811.32	0.72	2.36	0.2130	0.6988	0.56	1.84	0.1480	0.4858	24	43
16	30.45	99.90	247.31	811.38	0.67	2.20	0.2570	0.8432	0.54	1.77	0.1010	0.3314	34	43
17	31.35	102.85	247.33	811.45	0.64	2.10	0.2870	0.9416	0.50	1.64	0.1740	0.5709	44	41

Appendix 6.2.4 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 4 : Cross-section ID No. GR 517 (GR 1696)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	32.38	106.23	247.38	811.61	0.63	2.07	0.2420	0.7940	0.45	1.48	0.214	0.702	54	41
19	33.20	108.92	247.46	811.88	0.50	1.64	0.2570	0.8432	0.33	1.08	0.273	0.896	52	11
20	33.98	111.48	247.47	811.91	0.50	1.64	0.2570	0.8432	0.32	1.05	0.207	0.679	52	51
21	34.86	114.37	247.50	812.01	0.48	1.57	0.2280	0.7480	0.28	0.92	0.293	0.961	52	51
22	35.85	117.62	247.49	811.98	0.50	1.64	0.2420	0.7940	0.30	0.98	0.293	0.961	52	11
23	36.68	120.34	247.56	812.20	0.42	1.38	0.2280	0.7480	0.24	0.79	0.260	0.853	52	11
24	37.21	122.08	247.59	812.30	0.38	1.25	0.2280	0.7480	0.19	0.62	0.267	0.876	52	11
25	38.08	124.93	247.64	812.47	0.34	1.16	0.2280	0.7480	0.19	0.62	0.194	0.636	52	11
26	38.63	126.74	247.65	812.50	0.30	0.96	0.2130	0.6988	0.16	0.52	0.128	0.420	52	11
27	39.63	130.02	247.69	812.63	0.30	0.98	0.1980	0.6496	0.14	0.46	0.068	0.223	52	11
28	40.42	132.61	247.96	813.51	0.10	0.33	0.0650	0.2133			0.194	0.636	34	33
29	43.92	144.09	249.12	817.32							0.128	0.420	34	33
30	47.16	154.72	249.45	818.41							0.068	0.223	14	33
31	51.16	167.85	249.26	817.78			0.0650	0.2133					14	43
32	52.83	173.33	249.00	816.93									14	43
33	53.57	175.75	248.95	816.77									14	33
34	55.08	180.71	249.00	816.93									14	33
35	58.57	192.16	249.44	818.37									14	33
36	63.67	208.89	249.39	818.21									52	21
37	67.28	220.73	249.33	818.01									52	11
38	69.31	227.40	248.64	816.40									34	43
39	71.83	235.66	248.73	816.04									34	43
40	78.22	256.63	249.38	818.18									24	33
41	82.89	271.95	249.14	817.39									34	33
42	87.54	287.20	249.95	820.05									52	21
43	98.96	324.67	250.70	822.51									52	33
44	104.03	341.31	252.12	827.17									11	33
45	104.13	341.63	252.13	827.20									11	33

Appendix 6.2.5

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 5 : Cross-section ID No. GR 628 (GR 2060)

Reach length : 111.0 m 364.2 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.85

Reach length weight = upstream weighting factor

Slope : 0.0049

Stage of zero flow : 247.43 m 811.78 ft

Water Surface Elevation:	November :	249.05 m	817.09 ft
	February :	248.94 m	816.73 ft
	October :	249.33 m	818.01 ft
Calculated Discharge:	November :	2.939 m3/s	103.786 ft3/s
	February :	1.039 m3/s	36.681 ft3/s
	October :	9.416 m3/s	332.523 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	252.47	828.31									35	43
2	14.39	47.21	249.47	818.47									35	44
3	15.43	50.62	249.82	819.62									52	21
4	16.43	53.90	249.37	818.14									52	31
5	17.63	57.84	249.09	817.20									11	41
6	18.90	62.01	247.69	812.63	0.54	1.77	0.0360	0.1181	0.52	1.71	0.2000	0.6562	52	41
7	19.84	65.09	247.43	811.78	0.80	2.62	0.3460	1.1352	0.61	2.00	0.3380	1.1089	34	43
8	21.00	68.90	247.45	811.84	0.78	2.56	0.6410	2.1030	0.54	1.77	0.3920	1.2861	24	43
9	22.08	72.44	247.48	811.94	0.72	2.36	0.8900	2.9199	0.49	1.61	0.3130	1.0269	24	43
10	23.23	76.21	247.52	812.07	0.66	2.17	0.6710	2.2014	0.47	1.54	0.3200	1.0499	24	43
11	23.98	78.67	247.62	812.40	0.62	2.03	0.3900	1.2795	0.41	1.35	0.2530	0.8301	24	43
12	25.04	82.15	247.74	812.80	0.44	1.44	0.4790	1.5715	0.25	0.82	0.2000	0.6562	14	43
13	25.75	84.48	248.96	816.80	0.28	0.92	0.4640	1.5223					14	43
14	26.68	87.53	249.09	817.20									52	11
15	30.56	100.26	249.81	819.59									14	43
16	37.17	121.95	249.30	817.91									34	33
17	41.86	137.34	249.04	817.06	0.05	0.16	0.0001	0.0001					52	43

Appendix 6.2.5 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 5 : Cross-section ID No. GR 628 (GR 2060)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	43.55	142.88	248.29	814.60	0.73	2.40	0.0001	0.0001	0.64	2.10	0.0001	0.0001	24	43
19	44.69	146.62	248.21	814.34	0.80	2.62	0.0001	0.0001	0.69	2.26	0.0001	0.0001	14	33
20	45.96	150.79	248.27	814.53	0.78	2.56	0.0360	0.1181	0.71	2.33	0.0001	0.0001	14	33
21	47.06	154.40	248.31	814.67	0.70	2.30	0.0500	0.1640	0.63	2.07	0.0001	0.0001	14	33
22	47.99	157.45	248.27	814.53	0.75	2.46	0.0500	0.1640	0.65	2.13	0.0001	0.0001	24	33
23	49.32	161.81	248.20	814.30	0.80	2.62	0.0950	0.3117	0.70	2.30	0.0001	0.0001	24	33
24	50.17	164.60	248.20	814.30	0.84	2.76	0.0950	0.3117	0.76	2.49	0.0001	0.0001	24	33
25	51.19	167.95	248.26	814.50	0.74	2.43	0.0950	0.3117	0.70	2.30	0.0001	0.0001	24	33
26	52.24	171.39	248.05	813.81	1.00	3.28	0.0360	0.1181	0.82	2.69	0.0001	0.0001	54	31
27	53.37	175.10	247.89	813.29	1.14	3.74	0.0210	0.0689	1.05	3.44	0.0001	0.0001	44	31
28	54.31	178.18	247.82	813.06	1.16	3.81	0.0210	0.0689	1.11	3.64	0.0001	0.0001	44	31
29	55.42	181.82	247.76	812.86	1.20	3.94	0.0210	0.0689	1.16	3.81	0.0001	0.0001	34	33
30	56.27	184.61	247.60	812.99	1.20	3.94	0.0210	0.0689	1.18	3.87	0.0001	0.0001	34	33
31	57.69	189.27	247.65	812.50	1.30	4.27	0.0001	0.0001	1.24	4.07	0.0001	0.0001	24	33
32	58.67	192.49	247.59	812.30	1.30	4.27	0.0001	0.0001	1.28	4.20	0.0001	0.0001	24	33
33	60.07	197.08	247.60	812.34	1.30	4.27	0.0001	0.0001	1.28	4.20	0.0001	0.0001	54	31
34	62.13	203.84	247.79	812.96	1.00	3.28	0.0001	0.0001	1.00	3.28	0.0001	0.0001	52	31
35	63.15	207.19	249.05	817.09									52	31
36	64.68	212.20	249.89	819.85									52	21
37	73.48	241.01	249.53	818.67									52	21
38	82.47	270.57	250.19	820.83									52	21
39	96.31	315.98	252.11	827.13									52	11
40	107.07	351.28	256.16	840.42									52	11
41	107.17	351.61	256.17	840.45									52	11

Appendix 6.2.6

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 6 : Cross-section ID No. GR 695

Reach length : 67.0 m 219.8 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.99

Reach length weight = upstream weighting factor

Slope : 0.00010

Stage of zero flow : 247.51 m 812.04 ft

Water Surface Elevation:

November :	249.06 m	817.13 ft
February :	816.83 m	816.83 ft
October :	817.98 m	817.98 ft

Calculated Discharge:

November :	2.719 m3/s	96.006 ft3/s
February :	1.549 m3/s	54.702 ft3/s
October :	9.416 m3/s	332.523 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	252.38	828.02									11	21
2	12.92	42.39	249.81	819.59									11	21
3	17.34	56.89	249.62	818.96									11	21
4	21.46	70.41	249.62	817.85									11	31
5	23.42	76.84	249.62	817.85									52	31
6	28.20	92.52	249.28	817.85	0.54	1.77	0.0360	0.1181			0.2000	0.6562	34	33
7	31.66	103.87	249.38	818.18	0.80	2.62	0.3460	1.1352			0.3380	1.1089	34	43
8	32.46	106.50	249.09	817.20	0.78	2.56	0.6410	2.1030			0.0001	0.0001	11	31
9	34.08	111.81	247.85	813.16	1.16	3.81	0.169	0.554			0.0001	0.0001	14	33
10	34.85	114.34	247.83	813.09	1.30	4.27	0.183	0.600					14	33
11	36.31	119.13	249.06	817.13									15	33
12	38.81	127.33	250.22	820.93									15	34
13	40.94	134.32	249.06	817.13									15	33
14	42.79	140.39	247.60	812.34	1.50	4.92	0.228	0.748	1.45	4.76	0.1340	0.4396	14	33
15	43.93	144.13	247.51	812.04	1.40	4.59	0.257	0.843	1.45	4.76	0.1340	0.4396	14	33
16	45.11	148.00	248.35	814.80	1.20	3.94	0.169	0.554	1.45	4.76	0.1280	0.4199	34	33
17	46.40	152.23	247.99	813.62	1.20	3.94	0.169	0.554	1.18	3.81	0.0680	0.2231	34	33

Appendix 6.2.6 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 6 : Cross-section ID No. GR 695

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	48.39	158.76	248.47	815.19	0.54	1.77	0.139	0.456	0.46	1.51	0.1540	0.5052	34	33
19	49.73	163.16	248.43	815.06	0.58	1.84	0.169	0.554	0.52	1.71	0.1280	0.4199	24	33
20	50.92	167.06	248.41	814.99	0.63	2.07	0.183	0.600	0.45	1.48	0.1080	0.3543	24	33
21	52.51	172.28	248.51	815.32	0.50	1.64	0.124	0.407	0.40	1.31	0.0680	0.2231	24	33
22	53.58	175.79	248.63	815.72	0.41	1.35	0.109	0.358	0.30	0.98	0.0350	0.1148	24	33
23	55.20	181.10	248.61	815.65	0.41	1.35	0.079	0.259	0.30	0.98	0.0001	0.0001	24	33
24	56.26	184.58	248.60	815.62	0.44	1.44	0.065	0.213	0.30	0.98	0.0001	0.0001	24	33
25	57.57	188.88	248.64	815.75	0.40	1.31	0.050	0.164	0.31	1.02	0.0001	0.0001	24	33
26	59.03	193.67	248.65	815.78	0.37	1.21	0.065	0.213	0.29	0.95	0.0001	0.0001	34	33
27	60.46	198.36	248.68	815.88	0.29	0.95	0.036	0.118	0.25	0.82	0.0001	0.0001	52	11
28	61.34	201.25	248.73	816.04	0.26	0.85	0.021	0.069	0.25	0.82	0.0001	0.0001	52	21
29	62.73	205.81	249.06	817.13			0.0210				0.0001	0.0001	52	31
30	70.04	229.79	250.47	821.75	1.20	3.94	0.0210	0.0689			0.0001	0.0001	52	21
31	78.89	258.83	250.31	821.23	1.30	4.27	0.0001	0.0001			0.0001	0.0001	34	31
32	97.45	319.72	252.07	827.00	1.30	4.27	0.0001	0.0001	1.28	4.20	0.0001	0.0001	15	33
33	102.34	335.76	255.12	837.01	1.30	4.27	0.0001	0.0001	1.28	4.20	0.0001	0.0001	15	43
34	106.93	350.82	256.24	840.68	1.00	3.28	0.0001	0.0001	1.00	3.28	0.0001	0.0001	15	43

Appendix 6.2.7

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 7 : Cross-section ID No. GR 840 (GR 2756)

Reach length :	145.0 m	475.7 ft	Water Surface Elevation:	November :	249.08 m	817.19 ft	
Reach length = distance to next cross-section downstream				February :	249.00 m	816.93 ft	
Reach length weight :				October :	249.37 m	818.14 ft	
Reach length weight = upstream weighting factor							
Slope :	0.00010		Calculated Discharge:	November :	3.34 m3/s	117.951 ft3/s	
Stage of zero flow :	248.64 m	815.75 ft		February :	1.749 m3/s	61.765 ft3/s	
				October :	9.416 m3/s	332.522 ft3/s	

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Depth Oct. (m)	Depth Oct. (ft)	Velocity Oct. (m/s)	Velocity Oct. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	250.98	823.43													52	11
2	4.77	15.65	251.28	824.41													52	11
3	8.82	28.94	250.35	821.36													52	11
4	10.69	35.07	249.99	820.18													52	11
5	21.99	72.15	251.30	824.48													11	11
6	25.16	82.55	250.50	821.85													34	33
7	26.93	88.35	250.53	821.95													34	33
8	29.32	96.19	250.21	820.90													52	11
9	33.24	109.06	250.36	821.39													52	11
10	38.58	126.57	249.09	817.21													52	21
11	40.00	131.23	248.76	816.14	0.26	0.85	0.4200	1.3780	0.26	0.85	0.1280	0.4199	0.51	1.67	0.2870	0.9416	24	33
12	41.41	135.86	248.64	815.75	0.24	0.79	0.6260	2.0538	0.38	1.25	0.3920	1.2861	0.46	1.51	0.2420	0.7940	14	43
13	42.73	140.19	248.70	815.94	0.42	1.38	0.2720	0.8924	0.26	0.85	0.2930	0.9613	0.76	2.49	0.6560	2.1522	24	43
14	43.59	143.01	248.70	815.94	0.31	1.02	0.2720	0.8924	0.28	0.92	0.2860	0.9383	0.72	2.36	0.7590	2.4902	24	33
15	45.12	148.03	248.67	815.85	0.40	1.31	0.7440	2.4409	0.15	0.49	0.0680	0.2231	0.66	2.17	0.5680	1.8635	14	33
16	46.05	151.08	248.73	816.04	0.36	1.18	0.6560	2.1522	0.16	0.52	0.3060	1.0039	0.59	1.94	0.7730	2.5361	14	43
17	47.03	154.30	248.70	815.94	0.36	1.18	0.1390	0.4560	0.28	0.92	0.1280	0.4199	0.57	1.87	0.5970	1.9587	14	33

Appendix 6.2.7 continued

OLIFANTS RIVER (WESTERN CAPE) : GROOTFONTEIN SITE

Section No. 7 : Cross-section ID No. GR 840 (GR 2756)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Depth Oct. (m)	Depth Oct. (ft)	Velocity Oct. (m/s)	Velocity Oct. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	48.01	157.51	248.74	816.08	0.32	1.05	0.3900	1.2795	0.22	0.72	0.0950	0.3117	0.59	1.94	0.5520	1.8110	24	33
19	49.19	161.38	248.72	816.01	0.38	1.25	0.3600	1.1811	0.24	0.79	0.3330	1.0925	0.66	2.17	0.7730	2.5361	24	43
20	50.04	164.17	248.78	816.21	0.36	1.18	0.8470	2.7789	0.18	0.59	0.5910	1.9390	0.56	1.84	0.7000	2.2966	24	43
21	50.96	167.19	248.85	816.44	0.24	0.79	0.2570	0.8432	0.14	0.46	0.9420	3.0906	0.66	2.17	0.6850	2.2474	14	33
22	52.25	171.42	248.96	816.80	0.14	0.46	0.8180	2.6837	0.22	0.72	0.5380	1.7651	0.56	1.84	0.6260	2.0538	15	44
23	53.32	174.93	248.85	816.44	0.20	0.66	0.7740	2.5394	0.14	0.46	0.4720	1.5486	0.47	1.54	0.8030	2.6345	14	33
24	54.21	177.85	248.87	816.50	0.16	0.52	0.6710	2.2014	0.12	0.39	0.1410	0.4626	0.36	1.18	0.8900	2.9199	15	34
25	55.06	180.64	248.84	816.40	0.14	0.46	0.7150	2.3458	0.12	0.39	0.1740	0.5709	0.47	1.54	0.8620	2.8281	14	33
26	56.01	183.76	248.93	816.70	0.12	0.39	0.3900	1.2795	0.12	0.39	0.0480	0.1575	0.33	1.08	1.3760	4.5144	14	43
27	56.96	186.88	248.77	816.17	0.26	0.85	0.5380	1.7651	0.20	0.66	0.8490	2.7854	0.44	1.44	1.0380	3.4055	14	33
28	57.93	190.06	248.76	816.14	0.32	1.05	0.3160	1.0367	0.22	0.72	0.2670	0.8760	0.56	1.84	0.6560	2.1522	24	33
29	58.85	193.08	248.72	816.01	0.36	1.18	0.2720	0.8924	0.20	0.66	0.3920	1.2861	0.62	2.03	0.4480	1.4698	34	33
30	59.88	196.46	248.85	816.44	0.34	1.12	0.6120	2.0079	0.20	0.66	0.8180	2.6837	0.74	2.43	0.8180	2.6837	15	44
31	60.75	199.31	248.77	816.17	0.26	0.85	0.3600	1.1811	0.24	0.79	0.5840	1.9160	0.66	2.17	0.5080	1.6667	24	33
32	61.64	202.23	248.72	816.01	0.30	0.98	0.8900	2.9199	0.22	0.72	0.3130	1.0269	0.50	1.64	0.8180	2.6837	14	43
33	62.58	205.31	248.87	816.50	0.26	0.85	0.4050	1.3287	0.18	0.59	0.0680	0.2231	0.46	1.51	0.9940	3.2612	14	43
34	63.22	207.41	248.83	816.37	0.20	0.66	0.3600	1.1811	0.12	0.39	0.1480	0.4856	0.46	1.51	0.4930	1.6175	14	43
35	64.18	210.56	249.10	817.26													11	21
36	67.44	221.26	249.85	819.72													52	11
37	75.89	248.98	250.66	822.36													14	33
38	79.99	262.43	251.21	824.18													24	33
39	85.72	281.23	250.89	823.13													52	21
40	95.55	313.48	251.19	824.11													11	11
41	111.38	365.42	255.64	838.71													11	11
42	111.48	365.75	255.65	838.75													11	11

Appendix 6.3.1

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 1 : Cross-section ID No. KR 000 (KR 000)

Reach length : 0.0 m 0.0 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.50

Reach length weight = upstream weighting factor

Slope : 0.00017

Stage of zero flow : 103.98 m 341.14 ft

Water Surface Elevation :
November : 105.09 m 344.48 ft
February : 104.74 m 343.63 ft
October : 105.69 m 346.75 ft

Discharge :
November : 1.901 m3/s 67.136 ft3/s
February : 0.148 m3/s 5.227 ft3/s
October : 16.155 m3/s 570.53 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	109.31	358.62									11	21
2	10.83	35.53	107.86	353.87									11	21
3	15.16	49.74	106.70	350.06									11	21
4	17.71	58.10	107.13	351.47									11	21
5	22.66	74.34	105.68	346.71									11	21
6	24.03	78.84	105.09	344.78									11	41
7	25.85	84.81	104.17	341.76	0.86	2.82	0.0001	0.0001	0.52	1.71	0.0001	0.0001	52	11
8	26.59	87.24	104.20	341.86	0.88	2.89	0.0001	0.0001	0.52	1.71	0.0001	0.0001	52	11
9	27.48	90.16	104.24	341.99	0.84	2.76	0.0610	0.2000	0.50	1.64	0.0001	0.0001	52	11
10	28.52	93.57	104.21	341.89	0.90	2.95	0.0001	0.0001	0.55	1.80	0.0001	0.0001	52	11
11	29.85	97.93	104.17	341.76	0.91	2.99	0.0680	0.2230	0.58	1.90	0.0001	0.0001	52	11
12	30.42	99.80	104.13	341.63	0.94	3.08	0.0810	0.2650	0.62	2.03	0.0001	0.0001	52	11
13	31.08	101.97	104.08	341.47	1.00	3.28	0.0950	0.3120	0.60	1.97	0.0001	0.0001	52	11
14	31.96	104.85	104.11	341.56	0.96	3.15	0.0810	0.2650	0.56	1.84	0.0001	0.0001	52	11
15	32.66	107.15	104.19	341.83	0.88	2.89	0.1080	0.3540	0.55	1.80	0.0001	0.0001	52	11
16	33.61	110.27	104.16	341.73	0.80	2.62	0.0950	0.3120	0.60	1.97	0.0001	0.0001	52	11
17	34.26	112.40	104.13	341.63	0.96	3.15	0.1080	0.3540	0.58	1.90	0.0001	0.0001	52	11

Appendix 6.3.1 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 1 : Cross-section ID No. KR 000 (KR 000)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	35.20	115.48	104.17	341.76	0.91	2.99	0.1010	0.3310	0.65	2.13	0.0001	0.0001	52	11
19	35.78	117.39	104.11	341.56	0.98	3.22	0.0950	0.3120	0.62	2.03	0.0001	0.0001	52	11
20	36.39	119.39	104.11	341.56	0.96	3.15	0.1210	0.3970	0.66	2.17	0.0001	0.0001	52	11
21	37.00	121.66	104.09	341.50	1.00	3.28	0.1140	0.3740	0.69	2.26	0.0001	0.0001	52	11
22	37.50	123.03	104.02	341.27	1.04	3.41	0.1210	0.3970	0.72	2.36	0.0001	0.0001	52	11
23	37.95	124.51	104.06	341.40	1.04	3.41	0.1140	0.3740	0.75	2.48	0.0001	0.0001	52	11
24	38.97	127.85	104.02	341.27	1.06	3.48	0.1010	0.3310	0.76	2.49	0.0001	0.0001	52	11
25	40.20	131.89	104.02	341.27	1.08	3.54	0.0950	0.3120	0.75	2.46	0.0001	0.0001	52	11
26	41.08	134.77	104.04	341.33	1.06	3.48	0.1140	0.3740	0.74	2.43	0.0001	0.0001	52	11
27	42.62	139.83	104.16	341.73	1.06	3.48	0.0880	0.2890	0.75	2.46	0.0001	0.0001	52	11
28	44.27	145.24	103.98	341.14	1.10	3.61	0.0950	0.3120	0.74	2.43	0.0001	0.0001	52	11
29	45.47	149.18	104.08	341.47	1.04	3.41	0.0680	0.2230	0.55	1.80	0.0001	0.0001	52	11
30	48.17	156.04	104.99	344.45	0.06	0.20	0.1740	0.5710					52	11
31	49.16	161.28	104.99	344.45	0.07	0.23	0.2140	0.7020					52	11
32	50.36	165.22	104.99	344.45	0.07	0.23	0.3060	1.0040					52	11
33	51.45	168.80	104.95	344.32	0.12	0.39	0.2530	0.8300					52	11
34	52.56	172.50	104.95	344.32	0.14	0.46	0.2400	0.7900					52	11
35	54.20	177.82	104.99	344.45	0.02	0.07	0.2930	0.9600					52	11
38	55.55	182.25	104.95	344.32	0.04	0.13	0.2930	0.9600					52	11
37	57.08	187.27	105.14	344.94									52	11
38	66.94	219.62	105.52	346.19									52	11
39	69.03	226.47	106.24	348.55									52	11
40	82.62	271.06	105.98	347.70									52	11
41	94.37	309.61	105.80	347.11									52	11
42	97.23	318.99	106.93	350.82									52	11

Appendix 6.3.1 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 1 : Cross-section ID No. KR 000 (KR 000)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	105.77	347.01	107.43	352.46									52	11
44	116.56	382.41	107.60	353.02									52	11
45	128.64	422.04	108.17	354.88									52	11
46	153.16	502.49	109.06	357.80									52	11
47	153.26	502.82	109.07	357.84									52	11
48	153.36	503.14	109.06	357.80									52	11

Appendix 6.3.2

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 2 : Cross-section ID No. KR 119 (KR 389)

Reach length : 118.5 m 388.8 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.91

Reach length weight = upstream weighting factor

Slope : 0.00556

Stage of zero flow : 103.98 m 341.14 ft

Water Surface Elevation :			
November :	105.11 m	344.84 ft
February :	104.66 m	343.37 ft
October :	105.69 m	346.75 ft

Discharge:			
November :	3.330 m3/s	117.602 ft3/s
February :	0.155 m3/s	5.474 ft3/s
October :	16.155 m3/s	570.530 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	112.71	369.78									11	11
2	17.17	56.33	107.81	353.70									11	11
3	23.17	76.02	106.79	350.36									11	11
4	28.26	92.72	106.01	347.80									11	11
5	32.91	107.97	105.14	344.94									14	33
6	34.83	114.27	105.27	345.37									52	11
7	38.38	125.92	105.99	347.73									52	11
8	40.69	133.50	105.67	346.68									52	11
9	46.73	153.31	105.79	347.08									52	11
10	53.51	175.56	105.50	346.12									52	11
11	58.23	191.04	105.36	345.67									52	11
12	59.45	195.04	105.13	344.90									52	11
13	60.29	197.80	104.74	343.63	0.28	0.92	0.0001	0.0001					52	11
14	61.93	203.18	104.26	342.06	0.82	2.69	0.0001	0.0001	0.28	0.92	0.0001	0.0001	52	11
15	63.60	208.66	103.94	341.01	1.10	3.61	0.0001	0.0001	0.54	1.77	0.0001	0.0001	52	11
16	64.36	211.15	103.82	340.61	1.26	4.13	0.0001	0.0001	0.76	2.49	0.0001	0.0001	52	11
17	65.72	215.61	103.74	340.35	1.30	4.27	0.0420	0.1380	0.98	3.22	0.0001	0.0001	52	11

Appendix 6.3.2 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 2 : Cross-section ID No. KR 119 (KR 389)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	66.90	219.49	103.73	340.32	1.35	4.43	0.0520	0.1710	1.02	3.35	0.0001	0.0001	52	11
19	68.09	223.39	103.72	340.28	1.40	4.59	0.0610	0.2000	0.98	3.22	0.0001	0.0001	52	11
20	68.90	226.05	103.75	340.38	1.36	4.46	0.0810	0.2660	0.96	3.15	0.0001	0.0001	52	11
21	69.53	228.11	103.80	340.55	1.40	4.59	0.1010	0.3310	0.88	2.89	0.0001	0.0001	52	11
22	70.99	232.90	104.03	341.30	0.98	3.22	0.1140	0.3740	0.64	2.10	0.0001	0.0001	52	11
23	71.60	234.91	104.15	341.70	0.88	2.89	0.1480	0.4860	0.57	1.87	0.0001	0.0001	52	11
24	72.66	238.38	104.21	341.89	0.86	2.82	0.1410	0.4630	0.48	1.57	0.0001	0.0001	52	11
25	73.79	242.09	104.29	342.15	0.78	2.56	0.1940	0.6360	0.42	1.38	0.0001	0.0001	52	11
26	74.98	245.99	104.41	342.55	0.64	2.10	0.1480	0.4860	0.27	0.89	0.0001	0.0001	52	11
27	76.21	250.03	104.41	342.55	0.68	2.17	0.1280	0.4200	0.27	0.89	0.0001	0.0001	52	11
28	77.65	254.75	104.42	342.58	0.65	2.13	0.1210	0.3970	0.28	0.92	0.0001	0.0001	52	11
29	78.93	258.95	104.38	342.45	0.70	2.30	0.1210	0.3970	0.30	0.98	0.0001	0.0001	52	11
30	81.01	265.78	104.32	342.25	0.68	2.23	0.1140	0.3740	0.18	0.59	0.0001	0.0001	52	11
31	82.35	270.17	104.48	342.78	0.60	1.97	0.2400	0.7870	0.14	0.46	0.0001	0.0001	52	11
32	84.18	276.78	104.34	342.32	0.17	0.56	0.2340	0.7680	0.37	1.21	0.0001	0.0001	52	11
33	85.71	281.20	104.00	341.20	1.10	3.61	0.2140	0.7020	0.53	1.74	0.0001	0.0001	52	11
34	87.30	286.41	103.79	340.51	1.25	4.10	0.1870	0.6140	0.90	2.95	0.0001	0.0001	52	11
35	89.18	292.58	104.07	341.43	0.94	3.08	0.1010	0.3310	0.54	1.77	0.0001	0.0001	52	11
36	91.63	300.62	105.13	344.90									52	11
37	94.71	310.72	106.20	348.42									52	11
38	97.29	319.19	106.95	350.88									52	11
39	103.11	338.28	106.30	348.75									52	11
40	112.67	369.65	106.54	349.54									52	11
41	120.42	395.07	107.15	351.54									52	11
42	122.73	402.65	107.49	352.65									52	41

Appendix 6.3.2 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 2 : Cross-section ID No. KR 119 (KR 389)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	124.45	408.30	106.82	350.46									52	41
44	133.04	436.48	105.13	344.90									52	11
45	133.87	439.20	104.67	343.40	0.66	2.17	0.0001	0.0001					52	11
46	134.96	442.78	105.13	344.90									52	11
47	139.39	457.31	105.56	346.32									52	41
48	141.39	463.87	105.25	345.30									52	11
49	144.74	474.86	105.13	344.90									52	11
50	147.20	482.93	104.64	343.30	0.47	1.54	0.0150	0.0490					52	11
51	149.25	489.66	104.64	343.30	0.46	1.51	0.3000	0.9840					15	25
52	150.44	493.56	105.13	344.90									52	41
53	152.93	501.73	105.37	345.70									52	21
54	154.80	507.87	105.13	344.90									52	11
55	155.77	511.05	105.18	345.07									52	11
56	156.41	513.15	105.28	345.40									52	11
57	168.42	552.55	106.12	348.16									52	44
58	176.77	579.95	106.13	348.20									52	34
59	190.14	623.81	107.57	352.92									35	11
60	211.14	692.71	106.37	355.54									52	11
61	226.89	744.38	109.22	358.33									52	11
62	226.99	744.71	109.23	358.38									52	11
63	227.09	745.04	109.22	358.33									52	11

Appendix 6.3.3

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 3 : Cross-section ID No. KR 166 (KR 545)

Reach length : 47.5 m 155.8 ft
Reach length = distance to next cross-section downstream
Reach length weight : 0.05
Reach length weight = upstream weighting factor
Slope : 0.00827
Stage of zero flow : 104.67 m 343.4 ft

Water Surface Elevation :			
November :	105.63 m	346.55 ft
February :	105.17 m	345.04 ft
October :	105.59 m	346.42 ft

Discharge :		
November :	5.845 m3/s	206.422 ft3/s
February :	0.286 m3/s	10.100 ft3/s
October :	16.155 m3/s	570.530 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	117.48	385.43									11	11
2	25.24	82.81	111.10	365.74									11	21
3	41.90	137.47	108.22	355.05									52	11
4	50.65	166.17	105.91	347.47									34	33
5	55.91	183.43	105.64	346.60									34	33
6	61.92	203.15	105.64	346.60									52	21
7	71.42	234.31	108.29	355.28									52	21
8	75.28	246.98	107.73	353.44									52	21
9	78.80	258.53	105.64	346.60									52	21
10	82.01	269.06	105.64	346.60									52	41
11	85.49	280.48	105.75	346.94									52	11
12	89.41	293.33	105.85	347.27									52	11
13	93.70	307.41	105.64	346.80									52	11
14	95.78	314.24	105.64	346.60									52	11
15	102.56	336.48	105.97	347.67									52	11
16	108.45	355.80	105.64	346.80									52	41
17	114.51	375.69	105.64	346.60									52	41

Appendix 6.3.3 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 3 : Cross-section ID No. KR 166 (KR 545)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	117.33	384.94	105.64	346.60									52	41
19	120.76	396.19	105.64	346.60									52	21
20	122.34	401.37	105.19	345.10	0.12	0.39	0.0610	0.2000					52	21
21	124.41	408.16	105.19	345.10	0.44	1.44	0.0550	0.1800					15	25
22	126.07	413.61	105.16	345.00	0.36	1.18	1.2000	3.9370	0.10	0.33	0.0880	0.2890	15	25
23	127.57	418.53	105.16	345.00	0.38	1.25	0.3740	1.2270	0.10	0.33	0.0350	0.1150	15	25
24	128.32	420.99	105.19	345.10	0.50	1.64	1.0820	3.5500					15	25
25	128.84	422.70	104.90	344.16	0.50	1.64	2.1840	7.1650	0.12	0.39	0.7360	2.4150	15	25
26	130.00	426.50	105.16	345.00	0.32	1.05	2.6550	8.7110	0.14	0.46	0.2600	0.8530	15	25
27	131.09	430.08	104.67	343.40	0.34	1.12	1.2440	4.0810	0.28	0.92	0.2860	0.9380	15	25
28	132.05	433.23	105.19	345.10	0.34	1.12	1.2440	4.0810					15	25
29	133.96	439.50	105.19	345.10	0.12	0.39	0.6560	2.1520					15	25
30	134.79	442.22	105.19	345.10	0.01	0.03	0.0000	0.0000					15	25
31	136.11	446.55	105.19	345.10	0.10	0.33	0.2870	0.9420					15	25
32	136.77	448.72	105.24	345.28	0.08	0.26	1.1120	3.6480					15	25
33	137.41	450.81	105.38	345.73	0.12	0.39	1.3610	4.4650					15	25
34	138.73	455.15	105.20	345.14	0.14	0.46	1.8170	5.9610					15	25
35	139.64	458.13	105.19	345.10	0.12	0.39	0.9020	2.9590					15	25
36	140.18	459.90	105.19	345.10	0.34	1.12	0.2860	0.9380					15	25
37	140.69	462.23	105.19	345.10	0.32	1.05	0.4650	1.5260					15	25
38	142.25	466.69	105.19	345.10	0.18	0.59	0.1280	0.4200					52	21
39	143.89	472.07	105.19	345.10									52	21
40	146.79	481.59	106.07	347.99									52	41
41	150.36	493.30	105.19	345.10									52	25
42	151.09	496.58	105.19	345.10									52	25

Appendix 6.3.3 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 3 : Cross-section ID No. KR 166 (KR 545)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	152.61	498.98	105.63	346.56									52	25
44	156.04	511.94	106.37	348.98									52	41
45	161.28	529.13	106.36	348.95									52	41
46	166.68	546.84	105.19	345.10									52	41
47	170.68	559.97	105.19	345.10									52	11
48	175.18	574.73	105.19	345.10									52	11
49	182.38	598.35	105.84	347.24									52	41
50	186.08	610.49	105.71	348.81									52	41
51	188.68	619.02	106.00	347.77									52	41
52	196.08	643.30	105.79	347.08									52	41
53	199.88	655.77	105.19	345.10									52	41
54	203.38	667.25	105.37	345.70	0.17	0.56	0.5510	1.8080					52	11
55	206.88	678.73	105.79	347.08									14	41
56	221.58	726.96	106.98	350.98									52	11
57	221.68	727.29	106.99	351.01									52	11
58	221.78	727.62	106.98	350.98									52	11

Appendix 6.3.4

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 4 : Cross-section ID No. KR 352 (KR 1155)

Reach length : 186.00 m 610.20 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.70

Reach length weight = upstream weighting factor

Slope : 0.003

Stage of zero flow : 105.14 m 344.94 ft

Water Surface Elevation:	November:	106.67 m	349.96 ft
	February:	106.27 m	348.65 ft
	October:	107.76 m	353.54 ft
Discharge:	November:	3.201 m3/s	113.047 ft3/s
	February:	0.078 m3/s	2.755 ft3/s
	October:	16.155 m3/s	570.530 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	116.07	380.80									15	15
2	1.60	5.25	116.02	380.64									15	15
3	2.00	6.56	112.00	367.45									15	15
4	11.05	36.25	110.92	363.91									15	44
5	20.64	67.72	109.35	358.76									11	11
6	32.27	105.87	108.16	354.85									34	33
7	41.13	134.94	107.55	352.85									52	11
8	45.00	147.64	109.18	358.20									52	21
9	50.86	166.86	106.68	350.00									34	33
10	61.96	203.28	108.61	356.33									52	11
11	70.32	230.71	108.57	356.20									52	41
12	72.90	239.17	106.80	350.39									52	41
13	72.98	239.43	106.78	350.32									52	41
14	82.40	207.34	106.68	350.00									52	15
15	86.18	282.74	106.68	350.00									52	15
16	89.28	292.91	106.72	350.13									35	15
17	90.05	295.44	106.43	349.18	0.23	0.75	0.0001	0.0001					15	15

Appendix 6.3.4 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 4 : Cross-section ID No. KR 352 (KR 1155)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	90.97	298.45	106.29	348.70	0.87	2.85	0.0001	0.0001					52	11
19	91.62	300.59	106.29	348.70	1.12	3.67	0.0001	0.0001					52	11
20	92.80	304.46	106.29	348.70	1.20	3.94	0.0001	0.0001					52	11
21	93.52	306.82	105.85	347.27	1.16	3.81	0.1340	0.4400	0.01	0.03	0.0001	0.0001	15	15
22	94.18	308.99	105.14	344.94	1.70	5.58	0.1480	0.4860	0.19	0.62	0.0001	0.0001	15	15
23	95.72	314.04	105.37	345.70	1.35	4.43	0.2400	0.7870	0.57	1.87	0.0001	0.0001	15	15
24	96.85	317.75	105.41	345.83	1.22	4.00	0.1340	0.4400	0.90	2.95	0.0001	0.0001	52	11
25	97.51	319.91	105.48	346.06	1.20	3.94	0.0550	0.1800	0.76	2.49	0.0001	0.0001	52	11
26	99.09	325.09	105.77	347.01	1.12	3.67	0.0810	0.2660	0.56	1.84	0.0001	0.0001	15	15
27	99.92	327.82	105.60	346.45	1.08	3.54	0.0810	0.2660	0.51	1.67	0.0001	0.0001	15	15
28	100.86	330.90	105.48	345.99	1.28	4.20	0.0680	0.2230	0.38	1.25	0.0001	0.0001	15	15
29	101.54	333.13	105.96	347.63	0.76	2.49	0.1210	0.3970	0.34	1.12	0.0001	0.0001	15	15
30	103.08	338.18	105.20	345.14	1.50	4.92	0.1870	0.6140	0.25	0.82	0.0001	0.0001	15	15
31	104.25	342.02	105.36	345.67	1.50	4.92	0.3000	0.9840	0.01	0.03	0.0001	0.0001	15	15
32	104.95	344.32	105.38	345.73	1.20	3.94	0.3330	1.0930	0.01	0.03	0.0001	0.0001	15	15
33	105.81	347.14	105.46	345.99	1.50	4.92	0.2470	0.8100	0.85	2.79	0.0001	0.0001	15	15
34	110.47	362.43	106.55	349.57	0.48	1.57	0.0001	0.0001					52	41
35	111.57	366.04	106.32	348.81	0.44	1.44	0.0001	0.0001					52	41
36	112.83	369.52	106.29	348.70	0.48	1.57	0.0680	0.2230					52	41
37	114.63	376.08	106.68	350.00									52	41
38	116.52	382.28	107.92	354.06									52	11
39	122.92	403.28	108.06	354.52									52	11
40	126.82	415.41	108.45	355.80									52	11
41	130.36	427.69	108.11	354.69									52	41
42	134.47	441.17	106.87	350.62									52	41

Appendix 6.3.4 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 4 : Cross-section ID No. KR 352 (KR 1155)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	136.10	446.52	106.68	350.00									52	41
44	136.56	448.03	106.68	350.00									52	41
45	139.03	456.13	107.85	353.83									52	11
46	140.81	461.97	107.07	351.28									35	15
47	146.48	480.57	107.75	353.51									15	15
48	153.00	501.96	108.96	357.48									15	15
49	174.87	573.71	109.42	358.99									52	11
50	182.01	597.14	109.39	358.89									15	15
51	185.68	609.18	110.17	361.45									15	15
52	198.97	652.78	110.87	363.74									15	15
53	232.70	763.44	113.51	372.40									15	11
54	232.80	763.77	113.52	372.44									15	11
55	232.90	764.10	113.51	372.40									15	11

Appendix 6.3.5

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 5: Cross-section ID No. KR 497 (KR 1631)

Reach length : 144.50 m 474.10 ft

Reach length = distance to next cross-section downstream

Reach length weight : -

Reach length weight = upstream weighting factor

Slope : 0.00042

Stage of zero flow : 105.24 m 345.27 ft

Water Surface Elevation			
November:	106.73 m	350.16 ft
February:	106.13 m	348.19 ft
October:	107.89 m	353.97 ft

Discharge:		
November:	2.629 m3/s	92.846 ft3/s
February:	0.083 m3/s	2.931 ft3/s
October:	16.155 m3/s	570.530 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	118.14	387.59									14	33
2	24.44	80.18	111.48	365.74									14	33
3	46.63	153.64	110.95	364.00									15	34
4	63.65	208.82	109.83	360.33									11	11
5	81.20	266.40	109.36	358.79									25	15
6	95.09	311.97	109.35	358.76									52	11
7	99.30	325.78	108.25	355.15									24	33
8	101.50	333.00	108.97	357.51									52	21
9	109.87	360.46	107.65	353.18									15	15
10	117.36	385.03	106.77	350.30									35	15
11	119.78	392.97	107.31	352.06									52	11
12	124.85	409.61	107.98	354.26									52	11
13	130.47	428.05	109.39	358.89									52	21
14	138.12	453.14	110.21	361.58									52	41
15	141.58	464.50	108.88	357.21									52	41
16	144.77	474.96	106.74	350.19									52	41
17	145.40	477.03	106.16	348.30	0.92	3.02	0.0880	0.2890					52	21

Appendix 6.3.5 continued

OLIFANTS RIVER (WESTERN CAPE) : KRIEDOUWKRANS SITE

Section No. 5: Cross-section ID No. KR 497 (KR 1631)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	146.46	480.51	105.24	345.27	1.20	3.94	0.0950	0.3120	0.22	0.72	0.0001	0.0001	52	21
19	148.15	486.05	106.16	348.30	0.42	1.38	0.3060	1.0040					52	11
20	149.45	490.32	106.36	348.95	0.34	1.12	0.2470	0.8100					52	11
21	150.44	493.56	106.38	349.01	0.30	0.98	0.1940	0.6360					52	11
22	151.50	497.04	106.41	349.11	0.28	0.92	0.2270	0.7450					52	11
23	152.39	499.96	106.38	349.01	0.28	0.92	0.2730	0.8960					52	11
24	153.58	503.87	106.42	349.14	0.28	0.92	0.2600	0.8530					52	11
25	154.74	507.67	106.41	349.11	0.26	0.85	0.2530	0.8300					52	11
26	156.09	512.10	106.16	348.30	0.50	1.64	0.1810	0.5940					52	11
27	157.17	515.64	106.16	348.30	0.76	2.49	0.2200	0.7220					52	11
28	157.91	518.07	106.16	348.30	0.84	2.76	0.2400	0.7870					52	11
29	159.25	522.47	105.91	347.47	0.76	2.49	0.2070	0.6790	0.15	0.49	0.1340	0.4400	52	11
30	160.33	526.01	106.05	347.93	0.68	2.23	0.2340	0.7680	0.15	0.49	0.1140	0.3740	52	11
31	162.40	532.80	106.16	348.30	0.58	1.90	0.1870	0.6140					52	11
32	163.74	537.20	106.16	348.30	0.60	1.97	0.1670	0.5480					52	11
33	164.97	541.23	106.16	348.30	0.83	2.72	0.1140	0.3740					52	11
34	165.89	544.25	106.16	348.30	1.02	3.35	0.1340	0.4400					52	11
35	167.03	547.99	105.80	347.11	0.90	2.95	0.1080	0.3540	0.15	0.49	0.0001	0.0001	52	11
36	168.10	551.50	105.96	347.63	0.62	2.03	0.1010	0.3310	0.17	0.56	0.0001	0.0001	52	11
37	169.56	556.29	106.27	348.66	0.30	0.98	0.1010	0.3310					52	11
38	170.93	560.79	106.74	350.19									52	11
39	185.07	607.18	108.12	354.72									52	11
40	208.60	684.37	110.40	362.20									31	11
41	231.70	760.16	111.60	366.14									11	11
42	279.09	915.64	117.54	385.63									11	11
43	279.19	916.30	117.55	385.66									11	11
44	279.29	916.29	117.54	385.63									11	11

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 1 : Cross-section ID No. KL000 (KL000)

Reach length : 0.0 m 0.0 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.30

Reach length weight = upstream weighting factor

Slope : 0.00077

Stage of zero flow : 11.78 m 38.65 ft

Water Surface Elevation :
November : 12.04 m 39.50 ft
February : 12.06 m 39.57 ft
October : 14.38 m 47.18 ft

Discharge :
November : 1.061 m3/s 37.470 ft3/s
February : 0.677 m3/s 23.909 ft3/s
October : 33.916 m3/s 1197.777 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	20.19	66.24									11	11
2	5.50	18.04	20.01	65.65									11	11
3	13.78	45.21	17.77	58.30									31	11
4	62.55	205.21	17.43	57.18									31	11
5	111.44	365.61	17.72	58.14									31	11
6	119.88	393.30	18.85	61.84									52	11
7	130.96	429.66	17.81	58.43									31	11
8	137.90	452.42	16.02	52.56									52	11
9	147.36	483.46	13.32	43.70									52	21
10	170.46	559.24	13.28	43.57									52	21
11	190.71	625.68	12.24	40.16									52	41
12	195.30	640.74	12.07	39.60									41	41
13	197.05	646.48	12.07	39.11	0.06	0.20	0.0001	0.0001	0.20	0.66	0.3530	1.1580	52	41
14	198.79	652.19	11.89	39.01	0.10	0.33	0.2730	0.8960	0.14	0.46	0.3460	1.1350	52	11
15	200.25	656.98	11.87	38.94	0.10	0.33	0.3380	1.1090	0.11	0.36	0.3660	1.2010	52	11
16	202.00	662.72	11.87	38.94	0.14	0.46	0.2860	0.9380	0.12	0.39	0.3720	1.2200	52	11
17	203.51	667.66	11.91	39.07	0.10	0.33	0.2860	0.9380	0.06	0.20	0.2860	0.9380	52	11

Appendix 6.4.1 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 1 : Cross-section ID No. KL000 (KL000)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	204.99	672.53	11.95	39.21	0.08	0.26	0.3460	1.1350	0.02	0.07	0.2860	0.9380	52	11
19	206.48	677.42	11.93	39.14	0.08	0.26	0.3360	1.1020	0.01	0.03	0.2860	0.9380	52	11
20	207.70	681.42	11.89	39.01	0.08	0.26	0.2960	0.9710	0.01	0.03	0.1410	0.4630	52	11
21	209.16	686.21	11.92	39.11	0.09	0.30	0.3060	1.0040	0.01	0.03	0.1410	0.4630	52	11
22	210.48	690.54	11.91	39.07	0.08	0.26	0.2670	0.8760	0.04	0.13	0.1410	0.4630	52	11
23	212.13	695.96	11.79	38.68	0.20	0.66	0.3160	1.0370	0.12	0.39	0.2670	0.8760	52	11
24	213.39	700.09	11.94	39.17	0.22	0.72	0.3660	1.2010	0.19	0.62	0.4320	1.4170	52	11
25	214.87	704.95	11.78	38.65	0.22	0.72	0.4750	1.5580	0.14	0.46	0.3130	1.0270	52	11
26	216.44	710.10	11.82	38.78	0.20	0.66	0.3260	1.0700	0.01	0.03	0.0001	0.0001	52	11
27	217.54	713.71	11.88	38.98	0.12	0.39	0.3160	1.0370	0.02	0.07	0.0001	0.0001	52	11
28	218.62	717.25	11.93	39.14	0.08	0.26	0.2770	0.9090					52	11
29	220.60	723.74	11.83	38.81	0.16	0.52	0.3600	1.1810					52	11
30	221.65	727.19	11.85	38.88	0.14	0.46	0.2570	0.8430					52	41
31	223.31	732.64	12.07	39.60									52	41
32	228.09	748.32	12.10	39.70									52	11
33	233.78	766.99	12.61	41.37									52	21
34	236.69	776.53	12.58	41.27									52	21
35	239.78	786.78	13.16	43.18									52	21
36	248.10	813.97	13.02	43.18									52	21
37	255.72	838.97	13.49	44.26									52	21
38	264.78	868.69	13.22	43.37									52	21
39	267.82	878.66	14.52	47.64									11	41
40	287.40	942.90	22.77	74.70									11	21
41	287.50	943.23	22.78	74.74									11	21
42	287.60	943.56	22.77	74.70									11	21

Appendix 6.4.2

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 2 : Cross-section ID No. KL130 (KL427)

Reach length : 129.5 m 424.9 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.80

Reach length weight = upstream weighting factor

Slope : 0.00126

Stage of zero flow : 11.85 m 38.88 ft

Water Surface Elevation :	November :	12.14 m	39.83 ft
	February :	12.31 m	40.39 ft
	October :	14.47 m	47.47 ft
Discharge :	November :	1.536 m3/s	54.245 ft3/s
	February :	0.721 m3/s	25.463 ft3/s
	October :	33.916 m3/s	1197.777 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	20.19	66.24									11	11
2	5.00	16.40	20.00	65.62									11	11
3	12.16	39.89	17.69	58.04									11	11
4	55.65	182.58	17.38	57.02									11	11
5	97.43	319.65	17.63	57.84									11	11
6	106.82	350.46	19.99	65.58									52	11
7	110.53	362.63	20.39	66.90									52	11
8	110.63	362.96	20.40	66.93									52	11
9	110.73	363.28	20.39	66.90									52	11
10	119.84	393.17	19.88	65.22									52	11
11	127.93	419.71	16.40	53.81									52	11
12	136.97	449.37	14.79	48.52									52	11
13	151.17	495.96	43.01	13.11									52	11
14	155.94	511.61	12.22	40.10									52	11
15	156.71	514.13	11.79	38.68	0.34	1.12	0.3060	1.0040	0.18	0.59	0.1480	0.4860	52	11
16	158.24	519.15	11.58	37.99	0.54	1.77	0.4750	1.5580	0.28	0.92	0.3060	1.0040	52	11
17	158.99	521.61	11.56	37.93	0.62	2.03	0.6040	1.9820	0.30	0.98	0.2930	0.9610	52	41

Appendix 6.4.2 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 2 : Cross-section ID No. KL130 (KL427)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	159.94	524.73	11.84	38.84	0.30	0.98	0.2660	0.9380	0.28	0.92	0.2070	0.6790	52	41
19	160.92	527.95	12.07	39.60	0.15	0.49	0.3760	1.2340					52	41
20	161.00	528.21	12.20	40.03									52	41
21	161.63	530.28	11.82	38.78	0.17	0.56	0.1080	0.3540					52	11
22	162.46	533.00	11.71	38.42	0.44	1.44	0.3060	1.0040					52	11
23	162.84	534.25	11.86	38.91	0.28	0.92	0.4060	1.3320	0.36	1.18	0.2200	0.7220	52	11
24	163.38	536.02	11.85	38.88	0.30	0.98	0.3860	1.2660	0.30	0.98	0.1870	0.6140	52	11
25	164.00	538.05	11.90	39.04	0.26	0.85	0.3760	1.2340	0.22	0.72	0.3790	1.2430	52	11
26	164.66	540.22	11.89	39.01	0.22	0.72	0.3160	1.0370	0.22	0.72	0.3330	1.0930	52	11
27	165.35	542.48	11.92	39.11	0.26	0.85	0.3260	1.0700	0.23	0.75	0.3590	1.1780	52	11
28	165.93	544.38	11.93	39.14	0.22	0.72	0.4160	1.3650	0.22	0.72	0.3790	1.2430	52	11
29	166.76	547.11	11.94	39.17	0.24	0.79	0.3560	1.1680	0.22	0.72	0.3330	1.0930	52	11
30	167.38	549.14	11.91	39.07	0.26	0.85	0.3060	1.0040	0.23	0.75	0.3200	1.0500	52	11
31	168.01	551.21	11.91	39.07	0.26	0.85	0.2370	0.7780	0.15	0.49	0.1410	0.4630	52	11
32	168.99	554.42	12.22	40.10									52	41
33	170.99	560.98	13.46	44.16									52	21
34	180.55	592.35	13.76	45.14									52	21
35	189.73	622.47	14.07	46.16									52	21
36	202.06	662.92	14.00	45.93									52	21
37	221.49	726.68	13.76	45.14									52	11
38	250.82	822.90	13.88	45.54									52	21
39	262.12	859.96	13.98	45.87									31	41
40	280.30	919.61	13.94	45.73									11	41
41	298.89	980.60	13.82	45.34									11	41
42	310.70	1019.34	13.74	45.08									11	21

Appendix 6.4.2 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 2 : Cross-section ID No. KL130 (KL427)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	325.18	1066.85	13.74	43.67									11	21
44	327.37	1074.04	13.26	43.18									11	21
45	328.87	1078.96	13.51	44.32									11	21
46	334.39	1097.07	15.81	51.87									11	11
47	334.49	1097.39	15.82	51.90									11	11
48	334.59	1097.72	15.81	51.87									11	11
49	339.59	1114.13	16.00	52.49									11	11
50	344.59	1130.53	17.00	55.78									11	11
51	348.59	1143.66	18.00	59.05									11	11

Appendix 6.4.3

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 3 : Cross-section ID No. KL256 (KL840)

Reach length :	126.0 m	413.40 ft	Water Surface Elevation :	November :	12.36 m	40.55 ft
Reach length = distance to next cross-section downstream				February :	12.18 m	39.96 ft
Reach length weight :	0.50			October :	14.50 m	47.57 ft
Reach length weight = upstream weighting factor						
Slope :	0.00089		Discharge :	November :	1.194 m3/s	42.164 ft3/s
Stage of zero flow :	11.85 m	38.88 ft		February :	0.468 m3/s	16.527 ft3/s
				October :	33.916 m3/s	1197.777 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	20.73	68.01									15	44
2	4.11	13.48	20.73	68.01									15	44
3	10.04	32.94	17.67	57.97									11	11
4	55.54	182.22	17.42	57.15									11	11
5	96.36	316.14	17.54	57.55									52	11
6	104.24	341.99	19.38	63.58									52	11
7	107.93	353.10	20.51	67.29									52	21
8	112.32	360.50	19.84	65.09									52	11
9	118.28	388.05	20.47	67.16									52	11
10	123.79	406.13	20.04	65.75									52	11
11	123.89	406.46	20.05	65.78									52	11
12	123.99	406.79	20.04	65.75									52	11
13	135.85	445.70	18.59	60.99									11	11
14	145.19	476.34	17.82	58.48									11	11
15	157.01	515.12	17.31	56.79									11	11
16	162.61	533.49	14.81	48.59									52	11
17	177.89	583.62	15.00	49.21									52	11

Appendix 6.4.3 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 3 : Cross-section ID No. KL256 (KL840)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	189.50	621.71	15.19	49.84									52	11
19	198.48	651.17	16.77	55.11									52	21
20	205.35	673.71	15.63	51.28									52	11
21	210.01	689.00	12.36	40.55									52	11
22	210.99	692.22	12.06	39.57	0.30	0.98	0.3460	1.1350	0.16	0.52	0.2730	0.8960	52	11
23	211.69	694.51	12.03	39.47	0.33	1.08	0.4060	1.3320	0.17	0.56	0.2860	0.9380	52	11
24	212.43	696.94	12.02	39.44	0.34	1.12	0.2670	0.8760	0.14	0.46	0.3130	1.0270	52	11
25	213.21	699.50	12.08	39.63	0.28	0.92	0.3060	1.0040	0.13	0.43	0.2930	0.9610	52	11
26	214.21	702.78	11.81	38.75	0.55	1.80	0.1970	0.6460	0.50	1.64	0.3000	0.9840	52	11
27	214.80	704.72	11.60	38.06	0.76	2.49	0.2940	0.9650	0.55	1.80	0.2800	0.9190	52	11
28	216.45	710.13	11.52	37.79	0.84	2.76	0.2340	0.7680	0.37	1.21	0.0280	0.0920	52	11
29	217.79	714.53	12.22	40.10	0.70	2.30	0.2170	0.7120					52	11
30	218.29	716.17	12.22	40.10	0.53	1.74	0.1280	0.4200					52	11
31	218.90	718.17	12.22	40.10	0.17	0.56	0.0280	0.0920					52	11
32	220.00	721.78	12.36	40.56									52	11
33	220.79	724.37	12.40	40.68									52	11
34	223.38	732.87	12.36	40.56									52	11
35	224.59	736.83	12.15	39.86	0.12	0.39	0.0001	0.0001					52	11
36	225.54	739.95	12.09	39.66	0.16	0.52	0.0001	0.0001					52	11
37	226.52	743.17	12.05	39.53	0.20	0.66	0.0001	0.0001					52	11
38	227.54	746.51	12.13	39.80	0.16	0.52	0.0001	0.0001					52	11
39	228.34	749.14	12.17	39.93	0.16	0.52	0.0001	0.0001					52	11
40	229.74	753.73	11.97	39.27	0.18	0.59	0.0001	0.0001					52	11
41	230.45	756.06	12.06	39.57	0.21	0.69	0.0001	0.0001					52	11
42	231.74	760.30	12.07	39.60	0.24	0.79	0.0001	0.0001					52	11

Appendix 6.4.3 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 3 : Cross-section ID No. KL256 (KL840)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
43	232.73	763.54	12.37	40.58									52	11
44	237.80	780.17	14.52	47.64									52	21
45	258.78	849.01	14.24	46.72									52	41
46	266.37	873.91	13.98	45.87									11	41
47	291.41	956.06	13.81	45.31									11	21
48	298.20	978.33	13.84	45.41									11	21
49	300.55	986.04	13.21	43.34									11	21
50	307.44	1008.65	13.22	43.37									11	21
51	314.59	1032.11	13.47	44.19									11	21
52	323.39	1060.98	16.53	54.23									11	21
53	328.14	1076.56	16.90	55.45									11	21
54	340.17	1116.03	20.78	68.18									11	11
55	340.27	1116.36	20.79	68.21									11	11
56	340.37	1116.69	20.78	68.18									11	11

Appendix 6.4.4

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 4 : Cross-section ID No. KL1048 (KL3438)

Reach length : 792.0 m 2598.4 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0.50

Reach length weight = upstream weighting factor

Slope : 0.00017

Stage of zero flow : 11.85 m 38.88 ft

Water Surface Elevation :			
November :	12.38 m	40.62 ft
February :	12.48 m	40.94 ft
October :	14.62 m	47.97 ft

Discharge :		
November :	0.750 m3/s	26.485 ft3/s
February :	0.506 m3/s	17.869 ft3/s
October :	33.916 m3/s	1197.777 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	24.07	78.97									11	21
2	28.62	93.90	19.10	62.66									11	21
3	42.67	139.99	17.52	57.48									11	11
4	59.71	195.90	14.73	48.33									11	41
5	69.98	229.59	14.24	46.72									11	11
6	71.91	235.92	13.79	45.24									52	11
7	82.21	269.71	14.29	46.88									52	41
8	88.62	290.74	13.56	44.49									31	41
9	102.53	336.38	13.79	45.24									31	41
10	112.48	369.02	13.85	45.44									11	21
11	114.78	376.57	12.50	41.00									11	41
12	115.73	379.69	11.88	38.98	0.38	1.25	0.0001	0.0001	0.20	0.66	0.0001	0.0001	31	21
13	116.16	381.10	11.81	38.75	0.49	1.61	0.1140	0.3740	0.28	0.92	0.0001	0.0001	31	21
14	116.65	382.71	11.76	38.58	0.54	1.77	0.1410	0.4630	0.32	1.05	0.1080	0.3540	52	11
15	117.24	384.64	11.80	38.71	0.52	1.71	0.2470	0.8100	0.34	1.12	0.3200	1.0500	52	11
16	117.90	386.81	11.84	38.84	0.47	1.54	0.3000	0.9840	0.20	0.66	0.3260	1.0700	52	11
17	118.42	388.51	11.88	38.98	0.41	1.35	0.3390	1.1120	0.18	0.59	0.3390	1.1120	52	11

Appendix 6.4.4 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 4 : Cross-section ID No. KL1048 (KL3438)

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	119.01	390.45	11.82	38.78	0.43	1.41	0.3970	1.3020	0.20	0.66	0.3790	1.2430	52	11
19	119.68	392.65	11.93	39.14	0.35	1.15	0.4320	1.4170	0.22	0.72	0.3530	1.1580	52	11
20	120.48	395.27	11.99	39.34	0.32	1.05	0.4060	1.3320	0.26	0.85	0.3590	1.1780	52	11
21	121.33	398.06	12.03	39.47	0.26	0.85	0.3390	1.1120	0.21	0.69	0.3390	1.1120	52	11
22	122.11	400.62	12.17	39.93	0.10	0.33	0.3000	0.9840	0.14	0.46	0.3790	1.2430	52	11
23	123.01	403.57	12.37	40.58	0.06	0.20	0.2340	0.7680	0.12	0.39	0.3130	1.0270	52	11
24	123.86	406.38	12.29	40.32	0.02	0.07	0.0001	0.0001	0.10	0.33	0.2600	0.8530	52	11
25	125.26	410.95	12.38	40.62									52	11
26	135.18	443.50	12.52	41.08									52	41
27	138.67	454.95	12.50	41.00									52	41
28	145.38	476.90	14.93	48.98									52	41
29	153.32	503.01	15.40	50.52									52	11
30	156.73	514.20	16.42	53.87									52	21
31	165.73	543.73	16.26	53.35									52	21
32	171.45	562.49	16.67	54.69									52	41
33	174.84	573.62	16.45	53.97									52	41
34	179.79	589.86	17.54	57.55									11	21
35	184.31	604.69	17.35	56.92									11	11
36	189.75	622.53	19.62	64.37									11	11
37	193.68	635.43	21.02	68.96									11	11
38	193.78	635.75	21.03	69.00									11	11
39	193.88	636.00	21.02	68.96									11	11

Appendix 6.4.5

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 5 : Cross-section ID No. KL 1400 (KL 4593)

Reach length : 351.5 m 1153.2 ft

Reach length = distance to next cross-section downstream

Reach length weight : 0

Reach length weight = upstream weighting factor

Slope : 0.00031

Stage of zero flow : 11.92 m 39.11 ft

Water Surface Elevation :			
November :	12.49 m	40.98 ft
February :	13.10 m	42.98 ft
October :	14.80 m	48.56 ft

Discharge :		
November :	0.840 m3/s	29.663 ft3/s
February :	0.335 m3/s	11.830 ft3/s
October :	33.916 m3/s	1197.777 ft3/s

Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
1	0.10	0.33	24.24	79.53									11	11
2	15.35	50.36	18.54	60.83									11	11
3	22.45	73.65	18.25	59.88									11	11
4	25.88	84.91	17.00	59.87									11	11
5	48.92	160.50	16.85	55.28									11	11
6	51.34	168.44	17.45	57.25									11	11
7	63.74	209.12	14.54	47.70									11	11
8	69.08	226.64	14.54	47.70									11	11
9	70.95	232.77	14.77	48.46									11	11
10	72.97	239.40	13.11	43.00									52	41
11	74.16	243.30	12.17	40.03	0.46	1.51	0.0680	0.2230	0.38	1.25	0.0150	0.0490	52	21
12	74.75	245.24	12.16	39.89	0.46	1.51	0.0580	0.1900	0.37	1.21	0.0550	0.1800	52	11
13	75.35	247.21	12.12	39.76	0.44	1.44	0.1010	0.3310	0.35	1.15	0.0680	0.2230	52	11
14	75.62	248.09	12.12	39.76	0.48	1.57	0.1010	0.3310	0.36	1.18	0.0680	0.2230	52	11
15	76.24	250.13	12.14	39.83	0.49	1.61	0.1140	0.3740	0.36	1.18	0.0610	0.2000	52	11
16	76.64	251.44	12.13	39.80	0.50	1.64	0.1210	0.3970	0.38	1.25	0.0750	0.2460	52	11
17	77.36	253.80	12.11	39.73	0.48	1.57	0.1210	0.3970	0.42	1.38	0.0880	0.2890	52	11

Appendix 6.4.5 continued

OLIFANTS RIVER (WESTERN CAPE) : KLAWER SITE

Section No. 5 : Cross-section ID No. KL 1400 (KL 4593)

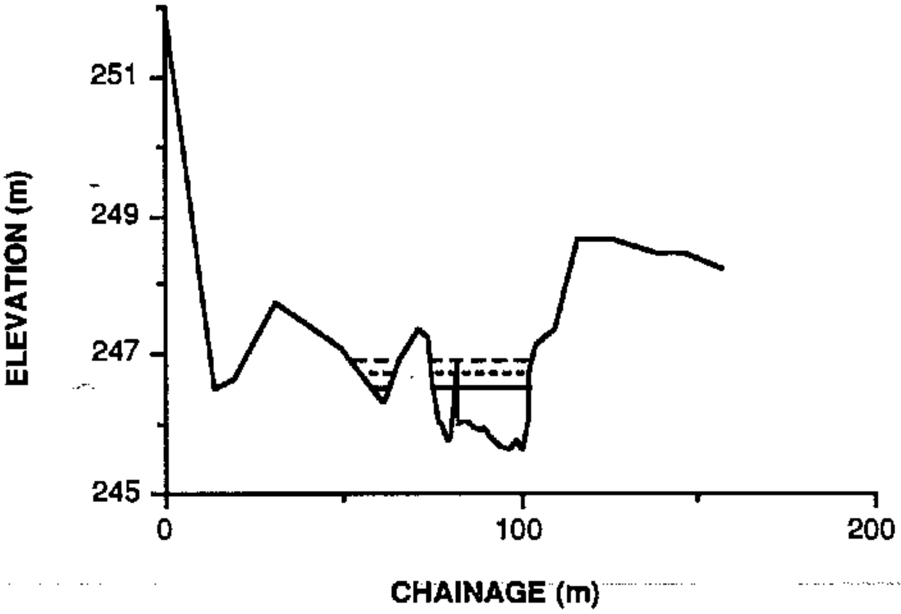
Vertical	Chainage (m)	Chainage (ft)	Elevation (m)	Elevation (ft)	Depth Nov. (m)	Depth Nov. (ft)	Velocity Nov. (m/s)	Velocity Nov. (ft/s)	Depth Feb. (m)	Depth Feb. (ft)	Velocity Feb. (m/s)	Velocity Feb. (ft/s)	Channel Index Invertebrates PHABSIM	Channel Index Fish PHABSIM
18	77.93	255.67	12.12	39.76	0.48	1.57	0.1410	0.4630	0.44	1.44	0.0810	0.2660	52	11
19	78.56	257.74	12.09	39.66	0.52	1.71	0.1210	0.3970	0.46	1.51	0.0680	0.2230	52	11
20	78.85	258.69	12.02	39.43	0.56	1.84	0.1410	0.4630	0.48	1.57	0.0610	0.2000	52	11
21	79.55	260.99	11.95	39.21	0.57	1.87	0.1610	0.5280	0.48	1.57	0.0550	0.1800	52	11
22	79.99	262.43	11.95	39.21	0.58	1.90	0.1340	0.4400	0.49	1.61	0.0680	0.2230	52	11
23	80.52	264.17	11.96	39.24	0.59	1.94	0.1410	0.4630	0.51	1.67	0.0480	0.1570	52	11
24	80.86	265.29	11.97	39.27	0.62	2.03	0.1410	0.4630	0.50	1.64	0.0610	0.2000	52	11
25	81.74	268.17	11.93	39.14	0.59	1.94	0.1610	0.5280	0.53	1.74	0.0680	0.2230	52	11
26	82.44	270.47	11.92	39.11	0.63	2.07	0.1540	0.5050	0.54	1.77	0.0810	0.2660	52	11
27	83.20	272.96	11.93	39.14	0.66	2.17	0.1140	0.3740	0.56	1.84	0.0750	0.2460	52	11
28	83.84	275.06	11.92	39.11	0.66	2.17	0.1140	0.3740	0.52	1.71	0.0810	0.2660	52	11
29	85.29	279.82	11.97	39.27	0.50	1.64	0.1140	0.3740	0.50	1.64	0.0001	0.0001	52	11
30	86.13	282.58	11.99	39.34	0.58	1.90	0.0150	0.0490	0.44	1.44	0.0001	0.0001	52	11
31	86.66	284.97	12.12	39.76	0.53	1.74	0.0001	0.0001	0.03	0.10	0.0001	0.0001	52	11
32	87.62	287.46	13.11	43.00									52	11
33	91.52	300.26	15.23	49.97									11	11
34	101.36	332.54	15.00	49.21									11	41
35	115.65	379.42	15.54	50.98									52	41
36	127.38	417.91	14.67	48.13									52	41
37	137.69	451.73	14.65	48.06									52	41
38	149.42	490.22	14.82	48.62									52	41
39	161.55	530.01	16.03	52.59									52	41
40	163.40	536.08	16.07	52.72									52	41
41	178.63	586.05	15.77	51.74									11	41
42	191.56	628.47	16.76	54.99									11	11
43	199.14	653.34	18.56	60.89									11	11
44	199.24	853.67	18.57	60.92									11	11
45	199.34	653.99	18.56	60.89									11	11

Appendix 6.5 Cross-section profiles of 14 of the 17 transects at the three PHABSIM II sites, showing WSLs and velocity distributions at the three calibration discharges

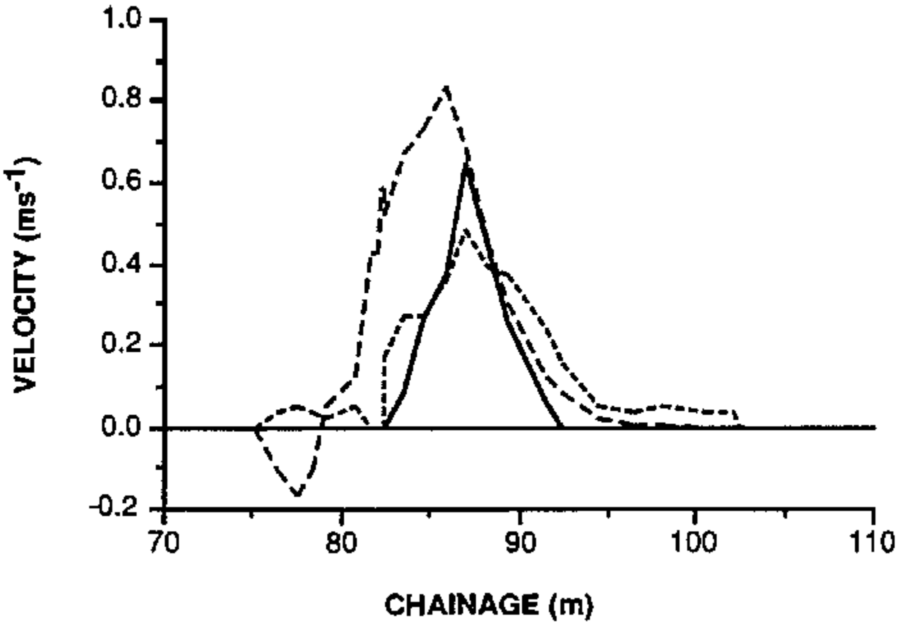
Appendix 6.5.1	Transect GR000
Appendix 6.5.2	Transect GR276
Appendix 6.5.3	Transect GR517
Appendix 6.5.4	Transect GR628
Appendix 6.5.5	Transect GR695
Appendix 6.5.6	Transect GR840
Appendix 6.5.7	Transect KR000
Appendix 6.5.8	Transect KR166
Appendix 6.5.9	Transect KR497
Appendix 6.5.10	Transect KL000
Appendix 6.5.11	Transect KL256
Appendix 6.5.12	Transect KL352
Appendix 6.5.13	Transect KL1048
Appendix 6.5.14	Transect KL1400

Cross-section profile GR302 is provided in the text as Figure 6.4
Cross-section profile KR119 is provided in the text as Figure 6.5
Cross-section profile KL130 is provided in the text as Figure 6.6

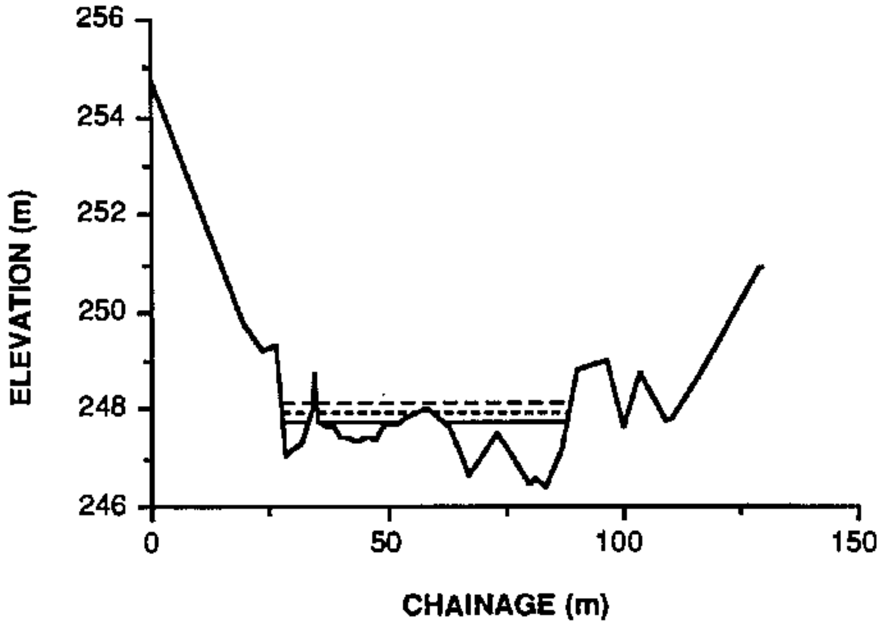
Appendix 6.5.1 Transect GR000



3.163 m^3s^{-1} ---------- NOVEMBER 1990
1.214 m^3s^{-1} ——— FEBRUARY 1991
4.942 m^3s^{-1} - - - - - - OCTOBER 1991



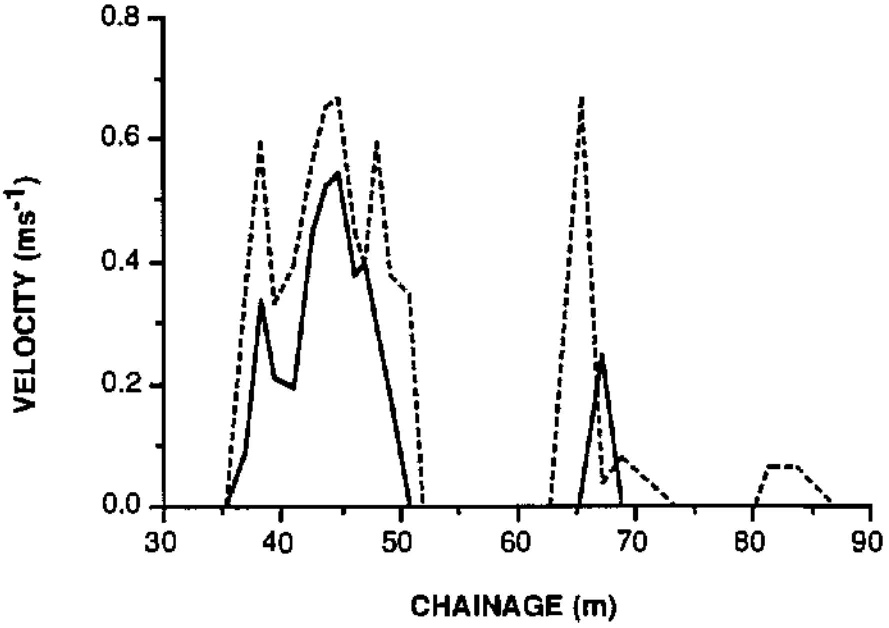
Appendix 6.5.2 Transect GR276



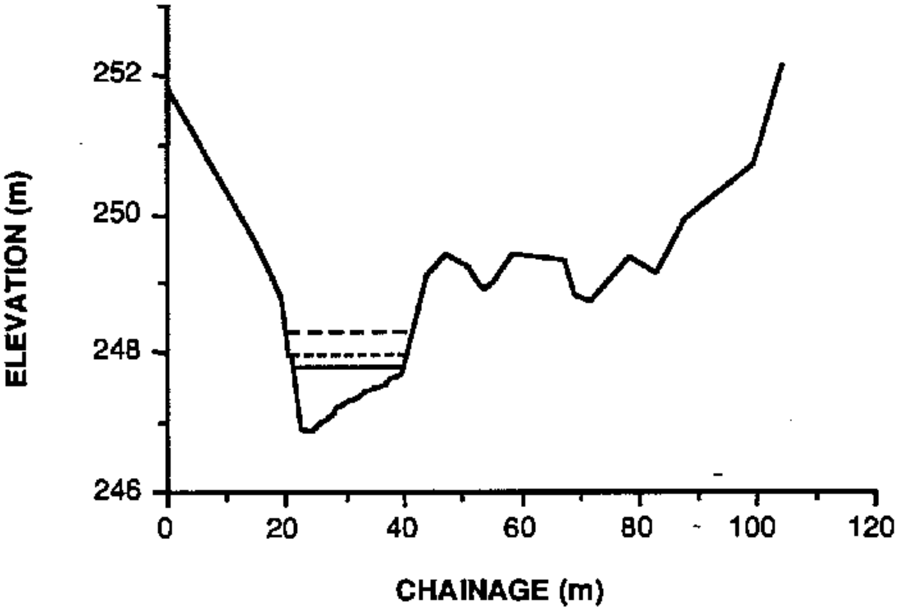
3.352 m^3s^{-1} ---------- November 1990

1.397 m^3s^{-1} ——— February 1991

9.416 m^3s^{-1} - - - - - - October 1991



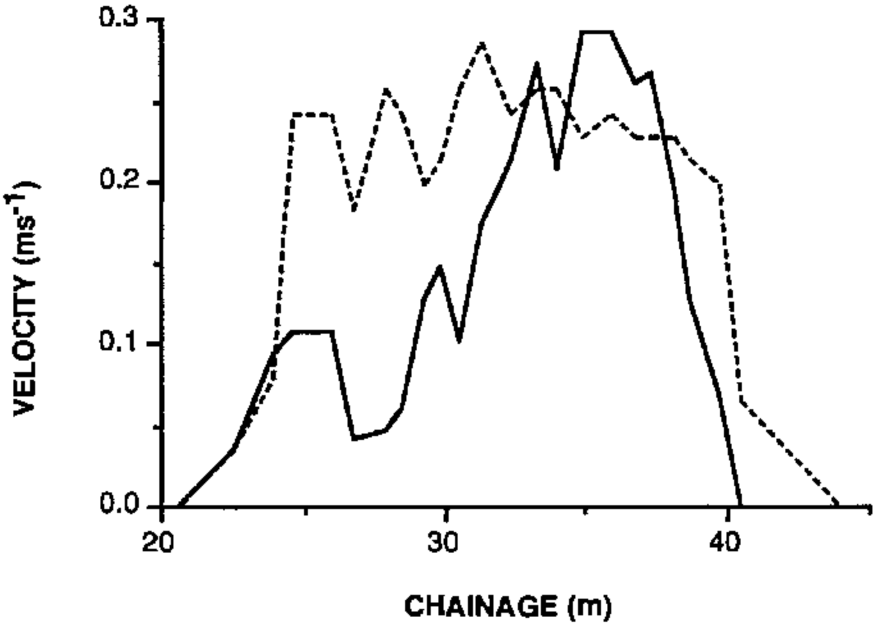
Appendix 6.5.3 Transect GR517



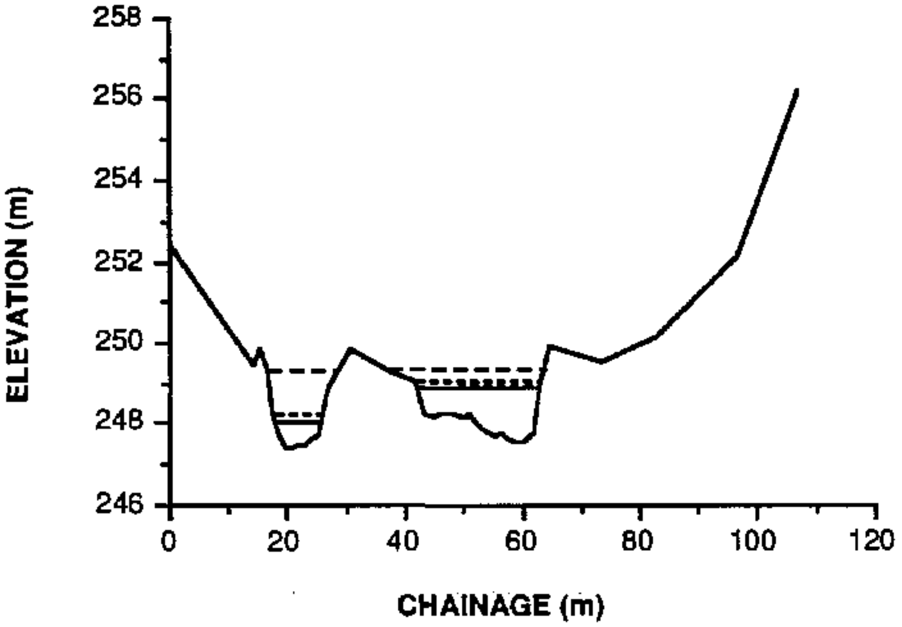
2.479 m^3s^{-1} ----------- NOVEMBER 1990

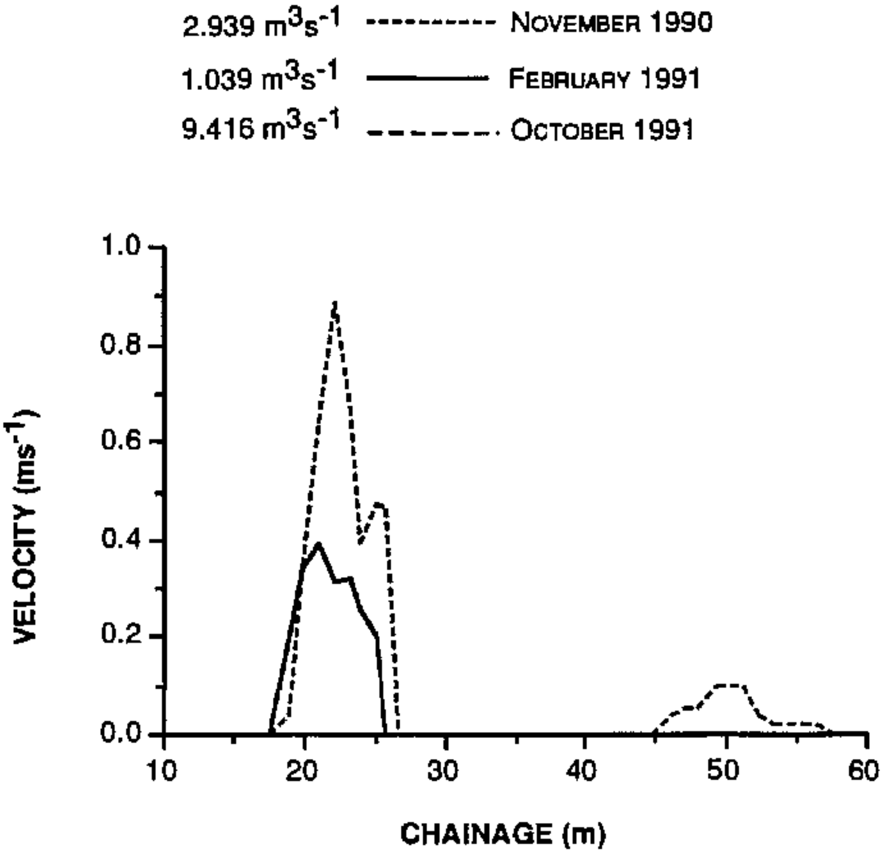
1.127 m^3s^{-1} ———— FEBRUARY 1991

9.416 m^3s^{-1} - - - - - - OCTOBER 1991

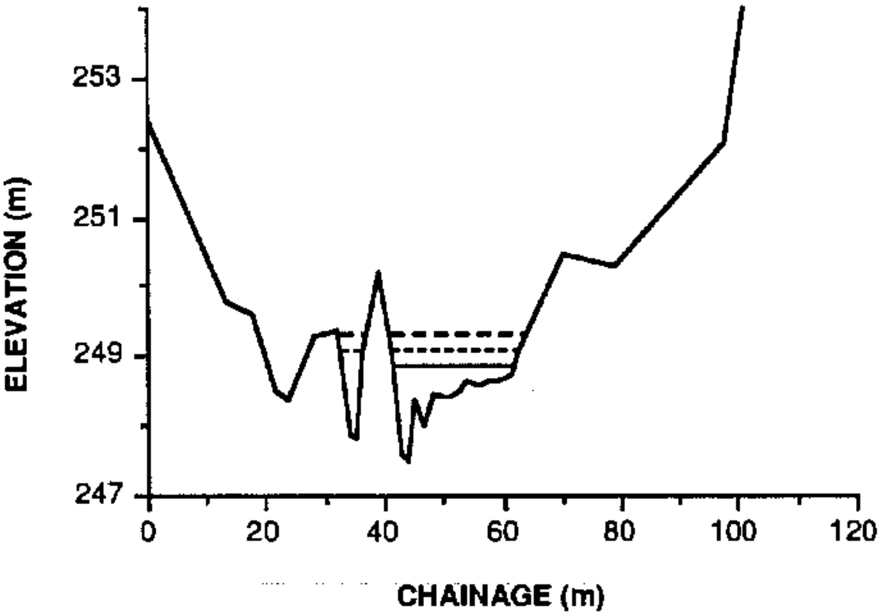


Appendix 6.5.4 Transect GR628

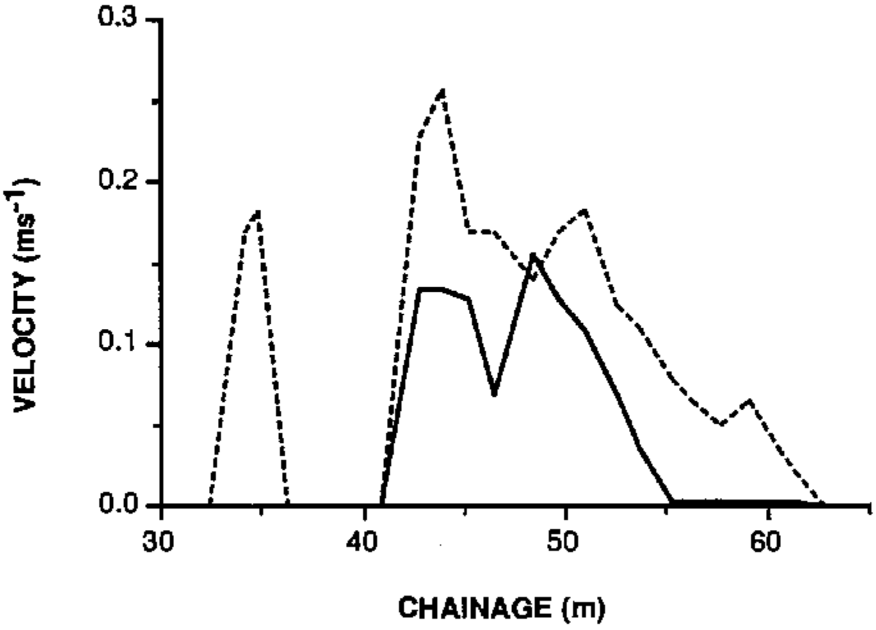




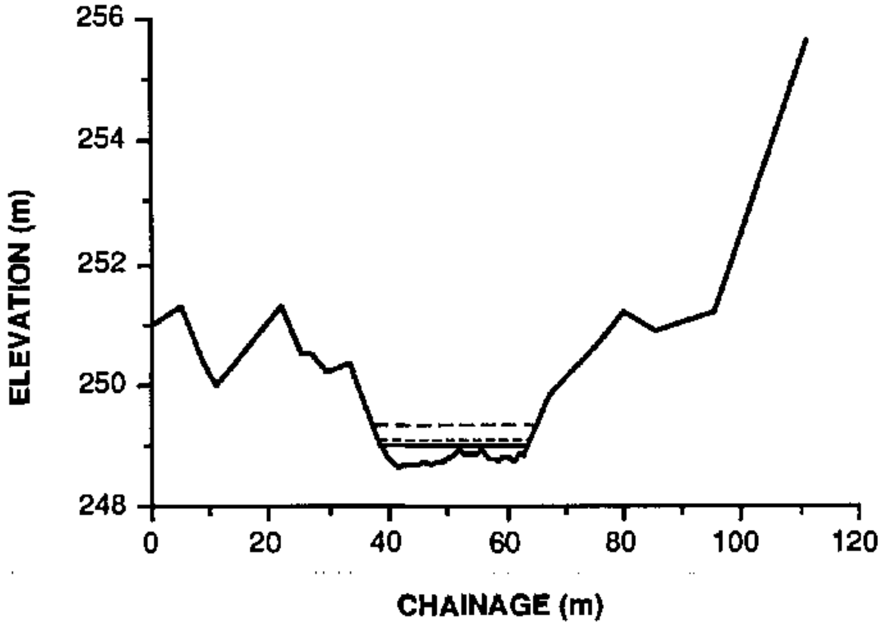
Appendix 6.5.5 Transect GR695

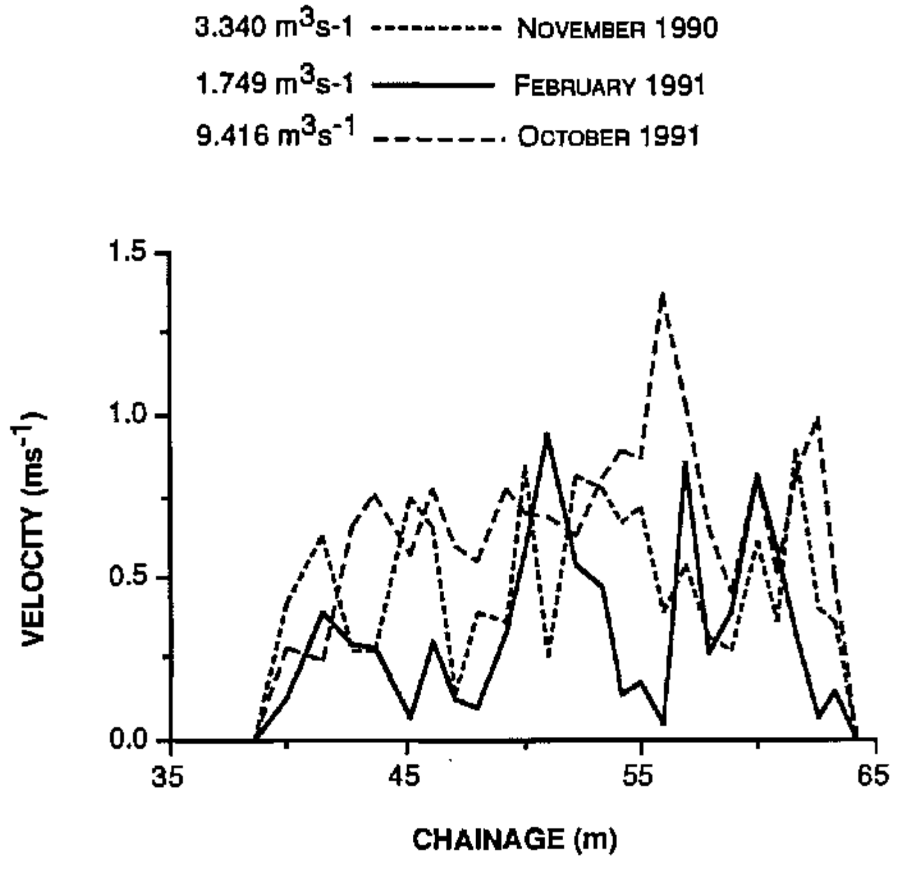


2.719 m^3s^{-1} --------- November 1990
1.197 m^3s^{-1} ——— February 1991
9.416 m^3s^{-1} – – – – October 1991

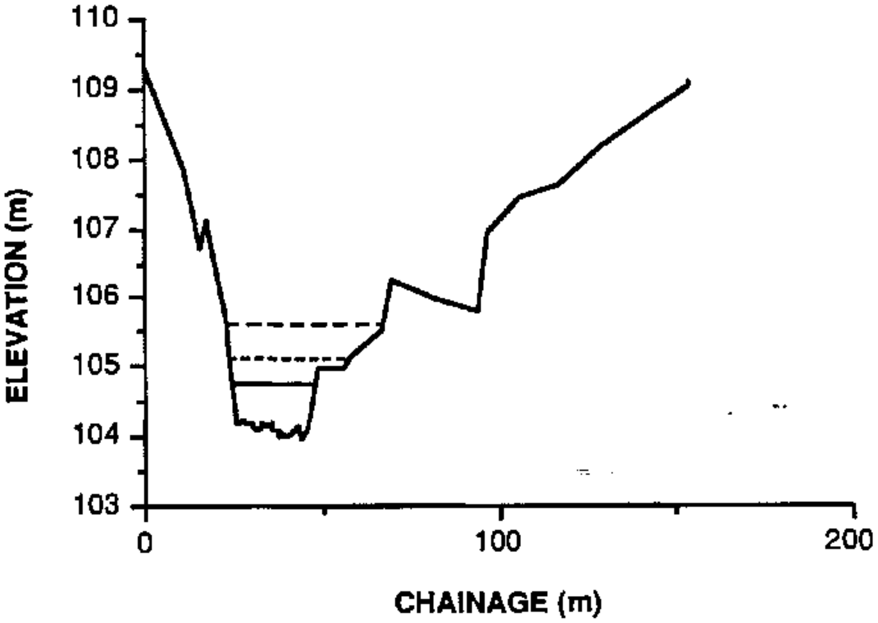


Appendix 6.5.6 Transect GR840

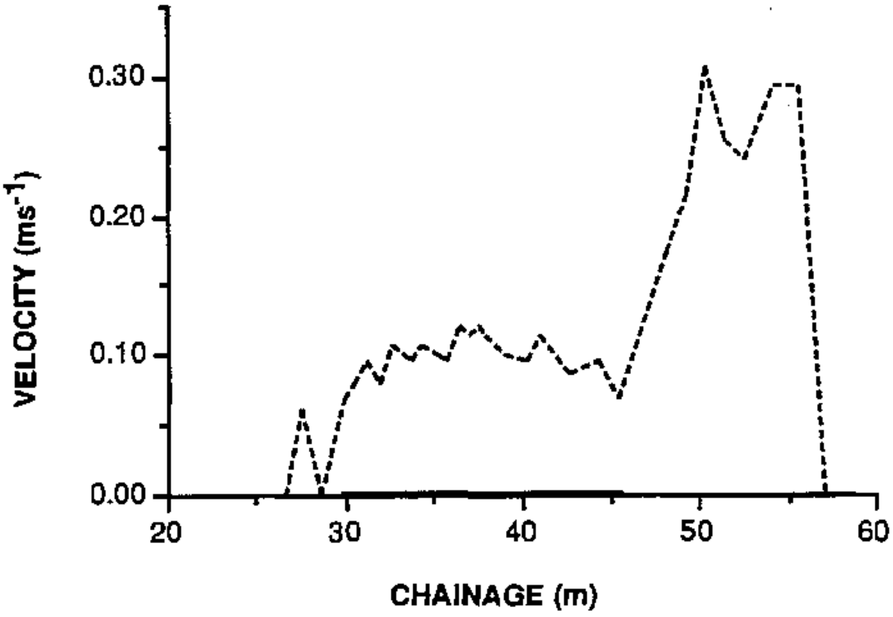




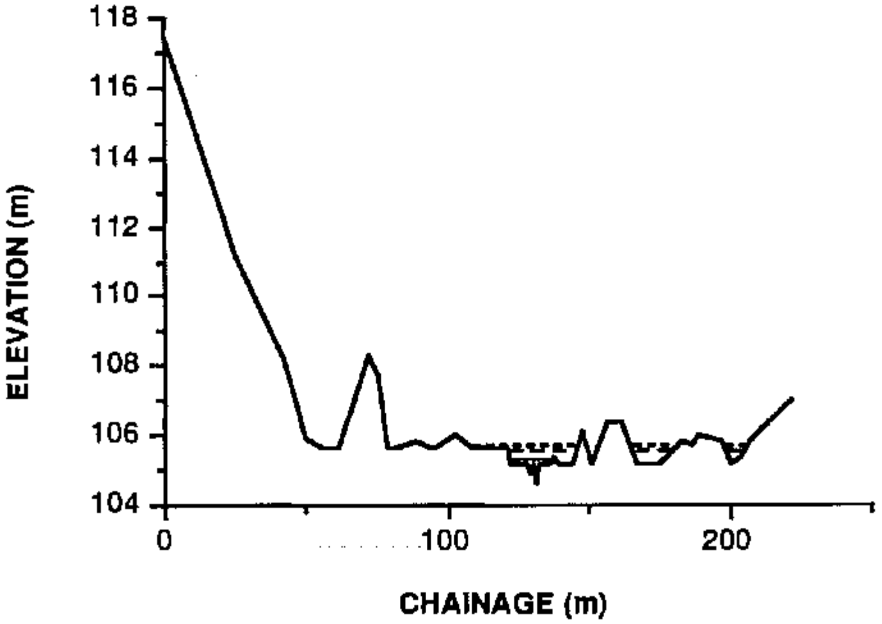
Appendix 6.5.7 Transect KR000



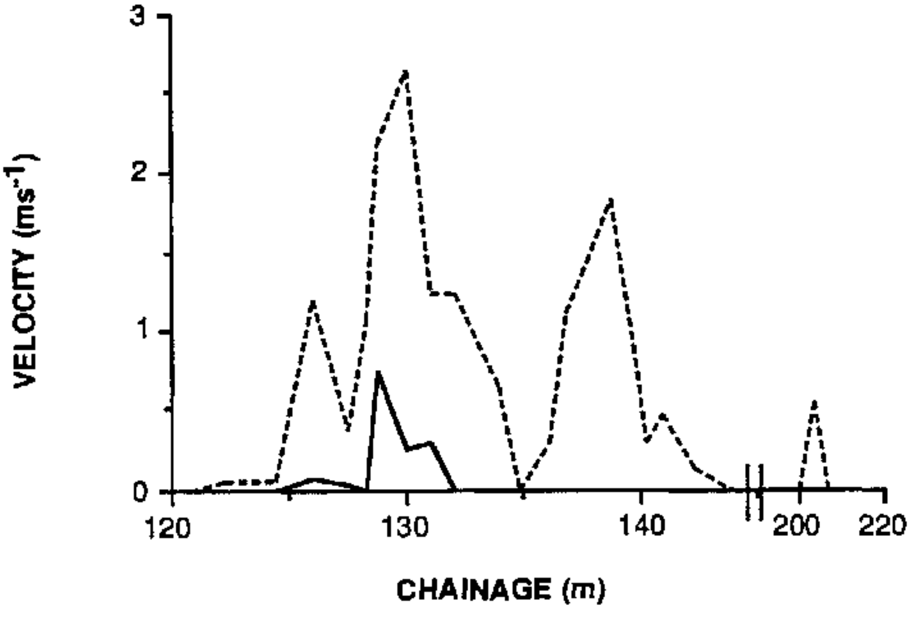
1.901m^{3}s-1 ---------- NOVEMBER 1990
0.148 m^{3}s^{-1} ——— FEBRUARY 1991
16.155 m^{3}s^{-1} - - - - - - OCTOBER 1991



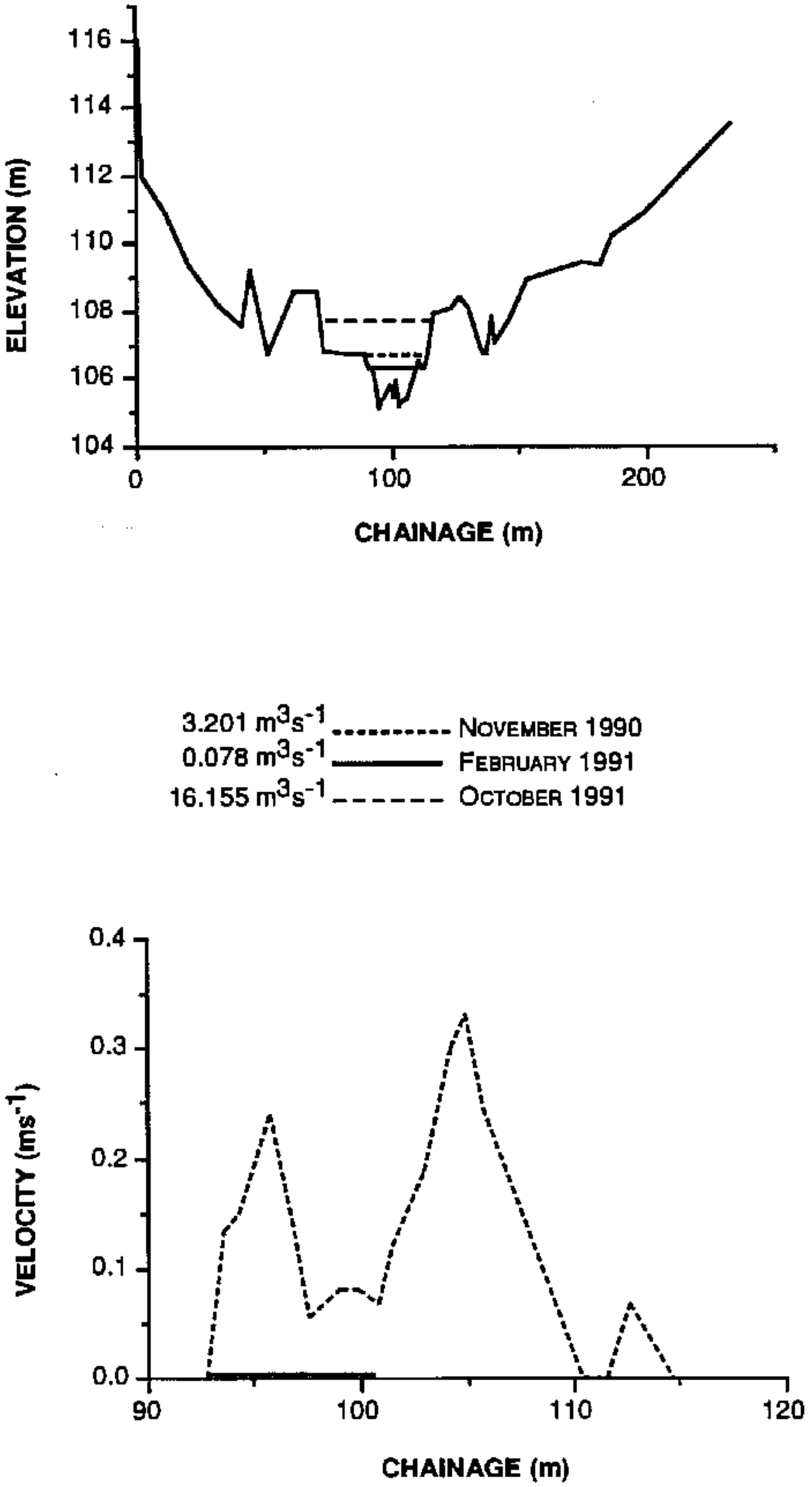
Appendix 6.5.8 Transect KR166



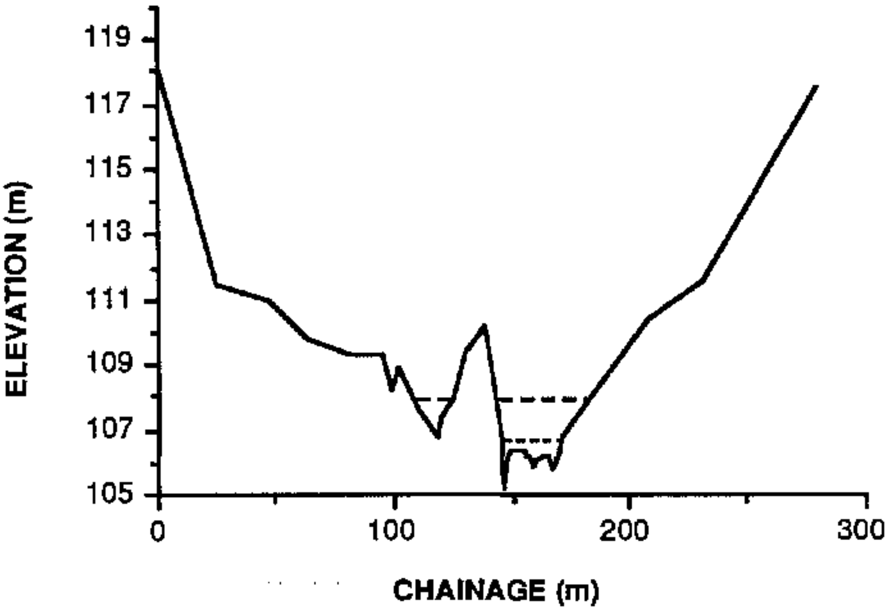
0.286 m^{3}s^{-1} ---------- NOVEMBER 1990
5.845 m^{3}s^{-1} ——— FEBRUARY 1991
16.155 m^{3}s^{-1} - - - - - - OCTOBER 1991



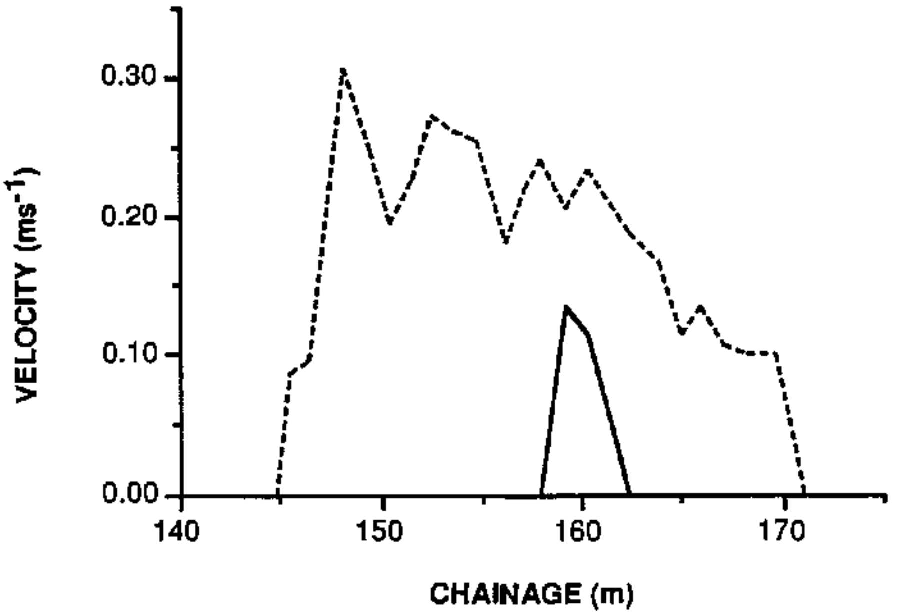
Appendix 6.5.9 Transect KR352



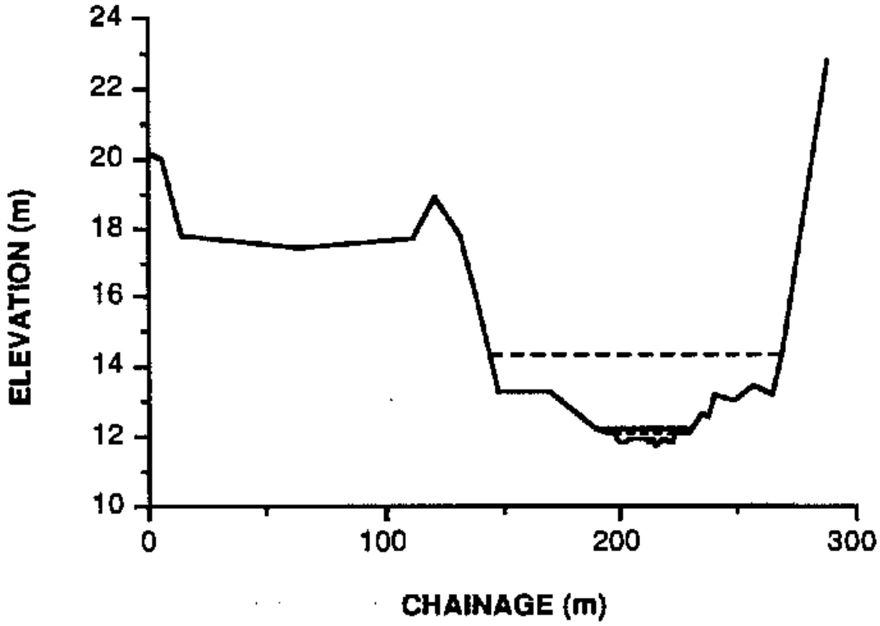
Appendix 6.5.10 Transect KR497



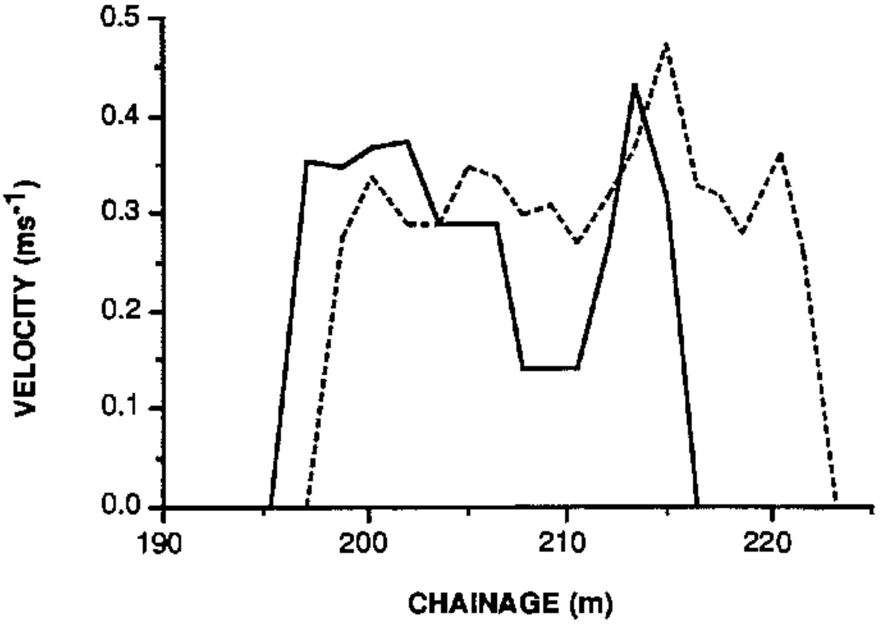
2.629 m^3s^{-1} ---------- NOVEMBER 1990
0.083 m^3s^{-1} ———— FEBRUARY 1991
16.155 m^3s^{-1} - - - - - - OCTOBER 1991



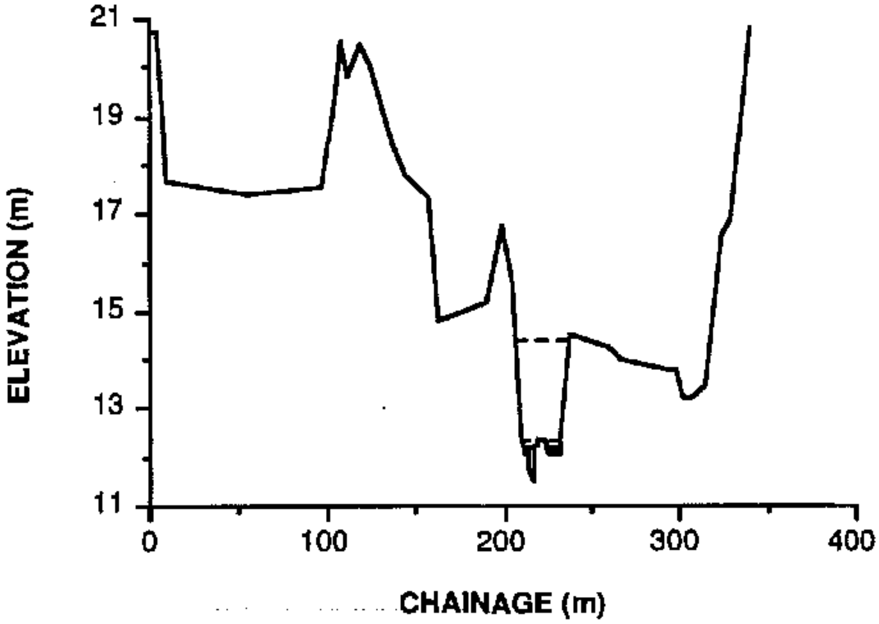
Appendix 6.5.11 Transect KL000

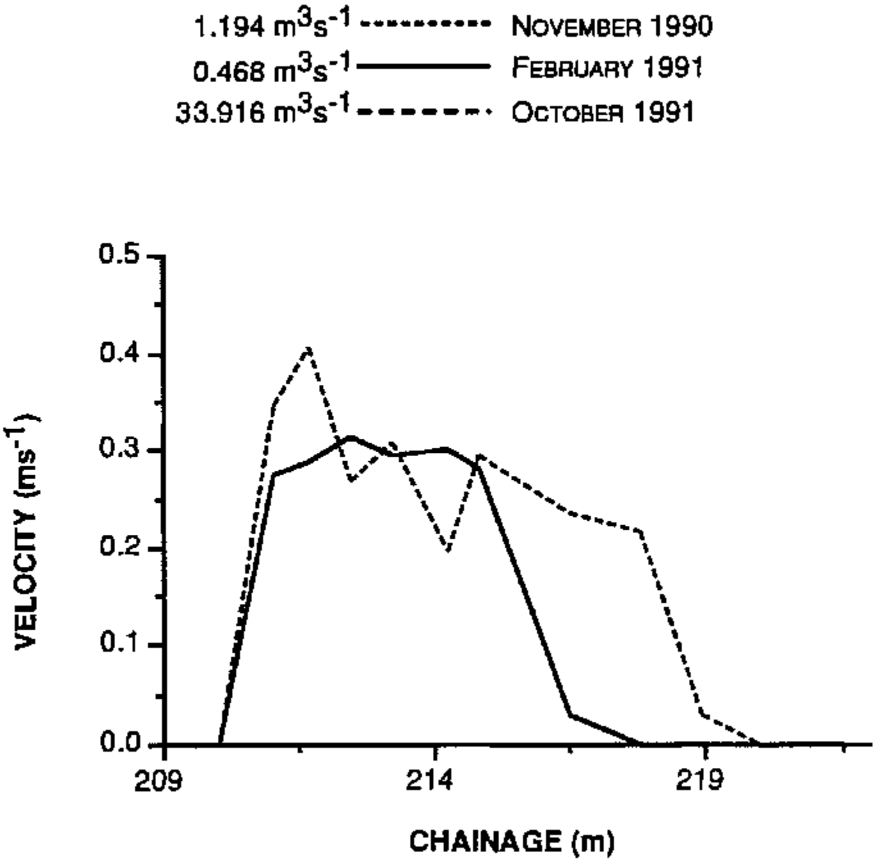


$1.061\ m^3s^{-1}$ ---------- NOVEMBER 1990
$0.677\ m^3s^{-1}$ ———— FEBRUARY 1991
$33.916\ m^3s^{-1}$ – – – – – – OCTOBER 1991

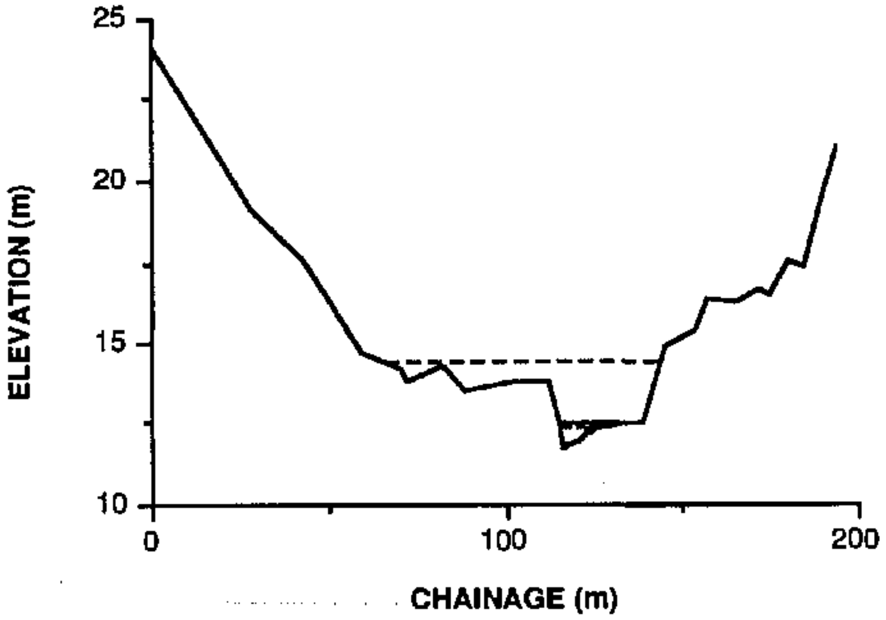


Appendix 6.5.12 Transect KL256

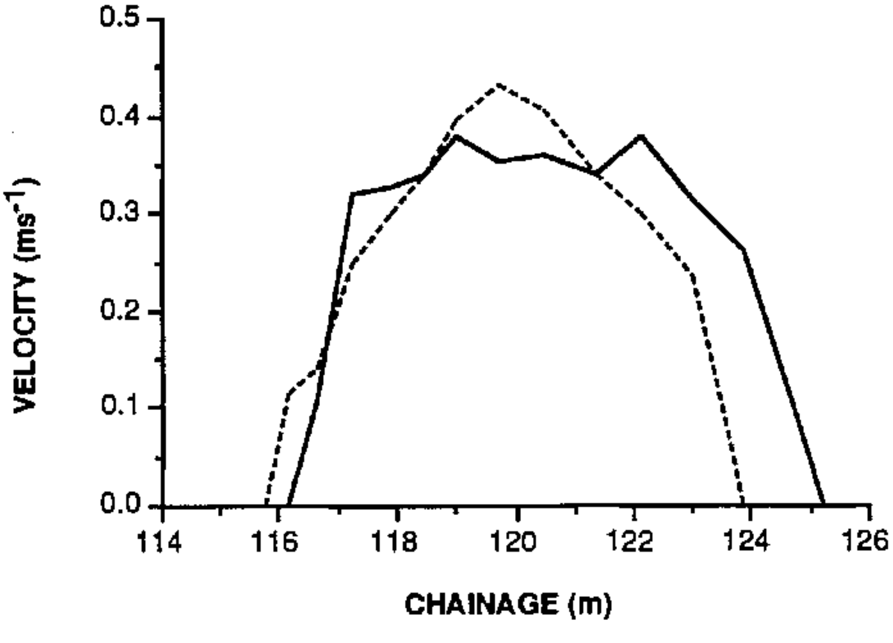




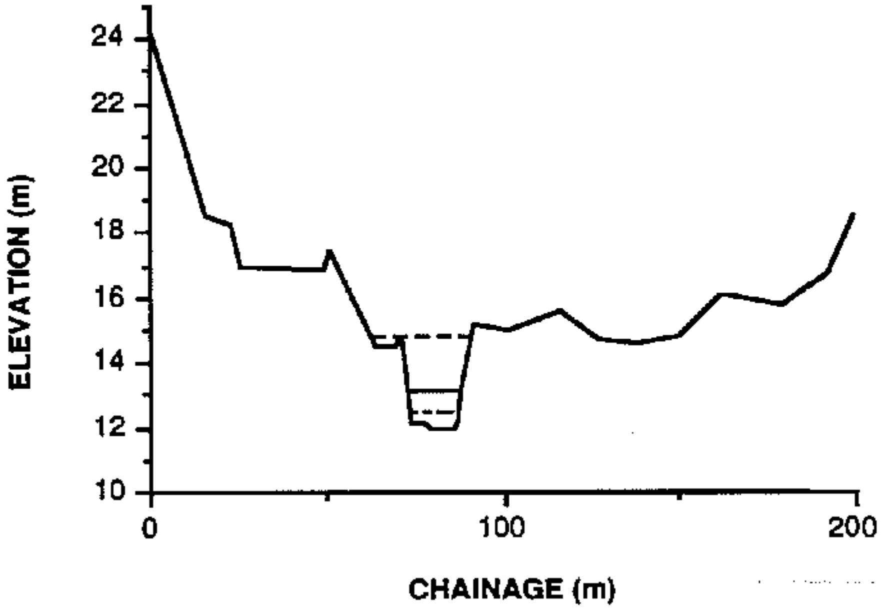
Appendix 6.5.13 Transect KL1048



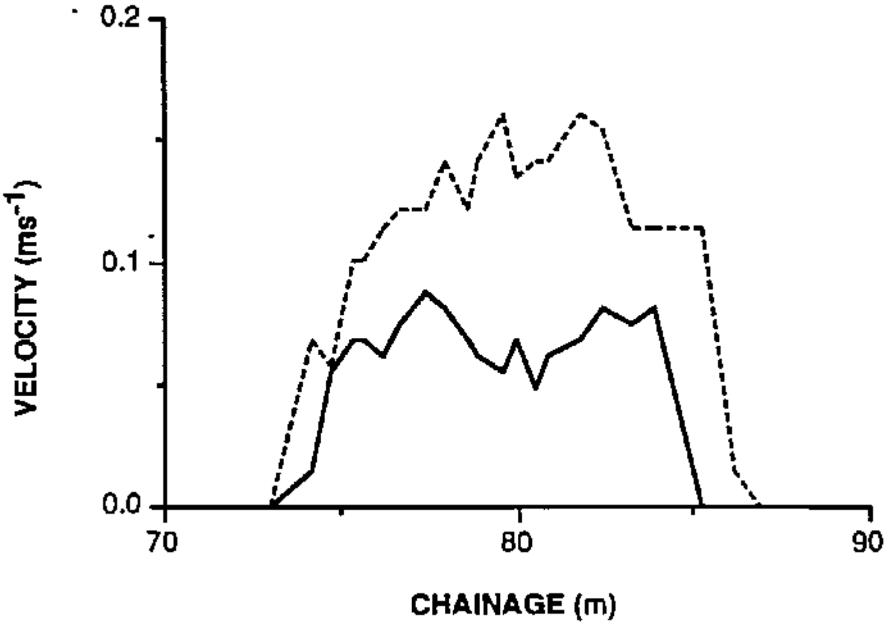
0.750 m^3s^{-1} ---------- NOVEMBER 1990
0.506 m^3s^{-1} ——— FEBRUARY 1991
33.916 m^3s^{-1} – – – – – – OCTOBER 1991



Appendix 6.5.14 Transect KL1400



0.840 m^3s^{-1} --------- NOVEMBER 1990
0.335 m^3s^{-1} ——— FEBRUARY 1991
33.916 m^3s^{-1} - - - - - - OCTOBER 1991



Appendix 8.1 Summary of types and numbers of macroinvertebrate samples collected at all study sites for the preliminary April (Autumn) and May (Autumn) field trips. Y/N signify that water quality samples were/were not collected

DATE	SITE	SAMPLES COLLECTED ROCK	SAND	VEGETATION	DRIFT	WATER QUALITY
04.90	NOORDHOEK R.	3	0	0	0	Y
04.90	DORING R. BRIDGE	0	1	1	1	Y
04.90	DORING R. UPPER REACH	0	0	0	0	Y
TOTAL NUMBER ROCK/SAND		3	1			
TOTAL NUMBER BENTHIC SAMPLES			4			
05.91	VISGAT	5	0	1	1	Y
05.91	GROOTFONTEIN	6	0	1	1	Y
05.91	RATEL R.	5	0	1	1	Y
05.91	NOORDHOEK R.	5	0	1	1	Y
05.91	TWEEFONTEIN	5	0	1	1	Y
05.91	KRIEDOUWKRANS	3	3	1	1	Y
05.91	CLANWILLIAM	5	0	1	1	Y
05.91	LANGKLOOF	0	5	1	1	Y
05.91	BULSHOEK	5	0	1	1	Y
05.91	ZYPHERFONTEIN	0	4	1	1	Y
05.91	DORING R.	3	3	1	1	Y
05.91	KLAWER	0	5	1	1	Y
05.91	BOTHA'S FARM	3	3	1	1	Y
05.91	IRRIGATION CANAL	0	0	0	0	Y
05.91	LUTZVILLE	0	0	0	0	Y
TOTAL NUMBER ROCK/SAND		45	23			
TOTAL NUMBER BENTHIC SAMPLES			68			

Appendix 8.2 Summary of types and numbers of macroinvertebrate samples collected at all study sites for July (Winter) and September/October (early Spring) field trips. Y/N signify that water quality samples were/were not collected

DATE	SITE	SAMPLES COLLECTED				
		ROCK	SAND	VEGETATION	DRIFT	WATER QUALITY
07.90	GROOTFONTEIN	4	6	1	1	Y
07.90	TWEEFONTEIN	0	0	0	1	N
07.90	KRIEDOUWKRANS	10	15	0	1	Y
07.90	CLANWILLIAM	0	0	0	1	N
07.90	LANGKLOOF	0	0	0	1	N
07.90	BULSHOEK	0	0	0	1	N
07.90	ZYPHERFONTEIN	0	0	0	1	N
07.90	DORING R.	2	3	0	1	Y
07.90	KLAWER	0	10	0	1	Y
TOTAL NUMBER ROCK/SAND		16	34			
TOTAL NUMBER BENTHIC SAMPLES			50			
09.90	VISGAT	5	0	1	1	Y
09.90	GROOTFONTEIN	13	2	1	1	Y
09.90	RATEL R.	6	0	1	1	Y
09.90	NOORDHOEK R.	5	0	0	1	Y
09.90	TWEEFONTEIN	6	0	1	1	Y
09.90	KRIEDOUWKRANS	0	3	1	1	Y
09.90	CLANWILLIAM	5	0	1	1	Y
09.90	LANGKLOOF	0	5	1	1	Y
09.90	BULSHOEK	5	0	1	1	Y
10.90	ZYPHERFONTEIN	5	0	1	1	Y
10.90	DORING R.	3	3	0	1	Y
10.90	KLAWER	0	15	0	1	Y
10.90	BOTHA'S FARM	0	3	0	1	Y
TOTAL NUMBER ROCK/SAND		53	31			
TOTAL NUMBER BENTHIC SAMPLES			84			
OVERALL WINTER/EARLY SPRING TOTAL NUMBER BENTHIC SAMPLES			134	134		

Appendix 8.3 Summary of types and numbers of macroinvertebrate samples collected at all study sites for November (Spring) and October (Spring) field trips. Y/N signify that water quality samples were/were not collected

DATE	SITE	SAMPLES COLLECTED				
		ROCK	SAND	VEGETATION	DRIFT	WATER QUALITY
11.90	VISGAT	6	0	0	1	Y
11.90	GROOTFONTEIN	22	3	0	1	Y
11.90	RATEL R.	5	0	0	1	Y
11.90	NOORDHOEK R.	5	0	0	1	Y
11.90	TWEEFONTEIN	6	0	1	1	Y
11.90	KRIEDOUWKRANS	10	15	1	1	Y
11.90	CLANWILLIAM	5	0	1	1	Y
11.90	LANGKLOOF	0	5	1	1	Y
11.90	BULSHOEK	5	0	0	1	Y
11.90	ZYPHERFONTEIN	0	3	1	0	Y
11.90	DORING R.	3	3	0	1	Y
11.90	KLAWER	0	25	0	1	Y
11.90	BOTHA'S FARM	0	5	0	1	Y
TOTAL NUMBER ROCK/SAND		67	59			
TOTAL NUMBER BENTHIC SAMPLES			126			
10.91	GROOTFONTEIN	0	0	0	0	Y
10.91	KRIEDOUWKRANS	0	0	0	0	Y
10.91	KLAWER	0	0	0	0	Y

Appendix 8.4 Summary of types and numbers of macroinvertebrate samples collected at all study sites for the February / March (Summer) field trip. Y/N signify that water quality samples were/were not collected

DATE	SITE	SAMPLES COLLECTED ROCK	SAND	VEGETATION	DRIFT	WATER QUALITY
03.91	SOURCE	0	0	0	0	Y
03.91	VISGAT	5	0	1	1	Y
03.91	BOSCHKLOOF	4	0	1	1	Y
02.91	GROOTFONTEIN	18	7	1	1	Y
02.91	RATEL R.	6	0	1	1	Y
03.91	NOORDHOEK R.	5	0	1	1	Y
03.91	TWEEFONTEIN	5	0	1	1	Y
03.91	KRIEDOUWKRANS	15	10	1	1	Y
03.91	CLANWILLIAM	5	0	1	1	Y
03.91	LANGKLOOF	0	5	1	1	Y
03.91	BULSHOEK	5	0	1	1	Y
03.91	ZYPHERFONTEIN	0	3	2	0	Y
03.91	DORING R.	3	3	1	1	Y
03.91	KLAWER	0	25	1	1	Y
03.91	BOTHA'S FARM	3	3	1	1	Y
TOTAL NUMBER ROCK/SAND		74	56			
TOTAL NUMBER BENTHIC SAMPLES			130			

Appendices 8.5 to 8.8 Summary of benthic macroinvertebrate microhabitat data for all field trips

Appendix 8.5	Benthic macroinvertebrate microhabitat data for Autumn field trips
Appendix 8.6	Benthic macroinvertebrate microhabitat data for Winter and Early Spring field trips
Appendix 8.7	Benthic macroinvertebrate microhabitat data for Spring field trip

The data for appendices 8.5 to 8.7 are available from the authors and are not presented here

Appendix 8.8 Benthic macroinvertebrate microhabitat data for Summer field trip

* sample BKR4 was discarded, due to poor preservation of animals.

substrate mean rod height and microprofile index are measures of substrate heterogeneity based on Gore's (1978) sampling method.

a modified version of Gore's substrate heterogeneity sampler was developed by the authors and a Fortran program was written to determine a corresponding index of heterogeneity based on slope variance (the results will be presented in scientific papers on the subject).

channel index values are coded as per Table 8.3.

Appendix 8.8 Benthic macroinvertebrate microhabitat data for summer (February/March) field trip

SITE	DATE	SAMPLE CODE	DEPTH (m)	DEPTH (ft)	VELOCITY (m/s)	VELOCITY (ft/s)	INSTREAM COVER (%)	INSTREAM COVER TYPE	OVERHEAD COVER (%)	OVERHEAD COVER TYPE
VISGAT	20.03.91	VGR1	0.44	1.44	0.114	0.374	15	Macrophytes	0	
	20.03.91	VGR2	0.23	0.75	0.128	0.420	0		100	Bridge
	20.03.91	VGR3	0.23	0.75	0.227	0.745	0		0	
	20.03.91	VGR4	0.18	0.59	0.187	0.614	0		0	
	20.03.91	VGR5	0.38	1.25	0.280	0.919	0		100	Bridge
BOSCHKLOOF	19.03.91	BKR1	0.14	0.46	0.445	1.460	0		0	
	19.03.91	BKR2	0.12	0.39	1.285	4.216	0		0	
	19.03.91	BKR3	0.15	0.49	0.028	0.092	0		0	
	19.03.91	BKR4*	0.15	0.49	0.187	0.614	0		0	
	19.03.91	BKR5	0.20	0.66	0.273	0.896	0		0	
GROOTFONTEIN	25.02.91	GFR1	0.60	1.97	0.118	0.387	5	Algae	0	
	25.02.91	GFR2	0.38	1.18	0.157	0.515	0		0	
	25.02.91	GFR3	0.44	1.44	0.212	0.696	5	Aponogeton	0	
	25.02.91	GFR4	0.41	1.35	0.152	0.499	0		0	
	25.02.91	GFR5	0.47	1.54	0.237	0.778	0		0	
	25.02.91	GFR6	0.33	1.08	0.227	0.745	0		0	
	25.02.91	GFR7	0.28	0.92	0.113	0.371	0		0	
	25.02.91	GFR8	0.46	1.51	0.252	0.827	20	Algae	0	
	25.02.91	GFR9	0.46	1.51	0.361	1.184	0		0	
	25.02.91	GFR10	0.40	1.31	0.262	0.860	0		0	
	26.02.91	GFR11	0.27	0.89	0.133	0.436	5	Macrophytes	0	
	26.02.91	GFR12	0.22	0.72	0.435	1.427	0		0	
	26.02.91	GFR13	0.22	0.72	0.832	2.730	0		0	
	26.02.91	GFR14	0.18	0.59	0.455	1.493	0		0	
	26.02.91	GFR15	0.28	0.92	0.177	0.581	50	Macrophytes	0	
	27.02.91	GFR16	0.20	0.66	0.000	0.000	0		0	
	27.02.91	GFR17	0.24	0.79	0.000	0.000	0		0	
	27.02.91	GFR18	0.29	0.95	0.000	0.000	0		0	
	27.02.91	GFS19	0.14	0.46	0.000	0.000	0		0	

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	DEPTH (m)	DEPTH (ft)	VELOCITY (m/s)	VELOCITY (ft/s)	INSTREAM COVER (%)	INSTREAM COVER TYPE	OVERHEAD COVER (%)	OVERHEAD COVER TYPE
GROOTFONTEIN	27.02.91	GFS20	0.34	1.12	0.277	0.909	0		0	
	27.02.91	GFS21	0.24	0.79	0.202	0.663	0		0	
	27.02.91	GFS22	0.19	0.62	0.187	0.614	0		0	
	27.02.91	GFS23	0.24	0.79	0.296	0.971	0		0	
	27.02.91	GFS24	0.23	0.75	0.282	0.925	0		0	
	27.02.91	GFS25	0.24	0.79	0.222	0.728	0		0	
RATEL R.	28.02.91	RTR1	0.08	0.26	0.280	0.919	0		0	
	28.02.91	RTR2	0.04	0.13	0.399	1.309	0		0	
	28.02.91	RTR3	0.26	0.85	0.028	0.092	0		0	
	28.02.91	RTR4	0.08	0.26	0.055	0.180	0		0	
	28.02.91	RTR5	0.13	0.43	0.022	0.072	0		0	
	28.02.91	RTR6	0.03	0.10	1.542	5.059	0		0	
NOORDHOEK R.	08.03.91	NHR1	0.18	0.59	0.088	0.289	0		0	
	08.03.91	NHR2	0.05	0.16	0.220	0.722	0		0	
	08.03.91	NHR3	0.10	0.33	0.386	1.266	0		0	
	08.03.91	NHR4	0.18	0.59	0.280	0.919	0		0	
	08.03.91	NHR5	0.15	0.49	0.465	1.526	0		0	
TWEEFONTEIN	08.03.91	TFR1	0.09	0.30	0.293	0.961	5	Scirpus	0	
	08.03.91	TFR2	0.06	0.20	0.631	2.070	5	Scirpus	0	
	08.03.91	TFR3	0.17	0.56	0.536	1.759	5	Scirpus	0	
	08.03.91	TFR4	0.21	0.69	0.061	0.200	15	Scirpus/algae	0	
	08.03.91	TFR5	0.24	0.79	0.141	0.463	0		0	
KRIEDOUWKRANS	01.03.91	KKR1	0.64	2.10	0.000	0.000	0		0	
	01.03.91	KKR2	0.34	1.12	0.000	0.000	0		0	
	01.03.91	KKR3	0.42	1.38	0.000	0.000	0		0	
	01.03.91	KKR4	0.24	0.79	0.000	0.000	0		0	
	01.03.91	KKR5	0.58	1.90	0.000	0.000	0		0	
	01.03.91	KKR6	0.08	0.26	0.028	0.092	0		0	

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	DEPTH (m)	DEPTH (ft)	VELOCITY (m/s)	VELOCITY (ft/s)	INSTREAM COVER (%)	INSTREAM COVER TYPE	OVERHEAD COVER (%)	OVERHEAD COVER TYPE
KRIEDOUWKRANS	01.03.91	KKR7	0.08	0.26	0.128	0.420	0		0	
	01.03.91	KKR8	0.11	0.36	0.181	0.594	0		0	
	01.03.91	KKR9	0.06	0.20	0.372	1.220	0		0	
	01.03.91	KKR10	0.14	0.46	0.207	0.679	0		0	
	02.03.91	KKR11	0.16	0.52	0.121	0.397	0		5	Palmiet
	02.03.91	KKR12	0.10	0.33	0.776	2.546	0		5	Palmiet
	02.03.91	KKR13	0.04	0.13	0.121	0.397	0		5	Palmiet
	02.03.91	KKR14	0.46	1.51	0.088	0.289	0		5	Palmiet
	02.03.91	KKR15	0.18	0.59	0.061	0.200	0		5	Palmiet
	02.03.91	KKS16	0.26	0.85	0.015	0.049	0		0	
	02.03.91	KKS17	0.06	0.20	0.015	0.049	0		0	
	02.03.91	KKS18	0.14	0.46	0.015	0.049	0		0	
	02.03.91	KKS19	0.08	0.26	0.000	0.000	0		0	
	02.03.91	KKS20	0.13	0.43	0.000	0.000	0		0	
	02.03.91	KKS21	0.10	0.33	0.000	0.000	0		0	
	02.03.91	KKS22	0.14	0.46	0.000	0.000	0		0	
	02.03.91	KKS23	0.14	0.46	0.000	0.000	0		0	
	02.03.91	KKS24	0.35	1.15	0.015	0.049	0		0	
	02.03.91	KKS25	0.24	0.79	0.000	0.000	0		0	
CLANWILLIAM	03.03.91	CBR1	0.02	0.07	0.306	1.004	0		0	
	03.03.91	CBR2	0.31	1.02	0.114	0.374	0		0	
	03.03.91	CBR3	0.36	1.18	0.081	0.266	0		0	
	03.03.91	CBR4	0.46	1.51	0.273	0.896	0		0	
	03.03.91	CBR5	0.42	1.38	0.095	0.312	0		0	
LANGKLOOF	03.03.91	LKS1	0.20	0.66	0.015	0.049	0		0	
	03.03.91	LKS2	0.12	0.39	0.015	0.049	0		0	
	03.03.91	LKS3	0.16	0.52	0.075	0.246	0		0	
	03.03.91	LKS4	0.15	0.49	0.081	0.266	0		0	
	03.03.91	LKS5	0.16	0.52	0.048	0.157	0		0	

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	DEPTH (m)	DEPTH (ft)	VELOCITY (m/s)	VELOCITY (ft/s)	INSTREAM COVER (%)	INSTREAM COVER TYPE	OVERHEAD COVER (%)	OVERHEAD COVER TYPE
BULSHOEK	07.03.91	BDR1	0.05	0.16	0.015	0.049	0		0	
	07.03.91	BDR2	0.04	0.13	0.326	1.070	5	Grass	5	Trees
	07.03.91	BDR3	0.26	0.85	0.000	0.000	0		0	
	07.03.91	BDR4	0.08	0.26	0.161	0.528	5	Grass	10	Trees
	07.03.91	BDR5	0.02	0.07	0.015	0.049	5	Algae/roots	10	Trees
ZYPHERFONTEIN	07.03.91	ZFS1	0.20	0.66	0.000	0.000	20	Grass	20	Trees
	07.03.91	ZFS2	0.20	0.66	0.000	0.000	20	Grass	20	Trees
	07.03.91	ZFS3	0.35	1.15	0.000	0.000	40	Grass/macrophytes	40	Trees
DORING R.	06.03.91	DRR1	0.22	0.72	0.000	0.000	0		0	
	06.03.91	DRR2	0.46	1.51	0.000	0.000	0		0	
	06.03.91	DRR3	0.37	1.21	0.000	0.000	0		0	
	06.03.91	DRS4	0.22	0.72	0.000	0.000	0		0	
	06.03.91	DRS5	0.15	0.49	0.000	0.000	0		0	
	06.03.91	DRS6	0.12	0.39	0.000	0.000	0		0	
KLAWER	04.03.91	KWS1	0.34	1.12	0.247	0.810	0		0	
	04.03.91	KWS2	0.18	0.59	0.022	0.072	0		0	
	04.03.91	KWS3	0.18	0.59	0.220	0.722	0		0	
	04.03.91	KWS4	0.26	0.85	0.234	0.768	0		0	
	04.03.91	KWS5	0.31	1.02	0.187	0.614	0		0	
	04.03.91	KWS6	0.35	1.15	0.240	0.787	0		0	
	04.03.91	KWS7	0.28	0.92	0.207	0.679	0		0	
	04.03.91	KWS8	0.18	0.59	0.108	0.354	0		0	
	04.03.91	KWS9	0.34	1.12	0.174	0.571	0		0	
	04.03.91	KWS10	0.31	1.02	0.200	0.656	0		0	
	05.03.91	KWS11	0.18	0.59	0.227	0.745	0		0	
	05.03.91	KWS12	0.19	0.62	0.200	0.656	0		0	
	05.03.91	KWS13	0.18	0.59	0.214	0.702	0		0	
	05.03.91	KWS14	0.21	0.69	0.207	0.679	0		0	

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	DEPTH (m)	DEPTH (ft)	VELOCITY (m/s)	VELOCITY (ft/s)	INSTREAM COVER (%)	INSTREAM COVER TYPE	OVERHEAD COVER (%)	OVERHEAD COVER TYPE
KLAWER	05.03.91	KWS15	0.20	0.66	0.207	0.679	0		0	
	05.03.91	KWS16	0.25	0.82	0.214	0.702	0		0	
	05.03.91	KWS17	0.25	0.82	0.452	1.483	0		0	
	05.03.91	KWS18	0.23	0.75	0.372	1.220	0		0	
	05.03.91	KWS19	0.20	0.66	0.465	1.526	0		0	
	05.03.91	KWS20	0.22	0.72	0.353	1.158	0		0	
	05.03.91	KWS21	0.20	0.66	0.459	1.506	0		0	
	05.03.91	KWS22	0.16	0.52	0.353	1.158	0		0	
	05.03.91	KWS23	0.32	1.05	0.445	1.460	0		0	
	05.03.91	KWS24	0.17	0.56	0.452	1.483	0		0	
	05.03.91	KWS25	0.16	0.52	0.207	0.679	0		0	
BOTHA'S FARM	06.03.91	BFR1	0.17	0.56	0.611	2.005	0		0	
	06.03.91	BFR2	0.16	0.52	0.703	2.306	0		0	
	06.03.91	BFR3	0.14	0.46	0.313	1.027	0		0	
	06.03.91	BFS4	0.15	0.49	0.412	1.352	0		0	
	06.03.91	BFS5	0.28	0.92	0.339	1.112	0		0	
	06.03.91	BFS6	0.29	0.95	0.300	0.984	0		0	

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	SUBSTRATE MEAN ROD HEIGHT	MICROPROFILE INDEX (S.D.)	HETEROGENEITY INDEX (SLOPE VARIANCE)	CHANNEL INDEX INVERTEBRATES PHABSIM	ORGANICS IN SAND (%)	BIOTOPE
VISGAT	20.03.91	VGR1	16.8	3.5	168.282	24		Cobble/bedrock riffle
	20.03.91	VGR2	19.2	1.1	0.473	15		Bedrock rapid
	20.03.91	VGR3	19.5	1.3	1.562	25		Bedrock run
	20.03.91	VGR4	14.6	3.2	2.780	25		Bedrock run
	20.03.91	VGR5	22.5	5.5	427.669	14		Cobble/bedrock riffle
BOSCHKLOOF	19.03.91	BKR1	16.9	2.5	104.11	24		Cobble riffle
	19.03.91	BKR2	25.8	4.7	284.017	14		Cobble riffle
	19.03.91	BKR3	21.4	1.5	45.892	15		Bedrock run
	19.03.91	BKR4*	20.6	1.1	2.514	15		Bedrock run
	19.03.91	BKR5	22.0	4.6	84.799	14		Cobble riffle
GROOTFONTEIN	25.02.91	GFR1	17.7	3.2	136.162	24		Cobble run
	25.02.91	GFR2	21.7	4.7	337.671	24		Cobble run
	25.02.91	GFR3	20.1	4.8	236.884	24		Cobble run
	25.02.91	GFR4	23.6	3.4	155.244	24		Cobble run
	25.02.91	GFR5	21.4	3.3	83.873	24		Cobble run
	25.02.91	GFR6	26.3	3.1	113.799	24		Cobble run
	25.02.91	GFR7	29.7	4.5	147.900	24		Cobble run
	25.02.91	GFR8	31.4	6.5	161.912	14		Cobble run
	25.02.91	GFR9	26.0	4.8	222.350	24		Cobble run
	25.02.91	GFR10	21.8	3.5	29.853	24		Cobble run
	26.02.91	GFR11	23.1	4.3	82.554	34		Cobble riffle
	26.02.91	GFR12	25.5	4.5	150.649	24		Cobble riffle
	26.02.91	GFR13	25.2	6.2	442.180	24		Cobble riffle
	26.02.91	GFR14	27.5	6.2	176.036	24		Cobble riffle
	26.02.91	GFR15	25.3	3.8	86.697	44		Cobble riffle
	27.02.91	GFR16	24.8	1.1	8.290	24		Cobble backwater
	27.02.91	GFR17	23.1	2.0	62.766	24		Cobble backwater
	27.02.91	GFR18	20.7	2.0	28.669	24		Gravel/cobble backwater
	27.02.91	GFS19				51	1.41	Sand run

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	SUBSTRATE MEAN ROD HEIGHT	MICROPROFILE INDEX (S.D.)	HETEROGENEITY INDEX (SLOPE VARIANCE)	CHANNEL INDEX INVERTEBRATES PHABSIM	ORGANICS IN SAND (%)	BIOTOPE
GROOTFONTEIN	27.02.91	GFS20				52	0.15	Sand run
	27.02.91	GFS21				52	0.27	Sand run
	27.02.91	GFS22				52	0.24	Sand run
	27.02.91	GFS23				52	0.56	Sand run
	27.02.91	GFS24				52	0.34	Sand run
	27.02.91	GFS25				51	0.46	Sand run
RATEL R.	28.02.91	RTR1	17.1	3.0	32.858	15		Bedrock rapid
	28.02.91	RTR2	19.4	1.2	4.592	15		Bedrock rapid
	28.02.91	RTR3	19.8	9.2	527.133	14		Bedrock/boulder pool
	28.02.91	RTR4	20.3	2.0	6.144	15		Bedrock/boulder pool
	28.02.91	RTR5	20.2	1.0	4.519	15		Bedrock pool
	28.02.91	RTR6	19.2	1.1	4.179	15		Bedrock rapid
NOORDHOEK R.	08.03.91	NHR1	22.0	3.9	90.782	14		Cobble riffle
	08.03.91	NHR2	21.5	3.0	74.065	14		Cobble riffle
	08.03.91	NHR3	24.2	3.5	143.075	14		Cobble riffle
	08.03.91	NHR4	25.0	2.4	40.998	14		Cobble riffle
	08.03.91	NHR5	23.6	2.3	62.804	14		Cobble riffle
TWEEFONTEIN	08.03.91	TFR1	22.6	3.5	66.956	14		Cobble riffle
	08.03.91	TFR2	24.4	3.9	67.490	14		Cobble riffle
	08.03.91	TFR3	28.5	4.5	246.767	14		Cobble riffle
	08.03.91	TFR4	26.7	4.1	164.446	14		Cobble run
	08.03.91	TFR5	25.7	3.3	105.442	24		Cobble run
KRIEDOUWKRANS	01.03.91	KKR1	23.6	2.1	3.216	15		Bedrock pool
	01.03.91	KKR2	24.4	2.4	26.707	15		Bedrock pool
	01.03.91	KKR3	27.3	5.2	237.711	14		Bedrock/cobble pool
	01.03.91	KKR4	22.3	0.9	2.408	15		Bedrock pool
	01.03.91	KKR5	22.1	1.1	2.191	15		Bedrock pool
	01.03.91	KKR6	22.4	1.2	0.737	15		Bedrock rapid

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	SUBSTRATE MEAN ROD HEIGHT	MICROPROFILE INDEX (S.D.)	HETEROGENEITY INDEX (SLOPE VARIANCE)	CHANNEL INDEX INVERTEBRATES PHABSIM	ORGANICS IN SAND (%)	BIOTOPE
KRIEDOUWKRANS	01.03.91	KKR7	24.3	3.6	70.155	14		Bedrock/cobble rapid
	01.03.91	KKR8	23.3	2.1	19.976	14		Bedrock/cobble rapid
	01.03.91	KKR9	22.4	5.0	134.899	15		Bedrock rapid
	01.03.91	KKR10	23.4	1.5	1.274	15		Bedrock rapid
	02.03.91	KKR11	21.0	2.4	23.035	15		Bedrock run
	02.03.91	KKR12	23.9	2.0	1.433	15		Bedrock run
	02.03.91	KKR13	32.2	5.5	80.912	15		Bedrock/boulder run
	02.03.91	KKR14	22.8	1.9	9.755	15		Bedrock run
	02.03.91	KKR15	23.4	1.5	2.455	15		Bedrock run
	02.03.91	KKS16				52	0.16	Sand run
	02.03.91	KKS17				52	0.18	Sand run
	02.03.91	KKS18				52	0.10	Sand run
	02.03.91	KKS19				52	0.13	Sand backwater
	02.03.91	KKS20				52	0.10	Sand backwater
	02.03.91	KKS21				52	0.15	Sand backwater
	02.03.91	KKS22				52	0.14	Sand backwater
	02.03.91	KKS23				52	0.12	Sand backwater
	02.03.91	KKS24				52	0.15	Sand pool
	02.03.91	KKS25				52	0.13	Sand pool
CLANWILLIAM	03.03.91	CBR1	24.8	1.8	1.298	15		Bedrock run
	03.03.91	CBR2	20.9	2.6	13.608	15		Bedrock run
	03.03.91	CBR3	27.6	4.4	108.444	14		Cobble/bedrock run
	03.03.91	CBR4	21.5	1.9	11.824	15		Bedrock run
	03.03.91	CBR5	23.2	1.9	14.493	14		Cobble run
LANGKLOOF	03.03.91	LKS1				52	0.12	Sand run
	03.03.91	LKS2				52	0.12	Sand run
	03.03.91	LKS3				52	0.13	Sand run
	03.03.91	LKS4				52	0.12	Sand run
	03.03.91	LKS5				52	0.11	Sand run

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	SUBSTRATE MEAN ROD HEIGHT	MICROPROFILE INDEX (S.D.)	HETEROGENEITY INDEX (SLOPE VARIANCE)	CHANNEL INDEX INVERTEBRATES PHABSIM	ORGANICS IN SAND (%)	BIOTOPE
BULSHOEK	07.03.91	BDR1	22.3	1.3	3.386	15		Bedrock pool
	07.03.91	BDR2	22.5	1.1	0.480	15		Bedrock rapid
	07.03.91	BDR3	21.3	1.3	4.663	15		Bedrock pool
	07.03.91	BDR4	22.2	1.0	3.786	15		Bedrock rapid
	07.03.91	BDR5	22.5	1.5	1.102	15		Bedrock rapid
ZYPHERFONTEIN	07.03.91	ZFS1				51	1.19	Sand/silt pool
	07.03.91	ZFS2				51		Sand/silt pool
	07.03.91	ZFS3				51	0.52	Sand/silt pool
DORING R.	06.03.91	DRR1	20.8	2.9	41.423	15		Bedrock pool
	06.03.91	DRR2	26.1	1.7	3.392	15		Bedrock pool
	06.03.91	DRR3	23.5	1.6	1.362	15		Bedrock pool
	06.03.91	DRS4				52	0.22	Sand pool
	06.03.91	DRS5				52	0.26	Sand pool
	06.03.91	DRS6				52	0.21	Sand pool
KLAWER	04.03.91	KWS1				52	0.17	Sand run
	04.03.91	KWS2				52	0.21	Sand run
	04.03.91	KWS3				52	0.15	Sand run
	04.03.91	KWS4				52	0.18	Sand run
	04.03.91	KWS5				52	0.16	Sand run
	04.03.91	KWS6				52	0.15	Sand run
	04.03.91	KWS7				52	0.20	Sand run
	04.03.91	KWS8				52	0.22	Sand run
	04.03.91	KWS9				52	0.16	Sand run
	04.03.91	KWS10				52	0.21	Sand run
	05.03.91	KWS11				52	0.24	Sand run
	05.03.91	KWS12				52	0.20	Sand run
	05.03.91	KWS13				52	0.17	Sand run
	05.03.91	KWS14				52	0.22	Sand run

Appendix 8.8 continued

SITE	DATE	SAMPLE CODE	SUBSTRATE MEAN ROD HEIGHT	MICROPROFILE INDEX (S.D.)	HETEROGENEITY INDEX (SLOPE VARIANCE)	CHANNEL INDEX INVERTEBRATES PHABSIM	ORGANICS IN SAND (%)	BIOTOPE
KLAWER	05.03.91	KWS15				52	0.21	Sand run
	05.03.91	KWS16				52	0.16	Sand run
	05.03.91	KWS17				52		Sand run
	05.03.91	KWS18				52	0.17	Sand run
	05.03.91	KWS19				52	0.23	Sand run
	05.03.91	KWS20				52	0.15	Sand run
	05.03.91	KWS21				52	0.18	Sand run
	05.03.91	KWS22				52	0.18	Sand run
	05.03.91	KWS23				52	0.18	Sand run
	05.03.91	KWS24				52	0.54	Sand run
	05.03.91	KWS25				52	0.23	Sand run
BOTHA'S FARM	06.03.91	BFR1	21.7	1.6	9.504	14		Cobble riffle
	06.03.91	BFR2	25.1	1.4	13.777	14		Cobble riffle
	06.03.91	BFR3	26.0	3.6	182.874	14		Cobble riffle
	06.03.91	BFS4				33	0.45	Sand/gravel run
	06.03.91	BFS5				43	0.29	Sand/gravel run
	06.03.91	BFS6				43	0.41	Sand/gravel run

Appendix 8.9 Taxonomic keys used for the identification of benthic macroinvertebrates

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Appendix 8.10 Family-level abundances of benthic macroinvertebrates for all samples for all summer mainstream sites

8.10.1	Visgat
8.10.2	Boschkloof
8.10.3	Grootfontein
8.10.4	Tweefontein
8.10.5	Kriedouwkrans
8.10.6	Clanwilliam
8.10.7	Langkloof
8.10.8	Bulshoek
8.10.9	Zypherfontein
8.10.10	Klawer
8.10.11	Botha's Farm

Abundances are per 1 m^2 unit area.

Sites are coded as in Figure 4.4

R - rock sample

S - sand sample

Appendix 8.10.1 Family-level benthic macroinvertebrate abundances for Visgat summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	VGR1	VGR2	VGR3	VGR4	VGR5	VGMEAN
ACARINA		0	10	0	0	0	2.0
CNIDARIA		0	0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	10	0	0	0	10	4.0
	Dytiscidae (larva)	0	0	0	0	0	0.0
	Elmidae (adult)	30	20	0	0	0	10.0
	Elmidae (larva)	390	730	20	0	190	266.0
	Helodidae (larva)	10	20	0	0	0	6.0
	Hydraenidae (adult)	0	0	0	0	0	0.0
	Hydrophilidae (larva)	0	0	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0	0.0
DIPTERA	Ceratopogonidae	0	0	0	0	0	0.0
	Chironomidae: Chironomini	10	0	45	13	40	21.6
	Chironomidae: Tanytarsini	20	0	15	0	40	15.0
	Chironomidae: Orthocladinae	550	305	315	84	650	380.8
	Chironomidae: Tanypodinae	50	155	35	23	70	66.6
	Chironomidae (pupa)	30	0	0	0	0	6.0
	Culicidae	0	0	0	0	10	2.0
	Empididae	0	0	0	0	0	0.0
	Rhagionidae	0	10	0	0	20	6.0
	Simuliidae (larva)	450	10	10	0	470	188.0
	Simuliidae (pupa)	0	0	0	0	0	0.0
	Tipulidae	20	50	0	10	0	16.0
	Adult spp.	0	10	0	10	20	8.0
	Pupa spp.	0	20	10	0	10	8.0
EPHEMEROPTERA	Baetidae	1490	2710	2280	610	380	1494.0
	Caenidae	60	170	50	10	10	60.0
	Ephemerellidae	80	0	10	0	60	30.0
	Heptageniidae	30	10	20	0	120	36.0
	Leptophlebiidae	50	0	0	20	240	62.0
	Tricorythidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	30	0	0	0	10	8.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0.0
MOLLUSCA		0	0	0	0	0	0.0
NEMATODA		0	0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	10	0	0	0	0	2.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	10	2.0
	Corduliidae	0	0	0	0	0	0.0
	Gomphidae	0	0	0	0	0	0.0
	Libellulidae	0	0	0	0	0	0.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0.0
	Naididae	20	130	0	0	10	32.0
PLATYHELMINTHES		0	10	0	0	10	4.0
PLECOPTERA	Notonemouridae	40	0	0	0	100	28.0
TRICHOPTERA	Barbarochthonidae	50	130	0	10	0	38.0
	Ecnomidae	0	0	0	0	0	0.0
	Glossosomatidae	0	0	0	0	60	12.0
	Hydropsychidae	0	10	0	0	0	2.0
	Hydroptilidae	0	0	0	0	0	0.0
	Leptoceridae	50	60	0	0	20	26.0
	Petrothrincidae	0	0	0	0	0	0.0
	Philopotamidae	10	0	0	0	10	4.0
	Polycentropodidae	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0

Appendix 8.10.2 Family-level benthic macroinvertebrate abundances for Boschkloof summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	BKR1	BKR2	BKR3	BKR5	BKMEAN
ACARINA		0	30	0	0	7.5
CNIDARIA		10	0	0	0	2.5
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	0.0
	Elmidae (adult)	0	0	0	0	0.0
	Elmidae (larva)	90	20	60	20	47.5
	Helodidae (larva)	90	40	0	20	37.5
	Hydraenidae (adult)	0	10	0	0	2.5
	Hydrophilidae (larva)	0	0	0	0	0.0
	Limnichidae (larva)	10	0	0	20	7.5
	Adult spp.	0	10	0	0	2.5
COLLEMBOLA		0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0.0
DIPTERA	Ceratopogonidae	0	0	0	0	0.0
	Chironomidae: Chironomini	47	80	133	62	80.5
	Chironomidae: Tanytarsini	97	10	42	32	45.3
	Chironomidae: Orthocladinae	538	990	603	693	706.0
	Chironomidae: Tanypodinae	218	50	22	93	95.8
	Chironomidae (pupa)	10	0	0	0	2.5
	Culicidae	0	0	0	0	0.0
	Empididae	0	0	0	0	0.0
	Rhagionidae	0	20	0	20	10.0
	Simuliidae (larva)	30	2580	90	40	685.0
	Simuliidae (pupa)	0	20	0	10	7.5
	Tipulidae	20	140	30	20	52.5
	Adult spp.	0	0	0	10	2.5
	Pupa spp.	20	30	10	0	15.0
EPHEMEROPTERA	Baetidae	680	1140	150	260	557.5
	Caenidae	30	0	10	20	15.0
	Ephemerellidae	820	410	20	510	440.0
	Heptageniidae	780	140	10	840	442.5
	Leptophlebiidae	160	120	0	180	115.0
	Tricorythidae	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0.0
	Veliidae (adult)	10	0	0	0	2.5
LEPIDOPTERA	Pyralidae	10	70	0	0	20.0
MEGALOPTERA	Corydalidae	0	20	0	10	7.5
MOLLUSCA		0	0	0	0	0.0
NEMATODA		0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0.0
	Gomphidae	0	0	0	0	0.0
	Libellulidae	10	0	0	0	2.5
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0.0
	Naididae	30	0	0	110	35.0
PLATYHELMINTHES		0	0	0	0	0.0
PLECOPTERA	Notonemouridae	30	0	0	0	7.5
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0.0
	Ecnomidae	30	0	50	10	22.5
	Glossosomatidae	0	0	0	0	0.0
	Hydropsychidae	0	140	20	20	45.0
	Hydroptilidae	60	10	190	30	72.5
	Leptoceridae	0	10	0	10	5.0
	Petrothrincidae	0	0	0	0	0.0
	Philopotamidae	0	10	10	0	5.0
	Polycentropodidae	0	0	30	10	10.0
	Sericostomatidae	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0.0

Appendix 8.10.3 Family-level benthic macroinvertebrate abundances for Grootfontein summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	GFR1	GFR2	GFR3	GFR4	GFR5	GFR6	GFR7
ACARINA		0	0	0	0	0	0	0
CNIDARIA		0	0	0	0	0	0	0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0	0
	Dytiscidae (larva)	0	0	0	0	0	0	0
	Elmidae (adult)	0	0	0	40	0	0	0
	Elmidae (larva)	170	40	80	380	230	190	120
	Helodidae (larva)	0	0	0	0	30	10	0
	Hydraenidae (adult)	0	0	0	40	0	0	0
	Hydrophilidae (larva)	0	0	0	0	0	0	0
	Limnichidae (larva)	0	20	0	10	0	30	40
	Adult spp.	0	0	0	0	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0
CRUSTACEA		0	0	0	0	0	0	0
DIPTERA	Ceratopogonidae	10	0	0	20	0	0	0
	Chironomidae: Chironomini	330	10	30	305	20	12	57
	Chironomidae: Tanytarsini	420	60	30	2345	120	72	187
	Chironomidae: Orthocladinae	20	30	50	10565	150	113	448
	Chironomidae: Tanypodinae	230	70	70	615	220	83	658
	Chironomidae (pupa)	30	20	20	250	0	10	10
	Culicidae	0	0	0	0	0	0	0
	Empididae	0	0	0	0	0	0	0
	Rhagionidae	0	10	0	10	10	40	20
	Simuliidae (larva)	0	0	10	1640	0	0	0
	Simuliidae (pupa)	0	0	0	0	0	0	0
	Tipulidae	0	0	0	120	0	0	0
	Adult spp.	0	0	0	0	0	10	0
	Pupa spp.	0	10	0	10	0	0	30
EPHEMEROPTERA	Baetidae	100	230	750	3880	380	960	1230
	Caenidae	820	50	390	640	190	110	190
	Ephemerellidae	0	0	0	10	10	10	20
	Heptageniidae	0	0	0	0	10	60	60
	Leptophlebiidae	0	10	10	80	40	30	60
	Tricorythidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0	0
	Mesoveliidae (adult)	0	0	0	0	0	0	0
	Pleidae (adult)	0	0	0	0	0	0	0
	Veliidae (adult)	0	0	0	0	0	0	0
LEPIDOPTERA	Pyralidae	10	0	0	0	10	0	0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0
MOLLUSCA		0	0	0	0	0	0	0
NEMATODA		0	0	0	40	0	0	0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0	10
	Corduliidae	20	0	0	20	0	0	0
	Gomphidae	20	0	0	0	0	20	10
	Libellulidae	0	0	0	0	0	0	10
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0	0
	Naididae	90	0	20	290	90	10	10
PLATYHELMINTHES		60	0	0	770	410	580	700
PLECOPTERA	Notonemouridae	0	0	0	10	0	10	0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	10	0	20
	Ecnomidae	20	30	10	290	20	100	330
	Glossosomatidae	0	0	0	0	0	0	0
	Hydropsychidae	0	0	0	130	10	40	0
	Hydroptilidae	0	0	0	70	70	30	30
	Leptoceridae	40	0	0	140	60	20	330
	Petrothrincidae	0	0	0	10	0	10	0
	Philopotamidae	0	0	0	0	0	0	0
	Polycentropodidae	0	0	0	0	0	0	0
	Sericostomatidae	10	0	0	0	0	0	0
	Xiphocentronidae	0	0	0	0	0	0	0
	Pupa spp.	10	0	0	0	0	0	20

Appendix 8.10.3 continued

ORDER/TAXON	FAMILY (subfamily/tribe)	GFR8	GFR9	GFR10	GFR11	GFR12	GFR13	GFR14
ACARINA		0	0	0	10	0	10	10
CNIDARIA		0	0	0	10	0	0	0
COLEOPTERA	Dryopidae (larva)	0	0	0	10	0	0	0
	Dytiscidae (larva)	0	0	0	0	0	0	0
	Elmidae (adult)	10	0	20	0	0	0	0
	Elmidae (larva)	1380	360	670	300	330	690	1320
	Helodidae (larva)	0	20	0	10	20	0	150
	Hydraenidae (adult)	10	0	0	0	0	0	10
	Hydrophilidae (larva)	0	0	0	0	0	0	0
	Limnichidae (larva)	0	30	40	10	20	30	110
	Adult spp.	0	0	0	0	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0
CRUSTACEA		10	0	0	0	0	0	0
DIPTERA	Ceratopogonidae	10	10	10	10	10	0	20
	Chironomidae: Chironomini	137	112	42	75	180	230	1070
	Chironomidae: Tanytarsini	1368	623	752	735	900	960	1500
	Chironomidae: Orthocladinae	1308	453	863	855	610	3090	2280
	Chironomidae: Tanypodinae	837	422	773	945	500	250	1290
	Chironomidae (pupa)	20	10	30	30	40	50	80
	Culicidae	0	0	0	0	0	0	0
	Empididae	0	0	0	0	0	0	0
	Rhagionidae	30	10	40	0	40	20	120
	Simuliidae (larva)	80	10	10	30	20	310	30
	Simuliidae (pupa)	0	0	0	0	10	0	0
	Tipulidae	10	10	10	20	80	190	110
	Adult spp.	0	0	0	0	0	0	0
	Pupa spp.	0	0	0	0	0	0	0
EPHEMEROPTERA	Baetidae	3530	2010	1870	1970	2160	2920	5330
	Caenidae	380	530	550	1310	80	40	0
	Ephemerellidae	60	10	10	20	120	50	50
	Heptageniidae	50	30	30	10	220	70	0
	Leptophlebiidae	50	20	130	200	110	40	30
	Tricorythidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	10	0
	Mesoveliidae (adult)	0	0	0	0	0	0	0
	Pleidae (adult)	0	0	0	0	0	0	0
	Veliidae (adult)	0	0	0	10	0	0	0
LEPIDOPTERA	Pyralidae	60	0	10	10	20	60	180
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0
MOLLUSCA		0	0	0	0	0	0	0
NEMATODA		0	0	0	0	0	0	0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0
ODONATA: Anisoptera	Aeshnidae	10	0	10	0	0	0	20
	Corduliidae	0	0	0	0	0	0	0
	Gomphidae	0	0	0	0	0	10	0
	Libellulidae	10	10	10	0	0	70	120
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0	0
	Naididae	380	230	600	280	10	0	140
PLATYHELMINTHES		650	1120	1160	810	0	50	0
PLECOPTERA	Notonemouridae	30	10	10	30	10	0	40
TRICHOPTERA	Barbarochthonidae	0	0	10	0	0	0	0
	Ecnomidae	280	240	130	30	40	0	50
	Glossosomatidae	0	0	0	0	0	0	0
	Hydropsychidae	680	510	370	30	2000	3750	3010
	Hydroptilidae	300	130	110	70	200	50	400
	Leptoceridae	160	280	40	40	40	40	680
	Petrothrincidae	0	0	0	0	0	0	0
	Philopotamidae	0	0	0	0	0	50	0
	Polycentropodidae	0	10	30	0	0	0	10
	Sericostomatidae	0	0	0	0	0	0	30
	Xiphocentronidae	0	0	10	0	0	0	30
	Pupa spp.	30	30	40	20	10	30	70

Appendix 8.10.3 continued

ORDER/TAXON	FAMILY (subfamily/tribe)	GFR15	GFR16	GFR17	GFR18	GFS19	GFS20	GFS21
ACARINA		40	0	0	0	0	0	0
CNIDARIA		0	0	10	0	0	0	0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0	0
	Dytiscidae (larva)	0	0	0	0	0	0	0
	Elmidae (adult)	40	0	0	0	0	0	0
	Elmidae (larva)	1250	70	270	20	0	0	56
	Helodidae (larva)	0	0	0	0	0	0	0
	Hydraenidae (adult)	20	0	0	0	0	0	0
	Hydrophilidae (larva)	0	0	0	0	0	0	0
	Limnichidae (larva)	30	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0
CRUSTACEA		0	0	0	0	0	0	0
DIPTERA	Ceratopogonidae	0	0	30	10	0	56	0
	Chironomidae: Chironomini	32	52	167	60	3211	280	2800
	Chironomidae: Tanytarsini	823	253	568	190	5563	56	1008
	Chironomidae: Orthocladinae	363	72	87	40	0	168	336
	Chironomidae: Tanypodinae	622	363	1568	650	690	0	112
	Chironomidae (pupa)	0	0	10	20	168	0	0
	Culicidae	0	0	0	0	0	0	0
	Empididae	0	0	0	0	0	0	0
	Rhagionidae	0	0	0	0	0	0	0
	Simuliidae (larva)	20	0	0	0	0	0	0
	Simuliidae (pupa)	0	0	0	0	0	0	0
	Tipulidae	10	0	0	0	0	0	0
	Adult spp.	0	0	0	0	56	0	0
	Pupa spp.	0	0	0	0	0	0	0
EPHEMEROPTERA	Baetidae	430	340	1080	170	56	0	168
	Caenidae	190	630	2640	1090	672	0	112
	Ephemerellidae	0	0	0	0	0	0	0
	Heptageniidae	0	0	0	0	0	0	0
	Leptophlebiidae	110	0	30	0	0	0	0
	Tricorythidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0	0
	Mesoveliidae (adult)	0	0	0	0	0	0	0
	Pleidae (adult)	0	0	0	0	0	0	0
	Veliidae (adult)	0	0	0	0	0	0	0
LEPIDOPTERA	Pyralidae	10	0	0	0	0	0	0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0
MOLLUSCA		0	0	0	0	0	0	0
NEMATODA		10	0	0	0	0	0	112
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0
ODONATA: Anisoptera	Aeshnidae	0	0	10	0	0	0	0
	Corduliidae	0	0	15	20	0	0	0
	Gomphidae	0	0	50	0	0	0	0
	Libellulidae	0	0	15	0	0	0	0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	112	0	0
	Naididae	60	60	140	100	0	112	112
PLATYHELMINTHES		10	0	0	0	0	0	0
PLECOPTERA	Notonemouridae	0	0	10	0	0	0	0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0	0
	Ecnomidae	0	20	0	20	0	0	0
	Glossosomatidae	0	0	0	0	0	0	0
	Hydropsychidae	30	0	0	0	0	0	0
	Hydroptilidae	0	0	0	10	0	0	0
	Leptoceridae	50	10	40	20	112	224	0
	Petrothrincidae	0	0	0	0	0	0	0
	Philopotamidae	20	0	0	0	0	0	0
	Polycentropodidae	0	0	0	0	0	0	0
	Sericostomatidae	50	10	0	0	0	0	0
	Xiphocentronidae	0	0	0	0	0	0	0
	Pupa spp.	10	0	0	0	0	0	0

Appendix 8.10.3 continued

ORDER/TAXON	FAMILY (subfamily/tribe)	GFS22	GFS23	GFS24	GFS25	GFMEAN
ACARINA		0	0	0	0	2.8
CNIDARIA		0	0	0	0	0.8
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0.4
	Dytiscidae (larva)	0	0	0	0	0.0
	Elmidae (adult)	0	0	0	0	4.4
	Elmidae (larva)	0	56	280	0	330.5
	Helodidae (larva)	0	0	0	0	9.6
	Hydraenidae (adult)	0	0	0	0	3.2
	Hydrophilidae (larva)	0	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0	14.8
	Adult spp.	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0.4
DIPTERA	Ceratopogonidae	168	0	0	0	14.6
	Chironomidae: Chironomini	2576	392	336	560	523.0
	Chironomidae: Tanytarsini	448	0	728	112	792.8
	Chironomidae: Orthocladinae	224	0	336	168	905.2
	Chironomidae: Tanypodinae	504	0	168	0	466.4
	Chironomidae (pupa)	56	0	0	0	34.2
	Culicidae	0	0	0	0	0.0
	Empididae	0	0	0	0	0.0
	Rhagionidae	0	0	0	0	14.0
	Simuliidae (larva)	0	0	0	0	85.6
	Simuliidae (pupa)	0	0	0	0	0.4
	Tipulidae	0	0	0	0	22.4
	Adult spp.	0	0	0	0	2.6
	Pupa spp.	0	0	0	0	2.0
EPHEMEROPTERA	Baetidae	336	0	56	0	1198.2
	Caenidae	336	112	0	0	442.5
	Ephemerellidae	0	0	0	0	14.8
	Heptageniidae	0	0	0	0	21.6
	Leptophlebiidae	0	0	0	0	38.0
	Tricorythidae	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0.4
	Mesoveliidae (adult)	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	0.4
LEPIDOPTERA	Pyralidae	0	0	0	0	14.8
MEGALOPTERA	Corydalidae	0	0	0	0	0.0
MOLLUSCA		112	0	0	0	4.5
NEMATODA		56	0	0	0	8.7
ODONATA: Zygoptera	Coenagrionidae	56	0	0	0	2.2
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	2.4
	Corduliidae	0	0	0	0	3.0
	Gomphidae	56	0	112	56	13.4
	Libellulidae	0	0	0	0	9.8
OLIGOCHAETA	Lumbriculidae	0	0	0	0	4.5
	Naididae	56	0	0	392	127.3
PLATYHELMINTHES		0	0	0	0	253.6
PLECOPTERA	Notonemouridae	0	0	0	0	6.4
TRICHOPTERA	Barbarochthonidae	0	0	0	0	1.6
	Ecnomidae	0	0	0	0	64.4
	Glossosomatidae	0	0	0	0	0.0
	Hydropsychidae	0	0	0	0	422.4
	Hydroptilidae	0	0	0	0	58.8
	Leptoceridae	0	0	0	0	92.2
	Petrothrincidae	0	0	0	0	0.8
	Philopotamidae	0	0	0	0	2.8
	Polycentropodidae	0	0	0	0	2.0
	Sericostomatidae	0	0	0	0	4.0
	Xiphocentronidae	0	0	0	0	1.6
	Pupa spp.	0	0	0	0	10.8

Appendix 8.10.4 Family-level benthic macroinvertebrate abundances for Tweefontein summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	TFR1	TFR2	TFR3	TFR4	TFR5	TFMEAN
ACARINA		0	40	20	10	0	14.0
CNIDARIA		0	0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	0	0.0
	Elmidae (adult)	20	70	0	0	0	18.0
	Elmidae (larva)	1030	680	100	190	240	448.0
	Helodidae (larva)	0	0	0	0	0	0.0
	Hydraenidae (adult)	20	30	0	20	0	14.0
	Hydrophilidae (larva)	0	0	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0	0	0.0
	Adult spp.	0	20	0	0	0	4.0
COLLEMBOLA		0	0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0	0.0
DIPTERA	Ceratopogonidae	20	50	0	0	0	14.0
	Chironomidae: Chironomini	1633	2873	90	670	40	1061.2
	Chironomidae: Tanytarsini	32	32	0	60	10	26.8
	Chironomidae: Orthocladinae	1183	1833	110	3120	1190	1487.2
	Chironomidae: Tanypodinae	82	92	0	230	150	110.8
	Chironomidae (pupa)	60	10	0	20	60	34.0
	Culicidae	0	0	0	0	0	0.0
	Empididae	0	0	0	0	0	0.0
	Rhagionidae	0	0	0	0	0	0.0
	Simuliidae (larva)	30	20	10	0	0	12.0
	Simuliidae (pupa)	0	0	0	0	0	0.0
	Tipulidae	10	40	20	10	10	18.0
	Adult spp.	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0
EPHEMEROPTERA	Baetidae	1430	980	370	50	20	570.0
	Caenidae	10	10	0	100	10	26.0
	Ephemerellidae	0	0	0	0	0	0.0
	Heptagenlidae	0	0	0	0	0	0.0
	Leptophlebiidae	0	10	0	0	0	2.0
	Tricorythidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0.0
MOLLUSCA		0	0	0	0	0	0.0
NEMATODA		0	0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0	0.0
	Gomphidae	0	0	0	0	0	0.0
	Libellulidae	60	80	0	20	0	36.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0.0
	Naididae	0	30	0	610	20	132.0
PLATYHELMINTHES		0	0	0	0	0	0.0
PLECOPTERA	Notonemouridae	70	60	0	0	0	26.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0.0
	Ecnomidae	20	0	0	20	20	12.0
	Glossosomatidae	0	0	0	0	0	0.0
	Hydropsychidae	780	630	370	20	0	360.0
	Hydroptilidae	0	0	0	0	0	0.0
	Leptoceridae	10	0	0	130	0	28.0
	Petrothrincidae	0	0	0	0	0	0.0
	Philopotamidae	50	10	0	0	0	12.0
	Polycentropodidae	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0.0
	Xiphocentronidae	10	0	0	0	0	2.0
	Pupa spp.	40	30	10	0	0	16.0

Appendix 8.10.5 Family-level benthic macroinvertebrate abundances for Kriedouwkrans summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	KKR1	KKR2	KKR3	KKR4	KKR5	KKR6	KKR7
ACARINA		0	0	0	0	0	0	0
CNIDARIA		0	0	0	0	0	0	0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0	0
	Dytiscidae (larva)	0	0	0	0	0	0	0
	Elmidae (adult)	0	0	0	0	0	0	0
	Elmidae (larva)	50	40	30	230	0	50	240
	Helodidae (larva)	0	0	0	0	0	0	0
	Hydraenidae (adult)	0	0	0	0	0	0	0
	Hydrophilidae (larva)	0	0	0	0	0	0	0
	Limnichidae (larva)	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0
CRUSTACEA		0	0	0	0	0	0	0
DIPTERA	Ceratopogonidae	0	0	0	0	0	50	0
	Chironomidae: Chironomini	40	190	40	1290	130	367	1978
	Chironomidae: Tanytarsini	40	60	30	2510	10	86	27
	Chironomidae: Orthocladinae	30	80	40	670	50	117	958
	Chironomidae: Tanypodinae	100	400	20	1960	30	0	27
	Chironomidae (pupa)	0	20	10	60	0	20	10
	Culicidae	0	0	0	0	0	0	0
	Empididae	0	0	0	0	0	0	0
	Rhagionidae	0	0	0	0	0	0	0
	Simuliidae (larva)	0	0	0	10	0	0	70
	Simuliidae (pupa)	0	0	0	0	0	0	10
	Tipulidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
	Pupa spp.	0	0	0	0	0	0	0
EPHEMEROPTERA	Baetidae	60	120	150	1560	60	940	210
	Caenidae	50	380	230	2160	150	20	180
	Ephemerellidae	0	0	0	0	0	0	0
	Heptageniidae	0	0	0	0	0	0	0
	Leptophlebiidae	0	0	0	0	0	0	0
	Tricorythidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
HEMIPTERA	Corixidae (adult)	10	30	50	270	0	0	0
	Mesoveliidae (adult)	0	0	0	0	0	0	0
	Pleidae (adult)	0	0	0	0	0	0	0
	Veliidae (adult)	0	0	0	0	0	0	0
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0	30
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0
MOLLUSCA		0	0	0	0	0	0	0
NEMATODA		0	0	0	0	0	0	0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0	0
	Corduliidae	0	0	0	0	0	0	0
	Gomphidae	0	0	10	0	0	0	0
	Libellulidae	0	0	0	40	0	0	0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0	0
	Naididae	610	10	10	140	0	0	10
PLATYHELMINTHES		0	0	0	0	0	0	0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0	0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0	0
	Ecnomidae	20	120	20	270	60	0	10
	Glossosomatidae	0	0	0	0	0	0	0
	Hydropsychidae	0	0	0	0	20	40	20
	Hydroptilidae	0	10	0	210	0	0	10
	Leptoceridae	0	0	10	30	0	0	0
	Petrothrincidae	0	0	0	0	0	0	0
	Philopotamidae	0	0	0	0	0	0	0
	Polycentropodidae	0	0	0	0	0	0	0
	Sericostomatidae	0	0	0	0	0	0	0
	Xiphocentronidae	0	0	0	0	0	0	0
	Pupa spp.	0	0	0	0	0	0	0

Appendix 8.10.5 continued

ORDER/TAXON	FAMILY (subfamily/tribe)	KKR8	KKR9	KKR10	KKR11	KKR12	KKR13	KKR14
ACARINA		0	0	0	0	0	0	0
CNIDARIA		0	0	0	0	0	0	0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0	0
	Dytiscidae (larva)	0	0	0	0	0	0	0
	Elmidae (adult)	0	10	0	0	0	0	0
	Elmidae (larva)	80	510	30	60	50	140	310
	Helodidae (larva)	0	0	0	0	0	0	0
	Hydraenidae (adult)	0	0	0	0	0	0	0
	Hydrophilidae (larva)	0	0	0	0	0	0	0
	Limnichidae (larva)	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0
CRUSTACEA		0	0	0	0	0	0	0
DIPTERA	Ceratopogonidae	10	30	0	0	10	10	0
	Chironomidae: Chironomini	340	3610	20	1743	684	2564	875
	Chironomidae: Tanytarsini	0	70	20	102	53	163	55
	Chironomidae: Orthocladinae	230	3660	40	2323	213	1273	115
	Chironomidae: Tanypodinae	30	70	0	72	0	0	125
	Chironomidae (pupa)	10	150	20	220	80	70	30
	Culicidae	0	0	0	0	0	0	0
	Empididae	0	0	0	0	0	0	0
	Rhagionidae	0	0	0	0	0	0	0
	Simuliidae (larva)	10	420	30	130	790	40	20
	Simuliidae (pupa)	0	20	0	20	0	20	10
	Tipulidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
	Pupa spp.	0	0	0	0	0	0	0
EPHEMEROPTERA	Baetidae	400	420	380	390	320	260	140
	Caenidae	460	50	30	70	190	280	350
	Ephemerellidae	0	0	0	0	0	0	0
	Heptageniidae	0	0	0	0	0	0	0
	Leptophlebiidae	0	0	0	0	0	0	0
	Tricorythidae	20	10	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	10	10
	Mesoveliidae (adult)	0	0	0	0	0	0	0
	Pleidae (adult)	0	0	0	0	0	0	0
	Veliidae (adult)	0	0	0	0	0	0	0
LEPIDOPTERA	Pyralidae	0	30	0	10	20	40	30
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0
MOLLUSCA		0	0	0	0	0	0	20
NEMATODA		0	0	0	0	0	0	0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0	0
	Corduliidae	10	0	0	0	0	10	0
	Gomphidae	0	0	0	0	0	0	0
	Libellulidae	0	30	0	40	0	0	0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0	0
	Naididae	20	20	0	0	0	0	10
PLATYHELMINTHES		0	0	0	0	0	0	0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0	0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0	0
	Ecnomidae	0	0	0	10	0	0	20
	Glossosomatidae	0	0	0	0	0	0	0
	Hydropsychidae	480	170	10	10	130	10	10
	Hydroptilidae	20	40	0	0	0	40	0
	Leptoceridae	0	0	0	0	0	0	0
	Petrothrincidae	0	0	0	0	0	0	0
	Philopotamidae	40	0	0	0	0	0	0
	Polycentropodidae	0	0	0	0	0	0	0
	Sericostomatidae	0	0	0	0	0	0	0
	Xiphocentronidae	0	0	0	0	0	0	0
	Pupa spp.	10	0	0	20	20	30	0

Appendix 8.10.5 continued

ORDER/TAXON	FAMILY (subfamily/tribe)	KKR15	KKS16	KKS17	KKS18	KKS19	KKS20	KKS21
ACARINA		0	0	0	0	0	0	0
CNIDARIA		0	0	0	0	0	0	0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0	0
	Dytiscidae (larva)	0	0	0	0	0	0	0
	Elmidae (adult)	0	0	0	0	0	0	0
	Elmidae (larva)	160	280	224	896	2072	504	2128
	Helodidae (larva)	0	0	0	0	0	0	0
	Hydraenidae (adult)	0	0	0	0	0	0	0
	Hydrophilidae (larva)	0	0	0	0	0	0	0
	Limnichidae (larva)	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
COLLEMBOLA		0	0	0	0	0	0	0
CRUSTACEA		0	0	0	0	0	0	0
DIPTERA	Ceratopogonidae	20	280	280	392	1008	56	504
	Chironomidae: Chironomini	410	299	224	224	336	168	56
	Chironomidae: Tanytarsini	20	659	784	1960	1904	1064	784
	Chironomidae: Orthocladinae	140	0	56	56	0	56	0
	Chironomidae: Tanypodinae	50	130	112	224	616	56	56
	Chironomidae (pupa)	60	0	0	0	56	0	0
	Culicidae	10	0	0	0	0	0	0
	Empididae	0	0	0	0	0	0	0
	Rhagionidae	0	0	0	0	0	0	0
	Simuliidae (larva)	30	0	0	0	0	0	0
	Simuliidae (pupa)	10	0	0	0	0	0	0
	Tipulidae	0	0	0	0	0	0	0
	Adult spp.	10	0	0	0	0	0	0
	Pupa spp.	0	0	0	0	0	0	0
EPHEMEROPTERA	Baetidae	450	0	168	224	112	0	280
	Caenidae	150	168	336	1680	616	112	280
	Ephemerellidae	0	0	0	0	0	0	0
	Heptageniidae	0	0	0	0	0	0	0
	Leptophlebiidae	0	0	0	0	0	0	0
	Tricorythidae	0	0	0	0	0	0	0
	Adult spp.	0	0	0	0	0	0	0
HEMIPTERA	Corixidae (adult)	0	0	0	0	56	0	0
	Mesoveliidae (adult)	0	0	0	0	0	0	0
	Pleidae (adult)	0	0	0	0	0	0	0
	Veliidae (adult)	0	0	0	0	0	0	0
LEPIDOPTERA	Pyralidae	30	0	0	0	0	0	0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0
MOLLUSCA		20	0	0	0	0	0	0
NEMATODA		0	0	0	112	0	56	56
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0	0
	Corduliidae	0	0	0	0	0	0	0
	Gomphidae	0	168	392	56	0	56	56
	Libellulidae	10	56	0	0	0	0	0
OLIGOCHAETA	Lumbriculidae	0	112	0	0	0	0	224
	Naididae	0	0	6552	112	29232	56	448
PLATYHELMINTHES		0	0	0	0	0	0	0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0	0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0	0
	Ecnomidae	0	0	0	0	0	0	0
	Glossosomatidae	0	0	0	0	0	0	0
	Hydropsychidae	10	0	0	0	0	0	0
	Hydroptilidae	0	0	0	0	0	0	0
	Leptoceridae	0	0	0	0	0	0	0
	Petrothrincidae	0	0	0	0	0	0	0
	Philopotamidae	0	0	0	0	0	0	0
	Polycentropodidae	0	0	0	0	0	0	0
	Sericostomatidae	0	0	0	0	0	0	0
	Xiphocentronidae	0	0	0	0	0	0	0
	Pupa spp.	0	0	0	0	0	0	0

Appendix 8.10.5 continued

ORDER/TAXON	FAMILY (subfamily/tribe)	KKS22	KKS23	KKS24	KKS25	KKMEAN
ACARINA		0	56	0	0	2.2
CNIDARIA		0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	0.0
	Elmidae (adult)	0	0	0	0	0.4
	Elmidae (larva)	56	168	728	392	377.1
	Helodidae (larva)	0	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0	0.0
	Hydrophilidae (larva)	0	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0.0
DIPTERA	Ceratopogonidae	392	616	616	1288	222.5
	Chironomidae: Chironomini	84	56	336	448	661.3
	Chironomidae: Tanytarsini	700	616	560	784	530.4
	Chironomidae: Orthocladinae	84	0	0	0	407.6
	Chironomidae: Tanypodinae	196	0	112	168	182.2
	Chironomidae (pupa)	0	0	0	56	34.9
	Culicidae	0	0	0	0	0.4
	Empididae	0	0	0	0	0.0
	Rhagionidae	0	0	0	0	0.0
	Simuliidae (larva)	0	0	0	0	62.0
	Simuliidae (pupa)	0	0	0	0	3.6
	Tipulidae	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0.4
	Pupa spp.	0	0	0	0	0.0
EPHEMEROPTERA	Baetidae	112	0	112	56	277.0
	Caenidae	784	504	1344	728	452.1
	Ephemerellidae	0	0	0	0	0.0
	Heptageniidae	0	0	0	0	0.0
	Leptophlebiidae	0	0	0	0	0.0
	Tricorythidae	0	0	0	0	1.2
	Adult spp.	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	17.4
	Mesoveliidae (adult)	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0	7.6
MEGALOPTERA	Corydalidae	0	0	0	0	0.0
MOLLUSCA		0	0	0	0	1.6
NEMATODA		0	0	0	56	11.2
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0.8
	Gomphidae	56	168	0	0	38.5
	Libellulidae	0	0	0	0	7.0
OLIGOCHAETA	Lumbriculidae	672	0	280	840	85.1
	Naididae	616	2912	8232	2464	2058.2
PLATYHELMINTHES		0	0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0.0
	Ecnomidae	0	0	0	0	21.2
	Glossosomatidae	0	0	0	0	0.0
	Hydropsychidae	0	0	0	0	36.4
	Hydroptilidae	0	0	0	0	13.2
	Leptoceridae	0	0	0	0	1.6
	Petrothrincidae	0	0	0	0	0.0
	Philopotamidae	0	0	0	0	1.6
	Polycentropodidae	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	3.2

Appendix 8.10.6 Family-level benthic macroinvertebrate abundances for Clanwilliam summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	CBR1	CBR2	CBR3	CBR4	CBR5	CBMEAN
ACARINA		0	10	0	0	0	2.0
CNIDARIA		0	0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	0	0.0
	Elmidae (adult)	0	0	0	0	0	0.0
	Elmidae (larva)	0	0	0	10	0	2.0
	Helodidae (larva)	0	0	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0	0	0.0
	Hydrophilidae (larva)	10	0	0	0	0	2.0
	Limnichidae (larva)	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0	0.0
DIPTERA	Ceratopogonidae	10	0	0	0	0	2.0
	Chironomidae: Chironomini	68	42	175	70	250	121.0
	Chironomidae: Tanytarsini	17	32	125	30	170	74.8
	Chironomidae: Orthocladinae	498	154	385	110	860	401.4
	Chironomidae: Tanypodinae	37	42	545	20	560	240.8
	Chironomidae (pupa)	20	0	10	10	40	16.0
	Culicidae	0	0	0	0	0	0.0
	Empididae	0	10	10	20	20	12.0
	Rhagionidae	0	0	0	0	0	0.0
	Simuliidae (larva)	0	0	0	0	0	0.0
	Simuliidae (pupa)	0	0	0	0	0	0.0
	Tipulidae	120	100	80	140	70	102.0
	Adult spp.	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0
EPHEMEROPTERA	Baetidae	30	0	0	20	0	10.0
	Caenidae	0	0	0	0	0	0.0
	Ephemerellidae	0	0	0	0	0	0.0
	Heptageniidae	0	0	0	0	0	0.0
	Leptophlebiidae	0	0	0	0	0	0.0
	Tricorythidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	20	4.0
	Mesoveliidae (adult)	0	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0.0
MOLLUSCA		10	0	10	0	0	4.0
NEMATODA		0	0	10	0	10	4.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0	0.0
	Gomphidae	0	0	0	0	0	0.0
	Libellulidae	0	0	0	0	0	0.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0.0
	Naididae	3090	400	740	600	1260	1218.0
PLATYHELMINTHES		0	0	0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0.0
	Ecnomidae	0	20	100	70	70	52.0
	Glossosomatidae	0	0	0	0	0	0.0
	Hydropsychidae	10	0	0	10	0	4.0
	Hydroptilidae	50	10	0	0	0	12.0
	Leptoceridae	10	0	0	0	0	2.0
	Petrothrincidae	0	0	0	0	0	0.0
	Philopotamidae	0	0	0	0	0	0.0
	Polycentropodidae	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0

Appendix 8.10.7 Family-level benthic macroinvertebrate abundances for Langkloof summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	LKS1	LKS2	LKS3	LKS4	LKS5	LKMEAN
ACARINA		0	0	0	0	0	0.0
CNIDARIA		0	0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	0	0.0
	Elmidae (adult)	0	0	0	0	0	0.0
	Elmidae (larva)	0	0	0	0	0	0.0
	Helodidae (larva)	0	0	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0	0	0.0
	Hydrophilidae (larva)	0	0	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0	0.0
DIPTERA	Ceratopogonidae	56	56	56	0	112	56.0
	Chironomidae: Chironomini	336	280	840	560	406	484.4
	Chironomidae: Tanytarsini	1008	560	1680	896	294	887.6
	Chironomidae: Orthocladinae	168	112	56	0	70	81.2
	Chironomidae: Tanypodinae	112	56	448	168	126	182.0
	Chironomidae (pupa)	0	0	0	0	0	0.0
	Culicidae	0	0	0	0	0	0.0
	Empididae	0	0	0	0	0	0.0
	Rhagionidae	0	0	0	0	0	0.0
	Simuliidae (larva)	0	0	0	0	0	0.0
	Simuliidae (pupa)	0	0	0	0	0	0.0
	Tipulidae	0	0	0	0	0	0.0
	Adult spp.	0	56	0	0	0	11.2
	Pupa spp.	0	0	0	0	0	0.0
EPHEMEROPTERA	Baetidae	0	112	56	0	0	33.6
	Caenidae	112	0	56	0	56	44.8
	Ephemerellidae	0	0	0	0	0	0.0
	Heptageniidae	0	0	0	0	0	0.0
	Leptophlebiidae	0	0	0	0	0	0.0
	Tricorythidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	56	11.2
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	56	11.2
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0.0
MOLLUSCA		0	0	0	0	0	0.0
NEMATODA		0	0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0	0.0
	Gomphidae	56	0	0	0	0	11.2
	Libellulidae	0	0	0	0	0	0.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0.0
	Naididae	392	7896	168	14000	6496	5790.4
PLATYHELMINTHES		0	0	0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0.0
	Ecnomidae	0	0	0	0	0	0.0
	Glossosomatidae	0	0	0	0	0	0.0
	Hydropsychidae	0	0	0	0	0	0.0
	Hydroptilidae	0	0	0	0	0	0.0
	Leptoceridae	0	0	0	0	0	0.0
	Petrothrincidae	0	0	0	0	0	0.0
	Philopotamidae	0	0	0	0	0	0.0
	Polycentropodidae	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0

Appendix 8.10.8 Family-level benthic macroinvertebrate abundances for Bulshoek summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	BDR1	BDR2	BDR3	BDR4	BDR5	BDMEAN
ACARINA		0	0	0	10	0	2.0
CNIDARIA		0	0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0.0
	Dytiscidae (larva)	40	0	0	0	0	8.0
	Elmidae (adult)	0	0	0	0	0	0.0
	Elmidae (larva)	0	0	0	0	0	0.0
	Helodidae (larva)	0	0	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0	0	0.0
	Hydrophilidae (larva)	0	0	0	0	10	2.0
	Limnichidae (larva)	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0	0.0
DIPTERA	Ceratopogonidae	200	0	0	30	10	48.0
	Chironomidae: Chironomini	240	680	10	170	193	258.6
	Chironomidae: Tanytarsini	3380	540	10	280	264	894.8
	Chironomidae: Orthocladinae	580	50	0	110	0	148.0
	Chironomidae: Tanypodinae	120	0	60	0	23	40.6
	Chironomidae (pupa)	40	50	0	0	30	24.0
	Culicidae	0	0	0	0	0	0.0
	Empididae	0	0	0	0	10	2.0
	Rhagionidae	0	0	0	0	0	0.0
	Simuliidae (larva)	0	120	0	0	10	26.0
	Simuliidae (pupa)	0	0	0	0	0	0.0
	Tipulidae	0	0	0	10	0	2.0
	Adult spp.	0	0	0	0	0	0.0
	Pupa spp.	0	10	0	10	20	8.0
EPHEMEROPTERA	Baetidae	0	210	0	700	580	298.0
	Caenidae	40	0	0	0	0	8.0
	Ephemerellidae	0	0	0	0	0	0.0
	Heptageniidae	0	0	0	0	0	0.0
	Leptophlebiidae	0	0	0	0	0	0.0
	Tricorythidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	360	0	0	0	0	72.0
	Mesoveliidae (adult)	0	0	0	0	0	0.0
	Pleidae (adult)	0	0	0	0	0	0.0
	Veliidae (adult)	0	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0.0
MOLLUSCA		0	0	0	0	0	0.0
NEMATODA		0	0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0	0.0
	Gomphidae	0	0	0	0	0	0.0
	Libellulidae	160	0	20	0	0	36.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	0	0.0
	Naididae	6050	270	0	180	88	1317.6
PLATYHELMINTHES		0	0	0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0.0
	Ecnomidae	0	0	0	0	0	0.0
	Glossosomatidae	0	0	0	0	0	0.0
	Hydropsychidae	0	10	0	10	20	8.0
	Hydroptilidae	40	0	0	40	30	22.0
	Leptoceridae	0	0	0	0	0	0.0
	Petrothrincidae	0	0	0	0	0	0.0
	Philopotamidae	0	0	0	0	0	0.0
	Polycentropodidae	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0

Appendix 8.10.9 Family-level benthic macroinvertebrate abundances for Zypherfontein summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	ZFS1	ZFS2	ZFS3	ZFMEAN
ACARINA		0	0	0	0.0
CNIDARIA		0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0.0
	Elmidae (adult)	0	0	0	0.0
	Elmidae (larva)	0	0	0	0.0
	Helodidae (larva)	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0.0
	Hydrophilidae (larva)	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0.0
	Adult spp.	0	0	0	0.0
COLLEMBOLA		0	0	0	0.0
CRUSTACEA		0	0	0	0.0
DIPTERA	Ceratopogonidae	0	0	1428	476.0
	Chironomidae: Chironomini	0	0	5012	1670.7
	Chironomidae: Tanytarsini	357	357	1085	599.7
	Chironomidae: Orthocladinae	357	0	2513	956.7
	Chironomidae: Tanypodinae	0	714	2870	1194.7
	Chironomidae (pupa)	357	0	4641	1666.0
	Culicidae	0	0	0	0.0
	Empididae	0	0	0	0.0
	Rhagionidae	0	0	0	0.0
	Simuliidae (larva)	0	0	0	0.0
	Simuliidae (pupa)	0	0	0	0.0
	Tipulidae	0	0	0	0.0
	Adult spp.	0	0	0	0.0
	Pupa spp.	0	0	0	0.0
EPHEMEROPTERA	Baetidae	0	0	0	0.0
	Caenidae	0	0	0	0.0
	Ephemerellidae	0	0	0	0.0
	Heptageniidae	0	0	0	0.0
	Leptophlebiidae	0	0	0	0.0
	Tricorythidae	0	0	0	0.0
	Adult spp.	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0.0
	Pleidae (adult)	0	0	0	0.0
	Veliidae (adult)	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0.0
MOLLUSCA		0	0	714	238.0
NEMATODA		1071	0	2499	1190.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0.0
	Corduliidae	0	0	0	0.0
	Gomphidae	0	0	0	0.0
	Libellulidae	0	0	0	0.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0.0
	Naididae	3927	0	0	1309.0
PLATYHELMINTHES		0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0.0
	Ecnomidae	0	0	357	119.0
	Glossosomatidae	0	0	0	0.0
	Hydropsychidae	0	0	0	0.0
	Hydroptilidae	0	0	0	0.0
	Leptoceridae	0	0	0	0.0
	Petrothrincidae	0	0	0	0.0
	Philopotamidae	0	0	0	0.0
	Polycentropodidae	0	0	0	0.0
	Sericostomatidae	0	0	0	0.0
	Xiphocentronidae	0	0	0	0.0
	Pupa spp.	0	0	0	0.0

Appendix 8.10.10 Family-level benthic macroinvertebrate abundances for Klawer summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	KWS1	KWS2	KWS3	KWS4	KWS5	KWMEAN
ACARINA		0	0	0	0	0	0.0
CNIDARIA		1680	0	0	784	0	492.8
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	56	11.2
	Elmidae (adult)	0	0	0	0	0	0.0
	Elmidae (larva)	0	0	0	0	0	0.0
	Helodidae (larva)	0	0	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0	0	0.0
	Hydrophilidae (larva)	56	0	0	0	0	11.2
	Limnichidae (larva)	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	0	0.0
CRUSTACEA		0	0	0	0	0	0.0
DIPTERA	Ceratopogonidae	224	0	1064	224	952	492.8
	Chironomidae: Chironomini	2576	1064	2632	952	6902	2825.2
	Chironomidae: Tanytarsini	23968	560	12432	21112	16142	14842.8
	Chironomidae: Orthocladinae	840	112	784	0	1526	652.4
	Chironomidae: Tanypodinae	1120	0	1232	3360	1806	1503.6
	Chironomidae (pupa)	168	112	280	56	224	168.0
	Culicidae	0	0	0	0	0	0.0
	Empididae	0	0	56	0	0	11.2
	Rhagionidae	0	0	0	0	0	0.0
	Simuliidae (larva)	0	0	0	0	0	0.0
	Simuliidae (pupa)	0	0	0	0	0	0.0
	Tipulidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0
EPHEMEROPTERA	Baetidae	3864	56	168	1512	784	1276.8
	Caenidae	448	0	112	504	56	224.0
	Ephemerellidae	0	0	0	0	0	0.0
	Heptageniidae	0	0	0	0	0	0.0
	Leptophlebiidae	0	0	0	0	0	0.0
	Tricorythidae	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0	0	0.0
	Pleidae (adult)	0	0	56	112	56	44.8
	Veliidae (adult)	0	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0.0
MOLLUSCA		336	0	112	56	0	100.8
NEMATODA		0	0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0	0.0
	Gomphidae	168	56	0	112	56	78.4
	Libellulidae	0	0	0	0	56	11.2
OLIGOCHAETA	Lumbriculidae	56	0	56	0	0	22.4
	Naididae	280	0	9632	11536	896	4468.8
PLATYHELMINTHES		0	0	0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0.0
	Ecnomidae	0	0	0	0	0	0.0
	Glossosomatidae	0	0	0	0	0	0.0
	Hydropsychidae	0	0	0	0	0	0.0
	Hydroptilidae	112	0	0	0	56	33.6
	Leptoceridae	0	0	0	0	0	0.0
	Petrothrincidae	0	0	0	0	0	0.0
	Philopotamidae	0	0	0	0	0	0.0
	Polycentropodidae	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0	0.0
	Pupa spp.	0	0	0	0	0	0.0

Appendix 8.10.11 Family-level benthic macroinvertebrate abundances for Botha's Farm summer samples

ORDER/TAXON	FAMILY (subfamily/tribe)	BFR1	BFR2	BFR3	BFS4	BFS5	BFS6	BFMEAN
ACARINA		0	0	0	0	0	0	0.0
CNIDARIA		0	0	0	0	0	0	0.0
COLEOPTERA	Dryopidae (larva)	0	0	0	0	0	0	0.0
	Dytiscidae (larva)	0	0	0	0	0	0	0.0
	Elmidae (adult)	0	0	0	0	0	0	0.0
	Elmidae (larva)	0	0	0	0	0	0	0.0
	Helodidae (larva)	0	0	0	0	0	0	0.0
	Hydraenidae (adult)	0	0	0	0	0	0	0.0
	Hydrophilidae (larva)	0	0	0	0	0	0	0.0
	Limnichidae (larva)	0	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0	0.0
COLLEMBOLA		0	0	0	0	56	0	9.3
CRUSTACEA		0	10	0	56	0	0	11.0
DIPTERA	Ceratopogonidae	0	0	0	56	56	0	18.7
	Chironomidae: Chironomini	210	97	132	112	2968	784	717.2
	Chironomidae: Tanytarsini	1550	357	542	1344	12712	17808	5718.8
	Chironomidae: Orthocladinae	910	2518	2963	504	2576	1960	1905.2
	Chironomidae: Tanypodinae	850	448	402	1792	2240	2912	1440.7
	Chironomidae (pupa)	70	50	100	112	112	560	167.3
	Culicidae	0	0	0	0	0	0	0.0
	Empididae	0	0	10	0	0	56	11.0
	Rhagionidae	0	0	0	0	0	0	0.0
	Simuliidae (larva)	20	10	30	0	0	0	10.0
	Simuliidae (pupa)	0	10	0	0	0	0	1.7
	Tipulidae	0	0	0	0	0	0	0.0
	Adult spp.	20	0	40	0	0	0	10.0
	Pupa spp.	0	0	0	0	0	0	0.0
EPHEMEROPTERA	Baetidae	250	120	140	224	560	560	309.0
	Caenidae	20	0	50	280	672	896	319.7
	Ephemerellidae	0	0	0	0	0	0	0.0
	Heptageniidae	0	0	0	0	0	0	0.0
	Leptophlebiidae	0	0	0	0	0	0	0.0
	Tricorythidae	0	0	0	0	0	0	0.0
	Adult spp.	0	0	0	0	0	0	0.0
HEMIPTERA	Corixidae (adult)	0	0	0	0	0	0	0.0
	Mesoveliidae (adult)	0	0	0	0	0	56	9.3
	Pleidae (adult)	0	0	10	0	0	0	1.7
	Veliidae (adult)	0	0	0	0	0	0	0.0
LEPIDOPTERA	Pyralidae	0	0	0	0	0	0	0.0
MEGALOPTERA	Corydalidae	0	0	0	0	0	0	0.0
MOLLUSCA		0	0	0	112	280	336	121.3
NEMATODA		0	0	0	0	0	0	0.0
ODONATA: Zygoptera	Coenagrionidae	0	0	0	0	0	0	0.0
ODONATA: Anisoptera	Aeshnidae	0	0	0	0	0	0	0.0
	Corduliidae	0	0	0	0	0	0	0.0
	Gomphidae	0	0	0	0	56	0	9.3
	Libellulidae	0	0	0	0	0	0	0.0
OLIGOCHAETA	Lumbriculidae	0	0	0	0	280	56	56.0
	Naididae	0	10	0	224	728	1904	477.7
PLATYHELMINTHES		0	0	0	0	0	0	0.0
PLECOPTERA	Notonemouridae	0	0	0	0	0	0	0.0
TRICHOPTERA	Barbarochthonidae	0	0	0	0	0	0	0.0
	Ecnomidae	0	0	0	0	56	0	9.3
	Glossosomatidae	0	0	0	0	0	0	0.0
	Hydropsychidae	1810	910	4660	1736	3920	4648	2947.3
	Hydroptilidae	10	0	0	56	0	224	48.3
	Leptoceridae	0	0	0	0	0	0	0.0
	Petrothrincidae	0	0	0	0	0	0	0.0
	Philopotamidae	0	0	0	0	0	0	0.0
	Polycentropodidae	0	0	0	0	0	0	0.0
	Sericostomatidae	0	0	0	0	0	0	0.0
	Xiphocentronidae	0	0	0	0	0	0	0.0
	Pupa spp.	20	0	20	0	56	0	16.0

Appendix 8.11 Species-level abundances of benthic macroinvertebrates for all samples for all summer mainstream sites

8.11.1	Visgat
8.11.2	Boschkloof
8.11.3	Grootfontein
8.11.4	Tweefontein
8.11.5	Kriedouwkrans
8.11.6	Clanwilliam
8.11.7	Langkloof
8.11.8	Bulshoek
8.11.9	Zypherfontein
8.11.10	Klawer
8.11.11	Botha's Farm

Abundances are per 1 m^2 unit area.

Sites are coded as in Figure 4.4

R - rock sample

S - sand sample

Appendix 8.11.1 Species-level benthic macroinvertebrate abundances for Visgat summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	VISGAT VGR1	VGR2	VGR3	VGR4	VGR5	VGMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0.0
Naididae adult	*Nais*	spp.	20	130	0	0	10	32.0
	Pristina	spp.	0	0	0	0	0	0.0
Hydracarina	Hydracarinid	spp.	0	10	0	0	0	2.0
	Hydracarinid	sp. A	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	10	0	0	0	10	4.0
Dytiscidae larva								
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0.0
Elmidae adult								
Elminthinae	*?Lobelmis*	sp. A	0	0	0	0	0	0.0
	Tropidelmis	sp. A	30	0	0	0	0	6.0
	Pachyelmis	sp. A	0	20	0	0	0	4.0
	Pachyelmis	sp. B	0	0	0	0	0	0.0
Elmidae larva	*Pelonolus*	*granulosus*	370	320	0	0	180	174.0
	Elpidelmis	*capensis*	20	230	20	0	10	56.0
	Elmid	sp. C	0	180	0	0	0	36.0
Helodidae larva	*Prionocyphon*	sp. A	10	10	0	0	0	4.0
	Prionocyphon	sp. B	0	10	0	0	0	2.0
	Helodid	sp. C	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	0	0	0	0	0	0.0
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	0	0.0
Chironomidae larva								
Chironominae								
Chironomini	*Polypedilum*	*?articola*	10	0	43	11	40	20.8
	Chironominid	sp. AX	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	10	0	0	0	10	4.0
	Tanytarsus	sp. B	0	0	0	0	0	0.0
	Rheotanytarsus	sp. A	10	0	13	0	30	10.6
Orthocladiinae	*Cricotopus*	*?flavozonatus*	50	11	0	11	0	14.4
	Cricotopus	sp. A	40	161	143	21	110	95.0
	Cricotopus	sp. B	0	0	0	0	0	0.0
	Cricotopus	sp. C	230	51	103	0	50	86.8
	Thienemanniella	sp. A	40	31	43	11	280	81.0
	Thienemanniella	sp. B	10	0	0	0	130	28.0
	Tvetenia	sp. A	0	51	0	31	30	22.4
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0.0
	Cricotopus	*scottae*	30	0	0	11	0	8.2
	Corynoneura	sp. A	150	0	33	0	50	46.6
Tanypodinae	*Conchapelopia*	sp. A	80	121	33	21	20	55.0
	Nilotanypus	comatus	10	31	0	0	20	12.2
	Nilotanypus	sp. A	0	0	0	0	10	2.0
	Ablabesmyia	*dusoleili*	10	0	0	0	20	6.0
	Macropelopia	sp. A	0	0	0	0	0	0.0
Chironomidae pupa	Chironomid	pupa spp.	30	0	0	0	0	6.0
Culicidae larva			0	0	0	0	10	2.0
Culicinae	*Culex*	sp. A						
Empididae larva	Empidid	sp. A	0	0	0	0	0	0.0

Appendix 8.11.1 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	VISGAT VGR1	VGR2	VGR3	VGR4	VGR5	VGMEAN
Rhagionidae larva	Rhagionid	sp. A	0	10	0	0	20	6.0
Simuliidae larva	Simuliid	larva spp.	450	10	10	0	470	188.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	20	50	0	10	0	16.0
	Dipteran	adult spp.	0	10	0	10	20	8.0
	Dipteran	pupa spp.	0	20	10	0	10	8.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	10	2.0
	Afroptilum	sp. B	226	54	0	0	40	64.0
	Afroptilum	*?indusii*	0	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0	0	0.0
	Afroptilum	sp. C	103	744	10	0	90	189.4
	Afroptilum	sp. D	0	0	0	0	0	0.0
	Baetis	*?latus*	0	0	0	0	0	0.0
	Baetis	*harrisoni complex*	0	224	50	20	90	76.8
	?Demoulinia	complex A	73	84	2090	560	0	561.4
	Demoulinia	*crassi*	0	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	34	0	0	20	10.8
	Pseudopannota	*maculosa*	0	0	0	0	0	0.0
	Baetid	juvenile spp.	1090	1570	130	30	130	590.0
Caenidae larva	*Caenis*	*capensis*	0	0	0	0	10	2.0
	Caenodes	sp. C	30	170	50	10	0	52.0
	Caenodes	sp. H	0	0	0	0	0	0.0
	Caenid	juvenile spp.	30	0	0	0	0	6.0
Ephemerellidae larva	*Lestagella*	*penicillata*	80	0	10	0	60	30.0
	Ephemerellina	complex A	0	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	30	10	20	0	120	36.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	30	0	0	0	220	50.0
	Aprionyx	complex A	20	0	0	0	0	4.0
	Euthraulus	*elegans*	0	0	0	0	20	4.0
	Choroterpes	*nigrescence*	0	0	0	0	0	0.0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	140	28.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0	0	0.0
	Corixid	sp. B	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	30	0	0	0	10	8.0
	Pyralid	sp. C	0	0	0	0	0	0.0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	10	0	0	0	0	2.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	10	2.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	0	0.0
	Libellulid	sp. C	0	0	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0	0	0.0
	Gomphid	juvenile spp.	0	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	40	0	0	0	100	28.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	50	120	0	10	0	36.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	0	0	0	0	0.0
	Ecnomid	juvenile spp.	0	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0.0
	Parecnomina	sp. A	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	60	12.0

Appendix B.11.1 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES			VISGAT			
			VGR1	VGR2	VGR3	VGR4	VGR5	VGMEAN
Hydropsychidae larva								
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	0	0	0.0
	Cheumatopsyche	*afra*	0	0	0	0	0	0.0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0.0
	Cheumatopsyche	spp.	0	10	0	0	0	2.0
	Cheumatopsyche	juvenile spp.	0	0	0	0	0	0.0
Macronematinae								
Macronematini	*Amphipsyche*	*?scottae*	0	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0.0
	Macrostemum	*capense*	0	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	0	0	0	0	0.0
	Hydroptila	*capensis*	0	0	0	0	0	0.0
	Hydroptila	capensis pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0.0
	Oxyethira	*?velocipes*	0	0	0	0	0	0.0
Leptoceridae larva								
Leptocerinae								
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	30	0	0	0	0	6.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	20	0	0	0	10	6.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0.0
Oecetini	Oecetis	sp. A	0	60	0	20	10	18.0
	Oecetis	sp. B	0	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	10	0	0	0	10	4.0
	Philopotamid	juvenile spp.	0	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	*?curvicosta*	0	0	0	0	0	0.0
Xiphocentronidae larva	*Aberia*	sp. A	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	10	0	0	10	4.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	0	0	0	0.0

Appendix 8.11.2 Species-level benthic macroinvertebrate abundances for Boschkloof summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BOSCHKLOOF				
			BKR1	BKR2	BKR3	BKR5	BKMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0.0
Naididae adult	*Nais*	spp.	30	0	0	110	35.0
	Pristina	spp.	0	0	0	0	0.0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0.0
	Hydracarinid	sp. A	0	30	0	0	7.5
	Hydracarinid	sp. B	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0.0
Dytiscidae larva							
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0.0
Elmidae adult							
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	170	0	20	10	50.0
	Elpidelmis	*capensis*	20	20	40	10	22.5
	Elmid	sp. C	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	10	2.5
	Prionocyphon	sp. B	0	0	0	0	0.0
	Helodid	sp. C	90	40	0	10	35.0
Hydraenidae adult	*Hydraena*	sp. A	0	10	0	0	2.5
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	10	0	0	20	7.5
	Coleopteran	adult spp.	0	10	0	0	2.5
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	0	0	0	0	0.0
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	0.0
Chironomidae larva							
Chironominae							
Chironomini	*Polypedilum*	*?articola*	23	0	0	51	18.5
	Chironominid	sp. AX	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	33	80	131	11	63.8
Tanytarsini	*Tanytarsus*	sp. A	23	0	11	0	8.5
	Tanytarsus	sp. B	43	0	31	21	23.8
	Rheotanytarsus	sp. A	23	10	0	11	11.0
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0.0
	Cricotopus	sp. A	13	100	31	21	41.3
	Cricotopus	sp. B	0	0	0	0	0.0
	Cricotopus	sp. C	43	20	51	41	38.8
	Thienemanniella	sp. A	73	20	51	111	63.8
	Thienemanniella	sp. B	413	840	301	501	513.8
	Tvetenia	sp. A	0	10	0	0	2.5
	Harnischia/Polypedilum type	sp. A	0	0	171	11	45.5
	Cricotopus	*scottae*	0	0	0	0	0.0
	Corynoneura	sp. A	0	0	0	11	2.8
Tanypodinae	*Conchapelopia*	sp. A	173	40	21	61	73.8
	Nilotanypus	*comatus*	43	0	0	0	10.8
	Nilotanypus	sp. A	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	0	10	0	31	10.3
	Macropelopia	sp. A	0	0	0	0	0.0
Chironomidae pupa	Chironomid	pupa spp.	10	0	0	0	2.5
Culicidae larva							
Culicinae	*Culex*	sp. A	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	0	0	0.0

Appendix 8.11.2 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BOSCHKLOOF BKR1	BKR2	BKR3	BKR5	BKMEAN
Rhagionidae larva	Rhagionid	sp. A	0	20	0	20	10.0
Simuliidae larva	Simuliid	larva spp.	30	2580	90	40	685.0
Simuliidae pupa	Simuliid	pupa spp.	0	20	0	10	7.5
Tipulidae larva	*Antocha*	sp. A	20	140	30	20	52.5
	Dipteran	adult spp.	0	0	0	10	2.5
	Dipteran	pupa spp.	20	30	10	0	15.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	10	0	2.5
	Afroptilum	sp. B	50	0	30	67	36.8
	Afroptilum	*?indusii*	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0	0.0
	Afroptilum	sp. C	390	590	30	97	276.8
	Afroptilum	sp. D	0	0	0	0	0.0
	Baetis	*?latus*	0	0	0	0	0.0
	Baetis	*harrisoni complex*	20	320	10	0	87.5
	?Demoulinia	complex A	0	0	30	17	11.8
	Demoulinia	*crassi*	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0	0.0
	Pseudopannota	*maculosa*	0	0	0	0	0.0
	Baetid	juvenile spp.	220	230	40	80	142.5
Caenidae larva	*Caenis*	*capensis*	30	0	10	20	15.0
	Caenodes	sp. C	0	0	0	0	0.0
	Caenodes	sp. H	0	0	0	0	0.0
	Caenid	juvenile spp.	0	0	0	0	0.0
Ephemerellidae larva	*Lestagella*	*penicillata*	820	410	20	510	440.0
	Ephemerellina	complex A	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	780	140	10	840	442.5
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0.0
	Euthraulus	*elegans*	140	90	0	110	85.0
	Choroterpes	*nigrescence*	0	0	0	0	0.0
	Leptophlebiid [?Choroterpes]	juvenile spp.	0	20	0	70	22.5
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0.0
	Ephemeropterun	adult spp.	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0	0.0
	Corixid	sp. B	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	10	0	0	0	2.5
Pyralidae larva	Pyralid	sp. A	10	60	0	0	17.5
	Pyralid	sp. C	0	10	0	0	2.5
Corydalidae larva	*Chloroniella*	sp. A	0	20	0	10	7.5
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	0.0
	Libellulid	sp. C	0	0	0	0	0.0
	Libellulid	juvenile spp.	10	0	0	0	2.5
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0	0.0
	Gomphid	juvenile spp.	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	30	0	0	0	7.5
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	30	0	50	0	20.0
	Ecnomid	juvenile spp.	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0.0
	Paracnomina	sp. A	0	0	0	10	2.5
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0.0

Appendix 8.11.2 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BOSCHKLOOF BKR1	BKR2	BKR3	BKR5	BKMEAN
Hydropsychidae larva							
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	65	0	0	16.3
	Cheumatopsyche	*s/m*	0	65	0	0	16.3
	Cheumatopsyche	pupa spp.	0	10	0	0	2.5
	Cheumatopsyche	spp.	0	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	0	0	20	20	10.0
Macronematinae							
Macronematini	*Amphipsyche*	?scottae	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0.0
	Macrostemum	*capense*	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	60	10	170	30	67.5
	Hydroptila	*capensis*	0	0	20	0	5.0
	Hydroptila	capensis pupa	0	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0.0
	Oxyethira	*?velocipes*	0	0	0	0	0.0
Leptoceridae larva							
Leptocerinae							
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	10	0	0	2.5
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	10	2.5
	Oecetis	sp. B	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	10	10	0	5.0
	Philopotamid	juvenile spp.	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	30	10	10.0
Sericostomatidae larva	*Petroplax*	?curvicosta	0	0	0	0	0.0
Xiphocentronidae larva	*Aberis*	sp. A	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	10	0	0	0	2.5
Tricladida	*Dugesia*	spp.	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	0	0	0.0

Appendix 8.11.3 Species-level benthic macroinvertebrate abundances for Grootfontein summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	GROOTFONTEIN							
			GFR1	GFR2	GFR3	GFR4	GFR5	GFR6	GFR7	GFR8
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0	0	0
Naididae adult	*Nais*	spp.	80	0	20	290	80	10	10	380
	Pristina	spp.	0	0	0	0	0	0	0	0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0	0	0
	Hydracarinid	sp. A	0	0	0	0	0	0	0	0
	Hydracarinid	sp. B	0	0	0	0	0	0	0	0
	Hydracarinid	sp. C	0	0	0	0	0	0	0	0
	Hydracarinid	sp. D	0	0	0	0	0	0	0	0
	Hydracarinid	sp. E	0	0	0	0	0	0	0	0
	Hydracarinid	sp. F	0	0	0	0	0	0	0	0
	Hydracarinid	sp. G	0	0	0	0	0	0	0	0
	Hydracarinid	sp. H	0	0	0	0	0	0	0	0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0	0	0
Dytiscidae larva										
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0	0	0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0	0	0
Elmidae adult										
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0	0	0	0
	Tropidelmis	sp. A	0	0	0	0	0	0	0	10
	Pachyelmis	sp. A	0	0	0	40	0	0	0	0
	Pachyelmis	sp. B	0	0	0	0	0	0	0	0
Elmidae larva	*Peloriolus*	*granulosus*	150	40	80	330	220	150	90	1280
	Elpidelmis	*capensis*	20	0	0	50	10	40	30	120
	Elmid	sp. C	0	0	0	0	0	0	0	0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0	0	0
	Prionocyphon	sp. B	0	0	0	0	0	0	0	0
	Helodid	sp. C	0	0	0	0	30	10	0	0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	40	0	0	0	10
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0	0	0
	Hydrophilid	sp. B	0	0	0	0	0	0	0	0
	Hydrophilid	sp. C	0	0	0	0	0	0	0	0
Limnichidae larva	Limnichid	sp. A	0	20	0	10	0	30	40	0
	Coleopteran	adult spp.	0	0	0	0	0	0	0	0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0	0	0
Ceratopogonidae larva	Ceratopogonid	spp.	10	0	0	20	0	0	0	10
Forcipomyinae	*Forcipomyia*	spp.	0	0	0	0	0	0	0	10
Chironomidae larva										
Chironominae										
Chironomini	*Polypedilum*	*?articola*	330	10	30	281	20	21	63	153
	Chironominid	sp. AX	0	0	0	0	0	0	0	0
	Orthocladius Eudactylocladius	sp. A	0	0	0	41	0	0	0	0
Tanytarsini	*Tanytarsus*	sp. A	420	50	0	1068	50	11	43	88
	Tanytarsus	sp. B	0	0	20	107	80	51	123	200
	Rheotanytarsus	sp. A	0	10	10	1148	10	0	13	1090
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	11	20	11	0	0
	Cricotopus	sp. A	0	0	0	1121	0	0	0	0
	Cricotopus	sp. B	0	0	0	0	0	0	0	0
	Cricotopus	sp. C	10	30	50	1481	100	81	303	1023
	Thienemanniella	sp. A	10	0	0	1381	0	0	0	0
	Thienemanniella	sp. B	0	0	0	4721	10	0	0	43
	Tvetenia	sp. A	0	0	0	1241	0	0	0	0
	Harnischia/Polypedilum type	sp. A	0	0	0	381	20	0	63	213
	Cricotopus	*scottae*	0	0	0	0	0	0	0	0
	Corynoneura	sp. A	0	0	0	281	0	41	83	33
Tanypodinae	*Conchapelopia*	sp. A	20	40	10	101	90	0	233	383
	Nilotanypus	*comatus*	190	0	0	301	90	51	343	383
	Nilotanypus	sp. A	0	0	0	0	0	0	0	0
	Ablabesmyia	*dusoleili*	20	30	80	181	40	31	73	83
	Macropelopia	sp. A	0	0	0	31	0	0	13	0
Chironomidae pupa	Chironomid	pupa spp.	30	20	20	250	0	10	10	20
Culicidae larva										
Culicinae	*Culex*	sp. A	0	0	0	0	0	0	0	0
Empididae larva	Empidid	sp. A	0	0	0	0	0	0	0	0

Appendix 8.11.3 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	GROOTFONTEIN GFR1	GFR2	GFR3	GFR4	GFR5	GFR6	GFR7	GFR8
Rhagionidae larva	Rhagionid	sp. A	0	10	0	10	10	40	20	30
Simuliidae larva	Simuliid	larva spp.	0	0	10	1640	0	0	0	60
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0	0	0
Tipulidae larva	*Antocha*	sp. A	0	0	0	120	0	0	0	10
	Dipteran	adult spp.	0	0	0	0	0	10	0	0
	Dipteran	pupa spp.	0	10	0	10	0	0	30	0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0	0	0
	Afroptilum	sp. B	30	20	220	153	90	216	254	330
	Afroptilum	*?indusii*	0	100	60	173	180	273	204	0
	Afroptilum	*?tarsale*	0	0	0	0	0	0	0	0
	Afroptilum	sp. C	30	0	170	393	0	23	0	0
	Afroptilum	sp. D	0	0	0	0	20	0	64	850
	Baetis	*?latus*	0	0	0	0	0	0	0	0
	Baetis	*harrisoni complex*	0	0	0	483	0	0	0	0
	?Demoulinia	complex A	40	110	270	246	60	183	424	100
	Demoulinia	*crassi*	0	0	0	0	0	0	0	0
	Pseudocloeon	*vinosum*	0	0	0	483	0	193	114	1200
	Pseudopannota	*maculosa*	0	0	0	1923	0	13	0	600
	Baetid	juvenile spp.	0	0	0	30	0	50	170	420
Caenidae larva	*Caenis*	*capensis*	83	20	280	123	140	60	160	350
	Caenodes	sp. C	758	30	110	406	50	30	30	20
	Caenodes	sp. H	0	0	0	0	0	0	0	0
	Caenid	juvenile spp.	0	0	0	10	0	0	0	10
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	10	10	10	20	50
	Ephemerellina	complex A	0	0	0	0	0	0	0	10
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	10	60	60	50
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0	0	0
	Aprionyx	complex A	0	0	0	0	0	0	0	0
	Euthraulus	*elegans*	0	0	0	10	20	0	0	20
	Choroterpes	*nigrescence*	0	0	0	0	0	0	0	0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	10	0	70	20	20	60	30
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0	0	0
	Ephemeropteran	adult spp.	0	0	0	0	0	0	0	0
Corixidae adult	Corixid	sp. A	0	0	0	0	0	0	0	0
	Corixid	sp. B	0	0	0	0	0	0	0	0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0	0	0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0	0	0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0	0	0
Pyralidae larva	Pyralid	sp. A	10	0	0	0	10	0	0	60
	Pyralid	sp. C	0	0	0	0	0	0	0	0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0	0	0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0	0	0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0	0	0
	Aeschna	sp. B	0	0	0	0	0	0	10	10
Corduliidae larva	Corduliid	sp. A	20	0	0	20	0	0	0	0
	Corduliid	juvenile spp.	0	0	0	0	0	0	0	0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0	10	10
	Libellulid	sp. B	0	0	0	0	0	0	0	0
	Libellulid	sp. C	0	0	0	0	0	0	0	0
	Libellulid	juvenile spp.	0	0	0	0	0	0	0	0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	10	0	0	0	0	10	10	0
	Gomphid	juvenile spp.	10	0	0	0	0	10	0	0
Notonemouridae larva	Notonemourid	spp.	0	0	0	10	0	10	0	30
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	10	0	20	0
Ecnomidae larva	*Ecnomus*	*thomasseti*	20	30	10	210	20	60	330	130
	Ecnomid	juvenile spp.	0	0	0	60	0	40	0	140
	Psychomyiellodes	sp. A	0	0	0	0	0	0	0	0
	Parecnomina	sp. A	0	0	0	0	0	0	0	10
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0	0	0

Appendix 8.11.3 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	GROOTFONTEIN GFR1	GFR2	GFR3	GFR4	GFR5	GFR6	GFR7	GFR8
Hydropsychidae larva										
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	130	10	20	0	440
	Cheumatopsyche	*afra*	0	0	0	0	0	0	0	0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0	0	0
	Cheumatopsyche	spp.	0	0	0	0	0	0	0	0
	Cheumatopsyche	juvenile spp.	0	0	0	0	0	20	0	240
Macronematinae										
Macronematini	*Amphipsyche*	*?scottae*	0	0	0	0	0	0	0	0
	Amphipsyche	*?scottae pupa*	0	0	0	0	0	0	0	0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0	0	0
	Macrostemum	*capense*	0	0	0	0	0	0	0	0
	Macrostemum	capense juvenile	0	0	0	0	0	0	0	0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	0	0	50	80	20	10	130
	Hydroptila	*capensis*	0	0	0	20	10	10	20	110
	Hydroptila	capensis pupa	0	0	0	0	0	0	0	80
	Orthotrichia	sp. A	0	0	0	0	0	0	0	0
	Orthotrichia	*barnardi*	0	0	0	0	0	0	0	0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0	0	0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0	0	0
	Oxyethira	*?velocipes*	0	0	0	0	0	0	0	0
Leptoceridae larva										
Leptocerinae										
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	20	0	0	0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	0	0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0	0	0
	Ceraclea	sp. A	0	0	0	0	0	0	10	0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	10	0	0	110	0	0	300	180
	Athripsodes ?(bergensis group)	sp. B	20	0	0	30	40	10	10	0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0	0	0
	Athripsodes (bergensis group)	sp. D	10	0	0	0	0	0	0	0
	Leptecho	*helicotheca*	0	0	0	0	0	10	0	0
	Leptecho	sp. E	0	0	0	0	0	0	0	10
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0	10	0
	Oecetis	sp. B	0	0	0	0	0	0	0	0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	10	0	10	0	0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0	0	0
	Philopotamid	juvenile spp.	0	0	0	0	0	0	0	0
	Philopotamid	pupa spp.	0	0	0	0	0	0	0	0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0	0	0
Sericostomatidae larva	*Petroplax*	*?curvicosta*	10	0	0	0	0	0	0	0
Xiphocentronidae larva	*Aberia*	sp. A	0	0	0	0	0	0	0	0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0	0	0
	Trichopteran	pupa spp.	10	0	0	0	0	0	20	40
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0	0	0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0	0	0
Tricladida	*Dugesia*	spp.	80	0	0	770	410	580	700	850
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0	0	0
Mollusca	Gastropod	spp.	0	0	0	0	0	0	0	0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0	0	0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0	0	0
Nematoda	Nematode	spp.	0	0	0	40	0	0	0	0

Appendix 8.11.3 continued

GENUS	SPECIES	GROOTFONTEIN GFR9	GFR10	GFR11	GFR12	GFR13	GFR14	GFR15	GFR16	GFR17
Lumbriculid	spp.	0	0	0	0	0	0	0	0	0
Nais	spp.	230	600	280	10	0	140	60	60	140
Pristina	spp.	0	0	0	0	0	0	0	0	0
Hydracarinid	spp.	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. A	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. B	0	0	10	0	10	10	20	0	0
Hydracarinid	sp. C	0	0	0	0	0	0	10	0	0
Hydracarinid	sp. D	0	0	0	0	0	0	10	0	0
Hydracarinid	sp. E	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. F	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. G	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. H	0	0	0	0	0	0	0	0	0
Dryopid	sp. A	0	0	10	0	0	0	0	0	0
Hydaticus	sp. A	0	0	0	0	0	0	0	0	0
Bidessus	sp. A	0	0	0	0	0	0	0	0	0
?Leielmis	sp. A	0	0	0	0	0	0	0	0	0
Tropidelmis	sp. A	0	0	0	0	0	0	0	0	0
Pachyelmis	sp. A	0	20	0	0	0	0	40	0	0
Pachyelmis	sp. B	0	0	0	0	0	0	0	0	0
Peloriolus	*granulosus*	180	510	270	70	210	320	1200	70	270
Elpidelmis	*capensis*	170	180	30	250	480	1000	50	0	0
Elmid	sp. C	0	0	0	0	0	0	0	0	0
Prionocyphon	sp. A	0	0	0	0	0	0	0	0	0
Prionocyphon	sp. B	0	0	0	0	0	0	0	0	0
Helodid	sp. C	20	0	10	20	0	150	0	0	0
Hydraena	sp. A	0	0	0	0	0	10	20	0	0
Hydrophilid	sp. A	0	0	0	0	0	0	0	0	0
Hydrophilid	sp. B	0	0	0	0	0	0	0	0	0
Hydrophilid	sp. C	0	0	0	0	0	0	0	0	0
Limnichid	sp. A	30	40	10	20	30	110	30	0	0
Coleopteran	adult spp.	0	0	0	0	0	0	0	0	0
Isotoma	sp. A	0	0	0	0	0	0	0	0	0
Ceratopogonid	spp.	0	10	10	10	0	10	0	0	30
Forcipomyia	spp.	0	10	0	0	0	10	0	0	0
Polypedilum	*?articola*	111	45	142	180	223	1070	51	71	183
Chironominid	sp. AX	0	0	0	0	23	0	0	0	0
Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0	0	0	0
Tanytarsus	sp. A	131	85	112	20	23	40	0	135	513
Tanytarsus	sp. B	161	515	532	280	43	430	791	74	43
Rheotanytarsus	sp. A	331	145	22	620	673	1030	11	24	13
Cricotopus	*?flavozonatus*	0	0	0	0	0	0	0	0	0
Cricotopus	sp. A	0	0	0	80	43	10	0	0	0
Cricotopus	sp. B	0	0	0	0	0	0	0	0	0
Cricotopus	sp. C	371	705	732	460	1703	1690	251	51	73
Thienemanniella	sp. A	0	0	0	0	0	20	0	0	0
Thienemanniella	sp. B	21	85	42	40	633	310	21	0	0
Tvetenia	sp. A	11	0	0	0	83	0	0	0	0
Harnischia/Polypedilum type	sp. A	31	65	42	0	453	0	11	0	0
Cricotopus	*scotiae*	0	0	0	20	0	220	0	0	13
Corynoneura	sp. A	21	15	42	0	0	30	81	21	0
Conchapelopia	sp. A	211	335	312	410	163	870	191	0	0
Nilotanypus	comatus	181	345	382	70	63	410	411	21	33
Nilotanypus	sp. A	0	0	0	0	0	0	0	0	0
Ablabesmyia	*dusoleili*	21	85	242	20	0	10	11	161	653
Macropelopia	sp. A	21	0	32	0	0	0	11	201	883
Chironomid	pupa spp.	10	30	30	40	50	60	0	0	10
Culex	sp. A	0	0	0	0	0	0	0	0	0
Empidid	sp. A	0	0	0	0	0	0	0	0	0

Appendix 8.11.3 continued

GENUS	SPECIES	GROOTFONTEIN GFR9	GFR10	GFR11	GFR12	GFR13	GFR14	GFR15	GFR16	GFR17
Rhagionid	sp. A	10	40	0	40	20	120	0	0	0
Simuliid	larva spp.	10	10	30	20	310	30	20	0	0
Simuliid	pupa spp.	0	0	0	10	0	0	0	0	0
Antocha	sp. A	10	10	20	80	190	110	10	0	0
Dipteran	adult spp.	0	0	0	0	0	0	0	0	0
Dipteran	pupa spp.	0	0	0	0	0	0	0	0	0
Acentrella	*?capensis*	0	0	0	0	0	0	0	0	0
Afroptilum	sp. B	110	102	150	190	11	80	0	150	0
Afroptilum	*?indusii*	210	182	410	0	181	0	0	10	0
Afroptilum	*?tarsale*	0	0	0	0	0	0	0	0	150
Afroptilum	sp. C	0	0	0	10	31	180	0	0	0
Afroptilum	sp. D	810	852	700	890	1101	3420	340	0	0
Baetis	*?latus*	0	0	0	0	0	0	0	0	0
Baetis	*harrisoni complex*	0	0	10	110	122	300	0	0	140
?Demoulinia	complex A	230	122	470	80	231	0	0	0	190
Demoulinia	*crassi*	0	0	0	0	0	0	0	180	340
Pseudocloeon	*vinosum*	430	382	0	130	0	0	0	0	0
Pseudopannota	*maculosa*	40	0	10	610	661	610	0	0	160
Baetid	juvenile spp.	180	250	220	180	570	730	90	0	100
Caenis	*capensis*	80	210	810	20	0	0	0	590	2440
Caenodes	sp. C	420	280	350	60	40	110	190	30	0
Caenodes	sp. H	0	0	0	0	0	0	0	0	0
Caenid	juvenile spp.	50	80	150	0	0	80	0	10	200
Lestagella	*penicillata*	10	10	20	120	50	160	0	0	0
Ephemerellina	complex A	0	0	0	0	0	0	0	0	0
Afronurus	*harrisoni*	30	30	10	220	70	250	0	0	0
Adenophlebia	*auriculata*	0	0	0	0	0	0	0	0	0
Aprionyx	complex A	0	0	0	0	0	0	0	0	0
Euthraulus	*elegans*	10	20	20	110	30	70	0	0	0
Choroterpes	*nigrescence*	0	0	0	0	0	0	0	0	30
Leptophlebiid (?Choroterpes)	juvenile spp.	10	110	180	0	0	40	110	0	0
Tricorythus	sp. A	0	0	0	0	0	0	0	0	0
Ephemeropteran	adult spp.	0	0	0	0	0	0	0	0	0
Corixid	sp. A	0	0	0	0	10	0	0	0	0
Corixid	sp. B	0	0	0	0	0	0	0	0	0
Plea	sp. A	0	0	0	0	0	0	0	0	0
Mesoveliid	sp. A	0	0	0	0	0	0	0	0	0
Veliid	sp. A	0	0	10	0	0	0	0	0	0
Pyralid	sp. A	0	10	10	20	60	180	10	0	0
Pyralid	sp. C	0	0	0	0	0	0	0	0	0
Chlorionella	sp. A	0	0	0	0	0	0	0	0	0
Coenagrionid	sp. A	0	0	0	0	0	0	0	0	0
Aeschna	sp. A	0	0	0	0	0	10	0	0	10
Aeschna	sp. B	0	10	0	0	0	10	0	0	0
Corduliid	sp. A	0	0	0	0	0	0	0	0	15
Corduliid	juvenile spp.	0	0	0	0	0	0	0	0	0
Libellulid	sp. A	10	10	0	0	70	70	0	0	0
Libellulid	sp. B	0	0	0	0	0	0	0	0	15
Libellulid	sp. C	0	0	0	0	0	0	0	0	0
Libellulid	juvenile spp.	0	0	0	0	0	50	0	0	0
Notogomphus (?Paragomphus)	sp. A	0	0	0	0	0	0	0	0	20
Gomphid	juvenile spp.	0	0	0	0	10	0	0	0	30
Notonemourid	spp.	10	10	30	10	0	40	0	0	10
Barbarochthon	*brunneum*	0	10	0	0	0	0	0	0	0
Ecnomus	*thomasseti*	120	20	10	30	0	40	0	0	0
Ecnomid	juvenile spp.	120	110	20	10	0	0	0	20	0
Psychomyiellodes	sp. A	0	0	0	0	0	10	0	0	0
Paracnomina	sp. A	10	0	0	0	0	0	0	0	0
Agapetus	sp. A	0	0	0	0	0	0	0	0	0

Appendix 8.11.3 **continued**

GENUS	SPECIES	GROOTFONTEIN GFR9	GFR10	GFR11	GFR12	GFR13	GFR14	GFR15	GFR16	GFR17
Cheumatopsyche	*thomasseti*	150	120	20	330	180	820	20	0	0
Cheumatopsyche	*s/n*	30	0	0	850	510	610	0	0	0
Cheumatopsyche	pupa spp.	0	0	0	0	20	0	0	0	0
Cheumatopsyche	spp.	0	0	0	0	0	0	0	0	0
Cheumatopsyche	juvenile spp.	310	250	10	850	2080	1470	10	0	0
Amphipsyche	*?scottae*	0	0	0	0	0	0	0	0	0
Amphipsyche	?scottae pupa	0	0	0	0	0	0	0	0	0
Amphipsyche	?scottae juvenile	0	0	0	0	0	0	0	0	0
Macrostemum	*capense*	10	0	0	40	40	80	0	0	0
Macrostemum	capense juvenile	10	0	0	30	20	50	0	0	0
Hydroptilid	juvenile instar (2-4th)	60	30	40	60	10	250	0	0	0
Hydroptila	*capensis*	80	70	20	90	40	140	0	0	0
Hydroptila	capensis pupa	10	10	10	20	0	10	0	0	0
Orthotrichia	sp. A	0	0	0	0	0	0	0	0	0
Orthotrichia	*barnardi*	0	0	0	0	0	0	0	0	0
Orthotrichia	barnardi pupa	0	0	0	0	0	0	0	0	0
Orthotrichia	sp. C prepupa	0	0	0	10	0	0	0	0	0
Oxyethira	*?velocipes*	0	0	0	0	0	0	0	0	0
Athripsodes (harrisoni group)	sp. A	0	0	0	0	0	0	0	0	0
Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	10	0	0
Athripsodes (Ps group)	sp. B	0	0	0	0	0	0	0	0	20
Ceraclea	sp. A	0	0	0	0	0	20	0	0	0
Athripsodes (bergensis group)	sp. A	270	40	20	40	20	610	40	0	10
Athripsodes ?(bergensis group)	sp. B	10	0	10	0	0	10	0	10	0
Athripsodes (bergensis group)	sp. C	0	0	10	0	0	0	0	0	0
Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0	0	0	0
Leptecho	*helicotheca*	0	0	0	0	0	0	0	0	10
Leptecho	sp. E	0	0	0	0	0	0	0	0	0
Oecetis	sp. A	0	0	0	0	20	20	0	0	0
Oecetis	sp. B	0	0	0	0	0	0	0	0	0
Petrothrincus	*circularis*	0	0	0	0	0	0	0	0	0
Chimarra	sp. A	0	0	0	0	50	0	10	0	0
Philopotamid	juvenile spp.	0	0	0	0	0	0	10	0	0
Philopotamid	pupa spp.	0	0	0	0	0	0	0	0	0
Nyctiophylax	sp. A	10	30	0	0	0	10	0	0	0
Petroplax	*?curvicosta*	0	0	0	0	0	10	50	10	0
Abaria	sp. A	0	0	0	0	0	30	0	0	0
Xiphocentronid	juvenile spp.	0	10	0	0	0	0	0	0	0
Trichopteran	pupa spp.	30	40	20	10	30	70	10	0	0
Potamonautes	spp.	0	0	0	0	0	0	0	0	0
Hydra	spp.	0	0	10	0	0	0	0	0	10
Dugesia	spp.	1120	1150	810	0	50	0	10	0	0
Ferrissia	spp.	0	0	0	0	0	0	0	0	0
Gastropod	spp.	0	0	0	0	0	0	0	0	0
Pisidium	spp.	0	0	0	0	0	0	0	0	0
Bulinus	*tropicus*	0	0	0	0	0	0	0	0	0
Nematode	spp.	0	0	0	0	0	0	10	0	0

Appendix 8.11.3 continued

GENUS	SPECIES	GROOTFONTEIN GFR18	GFS19	GFS20	GFS21	GFS22	GFS23	GFS24	GFS25	GFMEAN
Lumbriculid	spp.	0	112	0	0	0	0	0	0	4.5
Nais	spp.	100	0	112	112	56	0	0	392	127.3
Pristina	spp.	0	0	0	0	0	0	0	0	0.0
Hydracarinid	spp.	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. A	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. B	0	0	0	0	0	0	0	0	2.0
Hydracarinid	sp. C	0	0	0	0	0	0	0	0	0.4
Hydracarinid	sp. D	0	0	0	0	0	0	0	0	0.4
Hydracarinid	sp. E	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. F	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. G	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. H	0	0	0	0	0	0	0	0	0.0
Dryopid	sp. A	0	0	0	0	0	0	0	0	0.4
Hydaticus	sp. A	0	0	0	0	0	0	0	0	0.0
Bidessus	sp. A	0	0	0	0	0	0	0	0	0.0
?Leleimis	sp. A	0	0	0	0	0	0	0	0	0.0
Tropidelmis	sp. A	0	0	0	0	0	0	0	0	0.4
Pachyelmis	sp. A	0	0	0	0	0	0	0	0	4.0
Pachyelmis	sp. B	0	0	0	0	0	0	0	0	0.0
Peloriolus	*granulosus*	20	0	0	56	0	56	280	0	233.7
Elpidelmis	*capensis*	0	0	0	0	0	0	0	0	96.8
Elmid	sp. C	0	0	0	0	0	0	0	0	0.0
Prionocyphon	sp. A	0	0	0	0	0	0	0	0	0.0
Prionocyphon	sp. B	0	0	0	0	0	0	0	0	0.0
Helodid	sp. C	0	0	0	0	0	0	0	0	8.6
Hydraena	sp. A	0	0	0	0	0	0	0	0	3.2
Hydrophilid	sp. A	0	0	0	0	0	0	0	0	0.0
Hydrophilid	sp. B	0	0	0	0	0	0	0	0	0.0
Hydrophilid	sp. C	0	0	0	0	0	0	0	0	0.0
Limnichid	sp. A	0	0	0	0	0	0	0	0	14.8
Coleopteran	adult spp.	0	0	0	0	0	0	0	0	0.0
Isotomid	sp. A	0	0	0	0	0	0	0	0	0.0
Ceratopogonid	spp.	10	0	56	0	168	0	0	0	13.4
Forcipomyia	spp.	0	0	0	0	0	0	0	0	1.2
Polypedilum	*?articola*	70	3203	280	2800	2576	392	336	560	526.4
Chironominid	sp. AX	0	0	0	0	0	0	0	0	0.9
Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0	0	0	1.8
Tanytarsus	sp. A	160	5488	56	952	0	0	336	0	392.5
Tanytarsus	sp. B	20	67	0	56	448	0	392	112	180.2
Rheotanytarsus	sp. A	0	0	0	0	0	0	0	0	212.8
Cricotopus	*?flavozonatus*	0	0	0	0	0	0	0	0	1.7
Cricotopus	sp. A	0	0	0	0	0	0	0	0	50.6
Cricotopus	sp. B	0	0	0	0	0	0	0	0	0.0
Cricotopus	sp. C	30	0	0	280	0	0	0	0	375.4
Thienemanniella	sp. A	10	0	0	0	0	0	0	0	56.0
Thienemanniella	sp. B	0	0	0	0	0	0	0	0	245.0
Tvetenia	sp. A	0	0	0	0	0	0	56	0	54.8
Hemischia/Polypedilum type	sp. A	0	0	0	0	0	0	0	0	50.4
Cricotopus	*scottae*	0	0	0	0	112	0	0	0	14.6
Corynoneura	sp. A	0	0	168	56	112	0	280	168	57.7
Conchapelopia	sp. A	0	0	0	0	0	0	0	0	136.0
Nilotanypus	*comatus*	80	0	0	0	0	0	0	0	132.6
Nilotanypus	sp. A	0	0	0	0	0	0	0	0	0.0
Ablabesmyia	*dusoleili*	240	347	0	112	392	0	0	0	112.1
Macropelopia	sp. A	350	347	0	0	112	0	168	0	88.8
Chironomid	pupa spp.	20	168	0	0	56	0	0	0	34.2
Culex	sp. A	0	0	0	0	0	0	0	0	0.0
Empidid	sp. A	0	0	0	0	0	0	0	0	0.0

Appendix 8.11.3 continued

GENUS	SPECIES	GROOTFONTEIN GFR18	GFS19	GFS20	GFS21	GFS22	GFS23	GFS24	GFS25	GFMEAN
Rhagionid	sp. A	0	0	0	0	0	0	0	0	14.0
Simuliid	larva spp.	0	0	0	0	0	0	0	0	65.6
Simuliid	pupa spp.	0	0	0	0	0	0	0	0	0.4
Antocha	sp. A	0	0	0	0	0	0	0	0	22.4
Dipteran	adult spp.	0	56	0	0	0	0	0	0	2.6
Dipteran	pupa spp.	0	0	0	0	0	0	0	0	2.0
Acentrella	*?capensis*	0	0	0	0	0	0	0	0	0.0
Afroptilum	sp. B	0	56	0	0	56	0	0	0	88.1
Afroptilum	*?indusii*	0	0	0	0	0	0	56	0	83.6
Afroptilum	*?tarsale*	0	0	0	0	0	0	0	0	6.0
Afroptilum	sp. C	0	0	0	0	0	0	0	0	33.5
Afroptilum	sp. D	0	0	0	0	0	0	0	0	353.9
Baetis	*?latus*	0	0	0	0	0	0	0	0	0.0
Baetis	*harrisoni complex*	0	0	0	0	0	0	0	0	48.6
?Demoulinia	complex A	10	0	0	0	0	0	0	0	111.0
Demoulinia	*crassi*	140	0	0	0	0	0	0	0	28.4
Pseudocloeon	*vinosum*	0	0	0	0	0	0	0	0	116.5
Pseudopannota	*maculosa*	0	0	0	0	56	0	0	0	198.5
Baetid	juvenile spp.	20	0	0	168	224	0	0	0	135.3
Caenis	*capensis*	660	672	0	0	0	0	0	0	267.9
Caenodes	sp. C	80	0	0	0	0	0	0	0	119.7
Caenodes	sp. H	0	0	0	0	0	0	0	0	0.0
Caenid	juvenile spp.	330	0	0	112	336	112	0	0	58.4
Lestagella	*penicillata*	0	0	0	0	0	0	0	0	18.8
Ephemerellina	complex A	0	0	0	0	0	0	0	0	0.4
Afronurus	*harrisoni*	0	0	0	0	0	0	0	0	31.6
Adenophlebia	*auriculata*	0	0	0	0	0	0	0	0	0.0
Aprionyx	complex A	0	0	0	0	0	0	0	0	0.0
Euthraulus	*elegans*	0	0	0	0	0	0	0	0	12.4
Choroterpes	*nigrescence*	0	0	0	0	0	0	0	0	1.2
Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0	0	0	28.4
Tricorythus	sp. A	0	0	0	0	0	0	0	0	0.0
Ephemeropteran	adult spp.	0	0	0	0	0	0	0	0	0.0
Corixid	sp. A	0	0	0	0	0	0	0	0	0.4
Corixid	sp. B	0	0	0	0	0	0	0	0	0.0
Plea	sp. A	0	0	0	0	0	0	0	0	0.0
Mesoveliid	sp. A	0	0	0	0	0	0	0	0	0.0
Veliid	sp. A	0	0	0	0	0	0	0	0	0.4
Pyralid	sp. A	0	0	0	0	0	0	0	0	14.8
Pyralid	sp. C	0	0	0	0	0	0	0	0	0.0
Chlorionella	sp. A	0	0	0	0	0	0	0	0	0.0
Coenagrionid	sp. A	0	0	0	0	56	0	0	0	2.2
Aeschna	sp. A	0	0	0	0	0	0	0	0	0.8
Aeschna	sp. B	0	0	0	0	0	0	0	0	1.6
Corduliid	sp. A	0	0	0	0	0	0	0	0	2.2
Corduliid	juvenile spp.	20	0	0	0	0	0	0	0	0.9
Libellulid	sp. A	0	0	0	0	0	0	0	0	7.2
Libellulid	sp. B	0	0	0	0	0	0	0	0	0.6
Libellulid	sp. C	0	0	0	0	0	0	0	0	0.0
Libellulid	juvenile spp.	0	0	0	0	0	0	0	0	2.0
Notogomphus (?Paragomphus)	sp. A	0	0	0	0	56	0	112	56	11.0
Gomphid	juvenile spp.	0	0	0	0	0	0	0	0	2.4
Notonemourid	spp.	0	0	0	0	0	0	0	0	6.4
Barbarochthon	*brunneum*	0	0	0	0	0	0	0	0	1.6
Ecnomus	*thomasseti*	10	0	0	0	0	0	0	0	41.6
Ecnomid	juvenile spp.	10	0	0	0	0	0	0	0	22.0
Psychomyiellodes	sp. A	0	0	0	0	0	0	0	0	0.4
Parecnomina	sp. A	0	0	0	0	0	0	0	0	0.8
Agapetus	sp. A	0	0	0	0	0	0	0	0	0.0

Appendix 8.11.3 continued

GENUS	SPECIES	GROOTFONTEIN								
		GFR18	GFS19	GFS20	GFS21	GFS22	GFS23	GFS24	GFS25	GFMEAN
Cheumatopsyche	*thomasseti*	0	0	0	0	0	0	0	0	89.6
Cheumatopsyche	*afra*	0	0	0	0	0	0	0	0	72.0
Cheumatopsyche	pupa spp.	0	0	0	0	0	0	0	0	0.8
Cheumatopsyche	spp.	0	0	0	0	0	0	0	0	0.0
Cheumatopsyche	juvenile spp.	0	0	0	0	0	0	0	0	249.6
Amphipsyche	*?scottae*	0	0	0	0	0	0	0	0	0.0
Amphipsyche	?scottae pupa	0	0	0	0	0	0	0	0	0.0
Amphipsyche	?scottae juvenile	0	0	0	0	0	0	0	0	0.0
Macrostemum	*capense*	0	0	0	0	0	0	0	0	6.0
Macrostemum	capense juvenile	0	0	0	0	0	0	0	0	4.4
Hydroptilid	juvenile instar (2-4th)	10	0	0	0	0	0	0	0	30.0
Hydroptila	*capensis*	0	0	0	0	0	0	0	0	23.6
Hydroptila	capensis pupa	0	0	0	0	0	0	0	0	4.8
Orthotrichia	sp. A	0	0	0	0	0	0	0	0	0.0
Orthotrichia	*barnardi*	0	0	0	0	0	0	0	0	0.0
Orthotrichia	barnardi pupa	0	0	0	0	0	0	0	0	0.0
Orthotrichia	sp. C prepupa	0	0	0	0	0	0	0	0	0.4
Oxyethira	*?velocipes*	0	0	0	0	0	0	0	0	0.0
Athripsodes (harrisoni group)	sp. A	0	0	0	0	0	0	0	0	0.8
Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	0	0	0.4
Athripsodes (Ps group)	sp. B	10	0	0	0	0	0	0	0	1.2
Ceraclea	sp. A	0	0	0	0	0	0	0	0	1.2
Athripsodes (bergensis group)	sp. A	0	56	224	0	0	0	0	0	78.4
Athripsodes ?(bergensis group)	sp. B	10	56	0	0	0	0	0	0	6.8
Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0	0	0	0.4
Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0	0	0	0.4
Leptecho	*helicotheca*	0	0	0	0	0	0	0	0	0.8
Leptecho	sp. E	0	0	0	0	0	0	0	0	0.4
Oecetis	sp. A	0	0	0	0	0	0	0	0	2.0
Oecetis	sp. B	0	0	0	0	0	0	0	0	0.0
Petrothrincus	*circularis*	0	0	0	0	0	0	0	0	0.8
Chimarra	sp. A	0	0	0	0	0	0	0	0	2.4
Philopotamid	juvenile spp.	0	0	0	0	0	0	0	0	0.4
Philopotamid	pupa spp.	0	0	0	0	0	0	0	0	0.0
Nyctiophylax	sp. A	0	0	0	0	0	0	0	0	2.0
Petroplax	*?curvicosta*	0	0	0	0	0	0	0	0	3.2
Abaria	sp. A	0	0	0	0	0	0	0	0	1.2
Xiphocentronid	juvenile spp.	0	0	0	0	0	0	0	0	0.4
Trichopteran	pupa spp.	0	0	0	0	0	0	0	0	11.2
Potamonautes	spp.	0	0	0	0	0	0	0	0	0.0
Hydra	spp.	0	0	0	0	0	0	0	0	0.8
Dugesia	spp.	0	0	0	0	0	0	0	0	253.6
Ferrissia	spp.	0	0	0	0	0	0	0	0	0.0
Gastropod	spp.	0	0	0	0	56	0	0	0	2.2
Pisidium	spp.	0	0	0	0	56	0	0	0	2.2
Bulinus	*tropicus*	0	0	0	0	0	0	0	0	0.0
Nematode	spp.	0	0	0	112	56	0	0	0	6.7

Appendix 8.11.4 Species-level benthic macroinvertebrate abundances for Tweefontein summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	TWEEFONTEIN					
			TFR1	TFR2	TFR3	TFR4	TFR5	TFMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0.0
Naididae adult	*Nais*	spp.	0	30	0	610	20	132.0
	Pristina	spp.	0	0	0	0	0	0.0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	40	0	0	0	8.0
	Hydracarinid	sp. C	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	20	10	0	6.0
	Hydracarinid	sp. F	0	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0.0
Dytiscidae larva								
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0.0
Elmidae adult								
Elminthinae	*?Leielmis*	sp. A	20	30	0	0	0	10.0
	Tropidelmis	sp. A	0	10	0	0	0	2.0
	Pachyelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. B	0	30	0	0	0	6.0
Elmidae larva	*Peloriolus*	*granulosus*	110	20	10	120	180	88.0
	Elpidelmis	*capensis*	920	660	90	70	60	360.0
	Elmid	sp. C	0	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0	0	0.0
	Helodid	sp. C	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	20	30	0	20	0	14.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	20	0	0	0	4.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	0	0	0	0	0	0.0
Forcipomyiinae	*Forcipomyia*	spp.	20	50	0	0	0	14.0
Chironomidae larva								
Chironominae								
Chironomini	*Polypedilum*	*?articola*	1631	2866	90	670	40	1059.4
	Chironominid	sp. AX	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	0	0	0	60	10	14.0
	Tanytarsus	sp. B	0	0	0	0	0	0.0
	Rheotanytarsus	sp. A	31	26	0	0	0	11.4
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0	0.0
	Cricotopus	sp. A	0	26	0	0	0	5.2
	Cricotopus	sp. B	0	0	0	0	0	0.0
	Cricotopus	sp. C	981	1466	100	3100	1190	1367.4
	Thienemanniella	sp. A	131	206	10	0	0	69.4
	Thienemanniella	sp. B	71	146	0	0	0	43.4
	Tvetenia	sp. A	0	0	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0.0
	Cricotopus	*scottae*	0	0	0	20	0	4.0
	Corynoneura	sp. A	0	0	0	0	0	0.0
Tanypodinae	*Conchapelopia*	sp. A	61	46	10	90	100	61.4
	Nilotanypus	*comatus*	21	46	0	20	50	27.4
	Nilotanypus	sp. A	0	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	0	0	0	120	0	24.0
	Macropelopia	sp. A	0	0	0	0	0	0.0
Chironomidae pupa	Chironomid	pupa spp.	60	10	0	20	80	34.0
Culicidae larva								
Culicinae	*Culex*	sp. A	0	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	0	0	0	0.0

Appendix 8.11.4 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	TWEEFONTEIN TFR1	TFR2	TFR3	TFR4	TFR5	TFMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	30	20	10	0	0	12.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	10	40	20	10	10	18.0
	Dipteran	adult spp.	0	0	0	0	0	0.0
	Dipteran	pupa spp.	0	0	0	0	0	0.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0	0	0.0
	Afroptilum	sp. C	0	0	0	0	0	0.0
	Afroptilum	sp. D	0	27	10	0	0	7.4
	Baetis	*?latus*	0	0	0	0	0	0.0
	Baetis	*harrisoni complex*	0	0	0	0	0	0.0
	?Demoulinia	complex A	0	17	0	10	0	5.4
	Demoulinia	*crassi*	0	0	0	0	20	4.0
	Pseudocloeon	*vinosum*	0	0	0	0	0	0.0
	Pseudopannota	*maculosa*	1320	687	360	10	0	477.4
	Baetid	juvenile spp.	110	240	0	30	0	76.0
Caenidae larva	*Caenis*	*capensis*	0	10	0	0	0	2.0
	Caenodes	sp. C	10	0	0	100	10	24.0
	Caenodes	sp. H	0	0	0	0	0	0.0
	Caenid	juvenile spp.	0	0	0	0	0	0.0
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0.0
	Ephemerellina	complex A	0	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0	0	0.0
	Choroterpes	*nigrescens*	0	0	0	0	0	0.0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	10	0	0	0	2.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0	0	0.0
	Corixid	sp. B	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0	0	0.0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0.0
Aeshnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	80	80	0	0	0	32.0
	Libellulid	sp. B	0	0	0	20	0	4.0
	Libellulid	sp. C	0	0	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0	0	0.0
	Gomphid	juvenile spp.	0	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	70	60	0	0	0	26.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	20	0	0	20	20	12.0
	Ecnomid	juvenile spp.	0	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0.0
	Paracnomina	sp. A	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0.0

Appendix 8.11.4 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	TWEEFONTEIN TFR1	TFR2	TFR3	TFR4	TFR5	TFMEAN
Hydropsychidae larva								
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	350	230	190	10	0	156.0
	Cheumatopsyche	*afra*	60	60	50	0	0	38.0
	Cheumatopsyche	pupa spp.	10	0	10	0	0	4.0
	Cheumatopsyche	spp.	0	0	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	340	330	120	10	0	160.0
Macronematinae								
Macronematini	*Amphipsyche*	*?scottae*	0	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0.0
	Macrostemum	*capense*	0	10	0	0	0	2.0
	Macrostemum	capense juvenile	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	0	0	0	0	0.0
	Hydroptila	*capensis*	0	0	0	0	0	0.0
	Hydroptila	capensis pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0.0
	Oxyethira	*?velocipes*	0	0	0	0	0	0.0
Leptoceridae larva								
Leptocerinae								
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	10	0	0	0	0	2.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	130	0	26.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0.0
	Oecetis	sp. B	0	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	30	10	0	0	0	8.0
	Philopotamid	juvenile spp.	20	0	0	0	0	4.0
	Philopotamid	pupa spp.	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	*?curvicosta*	0	0	0	0	0	0.0
Xiphocentronidae larva	*Aberia*	sp. A	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	10	0	0	0	0	2.0
	Trichopteran	pupa spp.	40	30	10	0	0	16.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	0	0	0	0.0

Appendix 8.11.5 Species-level benthic macroinvertebrate abundances for Kriedouwkrans summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	KRIEDOUWKRANS KKR1	KKR2	KKR3	KKR4	KKR5	KKR6	KKR7	KKR8
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0	0	0
Naididae adult	*Nais*	spp.	810	10	10	140	0	0	10	20
	Pristina	spp.	0	0	0	0	0	0	0	0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0	0	0
	Hydracarinid	sp. A	0	0	0	0	0	0	0	0
	Hydracarinid	sp. B	0	0	0	0	0	0	0	0
	Hydracarinid	sp. C	0	0	0	0	0	0	0	0
	Hydracarinid	sp. D	0	0	0	0	0	0	0	0
	Hydracarinid	sp. E	0	0	0	0	0	0	0	0
	Hydracarinid	sp. F	0	0	0	0	0	0	0	0
	Hydracarinid	sp. G	0	0	0	0	0	0	0	0
	Hydracarinid	sp. H	0	0	0	0	0	0	0	0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0	0	0
Dytiscidae larva										
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0	0	0
Hydroporinae	*Sidessus*	sp. A	0	0	0	0	0	0	0	0
Elmidae adult										
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0	0	0	0
	Tropidelmis	sp. A	0	0	0	0	0	0	0	0
	Pachyelmis	sp. A	0	0	0	0	0	0	0	0
	Pachyelmis	sp. B	0	0	0	0	0	0	0	0
Elmidae larva	*Peloriolus*	*granulosus*	50	10	30	200	0	10	10	20
	Elpidelmis	*capensis*	0	30	0	30	0	40	230	60
	Elmid	sp. C	0	0	0	0	0	0	0	0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0	0	0
	Prionocyphon	sp. B	0	0	0	0	0	0	0	0
	Helodid	sp. C	0	0	0	0	0	0	0	0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0	0	0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0	0	0
	Hydrophilid	sp. B	0	0	0	0	0	0	0	0
	Hydrophilid	sp. C	0	0	0	0	0	0	0	0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0	0	0
	Coleopteran	adult spp.	0	0	0	0	0	0	0	0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0	0	0
Ceratopogonidae larva	Ceratopogonid	spp.	0	0	0	0	0	0	0	0
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	0	50	0	10
Chironomidae larva										
Chironominae										
Chironomini	*Polypedilum*	?articola	40	200	40	1360	130	364	1982	336
	Chironominid	sp. AX	0	0	0	0	0	0	0	0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0	0	0
Tanytarsini	*Tanytarsus*	sp. A	30	50	30	2260	10	0	0	0
	Tanytarsus	sp. B	10	0	0	160	0	0	0	0
	Rheotanytarsus	sp. A	0	0	0	0	0	84	0	0
Orthocladiinae	*Cricotopus*	?flavozonatus	0	0	0	0	0	0	0	0
	Cricotopus	sp. A	0	0	0	0	0	0	0	0
	Cricotopus	sp. B	0	0	0	0	0	44	212	126
	Cricotopus	sp. C	30	80	40	670	50	44	562	86
	Thienemanniella	sp. A	0	0	0	0	0	34	92	16
	Thienemanniella	sp. B	0	0	0	0	0	0	0	0
	Tvetenia	sp A	0	0	0	0	0	0	22	0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0	0	0
	Cricotopus	*scottae*	0	0	0	0	0	0	0	0
	Corynoneura	sp. A	0	0	0	0	0	0	0	0
Tanypodinae	*Conchapelopia*	sp. A	0	0	0	0	0	0	22	26
	Nilotanypus	*comatus*	40	60	0	20	0	0	0	0
	Nilotanypus	sp. A	0	0	0	0	0	0	0	0
	Ablabesmyia	*dusoleili*	20	340	20	1800	30	0	0	0
	Macropelopia	sp. A	40	0	0	40	0	0	0	0
Chironomidae pupa	Chironomid	pupa spp.	0	20	10	60	0	20	10	10
Culicidae larva										
Culicinae	*Culex*	sp. A	0	0	0	0	0	0	0	0
Empididae larva	Empidid	sp. A	0	0	0	0	0	0	0	0

Appendix 8.11.5 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	KRIEDOUWKRANS							
			KKR1	KKR2	KKR3	KKR4	KKR5	KKR6	KKR7	KKR8
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0	0	0
Simuliidae larva	Simuliid	larva spp.	0	0	0	10	0	0	70	10
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0	10	0
Tipulidae larva	*Antocha*	sp. A	0	0	0	0	0	0	0	0
	Dipteran	adult spp.	0	0	0	0	0	0	0	0
	Dipteran	pupa spp.	0	0	0	0	0	0	0	0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0	0	0
	Afroptilum	sp. B	0	0	0	0	0	0	0	0
	Afroptilum	*?indusii*	0	0	0	0	0	370	20	0
	Afroptilum	*?tarsale*	0	0	0	0	0	0	0	0
	Afroptilum	sp. C	0	0	0	0	0	0	0	0
	Afroptilum	sp. D	0	0	0	0	0	0	0	0
	Baetis	*?latus*	30	0	0	0	10	0	0	0
	Baetis	*harrisoni complex*	0	0	0	0	0	0	10	140
	?Demoulinia	complex A	0	10	0	160	30	570	60	150
	Demoulinia	*crassi*	30	100	150	1130	20	0	0	0
	Pseudocloeon	*vinosum*	0	0	0	0	0	0	0	10
	Pseudopannota	*maculosa*	0	0	0	0	0	0	0	30
	Baetid	juvenile spp.	0	10	0	270	0	0	100	70
Caenidae larva	*Caenis*	*capensis*	30	0	10	0	0	0	0	0
	Caenodes	sp. C	20	380	220	1840	150	0	0	0
	Caenodes	sp. H	0	0	0	0	0	20	180	450
	Caenid	juvenile spp.	0	0	0	220	0	0	0	10
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0	0	0
	Ephemerellina	complex A	0	0	0	0	0	0	0	0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0	0	0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0	0	0
	Aprionyx	complex A	0	0	0	0	0	0	0	0
	Euthraulus	*elegans*	0	0	0	0	0	0	0	0
	Choroterpes	*nigrescence*	0	0	0	0	0	0	0	0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0	0	0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0	0	20
	Ephemeropteran	adult spp.	0	0	0	0	0	0	0	0
Corixidae adult	Corixid	sp. A	10	30	50	270	0	0	0	0
	Corixid	sp. B	0	0	0	0	0	0	0	0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0	0	0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0	0	0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0	0	0
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0	30	0
	Pyralid	sp. C	0	0	0	0	0	0	0	0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0	0	0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0	0	0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0	0	0
	Aeschna	sp. B	0	0	0	0	0	0	0	0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0	0	0
	Corduliid	juvenile spp.	0	0	0	0	0	0	0	10
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0	0	10
	Libellulid	sp. B	0	0	0	40	0	0	0	0
	Libellulid	sp. C	0	0	0	0	0	0	0	0
	Libellulid	juvenile spp.	0	0	0	0	0	0	0	0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	10	0	0	0	0	0
	Gomphid	juvenile spp.	0	0	0	0	0	0	0	0
Notonemouridae larva	Notonemourid	spp.	0	0	0	0	0	0	0	0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0	0	0
Ecnomidae larva	*Ecnomus*	*thomasseti*	20	120	20	270	60	0	10	0
	Ecnomid	juvenile spp.	0	0	0	0	0	0	0	0
	Psychomyiellodes	sp. A	0	0	0	0	0	0	0	0
	Parecnomina	sp. A	0	0	0	0	0	0	0	0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0	0	0

Appendix 8.11.5 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	KRIEDOUWKRANS KKR1	KKR2	KKR3	KKR4	KKR5	KKR6	KKR7	KKR8
Hydropsychidae larva										
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	0	0	10	10	400
	Cheumatopsyche	*afra*	0	0	0	0	0	0	0	0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0	0	0
	Cheumatopsyche	spp.	0	0	0	0	10	0	0	0
	Cheumatopsyche	juvenile spp.	0	0	0	0	10	30	10	80
Macronematinae										
Macronematini	*Amphipsyche*	?scottae	0	0	0	0	0	0	0	0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0	0	0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0	0	0
	Macrostemum	capense	0	0	0	0	0	0	0	0
	Macrostemum	capense juvenile	0	0	0	0	0	0	0	0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	10	0	50	0	0	0	0
	Hydroptila	*capensis*	0	0	0	80	0	0	0	20
	Hydroptila	capensis pupa	0	0	0	80	0	0	0	0
	Orthotrichia	sp. A	0	0	0	0	0	0	10	0
	Orthotrichia	*barnardi*	0	0	0	0	0	0	0	0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0	0	0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0	0	0
	Oxyethira	*?velocipes*	0	0	0	0	0	0	0	0
Leptoceridae larva										
Leptocerinae										
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0	0	0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	0	0
	Athripsodes (Ps group)	sp. B	0	0	10	0	0	0	0	0
	Ceraclea	sp. A	0	0	0	0	0	0	0	0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0	0	0	0	0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	30	0	0	0	0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0	0	0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0	0	0
	Leptecho	*helicotheca*	0	0	0	0	0	0	0	0
	Leptecho	sp. E	0	0	0	0	0	0	0	0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0	0	0
	Oecetis	sp. B	0	0	0	0	0	0	0	0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0	0	0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0	0	30
	Philopotamid	juvenile spp.	0	0	0	0	0	0	0	0
	Philopotamid	pupa spp.	0	0	0	0	0	0	0	10
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0	0	0
Sericostomatidae larva	*Petroplax*	?curvicosta	0	0	0	0	0	0	0	0
Xiphocentronidae larva	*Aberis*	sp. A	0	0	0	0	0	0	0	0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0	0	0
	Trichopteran	pupa spp.	0	0	0	0	0	0	0	10
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0	0	0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0	0	0
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0	0	0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0	0	0
Mollusca	Gastropod	spp.	0	0	0	0	0	0	0	0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0	0	0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0	0	0
Nematoda	Nematode	spp.	0	0	0	0	0	0	0	0

Appendix 8.11.5 continued

GENUS	SPECIES	KRIEDOUWKRANS KKR9	KKR10	KKR11	KKR12	KKR13	KKR14	KKR15	KKS16	KKS17
Lumbriculid	spp.	0	0	0	0	0	0	0	112	0
Nais	spp.	20	0	0	0	0	10	0	0	6552
Pristina	spp.	0	0	0	0	0	0	0	0	0
Hydracarinid	spp.	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. A	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. B	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. C	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. D	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. E	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. F	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. G	0	0	0	0	0	0	0	0	0
Hydracarinid	sp. H	0	0	0	0	0	0	0	0	0
Dryopid	sp. A	0	0	0	0	0	0	0	0	0
Hydaticus	sp. A	0	0	0	0	0	0	0	0	0
Bidessus	sp. A	0	0	0	0	0	0	0	0	0
?Leielmis	sp. A	10	0	0	0	0	0	0	0	0
Tropidelmis	sp. A	0	0	0	0	0	0	0	0	0
Pachyelmis	sp. A	0	0	0	0	0	0	0	0	0
Pachyelmis	sp. B	0	0	0	0	0	0	0	0	0
Peloriolus	*granulosus*	30	20	0	0	20	40	0	280	224
Elpidelmis	*capensis*	480	10	60	50	120	270	160	0	0
Elmid	sp. C	20	0	0	0	0	0	0	0	0
Prionocyphon	sp. A	0	0	0	0	0	0	0	0	0
Prionocyphon	sp. B	0	0	0	0	0	0	0	0	0
Helodid	sp. C	0	0	0	0	0	0	0	0	0
Hydraena	sp. A	0	0	0	0	0	0	0	0	0
Hydrophilid	sp. A	0	0	0	0	0	0	0	0	0
Hydrophilid	sp. B	0	0	0	0	0	0	0	0	0
Hydrophilid	sp. C	0	0	0	0	0	0	0	0	0
Limnichid	sp. A	0	0	0	0	0	0	0	0	0
Coleopteran	adult spp.	0	0	0	0	0	0	0	0	0
Isotoma	sp. A	0	0	0	0	0	0	0	0	0
Ceratopogonid	spp.	30	0	0	10	0	0	0	280	280
Forcipomyia	spp.	0	0	0	0	10	0	20	0	0
Polypedilum	*?articola*	3545	10	1750	712	2640	913	430	291	224
Chironominid	sp. AX	0	0	0	0	0	0	0	0	0
Orthocladius Eudactylocladius	sp. A	65	10	60	12	50	13	0	0	0
Tanytarsus	sp. A	0	0	0	0	0	0	0	738	784
Tanytarsus	sp. B	0	0	0	0	0	0	0	123	0
Rheotanytarsus	sp. A	45	20	20	12	20	0	0	0	0
Cricotopus	*?flavozonatus*	0	0	0	0	0	0	0	0	0
Cricotopus	sp. A	0	0	0	0	0	0	0	0	0
Cricotopus	sp. B	1025	10	340	82	150	0	20	0	0
Cricotopus	sp. C	2485	30	1870	122	1030	33	20	0	0
Thienemanniella	sp. A	115	0	60	12	80	63	100	0	0
Thienemanniella	sp. B	45	0	50	0	0	0	0	0	0
Tvetenia	sp. A	25	0	0	0	30	0	0	0	0
Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0	0	0	0
Cricotopus	*scottae*	0	0	0	0	0	0	0	0	56
Corynoneura	sp. A	0	0	0	0	0	0	0	0	0
Conchapelopia	sp. A	25	0	0	0	0	13	10	0	0
Nilotanypus	*comatus*	25	0	20	0	0	33	0	0	0
Nilotanypus	sp. A	0	0	0	0	0	0	0	0	0
Ablabesmyia	*dusoleili*	25	0	50	0	0	83	40	67	0
Macropelopia	sp. A	0	0	0	0	0	0	0	67	112
Chironomid	pupa spp.	150	20	220	60	70	30	60	0	0
Culex	sp. A	0	0	0	0	0	0	10	0	0
Empidid	sp. A	0	0	0	0	0	0	0	0	0

Appendix 8.11.5 **continued**

GENUS	SPECIES	KRIEDOUWKRANS KKR9	KKR10	KKR11	KKR12	KKR13	KKR14	KKR15	KKS16	KKS17
Rhagionid	sp. A	0	0	0	0	0	0	0	0	0
Simuliid	larva spp.	420	30	130	780	40	20	30	0	0
Simuliid	pupa spp.	20	0	20	0	20	10	10	0	0
Antocha	sp. A	0	0	0	0	0	0	0	0	0
Dipteran	adult spp.	0	0	0	0	0	0	10	0	0
Dipteran	pupa spp.	0	0	0	0	0	0	0	0	0
Acentrella	*?capensis*	0	0	0	0	0	0	0	0	0
Afroptilum	sp. B	0	0	0	0	0	0	0	0	0
Afroptilum	*?indusii*	0	0	0	0	0	0	0	0	0
Afroptilum	*?tarsale*	0	0	0	0	0	0	0	0	0
Afroptilum	sp. C	0	0	0	0	0	0	0	0	0
Afroptilum	sp. D	0	0	0	0	0	0	0	0	0
Baetis	*?latus*	0	0	0	0	0	0	0	0	0
Baetis	*harrisoni complex*	280	230	110	90	0	0	0	0	0
?Demoulinia	complex A	0	110	240	60	140	70	210	0	0
Demoulinia	*crassi*	0	0	0	0	0	0	0	0	0
Pseudocloeon	*vinosum*	0	0	0	0	0	0	0	0	0
Pseudopannota	*maculosa*	50	0	0	140	0	0	0	0	0
Baetid	juvenile spp.	110	40	40	30	120	70	240	0	168
Caenis	*capensis*	0	0	0	0	0	0	0	56	0
Caenodes	sp. C	0	0	30	0	70	180	80	0	0
Caenodes	sp. H	50	30	40	190	210	150	70	0	0
Caenid	juvenile spp.	0	0	0	0	0	20	0	112	336
Lestagella	*penicillata*	0	0	0	0	0	0	0	0	0
Ephemerellina	complex A	0	0	0	0	0	0	0	0	0
Afronurus	*harrisoni*	0	0	0	0	0	0	0	0	0
Adenophlebia	*auriculata*	0	0	0	0	0	0	0	0	0
Aprionyx	complex A	0	0	0	0	0	0	0	0	0
Euthraulus	*elegans*	0	0	0	0	0	0	0	0	0
Choroterpes	*nigrescence*	0	0	0	0	0	0	0	0	0
Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0	0	0	0
Tricorythus	sp. A	10	0	0	0	0	0	0	0	0
Ephemeropteran	adult spp.	0	0	0	0	0	0	0	0	0
Corixid	sp. A	0	0	0	0	0	0	0	0	0
Corixid	sp. B	0	0	0	0	10	10	0	0	0
Plea	sp. A	0	0	0	0	0	0	0	0	0
Mesoveliid	sp. A	0	0	0	0	0	0	0	0	0
Veliid	sp. A	0	0	0	0	0	0	0	0	0
Pyralid	sp. A	30	0	10	20	40	30	30	0	0
Pyralid	sp. C	0	0	0	0	0	0	0	0	0
Chlorionella	sp. A	0	0	0	0	0	0	0	0	0
Coenagrionid	sp. A	0	0	0	0	0	0	0	0	0
Aeschna	sp. A	0	0	0	0	0	0	0	0	0
Aeschna	sp. B	0	0	0	0	0	0	0	0	0
Corduliid	sp. A	0	0	0	0	0	0	0	0	0
Corduliid	juvenile spp.	0	0	0	0	10	0	0	0	0
Libellulid	sp. A	0	0	40	0	0	0	0	0	0
Libellulid	sp. B	0	0	0	0	0	0	0	0	0
Libellulid	sp. C	0	0	0	0	0	0	0	56	0
Libellulid	juvenile spp.	30	0	0	0	0	0	10	0	0
Notogomphus (?Paragomphus)	sp. A	0	0	0	0	0	0	0	168	168
Gomphid	juvenile spp.	0	0	0	0	0	0	0	0	224
Notonemourid	spp.	0	0	0	0	0	0	0	0	0
Barbarochthon	*brunneum*	0	0	0	0	0	0	0	0	0
Ecnomus	*thomasseti*	0	0	10	0	0	20	0	0	0
Ecnomid	juvenile spp.	0	0	0	0	0	0	0	0	0
Psychomyiellodes	sp. A	0	0	0	0	0	0	0	0	0
Parecnomina	sp. A	0	0	0	0	0	0	0	0	0
Agapetus	sp. A	0	0	0	0	0	0	0	0	0

Appendix 8.11.5 continued

GENUS	SPECIES	KRIEDOUWKRANS								
		KKR9	KKR10	KKR11	KKR12	KKR13	KKR14	KKR15	KKS16	KKS17
Cheumatopsyche	*thomasseti*	130	10	10	30	0	0	10	0	0
Cheumatopsyche	*afra*	0	0	0	0	0	0	0	0	0
Cheumatopsyche	pupa spp.	0	0	0	0	0	0	0	0	0
Cheumatopsyche	spp.	0	0	0	0	0	0	0	0	0
Cheumatopsyche	juvenile spp.	40	0	0	100	10	10	0	0	0
Amphipsyche	?scottae	0	0	0	0	0	0	0	0	0
Amphipsyche	?scottae pupa	0	0	0	0	0	0	0	0	0
Amphipsyche	?scottae juvenile	0	0	0	0	0	0	0	0	0
Macrostemum	capense	0	0	0	0	0	0	0	0	0
Macrostemum	capense juvenile	0	0	0	0	0	0	0	0	0
Hydroptilid	juvenile instar (2-4th)	0	0	0	0	30	0	0	0	0
Hydroptila	*capensis*	20	0	0	0	0	0	0	0	0
Hydroptila	capensis pupa	20	0	0	0	0	0	0	0	0
Orthotrichia	sp. A	0	0	0	0	10	0	0	0	0
Orthotrichia	*barnardi*	0	0	0	0	0	0	0	0	0
Orthotrichia	barnardi pupa	0	0	0	0	0	0	0	0	0
Orthotrichia	sp. C prepupa	0	0	0	0	0	0	0	0	0
Oxyethira	*?velocipes*	0	0	0	0	0	0	0	0	0
Athripsodes (harrisoni group)	sp. A	0	0	0	0	0	0	0	0	0
Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	0	0	0
Athripsodes (Ps group)	sp. B	0	0	0	0	0	0	0	0	0
Ceraclea	sp. A	0	0	0	0	0	0	0	0	0
Athripsodes (bergensis group)	sp. A	0	0	0	0	0	0	0	0	0
Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0	0	0	0
Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0	0	0	0
Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0	0	0	0
Leptecho	*helicotheca*	0	0	0	0	0	0	0	0	0
Leptecho	sp. E	0	0	0	0	0	0	0	0	0
Oecetis	sp. A	0	0	0	0	0	0	0	0	0
Oecetis	sp. B	0	0	0	0	0	0	0	0	0
Petrothrincus	*circularis*	0	0	0	0	0	0	0	0	0
Chimarra	sp. A	0	0	0	0	0	0	0	0	0
Philopotamid	juvenile spp.	0	0	0	0	0	0	0	0	0
Philopotamid	pupa spp.	0	0	0	0	0	0	0	0	0
Nyctiophylax	sp. A	0	0	0	0	0	0	0	0	0
Petroplax	?curvicosta	0	0	0	0	0	0	0	0	0
Abaria	sp. A	0	0	0	0	0	0	0	0	0
Xiphocentronid	juvenile spp.	0	0	0	0	0	0	0	0	0
Trichopteran	pupa spp.	0	0	20	20	30	0	0	0	0
Potamonautes	spp.	0	0	0	0	0	0	0	0	0
Hydra	spp.	0	0	0	0	0	0	0	0	0
Dugesia	spp.	0	0	0	0	0	0	0	0	0
Ferrissia	spp.	0	0	0	0	0	20	20	0	0
Gastropod	spp.	0	0	0	0	0	0	0	0	0
Pisidium	spp.	0	0	0	0	0	0	0	0	0
Bulinus	*tropicus*	0	0	0	0	0	0	0	0	0
Nematode	spp.	0	0	0	0	0	0	0	0	0

Appendix 8.11.5 continued

GENUS	SPECIES	KRIEDOUWKRANS KKS18	KKS19	KKS20	KKS21	KKS22	KKS23	KKS24	KKS25	KKMEAN
Lumbriculid	spp.	0	0	0	224	672	0	280	840	85.1
Nais	spp.	112	29232	56	448	616	2912	4144	2408	1882.4
Pristina	spp.	0	0	0	0	0	0	4088	56	165.6
Hydracarinid	spp.	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. A	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. B	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. C	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. D	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. E	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. F	0	0	0	0	0	0	0	0	0.0
Hydracarinid	sp. G	0	0	0	0	0	56	0	0	2.2
Hydracarinid	sp. H	0	0	0	0	0	0	0	0	0.0
Dryopid	sp. A	0	0	0	0	0	0	0	0	0.0
Hydaticus	sp. A	0	0	0	0	0	0	0	0	0.0
Bidessus	sp. A	0	0	0	0	0	0	0	0	0.0
?Leielmis	sp. A	0	0	0	0	0	0	0	0	0.4
Tropidelmis	sp. A	0	0	0	0	0	0	0	0	0.0
Pachyelmis	sp. A	0	0	0	0	0	0	0	0	0.0
Pachyelmis	sp. B	0	0	0	0	0	0	0	0	0.0
Peloriolus	*granulosus*	896	2072	504	2128	56	168	728	392	315.5
Elpidelmis	*capensis*	0	0	0	0	0	0	0	0	60.8
Elmid	sp. C	0	0	0	0	0	0	0	0	0.8
Prionocyphon	sp. A	0	0	0	0	0	0	0	0	0.0
Prionocyphon	sp. B	0	0	0	0	0	0	0	0	0.0
Helodid	sp. C	0	0	0	0	0	0	0	0	0.0
Hydraena	sp. A	0	0	0	0	0	0	0	0	0.0
Hydrophilid	sp. A	0	0	0	0	0	0	0	0	0.0
Hydrophilid	sp. B	0	0	0	0	0	0	0	0	0.0
Hydrophilid	sp. C	0	0	0	0	0	0	0	0	0.0
Limnichid	sp. A	0	0	0	0	0	0	0	0	0.0
Coleopteran	adult spp.	0	0	0	0	0	0	0	0	0.0
Isotoma	sp. A	0	0	0	0	0	0	0	0	0.0
Ceratopogonid	spp.	392	1008	56	504	392	616	616	1288	218.9
Forcipomyia	spp.	0	0	0	0	0	0	0	0	3.6
Polypedilum	*?articola*	224	336	168	75	78	83	336	448	670.6
Chironominid	sp. AX	0	0	0	0	0	0	0	0	0.0
Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0	0	0	8.0
Tanytarsus	sp. A	1680	784	504	835	582	317	168	224	351.8
Tanytarsus	sp. B	280	1120	560	167	134	317	392	560	153.7
Rheotanytarsus	sp. A	0	0	0	0	0	0	0	0	8.0
Cricotopus	*?flavozonatus*	0	0	0	0	0	0	0	0	0.0
Cricotopus	sp. A	0	0	0	0	0	0	0	0	0.0
Cricotopus	sp. B	0	0	0	0	0	0	0	0	80.4
Cricotopus	sp. C	56	0	56	0	0	0	0	0	295.0
Thienemanniella	sp. A	0	0	0	0	0	0	0	0	24.5
Thienemanniella	sp. B	0	0	0	0	0	0	0	0	3.8
Tvetenia	sp. A	0	0	0	0	0	0	0	0	3.1
Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0	0	0	0.0
Cricotopus	*scottae*	0	0	0	0	78	0	0	0	5.4
Corynoneura	sp. A	0	0	0	0	0	0	0	0	0.0
Conchapelopia	sp. A	0	0	0	0	0	0	0	0	3.8
Nilotanypus	*comatus*	0	0	0	0	0	0	0	0	7.9
Nilotanypus	sp. A	0	0	0	0	0	0	0	0	0.0
Ablabesmyia	*dusoleili*	112	336	56	0	190	0	0	56	133.4
Macropelopia	sp. A	112	280	0	0	0	0	112	112	35.0
Chironomid	pupa spp.	0	56	0	0	0	0	0	56	34.9
Culex	sp. A	0	0	0	0	0	0	0	0	0.4
Empidid	sp. A	0	0	0	0	0	0	0	0	0.0

Appendix 6.11.5 continued

GENUS	SPECIES	KRIEDOUWKRANS KKS18	KKS19	KKS20	KKS21	KKS22	KKS23	KKS24	KKS25	KKMEAN
Rhagionid	sp. A	0	0	0	0	0	0	0	0	0.0
Simuliid	larva spp.	0	0	0	0	0	0	0	0	62.0
Simuliid	pupa spp.	0	0	0	0	0	0	0	0	3.8
Antocha	sp. A	0	0	0	0	0	0	0	0	0.0
Dipteran	adult spp.	0	0	0	0	0	0	0	0	0.4
Dipteran	pupa spp.	0	0	0	0	0	0	0	0	0.0
Acentrella	*?capensis*	0	0	0	0	0	0	0	0	0.0
Afroptilum	sp. B	0	0	0	0	0	0	0	0	0.0
Afroptilum	*?indusii*	0	0	0	0	0	0	0	0	15.6
Afroptilum	*?tarsale*	0	0	0	0	0	0	0	0	0.0
Afroptilum	sp. C	0	0	0	0	0	0	0	0	0.0
Afroptilum	sp. D	0	0	0	0	0	0	0	0	0.0
Baetis	*?latus*	0	0	0	0	0	0	0	0	1.8
Baetis	*harrisoni complex*	0	0	0	0	0	0	0	0	33.6
?Demoulinia	complex A	56	112	0	112	0	0	0	56	88.6
Demoulinia	*crassi*	0	0	0	0	0	0	112	0	61.7
Pseudocloeon	*vinosum*	0	0	0	0	0	0	0	0	0.4
Pseudopannota	*maculosa*	0	0	0	0	0	0	0	0	6.8
Baetid	juvenile spp.	168	0	0	168	112	0	0	0	55.8
Caenis	*capensis*	560	56	0	0	0	0	224	0	37.4
Caenodes	sp. C	112	0	0	56	504	0	0	280	160.9
Caenodes	sp. H	0	0	0	0	0	0	0	0	55.6
Caenid	juvenile spp.	1008	560	112	224	280	504	1120	448	198.2
Lestagella	*penicillata*	0	0	0	0	0	0	0	0	0.0
Ephemerellina	complex A	0	0	0	0	0	0	0	0	0.0
Afronurus	*harrisoni*	0	0	0	0	0	0	0	0	0.0
Adenophlebia	*auriculata*	0	0	0	0	0	0	0	0	0.0
Aprionyx	complex A	0	0	0	0	0	0	0	0	0.0
Euthraulus	*elegans*	0	0	0	0	0	0	0	0	0.0
Choroterpes	*nigrescens*	0	0	0	0	0	0	0	0	0.0
Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0	0	0	0.0
Tricorythus	sp. A	0	0	0	0	0	0	0	0	1.2
Ephemeropteran	adult spp.	0	0	0	0	0	0	0	0	0.0
Corixid	sp. A	0	56	0	0	0	0	0	0	16.6
Corixid	sp. B	0	0	0	0	0	0	0	0	0.8
Plea	sp. A	0	0	0	0	0	0	0	0	0.0
Mesoveliid	sp. A	0	0	0	0	0	0	0	0	0.0
Veliid	sp. A	0	0	0	0	0	0	0	0	0.0
Pyralid	sp. A	0	0	0	0	0	0	0	0	7.8
Pyralid	sp. C	0	0	0	0	0	0	0	0	0.0
Chlorolestes	sp. A	0	0	0	0	0	0	0	0	0.0
Coenagrionid	sp. A	0	0	0	0	0	0	0	0	0.0
Aeschna	sp. A	0	0	0	0	0	0	0	0	0.0
Aeschna	sp. B	0	0	0	0	0	0	0	0	0.0
Corduliid	sp. A	0	0	0	0	0	0	0	0	0.0
Corduliid	juvenile spp.	0	0	0	0	0	0	0	0	0.8
Libellulid	sp. A	0	0	0	0	0	0	0	0	2.0
Libellulid	sp. B	0	0	0	0	0	0	0	0	1.8
Libellulid	sp. C	0	0	0	0	0	0	0	0	2.2
Libellulid	juvenile spp.	0	0	0	0	0	0	0	0	1.8
Notogomphus (?Paragomphus)	sp. A	0	0	56	56	56	168	0	0	27.3
Gomphid	juvenile spp.	56	0	0	0	0	0	0	0	11.2
Notonemourid	spp.	0	0	0	0	0	0	0	0	0.0
Barbarochthon	*brunneum*	0	0	0	0	0	0	0	0	0.0
Ecnomus	*thomasseti*	0	0	0	0	0	0	0	0	21.2
Ecnomid	juvenile spp.	0	0	0	0	0	0	0	0	0.0
Psychomyiellodes	sp. A	0	0	0	0	0	0	0	0	0.0
Parecnomina	sp. A	0	0	0	0	0	0	0	0	0.0
Agapetus	sp. A	0	0	0	0	0	0	0	0	0.0

Appendix 8.11.5 continued

GENUS	SPECIES	KRIEDOUWKRANS KKS18	KKS19	KKS20	KKS21	KKS22	KKS23	KKS24	KKS25	KKMEAN
Cheumatopsyche	*thomasseti*	0	0	0	0	0	0	0	0	24.4
Cheumatopsyche	*afra*	0	0	0	0	0	0	0	0	0.0
Cheumatopsyche	pupa spp.	0	0	0	0	0	0	0	0	0.0
Cheumatopsyche	spp.	0	0	0	0	0	0	0	0	0.4
Cheumatopsyche	juvenile spp.	0	0	0	0	0	0	0	0	11.6
Amphipsyche	?*scottae*	0	0	0	0	0	0	0	0	0.0
Amphipsyche	?scottae pupa	0	0	0	0	0	0	0	0	0.0
Amphipsyche	?scottae juvenile	0	0	0	0	0	0	0	0	0.0
Macrostemum	capense	0	0	0	0	0	0	0	0	0.0
Macrostemum	capense juvenile	0	0	0	0	0	0	0	0	0.0
Hydroptilid	juvenile instar (2-4th)	0	0	0	0	0	0	0	0	3.6
Hydroptila	*capensis*	0	0	0	0	0	0	0	0	4.8
Hydroptila	capensis pupa	0	0	0	0	0	0	0	0	4.0
Orthotrichia	sp. A	0	0	0	0	0	0	0	0	0.8
Orthotrichia	*barnardi*	0	0	0	0	0	0	0	0	0.0
Orthotrichia	barnardi pupa	0	0	0	0	0	0	0	0	0.0
Orthotrichia	sp. C prepupa	0	0	0	0	0	0	0	0	0.0
Oxyethira	?*velocipes*	0	0	0	0	0	0	0	0	0.0
Athripsodes (harrisoni group)	sp. A	0	0	0	0	0	0	0	0	0.0
Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	0	0	0.0
Athripsodes (Ps group)	sp. B	0	0	0	0	0	0	0	0	0.4
Ceraclea	sp. A	0	0	0	0	0	0	0	0	0.0
Athripsodes (bergensis group)	sp. A	0	0	0	0	0	0	0	0	0.0
Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0	0	0	1.2
Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0	0	0	0.0
Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0	0	0	0.0
Leptecho	*helicotheca*	0	0	0	0	0	0	0	0	0.0
Leptecho	sp. E	0	0	0	0	0	0	0	0	0.0
Oecetis	sp. A	0	0	0	0	0	0	0	0	0.0
Oecetis	sp. B	0	0	0	0	0	0	0	0	0.0
Petrothrincus	*circularis*	0	0	0	0	0	0	0	0	0.0
Chimarra	sp. A	0	0	0	0	0	0	0	0	1.2
Philopotamid	juvenile spp.	0	0	0	0	0	0	0	0	0.0
Philopotamid	pupa spp.	0	0	0	0	0	0	0	0	0.4
Nyctiophylax	sp. A	0	0	0	0	0	0	0	0	0.0
Petroplex	?ourwicaura	0	0	0	0	0	0	0	0	0.0
Abaria	sp. A	0	0	0	0	0	0	0	0	0.0
Xiphocentronid	juvenile spp.	0	0	0	0	0	0	0	0	0.0
Trichopteran	pupa spp.	0	0	0	0	0	0	0	0	3.2
Potamonautes	spp.	0	0	0	0	0	0	0	0	0.0
Hydra	spp.	0	0	0	0	0	0	0	0	0.0
Dugesia	spp.	0	0	0	0	0	0	0	0	0.0
Ferrissia	spp.	0	0	0	0	0	0	0	0	1.8
Gastropod	spp.	0	0	0	0	0	0	0	0	0.0
Pisidium	spp.	0	0	0	0	0	0	0	0	0.0
Bulinus	*tropicus*	0	0	0	0	0	0	0	0	0.0
Nematode	spp.	112	0	58	56	0	0	0	56	11.2

Appendix 6.11.6 Species-level benthic macroinvertebrate abundances for Clanwilliam summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	CLANWILLIAM CBR1	CBR2	CBR3	CBR4	CBR5	CBMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0.0
Naididae adult	*Nais*	spp.	3090	400	710	600	1260	1212.0
	Pristina	spp.	0	0	30	0	0	6.0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0	0.0
	Hydracarinid	sp. F	0	10	0	0	0	2.0
	Hydracarinid	sp. G	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0.0
Dytiscidae larva								
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0.0
Elmidae adult								
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	0	0	0	0	0	0.0
	Elpidelmis	*capensis*	0	0	0	10	0	2.0
	Elmid	sp. C	0	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0	0	0.0
	Helodid	sp. C	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	10	0	0	0	0	2.0
	Hydrophilid	sp. B	0	0	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	10	0	0	0	0	2.0
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	0	0.0
Chironomidae larva								
Chironominae								
Chironomini	*Polypedilum*	*?articola*	66	52	203	70	250	128.2
	Chironominid	sp. AX	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	0	12	93	20	160	57.0
	Tanytarsus	sp. B	0	12	0	0	0	2.4
	Rheotanytarsus	sp. A	16	0	0	10	10	7.2
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0	0.0
	Cricotopus	sp. A	0	0	0	0	0	0.0
	Cricotopus	sp. B	0	0	0	0	0	0.0
	Cricotopus	sp. C	496	152	373	110	760	378.2
	Thienemanniella	sp. A	0	0	0	0	0	0.0
	Thienemanniella	sp. B	0	0	0	0	0	0.0
	Tvetenia	sp. A	0	0	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0.0
	Cricotopus	*scottae*	0	0	0	0	100	20.0
	Corynoneura	sp. A	0	0	13	0	0	2.6
Tanypodinae	*Conchapelopia*	sp. A	0	0	0	0	10	2.0
	Nilotanypus	*comatus*	16	42	413	10	420	180.2
	Nilotanypus	sp. A	0	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	26	0	123	10	130	57.8
	Macropelopia	sp. A	0	0	13	0	0	2.6
Chironomidae pupa	Chironomid	pupa spp.	20	0	10	10	40	16.0
Culicidae larva								
Culicinae	*Culex*	sp. A	0	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	10	10	20	20	12.0

Appendix 8.11.6 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	CLANWILLIAM CBR1	CBR2	CBR3	CBR4	CBR5	CBMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	0	0	0	0	0	0.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	120	100	80	140	70	102.0
	Dipteran	adult spp.	0	0	0	0	0	0.0
	Dipteran	pupa spp.	0	0	0	0	0	0.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0	0	0.0
	Afroptilum	sp. C	0	0	0	0	0	0.0
	Afroptilum	sp. D	0	0	0	0	0	0.0
	Baetis	*?latus*	0	0	0	0	0	0.0
	Baetis	*harrisoni complex*	0	0	0	0	0	0.0
	?Demoulinia	complex A	0	0	0	0	0	0.0
	Demoulinia	*crassi*	0	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0	0	0.0
	Pseudopannota	*maculosa*	0	0	0	0	0	0.0
	Baetid	juvenile spp.	30	0	0	20	0	10.0
Caenidae larva	*Caenis*	*capensis*	0	0	0	0	0	0.0
	Caenodes	sp. C	0	0	0	0	0	0.0
	Caenodes	sp. H	0	0	0	0	0	0.0
	Caenid	juvenile spp.	0	0	0	0	0	0.0
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0.0
	Ephemerellina	complex A	0	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0	0	0.0
	Choroterpes	*nigrescens*	0	0	0	0	0	0.0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0	20	4.0
	Corixid	sp. B	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0	0	0.0
Corydalidae larva	*Chlorionella*	sp. A	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	0	0.0
	Libellulid	sp. C	0	0	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0	0	0.0
	Gomphid	juvenile spp.	0	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	0	0	0	0	0	0.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	20	70	60	70	44.0
	Ecnomid	juvenile spp.	0	0	30	10	0	8.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0.0
	Paracnomina	sp. A	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0.0

Appendix 8.11.6 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	CLANWILLIAM CBR1	CBR2	CBR3	CBR4	CBR5	CBMEAN
Hydropsychidae larva								
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	10	0	2.0
	Cheumatopsyche	*afra*	0	0	0	0	0	0.0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0.0
	Cheumatopsyche	spp.	10	0	0	0	0	2.0
	Cheumatopsyche	juvenile spp.	0	0	0	0	0	0.0
Macronematinae								
Macronematini	*Amphipsyche*	?*scottae*	0	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0.0
	Macrostemum	*capense*	0	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	20	0	0	0	0	4.0
	Hydroptila	*capensis*	30	0	0	0	0	6.0
	Hydroptila	capensis pupa	0	10	0	0	0	2.0
	Orthotrichia	sp. A	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0.0
	Oxyethira	?*velocipes*	0	0	0	0	0	0.0
Leptoceridae larva								
Leptocerinae								
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0.0
	Oecetis	sp. B	10	0	0	0	0	2.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0.0
	Philopotamid	juvenile spp.	0	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	?*curvicosta*	0	0	0	0	0	0.0
Xiphocentronidae larva	*Aberis*	sp. A	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	10	0	10	0	0	4.0
Mollusca	Gastropod	spp.	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	10	0	10	4.0

Appendix 8.11.7 Species-level benthic macroinvertebrate abundances for Langkloof summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	LANGKLOOF					
			LKS1	LKS2	LKS3	LKS4	LKS5	LKMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0.0
Naididae adult	*Nais*	spp.	56	56	168	0	6496	1355.2
	Pristina	spp.	336	7640	0	14000	0	4435.2
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0.0
Dytiscidae larva								
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0.0
Elmidae adult								
Elminthinae	*?Leleimis*	sp. A	0	0	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	0	0	0	0	0	0.0
	Elpidelmis	*capensis*	0	0	0	0	0	0.0
	Elmid	sp. C	0	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0	0	0.0
	Helodid	sp. C	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	56	56	56	0	112	56.0
Forcipomyinae	*Forcipomyia*	spp.	0	0	0	0	0	0.0
Chironomidae larva								
Chironominae								
Chironomini	*Polypedilum*	?articola	336	280	840	560	406	484.4
	Chironominid	sp. AX	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	280	280	1176	392	0	425.6
	Tanytarsus	sp. B	728	280	504	504	294	462.0
	Rheotanytarsus	sp. A	0	0	0	0	0	0.0
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0	0.0
	Cricotopus	sp. A	0	0	0	0	0	0.0
	Cricotopus	sp. B	0	0	0	0	0	0.0
	Cricotopus	sp. C	168	112	56	0	70	81.2
	Thienemanniella	sp. A	0	0	0	0	0	0.0
	Thienemanniella	sp. B	0	0	0	0	0	0.0
	Tvetenia	sp. A	0	0	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0.0
	Cricotopus	*scottae*	0	0	0	0	0	0.0
	Corynoneura	sp. A	0	0	0	0	0	0.0
Tanypodinae	*Conchapelopia*	sp. A	0	0	0	0	0	0.0
	Nilotanypus	*comatus*	0	0	0	0	0	0.0
	Nilotanypus	sp. A	0	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	56	56	0	0	0	22.4
	Macropelopia	sp. A	56	0	448	168	126	159.6
Chironomidae pupa	Chironomid	pupa spp.	0	0	0	0	0	0.0
Culicidae larva								
Culicinae	*Culex*	sp. A	0	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	0	0	0	0.0

Appendix 8.11.7 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	LANGKLOOF LKS1	LKS2	LKS3	LKS4	LKS5	LKMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	0	0	0	0	0	0.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	0	0	0	0	0	0.0
	Dipteran	adult spp.	0	56	0	0	0	11.2
	Dipteran	pupa spp.	0	0	0	0	0	0.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0	0	0.0
	Afroptilum	sp. C	0	0	0	0	0	0.0
	Afroptilum	sp. D	0	0	0	0	0	0.0
	Baetis	*?latus*	0	56	0	0	0	11.2
	Baetis	*harrisoni complex*	0	0	0	0	0	0.0
	?Demoulinia	complex A	0	0	0	0	0	0.0
	Demoulinia	*crassi*	0	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0	0	0.0
	Pseudopannota	*maculosa*	0	0	0	0	0	0.0
	Baetid	juvenile spp.	0	56	56	0	0	22.4
Caenidae larva	*Caenis*	*capensis*	0	0	0	0	0	0.0
	Caenodes	sp. C	0	0	0	0	0	0.0
	Caenodes	sp. H	0	0	0	0	0	0.0
	Caenid	juvenile spp.	112	0	56	0	56	44.6
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0.0
	Ephemerellina	complex A	0	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0	0	0.0
	Choroterpes	*nigrescence*	0	0	0	0	0	0.0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	56	11.2
Corixidae adult	Corixid	sp. A	0	0	0	0	0	0.0
	Corixid	sp. B	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0	56	11.2
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0	0	0.0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	0	0.0
	Libellulid	sp. C	0	0	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	56	0	0	0	0	11.2
	Gomphid	juvenile spp.	0	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	0	0	0	0	0	0.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	0	0	0	0	0.0
	Ecnomid	juvenile spp.	0	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0.0
	Parecnomina	sp. A	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0.0

Appendix 8.11.7 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	LANGKLOOF LKS1	LKS2	LKS3	LKS4	LKS5	LKMEAN
Hydropsychidae larva								
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	0	0	0.0
	Cheumatopsyche	*afra*	0	0	0	0	0	0.0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0.0
	Cheumatopsyche	spp.	0	0	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	0	0	0	0	0	0.0
Macronematinae								
Macronematini	*Amphipsyche*	?scottae	0	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0.0
	Macrostemum	capense	0	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	0	0	0	0	0.0
	Hydroptila	*capensis*	0	0	0	0	0	0.0
	Hydroptila	capensis pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0.0
	Oxyethira	?*velocipes*	0	0	0	0	0	0.0
Leptoceridae larva								
Leptocerinae								
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0.0
	Oecetis	sp. B	0	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0.0
	Philopotamid	juvenile spp.	0	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	?curvicosta	0	0	0	0	0	0.0
Xiphocentronidae larva	*Aberia*	sp A	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	0	0	0	0.0

Appendix 8.11.8 Species-level benthic macroinvertebrate abundances for Bulshoek summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BULSHOEK					
			BDR1	BDR2	BDR3	BDR4	BDR5	BDMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	0	0.0
Naididae adult	*Nais*	spp.	6050	0	0	90	44	1236.8
	Pristina	spp.	0	270	0	90	44	80.8
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	10	0	2.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0.0
Dytiscidae larva								
Dytiscini	*Hydaticus*	sp. A	40	0	0	0	0	8.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0.0
Elmidae adult								
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	0	0	0	0	0	0.0
	Elpidelmis	*capensis*	0	0	0	0	0	0.0
	Elmid	sp. C	0	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0	0	0.0
	Helodid	sp. C	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	10	2.0
	Hydrophilid	sp. C	0	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	200	0	0	30	0	46.0
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	10	2.0
Chironomidae larva								
Chironominae								
Chirinomini	*Polypedilum*	*?articola*	240	660	10	170	192	254.4
	Chironominid	sp. AX	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	20	0	0	0	4.0
Tanytarsini	*Tanytarsus*	sp. A	3340	20	10	170	52	718.4
	Tanytarsus	sp. B	0	0	0	10	12	4.4
	Rheotanytarsus	sp. A	40	520	0	100	202	172.4
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0	0.0
	Cricotopus	sp. A	0	0	0	0	0	0.0
	Cricotopus	sp. B	0	50	0	0	0	10.0
	Cricotopus	sp. C	330	0	0	70	0	80.0
	Thienemanniella	sp. A	0	0	0	0	0	0.0
	Thienemanniella	sp. B	0	0	0	0	0	0.0
	Tvetenia	sp. A	0	0	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0.0
	Cricotopus	*scottae*	250	0	0	40	0	58.0
	Corynoneura	sp. A	0	0	0	0	0	0.0
Tanypodinae	*Conchapelopia*	sp. A	0	0	0	0	0	0.0
	Nilotanypus	*comatus*	0	0	0	0	0	0.0
	Nilotanypus	sp. A	0	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	120	0	40	0	22	36.4
	Macropelopia	sp. A	0	0	20	0	0	4.0
Chironomidae pupa	Chironomid	pupa spp.	40	50	0	0	30	24.0
Culicidae larva								
Culicinae	*Culex*	sp. A	0	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	0	0	10	2.0

Appendix 8.11.8 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BULSHOEK BDR1	BDR2	BDR3	BDR4	BDR5	BDMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	0	120	0	0	10	26.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	0	0	0	10	0	2.0
	Dipteran	adult spp.	0	0	0	0	0	0.0
	Dipteran	pupa spp.	0	10	0	10	20	8.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0	0	0.0
	Afroptilum	sp. C	0	0	0	0	0	0.0
	Afroptilum	sp. D	0	0	0	0	0	0.0
	Baetis	*?latus*	0	0	0	0	0	0.0
	Baetis	*harrisoni complex*	0	60	0	0	0	12.0
	?Demoulinia	complex A	0	20	0	30	30	16.0
	Demoulinia	*crassi*	0	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0	0	0.0
	Pseudopannota	*maculosa*	0	10	0	10	170	38.0
	Baetid	juvenile spp.	0	120	0	660	380	232.0
Caenidae larva	*Caenis*	*capensis*	0	0	0	0	0	0.0
	Caenodes	sp. C	0	0	0	0	0	0.0
	Caenodes	sp. H	0	0	0	0	0	0.0
	Caenid	juvenile spp.	40	0	0	0	0	8.0
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0.0
	Ephemerellina	complex A	0	0	0	0	0	0.0
Heptagenidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0	0	0.0
	Choroterpes	*nigrescence*	0	0	0	0	0	0.0
	Leptophlebiid (?*Choroterpes*)	juvenile spp.	0	0	0	0	0	0.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	360	0	0	0	0	72.0
	Corixid	sp. B	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0	0	0.0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	0	0.0
	Libellulid	sp. C	160	0	20	0	0	36.0
	Libellulid	juvenile spp.	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0	0	0.0
	Gomphid	juvenile spp.	0	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	0	0	0	0	0	0.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	0	0	0	0	0.0
	Ecnomid	juvenile spp.	0	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0.0
	Parecnomina	sp. A	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0.0

Appendix 8.11.8 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BULSHOEK BDR1	BDR2	BDR3	BDR4	BDR5	BDMEAN
Hydropsychidae larva								
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	0	10	2.0
	Cheumatopsyche	*afra*	0	0	0	10	0	2.0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0.0
	Cheumatopsyche	spp.	0	0	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	0	10	0	0	10	4.0
Macronematinae								
Macronematini	*Amphipsyche*	?scottae	0	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0.0
	Macrostemum	capense	0	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	0	0	20	10	6.0
	Hydroptila	capensis	0	0	0	0	0	0.0
	Hydroptila	capensis pupa	40	0	0	0	0	8.0
	Orthotrichia	sp. A	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0.0
	Oxyethira	*?velocipes*	0	0	0	20	20	8.0
Leptoceridae larva								
Leptocerinae								
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0.0
	Oecetis	sp. B	0	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	circularis	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0.0
	Philopotamid	juvenile spp.	0	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	?curvicosta	0	0	0	0	0	0.0
Xiphocentronidae larva	*Aberia*	sp. A	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	0	0	0	0.0

Appendix 8.11.9 Species-level benthic macroinvertebrate abundances for Zypherfontein summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	ZYPHERFONTEIN ZFS1	 ZFS2	 ZFS3	 ZFMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0.0
Naididae adult	*Nais*	spp.	3927	0	0	1309.0
	Pristina	spp.	0	0	0	0.0
Hydracarina	Hydracarinid	spp.	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0.0
Dytiscidae larva						
Dytiscini	*Hydaticus*	sp. A	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0.0
Elmidae adult						
Elminthinae	*?Leleimis*	sp. A	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	0	0	0	0.0
	Elpidelmis	*capensis*	0	0	0	0.0
	Elmid	sp. C	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0.0
	Helodid	sp. C	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	0	0	1428	476.0
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0.0
Chironomidae larva						
Chironominae						
Chironomini	*Polypedilum*	*?articola*	0	0	5069	1689.7
	Chironominid	sp. AX	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	357	0	1142	499.7
	Tanytarsus	sp. B	0	357	0	119.0
	Rheotanytarsus	sp. A	0	0	0	0.0
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0.0
	Cricotopus	sp. A	0	0	0	0.0
	Cricotopus	sp. B	0	0	0	0.0
	Cricotopus	sp. C	357	0	0	119.0
	Thienemanniella	sp. A	0	0	0	0.0
	Thienemanniella	sp. B	0	0	0	0.0
	Tvetenia	sp. A	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0.0
	Cricotopus	*scottae*	0	0	2570	856.7
	Corynoneura	sp. A	0	0	0	0.0
Tanypodinae	*Conchapelopia*	sp. A	0	0	0	0.0
	Nilotanypus	*comatus*	0	0	0	0.0
	Nilotanypus	sp. A	0	0	0	0.0
	Ablabesmyia	*dusoleili*	0	0	785	261.7
	Macropelopia	sp. A	0	714	2213	975.7
Chironomidae pupa	Chironomid	pupa spp.	357	0	0	119.0
Culicidae larva						
Culicinae	*Culex*	sp. A	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	0	0.0

Appendix 8.11.9 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	ZYPHERFONTEIN ZFS1	ZFS2	ZFS3	ZFMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	0	0	0	0.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	0	0	0	0.0
	Dipteran	adult spp.	0	0	0	0.0
	Dipteran	pupa spp.	0	0	0	0.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	0.0
	Afroptilum	sp. C	0	0	0	0.0
	Afroptilum	sp. D	0	0	0	0.0
	Baetis	*?latus*	0	0	0	0.0
	Baetis	*harrisoni complex*	0	0	0	0.0
	?Demoulinia	complex A	0	0	0	0.0
	Demoulinia	*crassi*	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0.0
	Pseudopannota	*maculosa*	0	0	0	0.0
	Baetid	juvenile spp.	0	0	0	0.0
Caenidae larva	*Caenis*	*capensis*	0	0	0	0.0
	Caenodes	sp. C	0	0	0	0.0
	Caenodes	sp. H	0	0	0	0.0
	Caenid	juvenile spp.	0	0	0	0.0
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0.0
	Ephemerelline	complex A	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0.0
	Choroterpes	*nigrascence*	0	0	0	0.0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0.0
	Corixid	sp. B	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	0	0.0
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0.0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0.0
	Libellulid	sp. C	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0.0
	Gomphid	juvenile spp.	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	0	0	0	0.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	0	0	0.0
	Ecnomid	juvenile spp.	0	0	357	119.0
	Psychomyiellodes	sp. A	0	0	0	0.0
	Parecnomina	sp. A	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0.0

Appendix 8.11.9 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	ZYPHERFONTEIN			
			ZFS1	ZFS2	ZFS3	ZFMEAN
Hydropsychidae larva						
Hydropsychinae	*Cheumatopsyche*	*thomassetti*	0	0	0	0.0
	Cheumatopsyche	*afra*	0	0	0	0.0
	Cheumatopsyche	pupa spp.	0	0	0	0.0
	Cheumatopsyche	spp.	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	0	0	0	0.0
Macronematinae						
Macronematini	*Amphipsyche*	*?scottae*	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0.0
	Macrostemum	*capense*	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	0	0	0	0.0
	Hydroptila	*capensis*	0	0	0	0.0
	Hydroptila	capensis pupa	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0.0
	Orthotrichia	barnardi pupa	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0.0
	Oxyethira	*?velocipes*	0	0	0	0.0
Leptoceridae larva						
Leptocerinae						
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0.0
	Oecetis	sp. B	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0.0
	Philopotamid	juvenile spp.	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	*?aurivicosta*	0	0	0	0.0
Xiphocentronidae larva	*Abaria*	sp. A	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	714	238.0
Mollusca: Planorbidae	Bulinus	*tropicus*	0	0	0	0.0
Nematoda	Nematode	spp.	1071	0	2499	1190.0

Appendix 8.11.10 Species-level benthic macroinvertebrate abundances for Klawer summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	KLAWER KWS1	KWS2	KWS3	KWS4	KWS5	KWMEAN
Lumbriculidae adult	Lumbriculid	spp.	56	0	56	0	0	22.4
Naididae adult	*Nais*	spp.	280	0	9072	11536	896	4356.8
	Pristina	spp.	0	0	560	0	0	112.0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0.0
Dytiscidae larva								
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	56	11.2
Elmidae adult								
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	0	0	0	0	0	0.0
	Elpidelmis	*capensis*	0	0	0	0	0	0.0
	Elmid	sp. C	0	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0	0	0.0
	Helodid	sp. C	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	0	0.0
	Hydrophilid	sp. C	56	0	0	0	0	11.2
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	0	0.0
Ceratopogonidae larva	Ceratopogonid	spp.	224	0	1064	224	952	492.8
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	0	0.0
Chironomidae larva								
Chironominae								
Chironomini	*Polypedilum*	*?articola*	2576	1064	2632	952	6896	2824.0
	Chironominid	sp. AX	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	0	0	0	0	0	0.0
	Tanytarsus	sp. B	23968	560	12432	21112	16136	14841.6
	Rheotanytarsus	sp. A	0	0	0	0	0	0.0
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0	0.0
	Cricotopus	sp. A	0	0	0	0	0	0.0
	Cricotopus	sp. B	0	0	0	0	0	0.0
	Cricotopus	sp. C	0	0	392	0	400	158.4
	Thienemanniella	sp. A	0	0	0	0	0	0.0
	Thienemanniella	sp. B	0	0	0	0	0	0.0
	Tvetenia	sp. A	0	0	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0.0
	Cricotopus	*scottae*	840	112	392	0	1128	494.4
	Corynoneura	sp. A	0	0	0	0	0	0.0
Tanypodinae	*Conchapelopia*	sp. A	1120	0	392	2744	1352	1121.6
	Nilotanypus	*comatus*	0	0	0	0	0	0.0
	Nilotanypus	sp. A	0	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	0	0	840	616	64	304.0
	Macropelopia	sp. A	0	0	0	0	400	80.0
Chironomidae pupa	Chironomid	pupa spp.	168	112	280	56	224	168.0
Culicidae larva								
Culicinae	*Culex*	sp. A	0	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	56	0	0	11.2

Appendix 8.11.10 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	KLAWER KWS1	KWS2	KWS3	KWS4	KWS5	KWMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	0	0	0	0	0	0.0
Simuliidae pupa	Simuliid	pupa spp.	0	0	0	0	0	0.0
Tipulidae larva	*Antocha*	sp. A	0	0	0	0	0	0.0
	Dipteran	adult spp.	0	0	0	0	0	0.0
	Dipteran	pupa spp.	0	0	0	0	0	0.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	0	0	0	0.0
	Afroptilum	*?tarsale*	0	0	0	382	0	76.4
	Afroptilum	sp. C	0	0	0	0	0	0.0
	Afroptilum	sp. D	0	0	0	0	0	0.0
	Baetis	*?latus*	0	0	0	0	0	0.0
	Baetis	*harrisoni complex*	0	0	0	0	0	0.0
	?Demoulinia	complex A	1512	56	0	0	56	324.8
	Demoulinia	*crassi*	0	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0	0	0.0
	Pseudopannota	*maculosa*	0	0	0	0	0	0.0
	Baetid	juvenile spp.	2352	0	168	1120	728	873.6
Caenidae larva	*Caenis*	*capensis*	0	0	0	0	0	0.0
	Caenodes	sp. C	112	0	0	168	0	56.0
	Caenodes	sp. H	0	0	0	0	0	0.0
	Caenid	juvenile spp.	336	0	112	336	56	168.0
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0.0
	Ephemerellina	complex A	0	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0	0	0.0
	Choroterpes	*nigrescence*	0	0	0	0	0	0.0
	Leptophlebiid (?*Choroterpes*)	juvenile spp.	0	0	0	0	0	0.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0	0	0.0
	Corixid	sp. B	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	56	112	56	44.8
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	0.0
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0	0	0.0
Corydalidae larva	*Chlorionella*	sp. A	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0.0
Aeschnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	56	11.2
	Libellulid	sp. C	0	0	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	112	56	0	56	56	56.0
	Gomphid	juvenile spp.	56	0	0	56	0	22.4
Notonemouridae larva	Notonemourid	spp.	0	0	0	0	0	0.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	0	0	0	0	0.0
	Ecnomid	juvenile spp.	0	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0.0
	Parecnomina	sp. A	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0.0

Appendix 8.11.10 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	KWS1	KWS2	KLAWER KWS3	KWS4	KWS5	KWMEAN
Hydropsychidae larva								
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	0	0	0	0	0	0.0
	Cheumatopsyche	*afra*	0	0	0	0	0	0.0
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0.0
	Cheumatopsyche	spp.	0	0	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	0	0	0	0	0	0.0
Macronematinae								
Macronematini	*Amphipsyche*	?*scottae*	0	0	0	0	0	0.0
	Amphipsyche	?scottae pupa	0	0	0	0	0	0.0
	Amphipsyche	?scottae juvenile	0	0	0	0	0	0.0
	Macrostemum	*capense*	0	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	56	0	0	0	0	11.2
	Hydroptila	*capensis*	0	0	0	0	56	11.2
	Hydroptila	capensis pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	56	0	0	0	0	11.2
	Orthotrichia	barnardi pupa	0	0	0	0	0	0.0
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0.0
	Oxyethira	?*velocipes*	0	0	0	0	0	0.0
Leptoceridae larva								
Leptocerinae								
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0	0	0.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0.0
	Oecetis	sp. B	0	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0.0
	Philopotamid	juvenile spp.	0	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplex*	?*curvicosta*	0	0	0	0	0	0.0
Xiphocentronidae larva	*Aberia*	sp. A	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0.0
	Trichopteran	pupa spp.	0	0	0	0	0	0.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	0	0	0	0	0.0
Hydridae adult	*Hydra*	spp.	1680	0	0	784	0	492.8
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	0	0	0.0
Mollusca	Gastropod	spp.	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	0	0	0.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	336	0	112	56	0	100.8
Nematoda	Nematode	spp.	0	0	0	0	0	0.0

Appendix 8.11.11 Species-level benthic macroinvertebrate abundances for Botha's Farm summer samples

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BOTHA'S FARM BFR1	BFR2	BFR3	BFS4	BFS5	BFS6	BFMEAN
Lumbriculidae adult	Lumbriculid	spp.	0	0	0	0	280	56	56.0
Naididae adult	*Nais*	spp.	0	10	0	168	728	1456	393.7
	Pristina	spp.	0	0	0	56	0	448	84.0
Hydracarina	Hydracarinid	spp.	0	0	0	0	0	0	0.0
	Hydracarinid	sp. A	0	0	0	0	0	0	0.0
	Hydracarinid	sp. B	0	0	0	0	0	0	0.0
	Hydracarinid	sp. C	0	0	0	0	0	0	0.0
	Hydracarinid	sp. D	0	0	0	0	0	0	0.0
	Hydracarinid	sp. E	0	0	0	0	0	0	0.0
	Hydracarinid	sp. F	0	0	0	0	0	0	0.0
	Hydracarinid	sp. G	0	0	0	0	0	0	0.0
	Hydracarinid	sp. H	0	0	0	0	0	0	0.0
Dryopidae larva	Dryopid	sp. A	0	0	0	0	0	0	0.0
Dytiscidae larva									
Dytiscini	*Hydaticus*	sp. A	0	0	0	0	0	0	0.0
Hydroporinae	*Bidessus*	sp. A	0	0	0	0	0	0	0.0
Elmidae adult									
Elminthinae	*?Leielmis*	sp. A	0	0	0	0	0	0	0.0
	Tropidelmis	sp. A	0	0	0	0	0	0	0.0
	Pachyelmis	sp. A	0	0	0	0	0	0	0.0
	Pachyelmis	sp. B	0	0	0	0	0	0	0.0
Elmidae larva	*Peloriolus*	*granulosus*	0	0	0	0	0	0	0.0
	Elpidelmis	*capensis*	0	0	0	0	0	0	0.0
	Elmid	sp. C	0	0	0	0	0	0	0.0
Helodidae larva	*Prionocyphon*	sp. A	0	0	0	0	0	0	0.0
	Prionocyphon	sp. B	0	0	0	0	0	0	0.0
	Helodid	sp. C	0	0	0	0	0	0	0.0
Hydraenidae adult	*Hydraena*	sp. A	0	0	0	0	0	0	0.0
Hydrophilidae larva	Hydrophilid	sp. A	0	0	0	0	0	0	0.0
	Hydrophilid	sp. B	0	0	0	0	0	0	0.0
	Hydrophilid	sp. C	0	0	0	0	0	0	0.0
Limnichidae larva	Limnichid	sp. A	0	0	0	0	0	0	0.0
	Coleopteran	adult spp.	0	0	0	0	0	0	0.0
Isotomidae larva	*Isotoma*	sp. A	0	0	0	0	56	0	9.3
Ceratopogonidae larva	Ceratopogonid	spp.	0	0	0	56	56	0	16.7
Forcipomyiinae	*Forcipomyia*	spp.	0	0	0	0	0	0	0.0
Chironomidae larva									
Chironominae									
Chironomini	*Polypedilum*	*?articola*	210	84	131	112	2968	784	716.5
	Chironominid	sp. AX	0	0	0	0	0	0	0.0
	Orthocladius Eudactylocladius	sp. A	0	0	0	0	0	0	0.0
Tanytarsini	*Tanytarsus*	sp. A	0	0	0	0	0	0	0.0
	Tanytarsus	sp. B	1550	354	541	1344	12712	17808	5718.2
	Rheotanytarsus	sp. A	0	0	0	0	0	0	0.0
Orthocladiinae	*Cricotopus*	*?flavozonatus*	0	0	0	0	0	0	0.0
	Cricotopus	sp. A	0	0	0	0	0	0	0.0
	Cricotopus	sp. B	210	354	1341	0	0	224	354.8
	Cricotopus	sp. C	210	264	71	0	336	0	146.8
	Thienemanniella	sp. A	0	0	0	0	0	0	0.0
	Thienemanniella	sp. B	0	0	0	0	0	0	0.0
	Tvetenia	sp. A	0	0	0	0	0	0	0.0
	Harnischia/Polypedilum type	sp. A	0	0	0	0	0	0	0.0
	Cricotopus	*scottae*	70	174	71	0	0	0	52.5
	Corynoneura	sp. A	420	1734	1481	504	2240	1736	1352.5
Tanypodinae	*Conchapelopia*	sp. A	780	354	401	1792	2240	2912	1413.2
	Nilotanypus	*comatus*	70	0	0	0	0	0	11.7
	Nilotanypus	sp. A	0	0	0	0	0	0	0.0
	Ablabesmyia	*dusoleili*	0	94	0	0	0	0	15.7
	Macropelopia	sp. A	0	0	0	0	0	0	0.0
Chironomidae pupa	Chironomid	pupa spp.	70	50	100	112	112	560	167.3
Culicidae larva									
Culicinae	*Culex*	sp. A	0	0	0	0	0	0	0.0
Empididae larva	Empidid	sp. A	0	0	10	0	0	56	11.0

Appendix 6.11.11 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BOTHA'S FARM BFR1	BFR2	BFR3	BFS4	BFS5	BFS6	BFMEAN
Rhagionidae larva	Rhagionid	sp. A	0	0	0	0	0	0	0.0
Simuliidae larva	Simuliid	larva spp.	20	10	30	0	0	0	10.0
Simuliidae pupa	Simuliid	pupa spp.	0	10	0	0	0	0	1.7
Tipulidae larva	*Antocha*	sp. A	0	0	0	0	0	0	0.0
	Dipteran	adult spp.	20	0	40	0	0	0	10.0
	Dipteran	pupa spp.	0	0	0	0	0	0	0.0
Baetidae larva	*Acentrella*	*?capensis*	0	0	0	0	0	0	0.0
	Afroptilum	sp. B	0	0	0	0	0	0	0.0
	Afroptilum	*?indusii*	0	0	10	0	0	0	1.7
	Afroptilum	*?tarsale*	0	0	0	0	0	0	0.0
	Afroptilum	sp. C	0	0	0	0	0	0	0.0
	Afroptilum	sp. D	0	0	0	0	0	0	0.0
	Baetis	*?latus*	220	90	120	168	0	0	99.7
	Baetis	*harrisoni complex*	0	0	0	0	0	0	0.0
	?Demoulinia	complex A	10	10	0	0	392	280	115.3
	Demoulinia	*crassi*	0	0	0	0	0	0	0.0
	Pseudocloeon	*vinosum*	0	0	0	0	0	168	28.0
	Pseudopannota	*maculosa*	0	0	0	0	0	0	0.0
	Baetid	juvenile spp.	20	20	10	56	168	112	64.3
Caenidae larva	*Caenis*	*capensis*	20	0	0	168	616	728	255.3
	Caenodes	sp. C	0	0	30	0	0	168	33.0
	Caenodes	sp. H	0	0	0	0	0	0	0.0
	Caenid	juvenile spp.	0	0	20	112	56	0	31.3
Ephemerellidae larva	*Lestagella*	*penicillata*	0	0	0	0	0	0	0.0
	Ephemerellina	complex A	0	0	0	0	0	0	0.0
Heptageniidae larva	*Afronurus*	*harrisoni*	0	0	0	0	0	0	0.0
Leptophlebiidae larva	*Adenophlebia*	*auriculata*	0	0	0	0	0	0	0.0
	Aprionyx	complex A	0	0	0	0	0	0	0.0
	Euthraulus	*elegans*	0	0	0	0	0	0	0.0
	Choroterpes	*nigrescence*	0	0	0	0	0	0	0.0
	Leptophlebiid (?Choroterpes)	juvenile spp.	0	0	0	0	0	0	0.0
Tricorythidae larva	*Tricorythus*	sp. A	0	0	0	0	0	0	0.0
	Ephemeropteran	adult spp.	0	0	0	0	0	0	0.0
Corixidae adult	Corixid	sp. A	0	0	0	0	0	0	0.0
	Corixid	sp. B	0	0	0	0	0	0	0.0
Pleidae adult	*Plea*	sp. A	0	0	10	0	0	0	1.7
Mesoveliidae adult	Mesoveliid	sp. A	0	0	0	0	0	56	9.3
Veliidae adult	Veliid	sp. A	0	0	0	0	0	0	0.0
Pyralidae larva	Pyralid	sp. A	0	0	0	0	0	0	0.0
	Pyralid	sp. C	0	0	0	0	0	0	0.0
Corydalidae larva	*Chloroniella*	sp. A	0	0	0	0	0	0	0.0
Coenagrionidae larva	Coenagrionid	sp. A	0	0	0	0	0	0	0.0
Aeshnidae larva	*Aeschna*	sp. A	0	0	0	0	0	0	0.0
	Aeschna	sp. B	0	0	0	0	0	0	0.0
Corduliidae larva	Corduliid	sp. A	0	0	0	0	0	0	0.0
	Corduliid	juvenile spp.	0	0	0	0	0	0	0.0
Libellulidae larva	Libellulid	sp. A	0	0	0	0	0	0	0.0
	Libellulid	sp. B	0	0	0	0	0	0	0.0
	Libellulid	sp. C	0	0	0	0	0	0	0.0
	Libellulid	juvenile spp.	0	0	0	0	0	0	0.0
Gomphidae larva	*Notogomphus (?Paragomphus)*	sp. A	0	0	0	0	56	0	9.3
	Gomphid	juvenile spp.	0	0	0	0	0	0	0.0
Notonemouridae larva	Notonemourid	spp.	0	0	0	0	0	0	0.0
Barbarochthonidae larva	*Barbarochthon*	*brunneum*	0	0	0	0	0	0	0.0
Ecnomidae larva	*Ecnomus*	*thomasseti*	0	0	0	0	56	0	9.3
	Ecnomid	juvenile spp.	0	0	0	0	0	0	0.0
	Psychomyiellodes	sp. A	0	0	0	0	0	0	0.0
	Paracnomina	sp. A	0	0	0	0	0	0	0.0
Glossosomatidae larva	*Agapetus*	sp. A	0	0	0	0	0	0	0.0

Appendix 6.11.11 continued

FAMILY/TAXON SUBFAMILY TRIBE	GENUS	SPECIES	BOTHA'S FARM BFR1	BFR2	BFR3	BFS4	BFS5	BFS6	BFMEAN
Hydropsychidae larva									
Hydropsychinae	*Cheumatopsyche*	*thomasseti*	686	341	1180	952	2240	2072	1245.2
	Cheumatopsyche	*afra*	914	168	2380	112	224	616	735.8
	Cheumatopsyche	pupa spp.	0	0	0	0	0	0	0.0
	Cheumatopsyche	spp.	0	0	0	0	0	0	0.0
	Cheumatopsyche	juvenile spp.	90	170	610	672	784	896	537.0
Macronematinae									
Macronematini	*Amphipsyche*	?*scotiae*	100	190	350	0	504	504	274.7
	Amphipsyche	?scotiae pupa	20	10	0	0	0	0	5.0
	Amphipsyche	?scotiae juvenile	0	10	160	0	168	560	149.7
	Macrostemum	capense	0	0	0	0	0	0	0.0
	Macrostemum	capense juvenile	0	0	0	0	0	0	0.0
Hydroptilidae larva	Hydroptilid	juvenile instar (2-4th)	10	0	0	0	0	0	1.7
	Hydroptila	capensis	0	0	0	0	0	56	9.3
	Hydroptila	capensis pupa	0	0	0	0	0	0	0.0
	Orthotrichia	sp. A	0	0	0	0	0	0	0.0
	Orthotrichia	*barnardi*	0	0	0	0	0	168	28.0
	Orthotrichia	barnardi pupa	0	0	0	56	0	0	9.3
	Orthotrichia	sp. C prepupa	0	0	0	0	0	0	0.0
	Oxyethira	?*velocipes*	0	0	0	0	0	0	0.0
Leptoceridae larva									
Leptocerinae									
Athripsodini	*Athripsodes (harrisoni group)*	sp. A	0	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. A	0	0	0	0	0	0	0.0
	Athripsodes (Ps group)	sp. B	0	0	0	0	0	0	0.0
	Ceraclea	sp. A	0	0	0	0	0	0	0.0
Leptocerini	*Athripsodes (bergensis group)*	sp. A	0	0	0	0	0	0	0.0
	Athripsodes ?(bergensis group)	sp. B	0	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. C	0	0	0	0	0	0	0.0
	Athripsodes (bergensis group)	sp. D	0	0	0	0	0	0	0.0
	Leptecho	*helicotheca*	0	0	0	0	0	0	0.0
	Leptecho	sp. E	0	0	0	0	0	0	0.0
Oecetini	*Oecetis*	sp. A	0	0	0	0	0	0	0.0
	Oecetis	sp. B	0	0	0	0	0	0	0.0
Petrothrincidae larva	*Petrothrincus*	*circularis*	0	0	0	0	0	0	0.0
Philopotamidae larva	*Chimarra*	sp. A	0	0	0	0	0	0	0.0
	Philopotamid	juvenile spp.	0	0	0	0	0	0	0.0
	Philopotamid	pupa spp.	0	0	0	0	0	0	0.0
Polycentropodidae larva	*Nyctiophylax*	sp. A	0	0	0	0	0	0	0.0
Sericostomatidae larva	*Petroplax*	?*curvicosta*	0	0	0	0	0	0	0.0
Xiphocentronidae larva	*Abaria*	sp. A	0	0	0	0	0	0	0.0
	Xiphocentronid	juvenile spp.	0	0	0	0	0	0	0.0
	Trichopteran	pupa spp.	20	0	20	0	56	0	16.0
Crustacea: Potamonidae	*Potamonautes*	spp.	0	10	0	56	0	0	11.0
Hydridae adult	*Hydra*	spp.	0	0	0	0	0	0	0.0
Tricladida	*Dugesia*	spp.	0	0	0	0	0	0	0.0
Mollusca: Ancylidae	*Ferrissia*	spp.	0	0	0	56	224	280	93.3
Mollusca	Gastropod	spp.	0	0	0	0	0	0	0.0
Mollusca: Sphaeriidae	*Pisidium*	spp.	0	0	0	56	56	56	28.0
Mollusca: Planorbidae	*Bulinus*	*tropicus*	0	0	0	0	0	0	0.0
Nematoda	Nematode	spp.	0	0	0	0	0	0	0.0

Appendix 8.12 Benthic macroinvertebrate species list for the Olifants River, based on the February/March 1991 samples for all mainstream sites

ANNELIDA
Oligochaeta

Lumbriculidae
Lumbriculid spp.

Naididae
Nais spp.
Pristina spp.

ARACHNIDA
Acarina

Hydracarinid spp.
Hydracarinid sp. A
Hydracarinid sp. B
Hydracarinid sp. C
Hydracarinid sp. D
Hydracarinid sp. E
Hydracarinid sp. F
Hydracarinid sp. G
Hydracarinid sp. H

CNIDARIA

Hydridae
Hydra spp.

COLEOPTERA

Dryopidae
Dryopid sp. A larva
Dryopid sp. B larva

Dytiscidae
Hydaticus sp. A larva
Bidessus sp. A larva

Elmidae
?*Leielmis* sp. A adult
Tropidelmis sp. A adult
Pachyelmis sp. A adult
Pachyelmis sp. B adult
Peloriolus granulosus larva
Elpidelmis capensis larva
Elmid sp. C larva

Helodidae
Prionocyphon sp. A larva
Prionocyphon sp. B larva
Helodid sp. C larva

Hydraenidae
Hydraena sp. A adult

Hydrophilidae
Hydrophilid sp. A larva
Hydrophilid sp. B larva
Hydrophilid sp. C. larva

Limnichidae
Limnichid sp. A larva

Coleopteran adult spp.

COLLEMBOLA

Isotomidae
Isotoma sp. A larva.

DIPTERA

Dipteran adult spp.

Dipteran Type B pupa
Dipteran Type C pupa
Dipteran Type D pupa
Dipteran Type E pupa
Dipteran Type F pupa
Dipteran pupa spp.

Ceratopogonidae
Ceratopogonid spp.
Forcipomyiinae
Forcipomyia larva spp.
Forcipomyia pupa spp.

Chironomidae
Chironominae
Chironomini
Polypedilum ?*articola* larva
Orthocladius subg. -
Eudactylocladius sp. A larva

Appendix 8.12 continued

Chironominid sp. AX larva

Tanytarsini
Tanytarsus sp. A larva
Rheotanytarsus sp. A larva
Tanytarsus sp. B larva

Orthocladinae
Cricotopus ?flavozonatus larva
Cricotopus sp. A larva
Cricotopus sp. B larva
Cricotopus sp. C larva
Thienemanniella sp. A larva
Thienemanniella sp. B larva
Tvetenia sp. A larva
Harnichia/Polypedilum type sp. A larva
Cricotopus scottae larva
Corynoneura sp. A larva

Tanypodinae
Conchapelopia sp. A larva
Nilotanypus comatus larva
Ablabesmyia dusoleili larva
Nilotanypus sp. A larva
Macropelopia sp. A larva

Chironomid larva spp.
Chironomid pupa spp.

Culicidae
Culex sp. A larva

Empididae
Empidid sp. A larva

Rhagionidae
Rhagionid sp. A larva

Simuliidae
Simulid larva spp.
Simuliid pupa spp.

Tipulidae
Antocha sp. A larva

EPHEMEROPTERA

Baetidae
Acentrella ?capensis larva
Afroptilum sp. B larva
Pseudocloeon vinosum larva
Afroptilum ?indusii larva
Baetis ?latus larva
Afroptilum ?tarsale larva
Baetis harrisoni complex larva
Cloeon complex B larva
Cloeon complex C larva
Cloeon complex D larva
?Demoulinia sp. A larva
Demoulinia crassi larva
Pseudopannota maculosa larva
Afroptilum sp. C larva
Afroptilum sp. D larva

Baetid larva juvenile
Baetid larva spp.

Caenidae
Caenis capensis larva
Caenodes sp. C larva
Caenodes sp. H larva

Caenid larva juvenile
Caenid larva spp.

Ephemerellidae
Lestagella penicillata larva
Ephemerellina complex A larva
Ephemerellid larva juvenile

Heptageniidae
Afronurus harrisoni larva
Heptageniid larva juvenile

Leptophlebiidae
Adenophlebia auriculata larva
Aprionyx complex A larva
Euthraulus elegans larva
Choroterpes nigrescence larva
Leptophlebiid larva juvenile

Tricorythidae
Tricorythus sp. A larva

Appendix 8.12 continued

HEMIPTERA

Corixidae
Corixid sp. A adult
Corixid sp. B adult

Mesoveliidae
Mesoveliid sp. A adult

Pleidae
Plea sp. A adult

Veliidae
Veliid sp. A adult

LEPIDOPTERA

Pyralidae
Pyralid sp. A larva
Pyralid sp. C larva

MEGALOPTERA

Corydalidae
Chlorionella sp. A larva

MOLLUSCA

Planorbidae
Bulinus tropicus adult

Sphaeriidae
Pisidium adult spp.

Ancylidae
Ferrissiinae
Ferrissia adult spp.

ODONATA

Anisoptera
Aeschnidae
Aeshna sp. A larva
Aeshna sp. B larva

Cordullidae
Corduliid sp. A larva
Corduliid larva juvenile

Gomphidae
Notogomphus (?*Paragomphus*) sp. A larva
Gomphid larva juvenile

Libellulidae
Libellulid sp. A larva
Libellulid sp. B larva
Libellulid sp. C larva

Zygoptera
Coenagrionidae
Coenagrionid larva spp.

PLATYHELMINTHES
Turbellaria
Tricladida
Dugesia spp.

PLECOPTERA

Notonemouridae
Notonemourid larva spp.

TRICHOPTERA

Barbarochthonidae
Barbarochthon brunneum larva

Ecnomidae
Ecnomus thomasseti larva
Parecnomina sp. A larva
Psychomyiellodes sp. A larva

Glossosomatidae
Agapetus sp. A

Hydropsychidae
Hydropsychinae
Cheumatopsyche thomasseti larva
Cheumatopsyche afra larva
Cheumatopsyche larva spp.
Macronematinae
Amphipsyche ?scottae larva
Macrostemum capense larva

Hydroptilidae
Hydroptila capensis larva
Hydroptila capensis pupa
Hydroptilid larva juvenile (2-4 instar)

Appendix 8.12 continued

Orthotrichia sp. A larva
Orthotrichia barnardi larva
Orthotrichia sp. C prepupa
Oxyethira ?velocipes larva

Leptoceridae
Leptocerinae
Leptecho helicotheca larva
Leptecho sp. E larva
Athripsodini
Athripsodes (*harrisoni* group) sp. A larva
Ceraclea sp. A larva
Leptocerini
Athripsodes (*bergensis* group) sp. A larva
Athripsodes ?(*bergensis* group) sp. B larva
Athripsodes (*bergensis* group) sp. C larva
Athripsodes (*bergensis* group) sp. D larva
Athripsodes (*Ps* group) sp. A larva
Athripsodes (*Ps* group) sp. B larva
Athripsodes juvenile larva spp.
Oecetini
Oecetis sp. A larva
Oecetis sp. B larva

Petrothrincidae
Petrothrincus circularis larva

Philopotamidae
Chimarra sp. A larva

Polycentropodidae
Nyctiophylax sp. A larva
Polycentropodid juvenile larva spp.

Sericostomatidae
Petroplax ?curvicosta larva

Xiphocentronidae
Abaria sp. A larva - probably misidentified
Hydropsychidae

Trichopteran pupa spp.

Appendix 8.13 Equations used in the methods of analysis of longitudinal zonation of benthic macroinvertebrate communities (from Field *et al.* 1982) (see Section 8.6)

Root-root transformation

$$Yij = \sqrt{\sqrt{Xij}} = Xij^{1/4} \quad \text{(Equation 8.1)}$$

Where X_{ij} = raw data score of the *i*th species in the *j*th sample; Y_{ij} = corresponding transformed score

Bray-Curtis dissimilarity measure

$$\delta_{jk} = \frac{\sum_{i=1}^{s} \left| Y_{ij} - Y_{ik} \right|}{\sum_{i=1}^{s} \left(Y_{ij} + Y_{ik} \right)} \quad \text{(Equation 8.2)}$$

Where Y_{ij} = score for the *i*th species in the *j*th sample; Y_{ik} = score for the *i*th species in the *k*th sample; δ_{jk} = dissimilarity between the *j*th and *k*th samples summed over all *s* species. δ_{jk} ranges from 0 (identical scores for all species) to 1 (no species in common) and is the complement of the similarity S_{jk}

Bray-Curtis similarity measure

$$S_{jk} = 1 - \delta_{jk} \quad \text{(Equation 8.3)}$$

Stress formula

$$\text{Stress } 1 = \frac{\sum_{j}^{n} \sum_{k>j}^{n} \left(d_{jk} - \hat{d}_{jk} \right)^2}{\sum_{j}^{n} \sum_{j>k}^{n} d_{jk}^2} \quad \text{(Equation 8.4)}$$

Where n = number of stations; d_{jk}: $k > j$; $j = 1, \ldots n$ = interpoint distances between *j*th and *k*th stations of the configuration (ordination plot), which are then regressed on the corresponding dissimilarities (δ_{jk}); $\hat{d}_{jk}$ = distance estimated from the regression, corresponding to dissimilarity, δ_{jk}

Appendix 8.14 Equations used for the calculation of diversity indices and measures of community attributes (from Clarke & Warwick 1993) (see Section 8.10)

Shannon-Weiner Diversity Index (H')

$$H' = -\sum_i p_i \left(\ell n\, p_i\right) \quad \text{(Equation 8.5)}$$

Where p_i = proportion of the total count arising from the *i*th species

Margalef's Species Richness Index (d)

$$d = \frac{(S-1)}{\ell n\, N} \quad \text{(Equation 8.6)}$$

Where S = total number of species; N = total number of individuals

Pielou's Evenness Index (J')

$$J' = \frac{H'(\text{observed})}{H'\text{max}} \quad \text{(Equation 8.7)}$$

Where H'_{max} = maximum possible diversity which would be achieved if all species were equally abundant $(= \ell n\, S)$

Appendix 8.15 Diversity indices and measures of community attributes for the summer benthic macroinvertebrate samples collected at each mainstream study site (see Appendix 8.14 for equations). Data are at the family-level, per 1 m^2 unit area

VISGAT SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
VGR1	cobble/bedrock riffle	3490	23	2.697	1.951	0.622
VGR2	bedrock rapid	4570	19	2.136	1.495	0.508
VGR3	bedrock run	2810	11	1.259	0.766	0.319
VGR4	bedrock run	790	9	1.199	0.923	0.420
VGR5	cobble/bedrock riffle	2570	24	2.929	2.335	0.735

BOSCHKLOOF SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
BKR1	cobble riffle	3830	24	2.788	2.259	0.711
BKR2	cobble riffle	6100	24	2.639	1.862	0.586
BKR3	bedrock run	1480	17	2.192	2.066	0.729
BKR5	cobble riffle	3050	24	2.867	2.167	0.682

Appendix 8.15 continued

GROOTFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
GFR1	cobble run	2410	18	2.183	2.074	0.718
GFR2	cobble run	590	13	1.881	2.053	0.800
GFR3	cobble run	1470	12	1.508	1.491	0.600
GFR4	cobble run	22730	28	2.692	1.874	0.563
GFR5	cobble run	2090	20	2.485	2.411	0.805
GFR6	cobble run	2560	24	2.931	2.135	0.672
GFR7	cobble run	4600	24	2.727	2.315	0.728
GFR8	cobble run	11850	29	2.985	2.350	0.698
GFR9	cobble run	7240	27	2.925	2.390	0.725
GFR10	cobble run	8410	31	3.320	2.453	0.714
GFR11	cobble riffle	7890	29	3.120	2.271	0.674
GFR12	cobble riffle	7780	26	2.790	2.178	0.668
GFR13	cobble riffle	13070	26	2.638	1.973	0.605
GFR14	cobble riffle	18270	30	2.955	2.278	0.670
GFR15	cobble riffle	4230	23	2.635	2.146	0.684

Appendix 8.15 continued

GROOTFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
GFS16	cobble backwater	1900	11	1.325	1.822	0.760
GFS17	cobble backwater	6740	18	1.928	1.746	0.604
GFS18	gravel/cobble backwater	2420	14	1.668	1.633	0.619
GFS19	sand run	10640	9	0.863	1.269	0.578
GFS20	sand run	896	6	0.736	1.630	0.910
GFS21	sand run	4816	9	0.943	1.347	0.613
GFS22	sand run	4984	13	1.409	1.744	0.680
GFS23	sand run	560	3	0.316	0.802	0.730
GFS24	sand run	2016	7	0.789	1.706	0.877
GFS25	sand run	1288	5	0.559	1.339	0.832

Appendix 8.15 continued

TWEEFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
TFR1	cobble riffle	6620	21	2.273	1.951	0.641
TFR2	cobble riffle	7630	22	2.349	1.820	0.589
TFR3	cobble riffle	1100	9	1.142	1.617	0.736
TFR4	cobble run	5280	16	1.750	1.469	0.530
TFR5	cobble run	1790	11	1.335	1.210	0.505

Appendix 8.15 continued

KRIEDOUWKRANS SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
KKR1	bedrock pool	1010	10	1.301	1.482	0.644
KKR2	bedrock pool	1460	12	1.510	1.977	0.796
KKR3	bedrock/cobble pool	650	13	1.853	2.001	0.780
KKR4	bedrock pool	11410	15	1.499	2.088	0.771
KKR5	bedrock pool	510	8	1.123	1.810	0.871
KKR6	bedrock rapid	1710	9	1.075	1.398	0.636
KKR7	bedrock/cobble rapid	3790	15	1.699	1.455	0.537
KKR8	bedrock/cobble rapid	2170	16	1.952	2.011	0.725
KKR9	bedrock rapid	9320	18	1.860	1.534	0.531
KKR10	bedrock rapid	580	9	1.257	1.339	0.610
KKR11	bedrock run	5220	15	1.635	1.507	0.556
KKR12	bedrock run	2560	12	1.402	1.890	0.760
KKR13	bedrock/boulder run	4960	16	1.763	1.500	0.541

Appendix 8.15 continued

KRIEDOUWKRANS SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
KKR14	bedrock run	2130	16	1.957	1.892	0.683
KKR15	bedrock run	1590	17	2.171	2.081	0.735
KKS16	sand run	2352	9	1.031	1.908	0.868
KKS17	sand run	9128	10	0.987	1.153	0.501
KKS18	sand run	5936	11	1.151	1.797	0.749
KKS19	sand backwater	36008	10	0.858	0.810	0.352
KKS20	sand backwater	2184	10	1.171	1.602	0.696
KKS21	sand backwater	4872	11	1.178	1.785	0.744
KKS22	sand backwater	3752	11	1.215	2.036	0.849
KKS23	sand backwater	5096	8	0.820	1.384	0.665
KKS24	*sand pool*	12320	9	0.849	1.238	0.564
KKS25	sand pool	7280	11	1.124	1.921	0.801

Appendix 8.15 continued

CLANWILLIAM SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
CBR1	bedrock run	3980	14	1.568	0.892	0.338
CBR2	bedrock run	820	10	1.341	1.604	0.696
CBR3	cobble/bedrock run	2190	11	1.300	1.744	0.727
CBR4	bedrock run	1110	12	1.569	1.613	0.649
CBR5	cobble run	3330	11	1.233	1.658	0.691

LANGKLOOF SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
LKS1	sand run	2240	8	0.907	1.627	0.783
LKS2	sand run	9128	8	0.768	0.605	0.291
LKS3	sand run	3360	8	0.862	1.385	0.666
LKS4	sand run	15624	4	0.311	0.430	0.310
LKS5	sand run	7672	9	0.894	0.701	0.319

Appendix 8.15 continued

BULSHOEK SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
BDR1	bedrock pool	11250	12	1.179	1.301	0.523
BDR2	bedrock rapid	1940	9	1.057	1.654	0.753
BDR3	bedrock pool	100	4	0.651	1.089	0.785
BDR4	bedrock rapid	1550	11	1.361	1.649	0.688
BDR5	bedrock rapid	1288	13	1.676	1.679	0.655

ZYPHERFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
ZFS1	sand/silt pool	6069	5	0.459	1.088	0.676
ZFS2	sand/silt pool	1071	2	0.143	0.637	0.918
ZFS3	sand/silt pool	21119	9	0.803	1.970	0.896

Appendix 8.15 continued

KLAWER SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
KWS1	sand run	35896	15	1.335	1.294	0.478
KWS2	sand run	1960	6	0.660	1.220	0.681
KWS3	sand run	28616	13	1.169	1.460	0.569
KWS4	sand run	40320	12	1.037	1.327	0.534
KWS5	sand run	29568	14	1.263	1.415	0.536

BOTHA'S FARM SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF FAMILIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
BFR1	cobble riffle	5740	12	1.271	1.693	0.682
BFR2	cobble riffle	4540	11	1.188	1.359	0.567
BFR3	cobble riffle	9099	13	1.316	1.289	0.502
BFS4	sand/gravel run	6608	13	1.364	1.917	0.747
BFS5	sand/gravel run	27328	16	1.468	1.751	0.631
BFS6	sand/gravel run	32760	14	1.250	1.598	0.606

Appendix 8.16 Diversity indices and measures of community attributes for the summer benthic macroinvertebrate samples collected at each mainstream study site (see Appendix 8.14 for equations). Data are at the species-level, per 1 m^2 unit area

VISGAT SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
VGR1	cobble/bedrock riffle	3542	39	4.650	2.650	0.723
VGR2	bedrock rapid	4557	32	3.680	2.431	0.701
VGR3	bedrock run	2811	17	2.015	1.186	0.419
VGR4	bedrock run	787	15	2.100	1.335	0.493
VGR5	cobble/bedrock riffle	2710	42	5.187	3.087	0.826

BOSCHKLOOF SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
BKR1	cobble riffle	3913	35	4.110	2.637	0.742
BKR2	cobble riffle	6090	35	3.902	2.181	0.613
BKR3	bedrock run	1479	29	3.836	2.839	0.843
BKR5	cobble riffle	3053	38	4.611	2.570	0.708

Appendix 8.16 continued

GROOTFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
GFR1	cobble run	2409	28	3.467	2.322	0.697
GFR2	cobble run	590	18	2.665	2.598	0.899
GFR3	cobble run	1460	17	2.196	2.330	0.822
GFR4	cobble run	22630	55	5.385	3.047	0.760
GFR5	cobble run	2090	35	4.447	2.974	0.836
GFR6	cobble run	2549	41	5.100	2.940	0.792
GFR7	cobble run	4603	42	4.861	3.081	0.824
GFR8	cobble run	11863	51	5.330	3.179	0.808
GFR9	cobble run	7263	55	6.074	3.240	0.809
GFR10	cobble run	8415	51	5.532	3.179	0.808
GFR11	cobble riffle	7894	53	5.795	3.113	0.784
GFR12	cobble riffle	7780	50	5.469	3.153	0.806
GFR13	cobble riffle	13054	49	5.065	2.867	0.737
GFR14	cobble riffle	18880	62	6.195	3.179	0.770
GFR15	cobble riffle	4231	37	4.311	2.488	0.689

Appendix 8.16 continued

GROOTFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
GFS16	cobble backwater	1899	20	2.517	2.378	0.794
GFS17	cobble backwater	6737	32	3.517	2.352	0.679
GFS18	gravel/cobble backwater	2420	24	2.952	2.354	0.741
GFS19	sand run	10639	12	1.186	1.356	0.546
GFS20	sand run	896	6	0.736	1.630	0.910
GFS21	sand run	4816	11	1.179	1.423	0.594
GFS22	sand run	4984	18	1.997	1.903	0.658
GFS23	sand run	560	3	0.316	0.802	0.730
GFS24	sand run	2016	9	1.051	2.031	0.924
GFS25	sand run	1288	5	0.559	1.339	0.832

Appendix 8.16 continued

TWEEFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
TFR1	cobble riffle	6617	30	3.296	2.295	0.675
TFR2	cobble riffle	7629	35	3.803	2.192	0.617
TFR3	cobble riffle	1110	16	2.139	2.113	0.762
TFR4	cobble run	5280	23	2.567	1.567	0.500
TFR5	cobble run	1790	13	1.602	1.339	0.522

Appendix 8.16 continued

KRIEDOUWKRANS SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
KKR1	bedrock pool	1010	15	2.024	1.684	0.622
KKR2	bedrock pool	1460	16	2.059	2.146	0.774
KKR3	bedrock/cobble pool	650	14	2.007	2.065	0.782
KKR4	bedrock pool	11410	24	2.462	2.367	0.745
KKR5	bedrock pool	510	11	1.604	1.957	0.816
KKR6	bedrock rapid	1710	14	1.746	1.873	0.710
KKR7	bedrock/cobble rapid	3792	22	2.548	1.728	0.559
KKR8	bedrock/cobble rapid	2180	27	3.382	2.520	0.765
KKR9	bedrock rapid	9325	31	3.282	1.962	0.571
KKR10	bedrock rapid	580	14	2.043	2.024	0.767
KKR11	bedrock run	5220	23	2.570	1.879	0.599
KKR12	bedrock run	2562	19	2.293	2.120	0.720
KKR13	bedrock/boulder run	4960	24	2.703	1.715	0.540

Appendix 8.16 continued

KRIEDOUWKRANS SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
KKR14	bedrock run	2141	23	2.869	2.164	0.690
KKR15	bedrock run	1590	21	2.713	2.377	0.781
KKS16	sand run	2351	12	1.417	2.143	0.862
KKS17	sand run	9128	11	1.097	1.183	0.493
KKS18	sand run	5936	16	1.726	2.221	0.801
KKS19	sand backwater	36008	13	1.144	0.863	0.336
KKS20	sand backwater	2184	11	1.301	1.939	0.809
KKS21	sand backwater	4873	13	1.413	1.911	0.745
KKS22	sand backwater	3750	13	1.458	2.255	0.879
KKS23	sand backwater	5151	9	0.936	1.492	0.679
KKS24	sand pool	12320	12	1.168	1.778	0.716
KKS25	sand pool	7280	15	1.574	2.103	0.777

Appendix 8.16 continued

CLANWILLIAM SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
CBR1	bedrock run	3980	16	1.810	0.909	0.328
CBR2	bedrock run	820	11	1.490	1.622	0.676
CBR3	cobble/bedrock run	2191	16	1.950	2.005	0.723
CBR4	bedrock run	1110	15	1.997	1.669	0.616
CBR5	cobble run	3330	15	1.726	1.867	0.690

LANGKLOOF SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
LKS1	sand run	2240	11	1.296	2.000	0.834
LKS2	sand run	9128	11	1.097	0.693	0.289
LKS3	sand run	3360	9	0.985	1.690	0.769
LKS4	sand run	15624	5	0.414	0.470	0.292
LKS5	sand run	7672	9	0.894	0.701	0.319

Appendix 8.16 continued

BULSHOEK SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
BDR1	bedrock pool	11250	14	1.394	1.355	0.514
BDR2	bedrock rapid	1940	14	1.717	1.857	0.704
BDR3	bedrock pool	100	5	0.869	1.471	0.914
BDR4	bedrock rapid	1550	18	2.314	2.050	0.709
BDR5	bedrock rapid	1288	20	2.653	2.244	0.749

ZYPHERFONTEIN SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
ZFS1	sand/silt pool	6069	5	0.459	1.088	0.676
ZFS2	sand/silt pool	1071	2	0.143	0.637	0.918
ZFS3	sand/silt pool	16777	9	0.822	1.952	0.888

Appendix 8.16 continued

KLAWER SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
KWS1	sand run	35896	19	1.716	1.379	0.468
KWS2	sand run	1960	6	0.660	1.220	0.681
KWS3	sand run	28616	16	1.462	1.581	0.570
KWS4	sand run	40320	16	1.414	1.398	0.504
KWS5	sand run	29568	18	1.651	1.493	0.517

BOTHA'S FARM SAMPLES	BIOTOPE	NUMBER OF INDIVIDUALS	NUMBER OF SPECIES	RICHNESS (d)	DIVERSITY (H')	EQUITABILITY (J')
BFR1	cobble riffle	5740	22	2.426	2.288	0.740
BFR2	cobble riffle	4542	22	2.494	2.243	0.726
BFR3	cobble riffle	9097	23	2.413	2.238	0.714
BFS4	sand/gravel run	6608	19	2.046	2.225	0.756
BFS5	sand/gravel run	27328	24	2.251	1.984	0.624
BFS6	sand/gravel run	32760	25	2.308	1.895	0.589

Appendix 11.1 Assumptions made by BMDP-KM non-hierarchical clustering technique and BMDP-7M stepwise discriminant analysis, and the applicability of these methods to the grouping of rivers in this study

11.1.1 CLUSTERING TECHNIQUES AND ANALYSES

Romesburg (1984) mentions the following measures of primary and secondary validity of group analysis:

Primary validity	1. achievement of research goals 2. generation of useful and interesting conclusions
Secondary validity	1. obtaining well-structured groups 2. agreement with existing classifications 3. agreement with expert intuition 4. agreement with classification using different variables 5. agreement of different multivariate methods (e.g. discriminant analysis) 6. agreement using split samples. 7. stability and robustness (e.g. adding objects or attributes) 8. agreement with prior expectations

Method One was felt to achieve both measures of primary validity as well as measures 1, 3, 5, 6 and, to a degree, 8 of the secondary measures of validity.

The analyses performed by other researchers to group rivers used a variety of multivariate analyses. There is a bewildering array of possible techniques available, with very little guidance to the layman as to assumptions, requirements and limitations of each method. Analyses have consisted of various grouping techniques, including: BMDP-KM non-hierarchical cluster analysis (Poff & Ward 1989), TWINSPAN (Jowett & Duncan 1990), SPSS-X hierarchical cluster analysis (Haines *et al.* 1988), as well as other methods such as principal components analysis (Hughes & James 1989) and discriminant analysis (Poff & Ward 1989). In addition to this, within in each cluster analysis package, there are various distance measures available, as well as ways of standardising data and defining centres of groups. Correspondence analysis has not been used elsewhere as this is regarded as being more suitable for contingency table type data or counts (Afifi & Clark 1984; James & McCulloch 1990).

11.1.1.1 BMDP-KM non-hierarchical cluster analysis

A non-hierarchical technique appears more appropriate than a hierarchical method, in this case, as it avoids the problem of chaining which occurs with some hierarchical methods, where cases are linked successively (Romesburg 1984) and a link made early in the cluster procedure persists throughout although it may be inappropriate (Afifi & Clark 1984). As a taxonomy of rivers is not required, an hierarchical procedure is not ideal in this case. When using very large databases, hierarchical techniques are additionally unwieldy and difficult to interpret.

By optimising a particular criterion a non-hierarchical cluster analysis is achieved. Maximising the Euclidean distance between groups, which is equivalent to minimising the within-class sum of squares, does not rely on assumptions of multi-normality or equal within- group dispersions, or variance-covariance matrices (Genstat 5 Manual 1988; pp 509-520).

Appendix 11.1 continued

In BMDP-KM, all cases begin in one group and at step one the cases are divided into two initial groups based on the variable with the largest variance or, in the case of standardised variables, the largest range. The Euclidean distance from each case to the centre of the group is calculated and the case reassigned to a closer group, if necessary. At each step, the group with the largest variance based on a particular variable (i.e. whichever variable has the largest variance over all groups at that step) is split into two, until the user-specified number of clusters is obtained, iteratively reassigning cases to the group whose centre is closest to the case at each step (Afifi & Clark 1984). The centre of the group is taken as the point whose coordinates are the mean of the cases in that cluster (BMDP Manual 1990).

11.1.1.2 BMDP-7M: Stepwise dicriminant analysis

The main problem is deciding on K, the number of cluster to be formed. This remains a problem with hierarchical methods as well where, in addition, once the dendrogram has been cut off at an appropriate level, the statistical properties of the groups are unclear (Genstat 5 Manual 1988). Supplying the data and groups as input into a discriminant analysis can help in this procedure (Afifi & Clark 1984), and this has been used as a measure of the validity of cluster analyses (Afifi & Clark 1984; Romesburg 1984). For each variable, for pairs of groups or as a whole, the F-test statistic can be used to compare the difference between means for various Ks, and to give an indication of the importance of each variable in the formation of each group (Afifi & Clark 1984). These test statistics can only be used comparatively and not in hypothesis testing.

An estimate of the reliability of the clusters formed is the number of cases misclassified during cross-validation. To achieve this, a random sample of cases is used to derive the discriminant function, and the remaining cases classified using the discriminant function thus derived. In addition, BMDP-7M performs a jack-knife procedure, which excludes one case, calculates the discriminant function based on the remaining cases in the group and then reclassifies the excluded case. This gives a non-parametric estimate of standard errors (James & McCulloch 1990).

Neither of the validation procedures described above require multivariate normal data (Hawkins 1982; Afifi & Clark 1984; James & McCulloch 1990).

With large data sets, the central limit theorem protects against failure of the assumption of normality (Tabachnik & Fidell 1983), where differences between means are being tested, as in the discriminant analysis described above, (although these were not, in any case, used in the sense of hypothesis testing).

Appendix 11.1 continued

Assumptions of the methods used required for hypothesis testing purposes:

1. **Multivariate normality**: The linear discriminant function does not formally require assumptions, but performs best with multivariate normal data and equal variance-covariance matrices, and with the minimum group size bigger than the number of variables (James & McCulloch 1990). Because classification makes greater demands on data than statistical inference, if for example, 95% accuracy in classification is achieved, the shape of distribution is not important (Tabachnik & Fidell 1983). Discriminant analysis is robust to violations of normality if this caused by skewness and not outliers. A smallest sample size of more than 20 ensures robustness. A bigger overall sample size is needed if the difference between group sizes is large (Tabachnik & Fidell 1983). If multivariate normality is violated, then the linear discriminant function performs best if the distribution is light tailed and homoscedastic, but can be applied with marked departure from model (Hawkins 1982).

2. **Unequal sample sizes**: The sample size of the smallest group should exceed the number of variables (Tabachnik & Fidell 1983; James & McCulloch 1990). Departures from this lead to overfitting.

3. **Outliers**: Discriminant analysis is highly sensitive to outliers (Tabachnik & Fidell 1983). Therefore three stations, which were outliers, were removed from the analysis of flow characteristics.
4. **Homogeneity of Variance-Covariance matrices**: Significance tests are misleading if samples are unequal and small (Tabachnik & Fidell 1983). If scatterplots of the first two canonical discriminant functions are roughly equal, then there is evidence of homogeneity. Overclassification will occur for groups with larger dispersion (Tabachnik & Fidell 1983).
5. **Linearity**: Violation leads to reduced power of the discriminant function, but otherwise this is not a problem (Tabachnik & Fidell 1983).
6. **Stepwise procedure**: The bias produced by the stepwise method is reduced by cross-validation (Tabachnik & Fidell 1983).

Appendix 11.2 Monthly proportions of annual flow of the stations used in the analysis of seasonal regimes showing group membership using cluster and discriminant analysis (METH1) and correspondence analysis (METH2) and the number of years of data used for each station

Station	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEARS	METH1	METH2
A229	4.164	3.829	7.005	25.733	20.164	13.106	9.669	4.529	3.722	3.360	2.622	1.895	21	1	6
A232	2.684	3.158	11.482	28.666	32.518	11.927	8.891	0.445	0.209	0.016	0.000	0.025	18	1	6
A239	3.337	5.438	9.077	16.652	16.238	20.583	10.867	5.957	3.628	2.760	2.220	3.243	14	6	6
A249	6.774	6.419	7.995	10.790	9.998	11.792	9.168	8.817	7.510	7.375	6.895	6.485	13	7	6
A250	5.964	5.811	7.419	18.023	17.291	15.805	9.221	4.978	4.270	4.122	3.319	3.677	14	7	6
A253	6.459	9.208	6.817	7.498	14.998	19.609	8.328	6.698	6.134	5.439	4.906	3.908	7	7	6
A301	1.758	10.227	10.784	18.284	16.216	16.036	7.866	8.047	4.048	2.407	2.298	2.211	31	7	6
A402	2.460	4.214	7.524	11.685	18.826	19.482	11.368	8.687	5.526	5.283	3.879	3.067	23	7	6
A405	1.451	1.995	7.045	16.726	24.342	19.282	12.087	6.258	3.805	3.166	2.281	1.581	20	6	6
A408	1.614	2.469	8.858	20.427	20.842	22.738	10.458	5.858	3.307	2.460	1.775	1.385	14	6	6
A504	1.913	4.076	13.064	16.848	23.288	16.609	9.404	5.585	3.458	2.579	1.825	1.357	21	6	6
A611	2.030	4.407	11.071	17.534	19.790	14.344	10.623	6.202	4.590	3.844	3.036	2.328	21	6	6
A612	0.885	5.831	12.543	17.162	25.434	21.425	7.792	3.415	2.016	1.634	1.126	0.738	20	6	6
A618	3.411	6.165	12.879	15.684	19.248	11.926	8.017	6.164	5.045	4.341	3.635	3.284	13	7	6
A619	4.069	5.161	6.905	8.575	13.094	14.229	10.847	9.512	8.248	7.785	6.496	5.059	14	7	6
A620	0.893	4.850	10.537	16.551	27.576	21.355	8.796	3.844	2.575	2.155	1.636	1.233	14	6	6
A621	0.000	6.403	25.921	18.932	15.912	29.836	0.992	0.004	0.000	0.000	0.000	0.000	9	6	6
A901	4.175	7.197	11.827	14.325	12.945	13.652	10.932	7.548	5.377	4.800	3.892	3.532	21	7	5
A902	4.037	5.085	7.816	12.243	14.457	15.868	12.178	8.979	6.330	5.272	4.223	3.515	38	7	5
A903	4.826	5.598	7.803	12.554	13.621	14.278	11.112	8.579	6.592	5.805	4.971	4.263	41	7	5
A904	3.870	4.350	6.754	14.686	16.773	16.617	11.685	7.499	5.342	4.785	3.995	3.462	13	7	5
B101	2.488	13.103	14.288	21.837	21.062	13.155	4.587	3.647	1.938	1.850	1.110	0.834	42	5	5
B102	6.611	12.210	11.003	16.422	15.495	9.877	10.629	4.387	3.383	2.683	2.019	3.102	20	5	5
B104	5.921	8.585	9.565	12.527	10.792	12.616	8.974	7.885	6.603	6.526	5.436	4.481	18	7	5
B201	5.649	6.308	13.184	17.666	14.787	13.207	6.733	5.778	3.924	4.076	3.395	3.289	20	7	5
B301	3.744	5.549	11.655	8.884	16.930	15.051	20.326	9.272	2.652	1.667	1.196	1.075	7	7	5
B405	3.978	8.873	16.906	14.883	11.515	13.160	8.689	6.330	4.985	4.317	3.489	3.076	17	7	5
B409	2.373	10.569	14.265	16.367	15.866	16.722	9.623	4.312	2.496	1.779	1.447	2.341	9	6	5
B502	3.031	7.350	14.615	15.851	24.147	13.292	8.765	5.799	2.501	2.145	1.339	1.165	25	6	5
B601	4.796	6.636	9.087	11.002	17.726	14.589	9.636	7.104	5.579	5.158	4.696	3.990	25	7	5
B602	1.813	5.581	16.243	22.184	21.312	17.642	7.050	3.424	1.403	1.189	1.282	0.877	23	6	5
B603	3.096	6.046	11.614	16.165	22.505	15.515	9.552	4.437	3.237	2.936	2.341	2.556	23	6	5
B606	1.656	3.517	10.527	17.547	19.569	18.913	11.666	7.274	3.663	2.507	1.618	1.320	16	6	5
B703	3.020	2.051	3.637	30.153	19.022	9.866	11.599	10.804	3.011	2.029	1.519	3.289	8	1	5
B704	1.733	3.786	9.005	17.006	23.922	16.772	11.528	5.419	3.063	2.491	1.791	1.481	26	6	5
B708	1.166	0.690	9.811	22.752	24.624	22.283	8.642	4.984	1.965	1.182	0.737	0.464	30	1	5
B709	1.709	6.464	15.288	16.937	19.487	17.610	7.708	3.302	2.860	2.086	1.287	1.255	9	6	5
B710	2.672	5.149	17.694	17.662	22.061	21.452	6.977	3.319	1.277	0.799	0.120	0.819	13	6	5
B714	0.444	1.458	5.626	12.366	33.069	25.915	10.050	4.964	2.416	1.600	1.251	0.620	9	6	5
B810	2.197	4.942	11.241	15.659	20.737	22.067	9.640	4.966	3.090	2.377	1.625	1.457	16	6	5
B901	0.798	1.931	8.062	37.004	35.225	15.094	0.006	0.000	0.000	0.000	0.000	1.883	16	1	5
C107	7.165	17.874	17.107	15.200	17.103	6.254	3.884	4.066	2.807	2.878	2.702	2.940	12	5	7
C226	8.746	6.370	9.801	11.857	8.337	10.823	9.457	9.470	7.516	6.350	9.422	3.852	14	7	7
C227	4.049	8.045	20.050	24.857	18.036	7.921	7.274	2.649	2.144	1.710	1.409	2.056	16	5	7
C228	4.766	5.929	9.801	14.006	14.091	14.126	12.050	6.961	5.654	4.661	4.125	3.609	17	7	7
C265	1.830	1.840	1.704	24.065	31.096	21.175	13.582	1.232	0.586	0.481	0.392	2.017	15	1	7
C267	15.726	1.356	0.576	22.573	35.287	22.147	1.574	0.726	0.016	0.000	0.008	0.000	12	1	7
C303	1.430	10.147	10.867	22.214	21.555	16.430	12.448	3.124	0.646	0.206	0.203	0.729	52	6	7
C402	8.070	13.773	11.957	6.908	20.015	13.253	13.049	5.012	2.343	1.971	1.919	1.731	10	7	7
C507	2.930	3.510	5.096	9.697	31.828	20.408	13.787	5.838	0.996	0.509	1.831	3.569	34	6	7
C508	10.598	7.673	15.292	32.834	15.108	9.585	4.379	0.210	0.129	0.601	1.658	1.732	14	1	7
C512	6.985	13.135	16.379	11.140	19.192	7.151	15.649	5.149	1.417	0.302	0.491	1.010	24	5	7
C603	5.677	10.988	10.323	25.946	22.074	6.878	13.606	1.716	0.730	0.043	0.007	0.009	17	1	7
C604	1.643	9.530	27.616	23.371	15.236	9.553	5.128	0.262	0.120	0.066	0.227	7.244	10	5	7
C703	9.694	22.213	10.672	16.263	17.911	9.188	5.687	2.913	0.141	0.747	0.000	2.360	36	5	7
C803	11.749	8.833	15.785	17.660	19.483	7.698	4.476	3.754	2.350	2.415	1.649	3.128	17	5	7
C805	5.893	7.932	12.231	19.030	27.951	11.160	5.201	1.563	0.917	0.547	1.039	6.515	8	6	7
C812	3.897	7.971	12.789	15.534	32.133	21.869	1.815	1.730	0.666	0.524	0.285	0.787	12	6	7
C822	3.510	8.749	10.372	19.345	25.010	16.253	8.919	2.283	1.449	1.292	0.943	0.875	7	6	7
D103	7.636	9.106	9.429	9.874	9.975	10.619	6.804	7.524	7.142	6.625	6.406	6.561	42	7	7
D109	6.874	9.887	9.516	12.737	17.551	16.064	10.280	3.962	2.719	1.605	2.580	3.924	24	7	7
D111	6.831	7.482	8.829	6.343	20.193	13.217	11.167	6.535	8.564	3.617	3.217	5.985	9	7	7
D201	4.901	10.134	10.126	16.811	17.675	14.071	15.193	5.516	2.995	0.758	0.409	1.210	24	7	7
D212	6.170	16.477	14.725	13.111	12.521	13.599	5.557	3.361	2.150	1.610	3.569	5.150	10	5	7
D303	5.357	11.101	12.538	13.987	14.118	17.616	9.637	5.631	2.633	1.605	1.523	4.055	33	7	7
D308	4.570	7.666	9.116	6.724	6.577	12.772	12.984	11.015	9.056	6.124	4.639	4.776	6	7	7
D503	0.502	1.998	3.106	3.554	5.910	7.928	3.011	3.700	17.833	25.117	20.601	6.939	33	2	1
D702	5.696	5.156	4.463	6.084	15.355	34.422	7.917	4.433	3.661	4.249	4.326	4.218	5	7	7

Appendix 11.2—continued

Station	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEARS	METH1	METH2
D803	6.740	9.665	10.859	8.341	15.362	19.738	11.731	7.948	3.438	2.085	1.571	2.520	21	7	7
E106	6.706	2.732	2.158	1.458	0.792	1.507	2.081	7.882	15.626	21.959	23.355	13.963	11	2	1
E202	5.611	3.141	1.469	0.710	0.312	0.748	1.655	8.150	21.318	23.077	21.217	12.592	47	2	1
E203	4.776	0.638	0.893	0.011	0.000	0.000	0.917	10.883	12.298	18.247	25.302	25.637	6	2	1
E207	4.428	1.345	0.669	0.187	0.027	0.607	0.448	9.105	13.067	27.344	25.659	17.115	10	2	1
G102	7.348	5.448	3.193	1.878	1.993	2.112	4.902	11.658	11.800	19.021	21.226	9.419	9	2	1
G103	10.372	4.754	1.561	0.681	0.409	0.560	1.415	6.752	15.540	21.473	19.762	16.723	20	2	1
G107	7.361	3.705	1.324	0.535	1.238	1.284	3.727	13.609	13.675	19.799	22.535	11.227	13	2	1
G108	9.192	3.616	1.890	0.808	0.548	1.045	1.827	9.433	15.027	17.056	25.089	14.671	25	2	1
G109	5.070	2.086	0.977	1.020	0.527	4.324	4.747	7.043	22.948	23.530	23.059	4.670	14	2	1
G110	4.080	2.552	0.079	0.005	0.000	0.007	0.008	15.248	21.422	24.131	23.545	8.924	20	2	1
G111	9.381	3.259	1.979	1.092	0.331	1.100	2.507	10.011	15.183	20.229	21.486	13.482	18	2	1
G112	7.848	2.613	1.631	1.061	0.426	0.744	1.966	9.941	17.572	20.278	21.897	14.403	17	2	1
G114	8.674	3.362	2.141	1.585	1.205	1.449	1.742	4.818	15.211	22.666	22.116	15.032	21	2	1
G115	8.483	2.820	2.163	1.241	0.899	1.314	1.919	10.604	19.602	22.106	20.291	10.759	23	2	1
G116	8.772	3.454	2.556	1.697	1.023	1.565	1.857	9.327	20.821	22.194	17.971	10.761	15	2	1
G117	9.159	3.224	1.862	1.148	0.604	0.911	1.377	4.621	15.975	22.969	22.915	14.993	14	2	1
G118	8.488	2.432	1.737	0.942	0.431	0.775	0.899	7.957	18.879	23.973	22.575	12.613	21	2	1
G119	10.349	3.209	3.092	1.897	1.063	1.895	3.158	9.878	15.447	19.670	15.736	14.807	10	2	1
G121	9.840	8.861	5.982	4.108	2.236	2.063	2.335	9.357	11.619	13.255	18.005	12.422	6	2	1
G208	7.370	3.760	1.628	0.600	2.161	0.322	4.981	14.069	18.079	19.360	19.487	10.143	25	2	1
G212	2.847	0.477	0.284	0.197	0.046	0.103	0.574	6.199	16.200	27.436	34.496	11.341	21	2	1
G301	7.027	0.993	0.655	0.465	0.008	0.032	1.300	7.015	15.883	20.848	26.059	19.915	16	2	1
G406	8.786	4.462	0.870	0.783	0.862	0.329	1.539	3.028	10.348	21.633	28.244	19.077	22	2	1
G408	10.061	6.430	3.512	2.814	1.592	1.373	3.180	7.527	11.157	15.596	21.239	15.520	19	2	1
G409	11.774	5.617	2.265	1.423	1.100	0.440	1.368	3.447	10.033	15.605	24.825	21.903	23	2	1
G410	11.216	6.202	1.530	0.363	0.167	0.227	2.217	6.210	13.260	17.485	22.227	18.854	17	2	1
G412	9.752	5.593	2.839	2.028	1.207	1.083	3.414	7.417	13.568	16.530	21.598	14.989	22	2	1
G413	9.448	5.074	2.856	2.132	1.139	0.726	2.757	7.098	11.412	18.361	20.604	18.383	17	2	1
G414	9.153	3.091	1.234	0.435	0.487	0.605	2.438	6.844	14.498	20.208	24.639	16.190	19	2	1
G506	7.962	7.587	6.322	4.821	4.365	5.033	6.330	6.736	10.664	12.565	18.201	11.193	10	3	2
G508	7.133	0.474	1.005	2.160	2.213	0.038	5.819	2.127	15.679	32.097	19.945	11.310	24	2	2
H107	8.604	3.618	2.465	1.263	1.445	1.949	5.205	13.311	14.675	17.275	16.337	11.453	28	2	1
H112	6.705	2.360	1.647	0.998	0.788	1.125	1.657	4.234	14.335	21.554	29.053	13.544	10	2	1
H113	7.268	4.781	3.010	1.529	0.835	1.576	2.072	9.244	13.977	21.636	20.167	13.705	13	2	1
H117	6.373	4.547	4.411	2.854	1.618	1.600	3.881	10.632	13.047	17.070	19.679	12.088	12	2	1
H118	5.882	3.918	3.785	2.144	1.289	2.431	3.109	13.125	14.459	18.165	19.073	12.822	15	2	1
H201	7.582	4.150	3.099	2.893	1.672	1.715	1.924	7.045	12.905	22.301	19.221	15.284	16	2	1
H203	7.081	2.682	1.289	1.194	0.711	1.204	0.841	11.065	17.260	22.407	22.875	11.590	18	2	1
H205	7.537	6.063	4.161	3.153	2.324	2.548	2.353	9.052	13.658	16.220	19.951	12.781	18	2	1
H301	14.308	15.352	8.198	8.012	6.884	2.674	1.444	10.683	1.387	3.172	12.985	14.725	16	3	2
H304	6.115	9.075	8.276	11.595	7.653	9.583	7.317	6.014	1.522	7.253	14.145	11.451	17	3	2
H305	19.602	19.096	5.518	2.208	1.317	0.687	7.352	8.174	2.830	6.352	5.441	21.424	20	3	2
H405	9.097	12.989	5.350	5.611	4.921	6.472	7.417	7.433	8.759	7.565	15.230	11.157	28	3	1
H412	12.954	2.057	1.440	2.494	2.168	0.136	2.837	2.694	4.327	16.543	30.634	21.717	17	2	1
H503	7.747	6.352	6.358	7.182	7.062	5.129	9.258	5.793	7.668	12.257	12.938	12.263	7	3	2
H603	12.186	7.424	1.892	0.508	0.234	0.303	2.262	10.927	14.936	18.286	18.434	12.809	10	2	1
H606	10.349	2.254	0.265	0.002	0.000	0.236	0.423	3.573	13.196	21.261	31.863	16.576	10	2	1
H607	8.448	7.459	7.429	7.032	6.317	7.084	7.570	8.981	9.639	10.242	10.448	9.354	23	3	1
H608	8.876	4.105	3.527	1.945	1.432	3.248	5.376	12.875	15.154	17.186	17.294	11.003	18	2	1
H610	7.035	5.071	5.060	8.943	4.447	4.222	5.852	6.293	7.594	13.050	18.565	14.046	11	3	1
H701	6.890	3.760	1.333	1.157	0.486	0.958	1.199	6.897	23.401	22.267	18.070	13.462	26	2	2
H703	11.011	12.053	3.754	4.800	4.261	7.311	8.518	10.104	5.344	7.665	13.784	11.484	21	3	2
H704	12.204	10.521	5.301	2.268	4.652	3.462	7.101	7.115	8.044	11.124	15.619	14.190	25	3	2
H705	11.178	9.630	5.733	6.002	6.293	7.722	9.686	6.133	4.515	9.251	11.619	9.836	14	3	2
H707	10.458	10.061	8.615	5.078	7.124	5.924	7.998	6.787	7.600	6.364	9.165	12.584	12	3	2
H902	17.933	16.623	11.518	3.767	3.002	3.037	10.750	6.567	4.532	2.543	11.274	8.255	7	3	2
H904	11.168	9.347	8.972	5.028	7.720	8.433	8.875	6.887	5.723	9.041	11.124	11.681	17	3	2
H905	12.322	11.196	8.092	4.543	8.810	8.830	8.226	5.044	3.110	7.830	11.180	13.838	15	3	2
J115	11.180	8.395	5.175	4.093	2.806	3.107	3.145	4.367	9.449	13.805	18.987	17.892	11	2	1
J116	5.880	3.322	2.844	1.045	0.473	0.848	1.218	9.129	17.218	17.161	19.138	21.927	10	2	1
J205	10.233	13.710	4.148	6.611	2.345	2.861	6.078	7.424	7.027	10.244	14.313	15.009	18	3	2
J206	12.463	14.665	8.951	9.822	1.628	1.726	6.850	6.243	6.606	9.432	10.136	13.475	21	3	2
J207	18.474	21.021	7.665	3.329	1.074	0.747	7.302	5.470	4.784	8.249	10.561	11.345	16	3	2
J312	7.808	7.629	3.298	3.232	2.481	4.658	4.516	13.239	13.702	8.522	11.688	16.629	9	3	2
J313	11.347	10.290	8.581	7.508	4.686	5.537	7.703	7.106	8.667	10.038	8.003	10.352	12	3	2
J316	16.546	6.564	3.536	1.393	0.799	1.240	2.592	3.651	7.883	30.337	10.346	15.110	6	2	2
J317	22.247	8.679	7.577	3.051	4.310	3.740	5.217	7.050	6.155	8.904	10.715	12.354	14	3	2
J318	13.447	10.203	4.461	3.339	5.762	4.892	8.176	9.626	8.149	11.063	12.769	10.092	10	3	2
J320	21.976	16.045	7.475	2.605	1.058	1.150	7.298	7.544	7.984	10.295	5.836	10.633	8	3	2
J403	8.382	11.879	7.146	6.045	6.469	8.094	13.560	6.145	5.136	4.506	6.781	9.676	16	3	2
J404	15.132	11.621	9.408	5.002	2.481	2.478	5.497	5.132	6.252	10.508	10.786	15.702	13	3	2
K301	7.407	5.648	6.440	8.023	9.792	7.601	11.637	8.124	4.732	5.859	15.181	9.356	8	3	2
K302	10.815	9.769	9.102	8.653	12.366	11.069	10.047	6.304	2.842	3.831	9.101	8.000	16	7	2
K303	7.776	8.987	7.650	9.102	6.576	13.264	9.488	6.102	2.228	4.049	14.760	7.975	9	3	2
K304	10.568	9.587	8.259	6.585	9.696	11.754	9.330	7.355	4.023	5.000	9.237	6.585	23	3	2
K305	12.229	9.132	10.379	5.034	7.300	6.792	10.480	4.993	3.617	10.846	10.063	9.135	14	3	2
K401	12.970	12.741	7.006	6.592	7.705	8.012	7.714	6.990	6.880	6.308	7.913	9.369	20	3	2

Appendix 11.2 continued

Station	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEARS	METH1	METH2
K402	11.593	10.972	8.331	7.028	9.248	6.157	9.745	7.567	5.240	4.228	9.233	8.661	17	3	2
K403	8.386	8.364	5.408	4.328	4.382	9.149	9.037	13.137	5.170	7.742	14.706	10.192	17	3	2
K502	12.829	9.880	6.632	5.009	5.369	5.994	13.346	7.375	8.067	5.909	8.962	10.826	15	3	2
K601	8.386	5.748	3.448	1.370	2.038	5.565	10.243	13.942	12.300	7.567	17.501	11.678	20	3	2
K701	10.559	6.900	7.286	6.036	9.330	9.854	8.098	6.709	8.027	6.245	8.414	8.538	14	3	2
K801	13.245	8.436	8.217	6.686	8.009	7.734	9.116	6.603	6.033	6.019	13.362	8.540	19	3	2
K802	12.471	8.597	5.742	4.814	5.703	8.458	9.748	8.386	7.330	8.210	9.200	11.341	18	3	2
L101	1.615	6.002	5.150	7.324	36.286	20.133	14.070	3.547	0.261	0.380	2.986	2.243	27	6	3
L601	5.281	7.598	10.231	19.899	18.187	16.736	5.263	1.318	0.484	0.006	14.332	0.664	32	6	3
L708	6.431	8.295	8.237	2.284	3.795	14.261	4.276	13.017	5.353	18.407	13.603	3.839	11	3	3
L801	10.476	6.745	7.481	5.951	4.352	8.852	6.282	7.690	7.913	10.810	11.899	11.788	11	3	2
L802	12.453	10.569	6.579	4.256	4.710	4.633	7.703	8.782	6.856	12.507	10.146	9.807	14	3	2
N209	9.344	9.978	10.792	10.643	6.759	10.723	11.337	6.052	1.967	7.236	6.661	6.509	7	3	3
P401	3.117	20.808	6.894	2.371	0.615	4.664	6.614	1.602	1.319	17.037	23.228	11.530	13	3	3
Q101	2.424	7.808	12.583	7.865	22.468	37.390	3.918	1.114	1.508	0.749	1.809	0.584	12	6	3
Q202	6.506	5.691	8.032	7.864	8.328	10.217	6.625	9.950	11.146	9.381	7.049	7.169	10	3	3
Q304	2.817	2.616	13.708	13.908	13.218	9.375	14.098	7.574	3.862	7.834	4.137	6.853	11	7	3
Q403	5.408	31.337	3.484	2.944	18.697	22.060	1.127	0.333	0.652	8.490	0.622	4.646	6	4	3
Q603	4.111	9.342	25.558	3.684	15.380	3.971	3.604	1.581	1.800	22.790	2.456	5.525	9	5	3
Q802	8.392	16.654	15.323	5.621	9.818	15.323	7.584	8.094	3.157	2.262	3.074	4.569	43	7	3
Q814	8.897	36.822	22.910	6.350	10.206	7.175	1.520	0.536	0.414	2.291	0.462	2.395	6	4	3
Q816	9.268	27.943	16.074	7.785	12.026	7.349	10.204	3.857	0.512	2.474	0.161	2.327	5	4	3
Q818	6.967	14.470	13.284	12.788	10.549	16.984	7.383	4.582	1.929	2.639	3.026	3.441	12	7	3
R101	9.677	12.604	12.049	11.110	11.213	12.658	8.531	5.716	2.874	3.569	4.967	4.813	40	7	3
R105	9.132	9.807	10.691	11.041	12.170	16.903	9.154	5.693	3.630	3.050	4.329	4.400	18	7	3
R106	6.484	6.517	9.688	13.354	15.723	16.603	11.510	6.073	3.635	2.545	2.503	5.185	11	7	3
R107	5.788	8.598	8.669	8.390	11.813	19.017	9.521	7.638	5.080	4.833	4.183	8.489	15	7	3
R114	8.242	13.748	11.619	8.015	9.882	11.936	8.522	6.860	4.806	4.345	6.365	5.480	24	7	3
R115	8.549	34.086	21.743	7.146	5.962	6.835	5.652	2.216	1.643	1.531	0.732	1.904	8	4	3
R201	6.636	12.164	12.162	11.418	16.040	14.436	9.707	4.686	2.752	2.275	4.013	3.513	37	7	3
R205	5.306	9.745	5.957	5.735	11.265	15.575	17.568	5.858	3.259	3.606	11.368	4.581	20	7	3
R206	6.624	13.667	10.342	12.303	11.744	12.170	11.746	5.461	2.659	4.203	3.590	5.270	19	7	3
R208	6.830	14.302	6.534	10.827	11.670	15.570	10.361	2.048	1.086	1.314	16.674	2.486	33	7	3
R212	5.920	11.235	12.185	14.263	15.566	16.219	8.073	3.277	2.119	1.942	5.793	3.387	19	7	3
S302	3.017	17.010	19.751	5.749	21.623	7.758	8.545	3.755	1.510	5.667	0.894	4.720	8	5	3
S304	5.916	15.638	23.568	10.746	9.905	10.082	2.083	1.997	1.473	6.642	5.958	5.773	10	5	3
S306	1.365	4.980	20.160	6.763	23.933	29.006	5.648	0.992	1.491	2.003	1.395	2.021	12	6	3
S601	10.926	6.169	8.378	11.113	11.676	17.476	16.330	6.175	2.227	1.498	1.248	2.566	9	7	3
S602	8.302	7.058	3.563	10.463	14.375	26.563	15.420	4.755	2.479	2.228	1.018	3.718	10	7	3
S603	4.892	4.177	9.234	8.507	23.531	16.167	9.827	3.574	2.332	2.949	11.162	3.646	13	6	3
T104	2.547	7.136	12.990	14.181	17.048	16.372	10.646	9.224	2.781	2.273	1.329	1.473	11	7	4
T202	4.544	7.983	9.210	12.069	16.390	19.849	12.389	5.392	3.311	2.542	2.435	1.868	15	7	4
T304	5.162	8.828	11.917	14.132	15.978	15.506	8.703	5.123	4.124	4.061	2.792	3.678	33	7	4
T306	3.440	7.002	13.287	19.550	21.357	17.656	7.312	2.088	1.868	2.639	1.862	2.141	14	6	4
T309	7.150	8.310	10.760	15.283	22.469	18.697	8.617	2.471	1.440	0.902	1.277	2.424	23	6	4
T401	6.571	8.539	10.251	10.512	14.854	15.123	11.463	7.883	3.874	2.974	2.614	5.544	23	7	4
T502	5.448	8.556	11.202	12.039	14.095	15.882	9.722	8.469	5.085	4.087	3.698	3.718	36	7	4
T503	4.396	6.978	13.680	16.730	20.184	18.804	7.065	4.320	1.991	1.426	1.259	3.388	22	6	4
T504	3.060	7.216	12.835	20.142	20.730	16.434	8.059	3.472	1.819	1.373	1.164	1.676	31	6	4
T505	4.506	6.005	12.284	15.297	17.258	15.738	12.326	5.152	3.773	2.260	1.773	1.626	8	7	4
U105	3.137	7.611	12.277	17.171	23.587	17.774	7.984	2.858	1.671	1.348	1.352	3.229	8	6	4
U106	3.881	7.207	11.045	17.552	19.205	17.890	10.938	3.971	2.465	1.919	1.962	1.928	21	6	4
U201	5.484	8.032	10.718	14.834	13.729	14.546	10.102	6.584	4.188	4.330	4.192	5.301	29	7	4
U206	3.819	6.470	12.785	17.481	18.093	18.681	9.233	4.742	2.502	1.780	1.761	2.854	20	8	4
U207	3.830	5.997	9.743	17.188	17.520	15.425	10.283	5.831	3.570	2.600	2.452	5.360	24	7	4
U211	7.713	8.144	9.499	12.966	15.530	16.923	10.332	5.612	3.751	3.212	2.828	3.471	21	7	4
U212	4.185	6.234	9.807	18.251	21.386	15.311	12.643	5.524	2.965	2.010	1.748	1.917	15	6	4
U213	5.053	7.043	11.900	18.054	17.003	17.715	10.059	4.374	2.719	2.684	2.431	2.983	27	6	4
U301	2.560	9.829	5.845	9.809	26.513	19.745	13.269	5.100	2.634	1.755	1.608	1.335	5	6	4
U302	6.326	6.427	11.005	13.774	14.336	12.092	10.044	8.850	4.487	4.056	3.720	4.882	18	7	4
U402	4.192	5.840	10.459	15.838	16.748	16.390	9.862	5.980	3.466	3.028	2.944	3.133	29	8	4
U403	12.543	9.818	15.369	21.087	13.200	5.531	3.606	4.083	1.814	1.731	1.771	9.628	8	5	4
U602	3.620	6.511	11.223	13.068	20.679	14.510	9.794	6.230	4.615	3.752	2.848	2.750	5	6	4
U701	4.680	6.132	10.298	15.028	18.054	11.224	7.757	4.254	3.335	2.718	2.605	11.938	6	7	4
U706	7.142	8.535	9.176	10.315	9.683	11.553	9.718	8.955	7.076	5.782	5.882	6.202	6	7	4
U707	11.121	7.480	7.785	9.105	13.943	16.987	12.153	6.711	3.794	3.072	2.354	5.516	13	7	4
V101	4.375	7.630	12.877	16.782	21.840	18.145	7.666	3.478	1.565	1.374	1.228	2.941	16	6	4
V102	5.045	9.440	12.359	13.521	13.075	14.822	11.314	6.913	4.185	3.211	2.795	3.220	32	7	4
V109	3.947	7.126	14.745	20.398	26.634	14.332	3.268	1.155	0.730	0.498	1.158	6.010	20	6	4
V110	4.725	6.602	11.364	13.076	21.640	19.954	8.757	3.770	2.459	2.134	1.717	3.602	11	6	4
V126	3.055	4.887	7.765	18.594	29.538	18.794	9.462	2.882	1.485	0.844	1.233	1.361	7	8	4
V129	4.388	4.679	9.088	17.830	32.016	18.692	7.579	2.106	0.938	0.792	0.956	0.935	6	6	4
V131	2.928	3.804	10.447	22.002	26.289	20.387	6.600	1.091	0.866	0.550	1.127	2.908	13	1	4
V138	3.608	7.824	11.585	19.712	26.719	16.245	7.008	2.061	0.979	0.673	0.626	2.763	13	6	4
V141	5.612	7.741	13.460	15.607	19.404	18.154	8.156	3.757	2.213	1.885	1.882	2.128	9	8	4
V201	2.521	7.121	12.660	17.573	15.844	17.672	10.596	4.933	2.678	2.101	3.381	2.919	13	6	4
V205	4.537	6.129	12.769	16.371	21.455	19.505	8.610	3.385	2.126	1.818	1.590	1.665	13	6	4
V206	5.546	6.075	13.865	16.823	21.557	17.385	7.782	2.483	1.566	1.418	1.235	2.162	10	6	4

Appendix 11.2 continued

Station	OCT.	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEARS	METH1	METH2
V207	4.515	6.720	13.195	18.721	18.660	17.312	6.472	3.194	2.281	1.883	2.052	5.005	10	6	4
V302	6.772	10.859	14.773	17.165	16.324	12.080	6.281	3.820	2.814	2.698	1.892	4.541	31	5	4
V303	4.962	9.233	12.763	16.997	19.808	15.170	9.125	4.316	2.290	1.975	1.086	2.487	29	6	4
V305	6.589	13.115	15.547	18.374	23.414	8.276	4.943	1.575	0.986	3.766	1.212	2.220	27	5	4
V307	4.495	10.524	13.160	21.123	22.624	13.909	6.016	2.630	1.227	1.233	0.728	2.330	29	6	4
V309	3.733	8.529	12.189	19.245	21.944	15.891	10.190	3.307	1.435	1.079	0.841	1.616	21	6	4
V502	4.159	10.021	11.134	18.356	25.536	14.295	6.015	3.245	1.607	1.113	1.051	1.464	9	6	4
V603	6.425	7.420	16.035	17.861	21.627	11.459	4.992	1.976	1.456	2.269	1.467	4.814	21	5	4
V604	4.731	6.638	10.686	19.800	26.951	14.710	6.692	2.179	1.100	1.612	0.944	3.977	24	6	4
V606	6.229	5.955	9.519	17.439	25.003	18.064	6.869	2.601	1.721	1.599	2.164	2.836	12	6	4
V712	5.413	8.787	8.343	15.486	22.347	17.485	9.213	3.391	2.450	2.056	2.244	2.808	21	6	4
V716	4.319	6.952	13.526	14.694	21.180	16.370	8.783	3.650	2.267	1.814	1.719	2.726	14	6	4
V717	4.854	6.309	10.640	18.516	19.425	16.716	6.416	3.983	2.710	2.331	2.061	2.817	14	6	4
V718	2.397	4.706	14.691	14.743	23.102	19.039	6.549	3.155	1.863	1.315	3.223	5.214	9	6	4
W104	5.590	7.767	12.372	12.744	17.480	17.770	9.280	4.315	2.987	3.274	1.874	4.427	20	7	5
W110	15.619	10.316	13.521	10.499	8.543	19.653	8.794	4.431	2.165	1.562	2.130	2.589	6	7	5
W125	10.486	9.418	8.892	9.215	16.274	11.776	7.736	5.055	4.583	6.401	4.848	5.224	10	7	5
W202	6.673	10.306	25.813	15.107	11.243	6.547	6.637	5.895	2.772	2.217	2.621	2.170	7	5	5
W206	12.617	12.507	15.403	11.566	8.722	14.323	8.733	6.422	3.128	2.682	1.744	1.951	5	7	5
W209	6.079	7.948	14.138	15.913	22.229	13.323	7.429	5.335	2.174	1.702	1.619	2.114	6	6	5
W314	11.230	9.542	6.523	5.404	17.417	14.707	4.765	9.493	5.504	6.357	3.912	5.146	11	7	5
W404	6.295	9.470	14.252	15.820	18.632	12.519	8.422	4.707	2.951	2.588	2.371	1.974	23	5	5
W408	12.990	8.657	6.046	6.481	9.356	8.517	7.396	9.562	8.455	7.162	6.616	6.524	6	3	5
W501	5.520	12.447	12.914	14.236	13.959	12.475	8.086	5.761	4.953	4.013	3.124	2.513	43	7	5
W504	4.109	10.514	19.202	16.031	18.459	11.825	6.578	3.587	1.921	2.377	1.514	1.882	29	5	5
W506	5.698	11.463	15.585	16.785	16.417	12.208	8.086	4.107	2.411	2.943	1.721	2.415	28	5	5
W507	2.513	6.248	16.153	17.985	27.161	17.344	7.217	2.965	1.011	0.797	0.339	0.269	6	6	5
W508	5.707	9.647	16.256	15.570	17.724	10.681	7.087	3.936	2.962	3.380	2.331	2.696	30	5	5
W511	7.166	13.373	16.348	16.243	17.793	10.718	8.592	3.172	1.996	1.642	1.293	1.663	10	5	5
X103	5.626	6.879	10.823	11.656	13.166	14.169	9.971	7.076	5.109	4.913	4.669	3.519	25	7	5
X114	3.931	8.016	10.239	11.521	24.287	18.731	7.742	5.003	3.066	2.660	2.333	2.472	7	6	5
X202	4.502	7.549	11.207	13.168	11.692	13.410	12.225	8.323	5.756	4.919	3.283	3.984	16	7	5
X205	2.976	7.052	13.326	14.316	15.810	14.384	11.693	7.470	4.547	3.686	2.650	2.077	11	7	5
X208	4.623	7.885	13.934	15.959	18.801	14.550	8.421	5.140	3.404	2.776	2.256	2.450	34	6	5
X210	5.239	8.661	14.813	14.929	14.176	10.836	9.274	6.077	4.587	4.116	3.776	3.536	29	7	5
X211	5.673	9.847	12.436	17.648	17.050	11.842	7.679	4.555	3.617	3.566	2.895	3.188	25	5	5
X212	5.880	12.282	13.577	18.330	16.146	9.499	6.700	4.443	3.697	3.537	3.023	2.688	24	5	5
X213	3.943	7.240	11.366	14.679	17.946	15.032	8.673	5.753	4.049	3.705	3.896	3.720	17	7	5
X214	3.949	6.387	10.420	13.429	17.225	13.966	9.914	7.101	5.276	4.703	4.042	3.589	18	7	5
X215	4.591	8.254	12.799	15.019	16.868	12.910	8.748	5.842	4.701	4.154	3.240	2.674	16	7	5
X222	5.331	8.684	17.734	14.545	15.230	10.870	8.616	5.456	4.504	3.962	2.910	2.158	14	5	5
X224	5.713	7.133	11.004	11.002	15.314	12.943	10.035	7.352	5.698	5.174	4.507	4.125	18	7	5
X225	3.759	5.704	9.896	14.396	17.673	14.206	11.674	7.072	4.877	4.153	3.447	3.136	14	7	5
X226	3.896	5.580	10.296	13.059	18.761	15.426	10.751	6.900	4.785	4.013	3.386	3.141	16	7	5
X227	3.109	5.327	9.763	12.616	22.467	15.595	11.030	6.460	4.313	3.566	2.924	2.590	12	6	5
X228	4.250	5.475	9.509	12.403	16.371	13.830	12.037	7.946	5.767	4.920	4.115	3.375	13	7	5
X230	5.850	8.316	11.765	10.633	13.231	12.278	9.334	7.567	6.081	5.591	4.927	4.447	10	7	5
X231	4.517	6.626	13.877	13.400	16.749	14.559	9.276	8.152	4.478	3.901	3.226	3.036	19	7	5
X301	3.654	5.145	9.060	13.109	21.447	15.660	10.107	6.449	4.619	4.127	3.461	3.144	26	6	5
X302	4.719	5.366	6.707	9.317	15.161	15.251	11.366	6.736	6.898	6.124	5.436	4.888	21	7	5
X303	1.656	2.137	2.645	33.893	20.478	24.664	3.745	2.780	2.204	2.027	1.786	1.565	38	1	5
X304	2.557	4.643	11.721	18.041	20.836	17.576	9.740	5.230	2.926	2.323	1.905	2.293	33	6	5
X306	3.621	6.429	10.214	12.565	17.635	15.433	9.609	6.779	5.153	4.466	4.052	3.644	20	7	5
X307	2.076	4.056	9.961	15.387	22.177	19.223	10.092	5.762	3.822	3.300	2.259	1.866	14	6	5

Appendix 11.3 Variables describing flow characteristics derived for the stations used in the analysis of flow types showing group membership using cluster and discriminant analysis (METH1) and covariance biplots (METH2). The number of years of data used and the catchment area for each station are also shown

Station	GRMEAN	GRCV	GRMIN	GRMAX	ZERODAY	PRED	PROP	FLOINT	FLODUR	FLOFRQ	FLOPRD	SPMEAN	AREA	YEARS	METH1	METH2
A229	2.770	1.814	0.531	7.727	104.429	0.154	0.799	50	2.4	1.805	0.690	0.022	129	21	G	4
A232	1.141	2.996	0.000	9.340	283.556	0.780	0.936	24	1.5	1.389	0.706	0.002	522	18	A	9
A239	3.264	0.265	1.259	7.214	1.288	0.385	0.753	151	1.3	1.071	0.550	0.907	4	14	H	2
A249	7.218	0.051	5.014	9.244	0.231	0.700	0.989	119	2.6	1.231	0.808	0.020	371	13	C	0
A250	5.570	0.149	2.564	8.872	1.429	0.582	0.918	168	2.7	1.143	0.758	0.038	148	14	C	1
A301	2.733	1.179	0.303	9.108	149.518	0.230	0.865	170	2.0	1.290	0.823	0.002	1165	31	G	7
A402	6.736	0.264	2.818	9.515	28.217	0.408	0.877	18	9.6	2.696	0.861	0.004	1777	23	B	4
A405	6.482	0.737	1.886	10.748	80.100	0.344	0.765	17	13.5	1.850	0.679	0.002	3786	20	B	4
A408	6.235	0.347	2.098	10.143	29.500	0.347	0.781	12	5.6	1.857	0.733	0.012	504	14	G	4
A504	6.677	0.229	2.454	10.081	10.714	0.470	0.819	23	3.5	1.867	0.720	0.011	629	21	G	4
A611	4.897	0.209	1.898	8.103	0.429	0.390	0.828	16	3.3	1.857	0.733	0.067	73	21	G	3
A612	4.350	0.441	0.797	9.213	21.350	0.277	0.592	194	2.1	0.850	0.657	0.038	120	20	D	5
A618	3.724	0.145	1.724	6.111	0.462	0.624	0.881	52	4.1	1.815	0.697	0.310	12	13	E	0
A619	4.202	0.145	2.100	6.303	2.000	0.549	0.920	47	1.7	1.071	0.926	0.263	16	14	C	1
A620	3.876	0.342	0.886	7.464	16.000	0.420	0.619	13	4.2	1.857	0.811	0.090	43	14	G	4
A802	7.289	0.097	4.441	8.767	0.421	0.722	0.902	209	5.9	0.289	0.742	0.078	98	38	C	1
A903	6.827	0.083	4.417	8.328	0.244	0.748	0.936	25	4.1	0.683	0.710	0.110	62	41	C	0
A904	8.158	0.094	4.824	9.661	0.306	0.782	0.910	186	11.1	1.365	0.745	0.026	320	13	B	0
B101	6.913	0.298	1.633	12.010	16.310	0.399	0.799	66	2.3	1.643	0.578	0.002	3904	42	G	5
B102	4.153	0.362	0.704	8.584	25.950	0.315	0.892	52	2.0	1.750	0.531	0.017	252	20	G	5
B104	6.614	0.115	3.560	9.343	0.250	0.633	0.942	263	2.0	0.613	0.600	0.018	376	16	C	1
B201	8.406	0.218	1.930	10.170	2.050	0.418	0.902	27	2.3	1.950	0.488	0.004	1594	20	E	3
B405	6.797	0.112	3.793	9.626	0.294	0.714	0.696	355	1.3	0.624	0.733	0.038	168	17	C	1
B502	9.271	0.169	5.050	13.194	0.400	0.537	0.877	301	4.2	1.000	0.780	0.000	31416	25	C	1
B601	8.904	0.084	5.536	10.970	0.320	0.801	0.879	158	2.5	0.640	0.960	0.017	518	25	C	1
B602	7.158	0.191	3.929	10.731	4.435	0.696	0.819	49	4.5	1.130	0.670	0.074	97	23	C	0
B603	7.301	0.118	4.779	10.750	0.217	0.762	0.858	124	1.5	1.043	0.629	0.079	92	23	C	1
B606	4.364	0.296	1.723	7.153	5.125	0.397	0.685	22	6.2	1.868	0.740	0.102	43	18	G	3
B704	6.624	0.174	3.306	9.712	0.692	0.588	0.602	25	3.4	2.000	0.702	0.049	136	28	E	3
B708	2.316	3.211	0.000	8.457	237.167	0.603	0.940	31	14.5	2.000	0.562	0.003	832	30	B	9
B710	2.137	1.756	0.000	9.004	225.077	0.588	0.898	32	2.2	1.462	0.632	0.007	318	13	G	9
B801	0.401	3.987	0.000	7.238	339.313	0.915	0.976	68	4.0	1.836	0.640	0.001	648	18	A	9
C107	8.098	0.240	4.275	12.120	18.750	0.590	0.869	57	3.8	1.250	0.548	0.002	4886	12	E	7
C226	1.992	0.678	0.079	5.713	115.786	0.229	0.821	47	1.8	1.643	0.351	0.077	26	14	G	4
C227	0.478	3.652	0.000	5.170	280.750	0.727	0.986	72	1.1	1.125	0.579	0.120	4	18	A	8
C228	2.591	0.711	0.274	6.641	73.941	0.145	0.759	47	2.0	1.471	0.529	0.084	31	17	G	4
C265	2.559	1.716	0.000	9.078	134.800	0.304	0.897	22	2.6	2.867	0.844	0.000	860	15	G	4
C267	0.679	3.385	0.000	5.748	313.667	0.841	0.964	15	6.2	2.250	0.844	0.000	1695	12	A	9
C303	2.865	1.509	0.160	11.480	213.885	0.481	0.936	30	7.9	1.423	0.449	0.000	10990	52	B	9
C507	1.598	2.827	0.000	9.577	257.971	0.682	0.979	140	1.9	1.059	0.712	0.005	348	34	A	8
C508	0.557	3.816	0.000	9.854	328.143	0.861	0.992	388	1.8	0.929	0.667	0.001	593	14	A	8
C512	1.800	2.945	0.000	10.929	276.833	0.718	0.986	71	2.7	1.542	0.421	0.001	2372	24	A	9
C603	2.882	1.483	0.000	12.581	216.000	0.530	0.880	340	1.4	0.941	0.887	0.000	7765	17	C	8
C703	1.064	2.971	0.000	9.238	298.211	0.792	0.960	51	3.1	2.132	0.440	0.001	914	38	A	9
C803	5.558	0.486	1.031	11.003	45.353	0.262	0.748	122	1.4	1.412	0.606	0.007	806	17	G	5
C812	3.226	0.932	0.858	8.365	104.667	0.192	0.661	24	2.3	2.167	0.597	0.008	386	12	G	4
D103	12.890	0.114	6.512	15.287	4.048	0.971	0.994	31	5.2	2.214	0.394	0.000	37075	42	E	0
D108	11.463	0.115	6.358	14.667	0.417	0.999	0.999	381	2.6	0.750	0.609	0.001	24550	24	C	1
D201	6.295	0.858	0.513	12.520	83.917	0.233	0.667	33	4.3	2.292	0.459	0.001	13421	24	G	4
D303	11.885	0.128	6.778	15.238	1.333	0.993	0.998	144	2.9	1.242	0.495	0.000	94765	33	E	0
D503	0.499	5.498	0.000	10.574	344.272	0.915	0.992	102	1.9	1.606	0.505	0.000	1509	33	A	9
D511	0.094	8.794	0.000	7.093	358.571	0.987	0.995	179	1.7	1.071	0.423	0.000	1656	14	A	8
E106	6.788	0.183	3.668	10.736	0.818	0.667	0.758	360	1.1	0.618	0.800	0.042	160	11	C	1
E202	8.122	0.239	3.526	13.077	1.553	0.599	0.856	384	1.6	0.787	0.887	0.001	6903	47	D	1
G103	5.437	0.449	0.465	9.457	35.700	0.473	0.480	234	1.7	1.250	0.858	0.118	46	20	D	5
G107	6.823	0.232	3.729	12.951	8.154	0.593	0.739	49	1.6	1.365	0.739	0.012	713	13	C	2
G108	6.865	0.251	1.747	10.951	1.840	0.578	0.858	51	2.2	1.240	0.856	0.018	395	25	G	2
G109	1.373	0.933	0.079	7.146	97.429	0.357	0.667	314	1.1	0.766	0.667	0.241	6	14	D	7
G110	0.617	2.682	0.000	6.865	290.900	0.840	0.921	64	1.3	1.100	0.615	0.062	10	20	A	8
G111	5.010	0.450	0.671	9.649	32.000	0.409	0.487	328	1.2	0.947	0.632	0.186	27	19	D	6
G112	4.860	0.581	0.000	9.288	53.941	0.358	0.382	343	1.3	0.862	0.765	0.129	36	17	D	6
G114	3.472	0.311	1.704	6.647	0.238	0.598	0.582	343	1.9	0.762	0.833	1.240	3	21	D	1
G115	3.582	0.388	1.365	7.550	0.261	0.518	0.578	317	1.4	0.913	0.750	1.885	2	23	D	2
G116	4.301	0.273	1.858	7.970	0.333	0.585	0.628	322	2.0	0.600	0.824	1.303	3	15	D	1
G117	2.798	0.449	0.845	6.128	0.288	0.473	0.457	370	1.9	0.643	0.936	1.648	2	14	D	2
G118	3.648	0.430	1.088	7.841	0.619	0.449	0.465	68	1.4	1.048	0.667	1.073	3	21	D	2
G206	4.713	0.633	0.540	10.153	69.600	0.284	0.482	362	1.4	0.600	0.444	0.238	20	25	D	6
G212	2.676	1.137	0.000	9.755	185.000	0.548	0.595	29	1.9	1.905	0.661	0.011	244	21	G	9
G301	3.700	0.855	0.000	9.878	132.938	0.499	0.449	27	4.6	2.813	0.487	0.008	647	16	G	4

Appendix 11.3 continued

Station	GRMEAN	GRCV	GRMIN	GRMAX	ZERODAY	PRED	PROP	FLOINT	FLODUR	FLOFRQ	FLOPRD	SPMEAN	AREA	YEARS	METH1	METH2
G406	4.066	0.906	0.000	10.097	141.182	0.464	0.532	51	2.3	1.818	0.747	0.007	600	22	G	5
G408	2.986	0.432	0.601	6.512	7.947	0.384	0.506	414	1.5	0.528	0.467	1.991	2	19	D	2
G409	1.787	0.984	0.048	5.469	129.829	0.348	0.526	240	2.9	1.087	0.565	0.893	2	23	D	5
G410	2.830	0.770	0.065	7.021	100.118	0.342	0.389	418	1.8	0.708	0.638	0.422	7	17	D	6
G412	2.219	0.593	0.100	5.936	42.773	0.307	0.349	514	1.3	0.500	0.500	3.414	1	22	D	6
G413	2.762	0.853	0.095	6.633	65.765	0.284	0.380	377	1.7	0.708	0.471	1.315	2	17	D	6
G414	5.535	0.355	0.870	9.651	7.769	0.466	0.536	35	2.1	1.842	0.548	0.022	252	19	G	3
G508	1.411	1.721	0.000	7.347	264.917	0.723	0.913	45	8.4	1.542	0.615	0.004	382	24	B	9
H107	7.685	0.193	4.195	10.647	0.214	0.623	0.766	17	1.7	3.071	0.488	0.092	64	28	E	3
H113	6.013	0.225	2.774	10.235	0.365	0.548	0.773	178	1.5	0.692	0.692	0.114	53	13	C	1
H117	7.495	0.137	4.565	9.992	0.250	0.779	0.843	16	1.8	3.500	0.613	0.123	61	12	E	3
H118	8.192	0.141	4.392	11.791	0.333	0.744	0.836	190	1.4	1.067	0.568	0.073	113	15	C	1
H201	7.881	0.135	5.057	11.368	0.188	0.726	0.829	307	3.5	1.000	0.796	0.011	697	18	C	1
H203	7.348	0.207	3.580	11.906	0.444	0.591	0.763	110	1.5	1.667	0.539	0.010	718	18	E	2
H205	5.340	0.162	3.356	8.519	0.222	0.676	0.821	51	2.1	1.389	0.537	0.356	15	18	E	2
H301	0.375	6.448	0.000	10.127	348.436	0.926	0.996	153	2.0	1.625	0.340	0.001	593	16	A	8
H304	0.581	3.707	0.000	6.574	317.000	0.839	0.986	90	6.4	1.235	0.279	0.042	14	17	A	8
H305	0.850	3.586	0.000	4.186	303.850	0.800	0.989	13	12.7	2.200	0.343	0.009	79	20	B	9
H405	5.203	0.181	2.587	9.171	0.286	0.552	0.928	312	1.3	0.679	0.375	0.217	24	28	H	1
H412	0.957	2.969	0.000	7.301	269.568	0.818	0.934	365	2.0	0.765	0.640	0.066	14	17	A	6
H608	7.231	0.183	3.465	10.851	0.333	0.834	0.874	384	1.2	0.944	0.611	0.190	38	18	C	1
H610	4.603	0.134	2.777	7.368	0.273	0.641	0.661	626	2.8	0.364	0.583	0.307	15	11	F	1
H701	9.448	0.242	3.948	13.957	0.231	0.609	0.737	153	2.7	0.865	0.687	0.001	8629	28	C	1
H703	6.819	0.237	2.890	11.585	2.048	0.450	0.916	410	1.7	0.687	0.348	0.015	450	21	H	1
H704	3.183	0.685	0.132	9.194	58.320	0.179	0.581	455	1.3	0.600	0.429	0.114	28	25	D	6
H904	6.121	0.145	3.431	9.133	0.294	0.630	0.970	59	1.8	2.059	0.417	0.122	50	17	E	2
H905	5.916	0.279	2.261	10.281	7.267	0.389	0.897	38	1.5	2.133	0.467	0.026	228	15	E	3
J115	4.803	0.172	2.673	7.645	0.273	0.732	0.824	315	1.5	1.000	0.571	0.546	9	11	C	1
J205	3.691	0.576	0.785	6.572	44.167	0.182	0.599	101	5.0	1.500	0.333	0.015	253	18	G	4
J206	1.912	1.347	0.000	6.564	164.810	0.334	0.808	61	3.1	1.429	0.407	0.009	225	21	G	7
J207	2.415	0.866	0.160	6.318	119.313	0.267	0.685	45	5.8	1.168	0.649	0.097	25	16	G	4
J304	2.513	1.207	0.261	10.255	96.630	0.254	0.933	193	2.2	1.574	0.391	0.001	4252	54	H	7
J313	5.857	0.095	3.739	8.231	0.250	0.696	0.963	222	2.9	1.063	0.357	0.702	29	12	H	1
J317	2.069	1.728	0.000	7.558	208.143	0.455	0.919	33	2.3	1.143	0.684	0.006	348	14	G	9
J403	5.488	0.378	0.432	10.408	32.750	0.372	0.647	92	1.4	1.063	0.360	0.058	85	18	H	5
J404	4.885	0.253	1.798	6.450	9.538	0.393	0.655	51	2.6	1.077	0.514	0.048	99	13	H	3
K302	2.277	0.568	0.206	7.119	18.063	0.146	0.849	317	1.1	0.875	0.375	2.190	1	18	H	6
K304	5.779	0.211	2.865	10.379	0.261	0.472	0.964	140	1.1	0.913	0.417	0.170	34	23	H	2
K305	5.733	0.184	3.862	9.913	0.843	0.572	0.958	442	1.2	0.857	0.400	0.074	76	14	H	1
K401	5.450	0.351	1.207	9.447	13.250	0.282	0.926	198	1.5	0.950	0.348	0.049	111	20	H	5
K402	5.313	0.223	2.913	9.626	0.176	0.478	0.982	116	1.3	1.235	0.385	0.242	22	17	H	2
K403	5.526	0.152	3.325	9.594	0.235	0.554	0.969	130	1.8	0.824	0.462	0.077	72	17	H	1
K502	6.734	0.128	4.041	10.536	0.267	0.644	0.986	171	1.1	1.333	0.435	0.051	133	15	H	1
K601	5.094	0.302	1.410	9.293	10.150	0.346	0.795	200	3.0	1.050	0.443	0.031	165	20	H	5
K701	6.566	0.140	3.666	10.655	0.286	0.642	0.977	195	1.2	0.857	0.429	0.115	57	14	H	1
K801	6.014	0.198	3.207	10.521	0.263	0.524	0.981	155	1.1	0.895	0.556	0.172	35	19	H	1
K802	5.829	0.175	3.331	10.202	0.556	0.573	0.970	185	1.2	0.944	0.428	0.169	35	18	H	1
L101	0.453	5.252	0.000	11.248	345.963	0.923	0.990	209	1.6	0.926	0.641	0.000	3938	27	A	8
L601	0.387	4.802	0.000	11.619	344.906	0.918	0.991	422	1.4	0.658	0.448	0.000	1290	32	A	8
L801	5.810	0.165	3.610	9.363	0.182	0.544	0.947	68	1.3	1.545	0.526	0.277	21	11	E	2
L802	5.169	0.275	1.585	10.058	0.714	0.362	0.859	154	1.4	0.929	0.333	0.100	52	14	H	2
M104	2.010	0.998	0.000	7.249	221.769	0.528	0.880	21	10.5	2.154	0.426	0.005	400	13	B	9
P401	2.807	1.305	0.150	9.629	180.000	0.342	0.883	100	4.3	1.154	0.455	0.005	578	13	G	9
Q101	0.842	4.108	0.000	11.710	331.417	0.880	0.990	168	1.7	1.000	0.657	0.000	9091	12	A	8
Q304	4.287	0.370	1.622	9.020	31.000	0.227	0.841	49	2.4	1.273	0.400	0.005	672	11	H	5
Q802	2.500	1.848	0.000	11.010	235.349	0.560	0.973	80	2.3	1.209	0.400	0.002	1245	43	A	9
Q819	4.775	0.401	1.407	9.314	22.500	0.303	0.766	51	1.9	1.417	0.423	0.083	76	12	G	5
R101	4.255	0.997	0.745	10.343	134.025	0.297	0.918	249	1.6	1.025	0.328	0.018	238	40	H	7
R105	7.252	0.144	3.990	10.687	0.222	0.606	0.939	126	2.3	1.167	0.483	0.015	492	16	H	1
R106	5.096	0.302	1.055	6.467	21.364	0.502	0.855	170	2.0	1.000	0.476	0.051	100	11	H	7
R107	4.554	0.181	2.479	7.556	1.287	0.544	0.930	358	1.7	0.733	0.558	0.138	33	15	H	1
R114	6.613	0.137	3.986	9.991	0.250	0.817	0.981	165	2.3	1.042	0.511	0.095	70	24	H	1
R201	5.274	0.225	2.176	6.541	0.324	0.468	0.844	71	2.5	1.162	0.412	0.182	29	37	H	2
R205	6.405	0.274	1.602	11.267	24.100	0.469	0.934	607	1.7	0.650	0.381	0.018	411	20	F	7
R206	5.033	0.303	1.788	9.106	20.000	0.432	0.863	263	2.5	0.947	0.472	0.042	119	19	H	7
R208	3.326	0.799	0.547	9.430	83.909	0.199	0.774	186	1.5	0.939	0.370	0.055	81	33	H	5
R212	4.488	0.253	2.231	6.605	1.000	0.419	0.788	227	1.5	1.158	0.429	0.299	15	19	H	2
S306	2.668	1.113	0.134	10.808	136.083	0.211	0.796	50	1.9	1.333	0.615	0.001	2170	12	G	4
S603	5.066	0.396	1.188	9.820	35.231	0.323	0.645	104	2.7	1.154	0.641	0.024	215	13	G	7
T104	9.373	0.168	4.842	13.299	7.000	0.679	0.847	366	2.0	0.636	0.667	0.002	4908	11	C	1
T202	8.720	0.127	5.445	12.069	0.200	0.720	0.862	42	1.9	1.933	0.618	0.007	1199	15	E	2
T304	7.820	0.135	4.165	10.022	1.465	0.642	0.694	29	5.9	3.030	0.500	0.006	1029	33	E	3
T306	7.969	0.210	3.787	11.456	9.843	0.570	0.814	119	6.5	1.071	0.711	0.003	2471	14	C	0
T309	7.261	0.207	3.463	10.969	0.261	0.557	0.786	35	2.6	2.391	0.622	0.024	307	23	E	3
T401	8.814	0.093	5.699	11.706	0.217	0.791	0.871	694	2.1	0.478	0.474	0.012	715	23	F	1
T502	8.620	0.082	6.004	10.673	0.222	0.785	0.899	30	2.6	0.889	0.571	0.010	867	36	C	0
T503	7.251	0.181	3.605	10.292	0.409	0.918	0.780	297	3.5	0.864	0.660	0.052	140	22	C	1
T504	8.686	0.148	5.200	11.987	0.164	0.735	0.610	275	2.1	0.839	0.750	0.016	545	31	C	1

Appendix 11.3 continued

Station	GRMEAN	GRCV	GRMIN	GRMAX	ZERODAY	PRED	PROP	FLOINT	FLODUR	FLOFRQ	FLOPRD	SPMEAN	AREA	YEARS	METH1	METH2
U106	10.145	0.108	6.814	12.511	0.190	1.000	1.000	13	4.5	2.667	0.620	0.002	4349	21	E	0
U201	8.696	0.094	5.664	10.667	0.207	0.710	0.938	252	6.4	0.828	0.516	0.009	937	29	C	0
U206	7.657	0.152	4.038	10.521	0.250	0.656	0.816	64	3.5	1.650	0.602	0.023	339	20	E	2
U207	7.758	0.124	4.654	10.484	0.208	0.712	0.862	334	3.7	0.875	0.689	0.022	358	24	C	1
U211	7.050	0.133	3.841	9.655	0.288	0.701	0.874	100	2.0	0.810	0.867	0.040	178	21	C	1
U212	7.222	0.163	3.579	10.498	0.267	0.828	0.822	88	1.8	1.000	0.821	0.017	438	15	C	1
U213	7.673	0.128	4.410	10.651	0.296	0.704	0.864	288	2.5	1.037	0.662	0.026	299	27	C	1
U302	7.787	0.090	4.845	10.385	0.278	0.752	0.910	147	1.4	1.500	0.571	0.022	356	18	E	1
U402	7.303	0.128	4.420	9.494	0.278	0.730	0.851	18	4.4	1.069	0.730	0.023	316	29	C	0
U707	6.190	0.151	3.083	9.149	0.308	0.611	0.851	317	4.3	0.692	0.667	0.054	114	13	C	1
V101	10.172	0.127	5.754	13.218	0.278	1.000	1.000	24	2.4	1.558	0.677	0.002	4178	18	E	0
V102	9.485	0.093	5.604	10.418	0.281	0.842	0.637	7	15.0	3.281	0.401	0.008	1689	32	B	3
V109	3.796	0.746	0.273	10.233	93.900	0.218	0.642	83	1.2	1.300	0.613	0.019	196	20	G	5
V110	6.247	0.374	1.688	12.449	45.727	0.553	0.781	70	1.8	1.273	0.782	0.011	782	11	C	7
V131	4.530	0.483	1.013	9.911	18.077	0.199	0.548	13	2.6	1.692	0.854	0.028	182	13	G	4
V138	7.883	0.314	1.989	12.126	18.923	0.474	0.724	37	1.9	1.692	0.692	0.005	1644	13	G	5
V201	9.125	0.271	2.304	12.196	23.487	0.533	0.878	13	9.6	3.848	0.442	0.005	1976	13	B	4
V205	8.140	0.133	4.426	11.223	0.306	0.754	0.836	38	2.2	1.000	0.917	0.031	260	13	C	0
V302	6.177	0.173	3.979	10.503	3.516	0.597	0.656	17	6.3	2.516	0.446	0.005	1516	31	B	3
V303	7.688	0.207	3.076	10.797	1.655	0.540	0.785	24	2.6	1.897	0.574	0.009	650	29	E	3
V305	7.088	0.241	3.223	11.587	0.259	0.445	0.811	267	3.1	0.852	0.458	0.011	676	27	H	2
V307	6.347	0.274	2.405	10.314	6.241	0.458	0.721	19	2.4	1.517	0.644	0.049	129	29	G	3
V309	5.262	0.363	1.611	9.561	12.810	0.293	0.693	23	2.3	2.762	0.570	0.038	148	21	G	4
V603	6.105	0.342	1.057	10.684	31.429	0.458	0.838	49	1.8	1.333	0.535	0.020	312	21	H	5
V604	6.973	0.320	1.643	11.582	22.858	0.485	0.755	80	1.5	1.625	0.769	0.011	658	24	G	5
V606	5.771	0.235	1.966	9.589	5.500	0.448	0.806	66	1.7	1.750	0.807	0.053	109	12	G	2
V712	6.411	0.165	3.099	9.690	0.288	0.604	0.887	41	1.6	1.571	0.843	0.033	196	21	C	2
V716	7.144	0.152	3.492	10.155	0.429	0.735	0.815	262	2.3	0.857	0.690	0.059	121	14	C	1
V717	8.469	0.116	5.406	11.091	0.214	0.775	0.855	61	3.1	1.357	0.768	0.031	276	14	C	0
W104	4.572	0.388	1.219	8.487	32.950	0.342	0.781	344	2.0	1.100	0.564	0.229	20	20	H	7
W314	3.682	0.518	0.595	7.760	48.091	0.217	0.829	55	2.0	1.636	0.553	0.077	48	11	G	5
W404	8.588	0.124	4.926	11.298	0.261	0.689	0.866	25	2.1	2.130	0.677	0.009	948	23	E	2
W501	2.616	0.598	1.089	5.777	88.279	0.188	0.734	41	7.3	2.023	0.396	0.188	15	43	G	4
W504	6.580	0.205	3.200	10.473	0.241	0.506	0.831	39	1.7	1.241	0.541	0.014	480	29	H	2
W506	6.803	0.184	3.330	9.871	0.250	0.580	0.809	283	1.8	1.000	0.653	0.038	180	28	C	1
W508	5.853	0.156	3.096	9.264	0.487	0.561	0.888	298	1.4	0.833	0.714	0.050	118	30	C	1
X103	10.543	0.072	6.638	12.314	0.280	1.000	1.000	38	9.2	2.320	0.472	0.001	6614	25	B	0
X205	7.967	0.147	3.408	9.917	0.273	0.700	0.881	19	4.6	2.818	0.754	0.012	642	11	E	3
X208	6.246	0.164	2.967	9.772	0.676	0.506	0.859	262	1.7	0.971	0.768	0.035	180	34	C	1
X210	7.269	0.093	4.435	10.196	0.690	0.693	0.938	34	1.6	1.897	0.500	0.058	126	29	E	2
X211	7.684	0.110	4.502	10.639	0.240	0.695	0.879	441	1.2	0.840	0.739	0.019	402	25	C	1
X212	5.681	0.126	3.378	9.400	0.292	0.680	0.897	101	1.3	0.633	0.720	0.065	91	24	C	1
X213	8.798	0.094	5.542	11.088	0.235	0.729	0.933	72	2.4	1.647	0.750	0.008	1518	17	E	0
X214	7.802	0.079	4.972	9.721	0.278	0.792	0.880	281	3.5	0.944	0.848	0.031	250	18	C	1
X215	9.178	0.087	4.989	11.598	0.375	0.821	0.858	352	1.1	0.938	0.824	0.008	1554	16	C	1
X222	7.956	0.127	4.384	10.707	0.571	0.582	0.881	19	1.7	2.643	0.607	0.005	1639	14	E	3
X224	6.812	0.077	4.980	9.087	0.187	0.713	0.948	30	1.6	1.500	0.649	0.085	80	18	E	2
X225	6.145	0.110	3.610	8.177	0.268	0.777	0.837	35	3.3	1.214	0.714	0.248	25	14	C	0
X226	5.243	0.130	2.734	7.469	0.313	0.688	0.826	373	3.9	0.688	0.955	0.375	14	16	C	1
X227	6.905	0.113	3.324	8.404	0.417	0.789	0.831	332	3.0	0.750	0.880	0.089	78	12	C	1
X228	4.040	0.148	2.262	5.981	0.231	0.564	0.829	141	3.4	1.231	0.824	0.709	6	13	C	1
X231	6.945	0.122	3.874	9.839	1.789	0.621	0.913	26	1.7	1.579	0.608	0.027	262	19	E	2
X301	7.398	0.131	3.692	9.847	0.750	0.593	0.901	27	4.2	1.214	0.825	0.043	174	28	C	0
X302	6.294	0.086	3.381	7.884	1.524	0.702	0.932	28	10.9	1.180	0.807	0.114	55	21	B	0
X303	7.202	0.081	4.618	9.292	0.289	0.771	0.898	81	6.2	0.805	0.733	0.139	52	38	C	0
X306	9.121	0.070	6.098	11.080	0.250	0.784	0.890	37	3.3	1.750	0.853	0.012	766	20	E	0
X307	5.480	0.238	1.273	6.213	3.714	0.486	0.745	19	4.0	2.500	0.787	0.119	46	14	E	3