ASSESSMENT OF TROPHIC STATUS IN AQUATIC RESOURCES WITH PARTICULAR REFERENCE TO THE WATER QUALITY RESERVE

HL Malan • JA Day

WRC Report No. 1311/2/05

Water Research Commission

RESERVE WATER QUALITY
VOLUME 2

ASSESSMENT OF TROPHIC STATUS IN AQUATIC RESOURCES WITH PARTICULAR REFERENCE TO THE WATER QUALITY RESERVE

By

HL Malan and JA Day

University of Cape Town,
Freshwater Research Unit,
RONDEBOSCH, SOUTH AFRICA

Report to the Water Research Commission

WRC Report No.: 1311/2/05
ISBN No.: 1-77005-357-3
Set Number: 1-77005-355-7

SEPTEMBER 2005

The Report is obtainable from:

Water Research Commission
Private Bag X03
Gezina
0031

This report emanates from a WRC research projects entitled:

"Refinement of aspects of the reserve determination methodology for water quality, including the assessment of potential impacts to aquatic biota"

Project Leaders:

Dr HL Malan and Prof JA Day
University of Cape Town
Freshwater Research Unit
Private Bag RONDEBOSCH
South Africa

EXECUTIVE SUMMARY

A Water Research Commission-funded project titled "*Refinement of aspects of the Reserve determination methodology for water quality including the assessment of potential impacts to aquatic biota*" was undertaken from July 2002 to December 2004. Two reports emanate from this work:

- Volume 1: "*Wetland water quality and the ecological Reserve*" (Malan and Day 2005), and including WetlandsJet, an Access database on CD;and
- Volume 2: "*Assessment of trophic status in aquatic resources with particular reference to the water quality Reserve*" (Malan and Day 2005).

Because the subjects covered in the two research thrusts of the project are somewhat disparate, they have been recorded in separate documents (each addressing separate objectives – see below). But at the same time, there is also some overlap in the topics, and for this reason the same executive summary precedes each.

OBJECTIVES

The objectives of this project were to:

A) *assess the methodology and the availability of tools (and data) for carrying out water quality Reserve determinations in wetlands and where possible, develop tools/methodology still outstanding;*

B) *refine existing Reserve protocols for nutrients by;*

i) *recommending the nutrient criteria (e.g. total phosphate, dissolved phosphate, total nitrogen or a ratio of two or more nutrients) that should be used to assess the nutrient status of a river or wetlands. A critique of the method now being used will be included;*

ii) *validating (or otherwise) the assumption in the Reserve methodology that the Reference Condition (i.e. the un-impacted state) levels of nutrients in all ecoregions are equal to or less than the Target Water Quality Ranges as given in the South African Water Quality Guidelines.*

Objective A is addressed in **Volume 1**, and the objectives grouped under **Objective B** are considered in **Volume 2** (the present document).

RATIONALE

The aim of this project is to fill in some gaps in the methodology for the determination of the water quality part of the ecological Reserve.

Although the basic ideas and concepts of determining the Ecological Reserve are documented in DWAF (1999a,b,c,d) there are some areas that require more attention. This may be either because a proper methodology for that step has not yet been developed (in the case of the water quality method for wetlands) or because it has, but it needs further evaluation (in the case of the nutrient assessment method). By far the greatest effort was spent on development of methods for setting the water quality component of the ecological Reserve for wetlands. Less effort was directed towards the assessment of trophic status in aquatic resources (rivers, lakes and wetlands) because nationally, considerable progress has already been made in this field.

Wetlands water quality

Wetlands are an important, but neglected, component of the limited water resources in South Africa. The National Water Act (1998) recognises that both the water quantity and water quality aspects of the ecological Reserve need to be determined for this type of aquatic ecosystem. The method for water quality, however, is rudimentary and procedures for determining this aspect of the Reserve need to be developed and refined. At the same time, there is considerable pressure on these systems with regard to development in the surrounding catchments, as well as with regard to the discharge of effluent into them.

Nonetheless, setting water quality specifications for wetlands is not a straight–forward process. Wetlands are naturally variable with regard to water quality – both spatially and temporally. This is a consequence of the many different types of wetlands, differing in (amongst other attributes) water chemistry and geology, and also because levels of inundation (and hence the dilution capacity) vary with time. In addition, water quality data are limited, and in general we have only a poor understanding of the ecological functioning of these systems. A further complicating factor to this project is, that any method that is developed to determine the water quality Reserve for wetlands, and consequently any water quality specifications that are derived, need to be linked to different levels of utilization of the resource. Thus, whatever system for setting water quality standards is developed, it needs to address the problem of allowing maximum benefits from the aquatic resource, but at the same time ensuring sustainable use and minimised impacts.

Assessment of trophic status

There are many different water quality variables that can be measured to describe the nutrient status of an aquatic ecosystem. These range, in the case of phosphorus from total phosphorus (TP) to dissolved forms containing this element (soluble reactive phosphorus, ortho-phosphate). In the case of nitrogen there are also many different chemical species (examples are, nitrate, nitrite, ammonia/ammonium, total inorganic nitrogen (TIN)), all of which can be measured. Furthermore, biotic response variables such as the measurement of chlorophyll *a*, the biomass of phytoplankton, or dissolved oxygen concentrations are also potentially useful assessment indicators. In the original method as given in the RDM manual (DWAF 1999a) ratios of total inorganic nitrogen to total phosphate, or total phosphate to ortho-phosphate were used to describe the nutrient status of rivers. This was often problematic, since data on some of these variables (especially total phosphate) were often lacking at a site. Although this method has been superseded by a new approach, there is still a need to evaluate what criteria should be used to assess nutrient status and the validity of the new method.

STRUCTURE OF THE REPORTS

A brief outline of each of the two reports is given below:

Volume 1: "Wetland water quality and the ecological Reserve"

- **Chapter 1, Introduction:** explains the original objectives for the project, how and why these were amended, and presents the final objectives. The rationale for undertaking this study is discussed and an explanation of the overall approach used to achieve the objectives is given;
- **Chapter 2, Literature review:** presents a wide scope of issues pertinent to water quality and wetlands. Topics covered include; the types of wetlands found in South Africa and their water chemistry, benefits to humans, ecological functioning, and causes of degradation. The project is contextualised by providing a discussion of DWAF's Resource Directed Measures (RDM) methodology as it applies to wetlands. The topic of water quality standards that have been developed internationally is also explored;
- **Chapter 3, Wetland water quality ranges in South Africa:** discusses the need for, the development of and the attributes of the database developed during the project. Results from interrogation of the database are presented, including the ranges of water quality variables (the concentration of chemical

constituents and values of physical variables) exhibited by different wetland types, and the effect of geographic region on these ranges;

- **Chapter 4, Wetland water quality objectives:** explains theoretical approaches to setting water quality objectives, and some of the inherent problems and limitations. A Decision Support System (DSS) is formulated which gives a proposed method of how to set the water quality specifications for a given wetland. A description of the "best-guess" default values for the key water quality variables, how these were derived, when and how they should be used, and the limitations to this approach, is provided;
- **Chapter 5, Application of the DSS:** describes how the DSS developed in this project can be applied to real wetlands in order to determine the water quality component of the Reserve. The systems investigated are; Nylsvlei, Rocher Pan and Verlorenvlei;
- **Chapter 6, Major results, conclusions and recommendations:** summarises the major results and products of the wetland part of the project. Recommendations for further work are discussed.

Volume 2: "Assessment of trophic status in aquatic resources with particular reference to the water quality Reserve."

This report considers the refinement of nutrient assessment methods within the ecological Reserve process. It presents a review of the indicators used internationally to describe the nutrient status of an aquatic resource, and discusses the latest method prescribed for use in South African rivers. A critical evaluation is given of the Target Water Quality Range (TWQR) values for nutrients that are given in the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996A).

APPROACH USED IN THIS STUDY

Wetlands water quality

The following approach was used to achieve Objective A (setting the water quality Reserve for wetlands):

1) a literature review was carried out to identify the important issues relevant to wetland water quality and to establish how other countries manage this aspect;
2) an attempt was made to establish the extent and availability of water quality data for wetlands in South Africa and to collate these data;
3) a database was developed to house the above water quality data;

4) the database was interrogated and the range and median values of key water quality variables examined. How these varied with wetland type, climatic region and season was also investigated;
5) from theoretical approaches and examination of water quality data-sets for several wetlands a Decision Support System for setting the water quality Reserve was designed;
6) using the information obtained from step 4), in conjunction with standards from the literature, "best-guess" default values for key water quality variables were drawn-up. These values were verified by the scrutiny of wetland experts in the country;
7) the DSS was applied to several wetlands, and the method amended as required.

Assessment of trophic status

The approach used to achieve Objective B (assessment of trophic status in aquatic ecosystems) is detailed below:

1) a literature review was carried out to assess how the nutrient status of aquatic ecosystems is described internationally;
2) this was followed by critical examination of the latest method for assessing nutrients (DWAF 2002);
3) reference condition values of nutrients were examined at different sites on rivers in different ecoregions. The sites were first screened for possible impacts by examining the land use in the catchment and using biomonitoring (SASS) data;
4) a comparison was made between the reference condition values of nutrients obtained above and the South African Water Quality Guidelines for aquatic ecosystems;
5) conclusions regarding the validity of the guidelines were made.

THE MAJOR PRODUCTS

The major products emanating from this project are:

- a literature review of water quality and wetlands;
- a database (Access 2000) of water quality and other information for South African wetlands;
- an analysis of some of the major trends and patterns in water quality in South African wetlands;
- a Decision Support System to aid in setting the water quality component of the wetland ecological Reserve;
- a review of some issues concerned with nutrients in aquatic ecosystems.

THE MAJOR RESULTS

The major results obtained from interrogation of the Wetland Water Quality database are given below.

- The lowest median values for electrical conductivity (EC), phosphate and ammonia in all the types of wetland examined, were found in springs ("eyes"). This is perhaps to be expected because the data are all from DWAF and many are used as sources of potable water in arid areas.
- Lakes were significantly different from all non-impacted wetland types with regard to EC, but were not different to impacted wetlands. Lakes were thus higher in conductivity than springs, but lower in conductivity than endorheic and palustrine systems.
- Endorheic wetlands (pans) showed the highest median conductivity of all the wetland types.
- Preliminary results indicate that for some wetlands, anthropogenic impacts have taken the form of dilution, rather than concentration of some water quality constituents (although these results were not statistically significant).
- The range in median pH values for the different wetland types in the non-impacted state was small and pH tended to be circumneutral. There were no significant differences between the non-impacted wetland types. Impacted lakes, on the other hand, exhibited a significantly higher median pH value than all other groups (a likely consequence of eutrophication).
- The highest phosphate levels exhibited by non-impacted wetlands were found in palustrine systems and these were significantly different with regard to all other natural wetland systems. The difference between palustrine and *impacted* wetlands, however, was not significant.
- The median nitrate concentrations exhibited by the non-impacted wetlands (lacustrine, palustrine and endorheic systems) did not vary significantly between the different types. Nitrate levels in the water column of impacted wetlands on the other hand, were significantly higher than in natural systems.
- The lowest median EC values were exhibited by the wetlands that fell into the "All year, summer maximum" (the eastern coastal) region of the country. This area was statistically different from all the other rainfall regions. This region is one of the most mesic in the country and thus the "dilution capacity" is likely to be high.

- The highest median EC values (1 985 mS/m) were exhibited by the wetlands of the summer rainfall region and this value was significantly higher than all other wetland groups.
- It was concluded that whilst there seems to be ranges of water quality variables characteristic of different rainfall regions, it is difficult to pick out clear patterns. Water quality also varies with wetland type and this is likely to confuse any regional patterns.

CONCLUSIONS ARISING FROM THIS PROJECT

Wetland water quality

The following major conclusions were reached with regard to Objective A (setting the water quality Reserve for wetlands) in this project.

- There is a lack of water quality monitoring data for wetlands, in conjunction with limited research that has been carried out into the fundamental understanding of ecological functioning of these systems. Until the knowledge base concerning wetland water quality and ecological response is increased, the ecological status of a wetland under a particular water quality regime cannot be predicted with any certainty. As a consequence the DSS developed in this project is only a first step towards development of an effective water quality approach for wetlands.
- For non-marine-influenced wetlands there are four basic wetland water quality types, based on drainage pattern and the water source. These are riverine, runoff-fed, and groundwater-fed systems and freshwater lakes.
- The 'best-guess" default values should be used only where no site-specific data are available since objectives defined in this manner represent a low level of confidence. Whatever the approach used, a monitoring programme would need to be implemented to ensure that water quality objectives were appropriate and to ensure compliance.
- Useful approaches to setting water quality guidelines for wetlands were obtained from examination of international practices, especially those of the USA and Australia/New Zealand. No approach, however, was transferable in its entirety to the South African situation, but rather a combination of adapted methods was considered to be the most useful.
- Narrative statements may be useful as a management tool, until the links between concentration and ecosystem response are better understood.

Assessment of trophic status

The following major conclusions were reached with regard to Objective B (assessment of nutrients in aquatic ecosystems) in this project.

- From the analysis, it would appear that the current TWQR of 0.005 mg/L for inorganic phosphate as specified in DWAF (1996a) is too conservative. From consideration of the 75%ile for the DWAF chemical monitoring data and from the data collected during biomonitoring, a more reasonable value would be around 0.02 mg/L (rather than 0.005mg/L). With regard to Total Inorganic Nitrogen, it would appear that the value of 0.5 mg/L is possibly too high and that a value of around 0.25 – 0.3 mg/L should be used. Because of the critical role that phosphate plays in limiting eutrophication, however, it is important that although realistic values be set, these should err on the side of conservatism (see below).
- The detection limits for DWAF during the time period from which the data were extracted was 0.011 mg/L for SRP and 0.04 mg/L for combined nitrate and nitrite Thus records with measurements lower than these values (roughly 42% of the SRP and 75% of TIN data points) may be unreliable in terms of the exact concentrations determined. Given this uncertainty, **the present TWQR values should be retained, especially with regard to SRP,** until the detection limits of routine sample analyses have been improved.
- It should be noted that in the revised method for assessing the present state for nutrients (Approach 2, DWAF 2002), the default value of TIN used to differentiate between the Natural and Good categories is 0.25 mg/L (and 0.005 mg/L for SRP). A mechanism is included in the assessment method to take into account *naturally* high nutrient levels. Thus, if the Reference Condition level of a nutrient is higher than the TWQR, this can be accommodated and the entire set of boundary values used to delineate management categories is adjusted accordingly. Nevertheless the results from the current project are useful in that it indicates that most values for SRP would need to be adjusted.

RECOMMENDATIONS AND FUTURE RESEARCH AREAS

Wetlands water quality

The recommendations and topics for further research in wetland water quality are presented below.

- Development of assessment techniques, and if possible a rapid biomonitoring system for water quality in wetlands should be a high research priority. This should be underpinned by research into abiotic stressor-biotic response relationships, where water quality is one of the abiotic stressors included.
- The DSS developed in this project to facilitate setting water quality objectives for wetlands needs to be refined through use by wetland specialists. The particular aspects, *inter alia*, that requires further investigation are:
    - the recommended allowable % deviation from the median,
    - the use of the 80%ile from a comparable wetland,
    - the default "best-guess" values.
    - the classification system of wetland water quality types.
- It would be useful to continue adding data to the Wetlands Water Quality Database, and in particular, wetlands from regions other than the winter rainfall region should be included. This would aid in making the statistical analysis of wetland water quality more robust. In order to ensure compatibility, however, and to maximize the value, cognizance needs to be taken of the final form of the database used to house the National Wetlands Inventory, so that the two can be merged.
- During interrogation of the Wetland Water Quality database, the correlation between rainfall areas and water quality was investigated. It would be useful to extend this work to ascertain if a link between for example, bioregions or water management areas and water quality could be found. This would further our understanding of water quality in the wetlands of this country.
- It was found that very few of the literature sources that were used to compile the Wetlands Water Quality Database recorded linked (i.e. measured at the same place and time) hydrological and water quality data. The question of linking water quantity and water quality requirements in wetlands is another important topic of research that requires attention.
- It would be useful if during the compilation of the National Wetland Inventory or during extension of the Wetlands Water Quality Database a system of Reference Condition sites could be identified. These would be wetlands of different types and regions that were un-impacted with regard to water quality (and other aspects e.g. habitat).
- It may also be useful to extend the database to the inclusion of biotic data e.g. the plant, fish or macroinvertebrate species present at a wetland site. These could then be correlated with water quality so that eventually an understanding

of the tolerances and relationships between water chemistry and various species of wetland plants and animals could be established.

- In order to limit the levels of pollutants that enter into wetlands, it is suggested that there should be more stringent enforcement of existing legislation (e.g. Conservation of Agricultural Resources Act – act 43 of 1983) protecting natural vegetation adjacent to wetlands.
- The topic of setting the lower limits of water quality objectives for wetlands, specifically for salinity requires further research. Minimum concentrations of inorganic salts need to be incorporated into the DSS.
- Ultimately sediment quality guidelines should be drawn up for aquatic ecosystems, and particularly those such as wetlands in which these materials accumulate. At the moment, however, not enough is known about water quality in general and that of sediments in particular to draw up such guidelines but future work should be directed towards this goal.

Assessment of trophic status

Recommendations arising from Objective B (assessment of nutrients in aquatic ecosystems) are as follows:

- Total N and TP should be used as indicators of rivers, streams, lakes and wetlands in addition to measures of dissolved nutrients. Even seasonal measurements of TN and TP (in addition to more frequent measurement of dissolved nutrients) would be useful.
- Research needs to be carried out to draw up default boundary values between Reserve categories for TP and TN in order to demarcate the assessment categories.
- It is important that there is integration between the water quality and River Health Programme monitoring systems. Collecting measurements of water quality as well as biological data (presence/absence of macroinvertebrate taxa and SASS scores) at the same time and same place maximises the usefulness of both.

CONCLUSION

For effective protection of water quality in wetlands it is essential that reasonably stringent pollution limits be set. At the same time, to enable optimum utilization of those systems for economic development, the water quality objectives should not be too conservative.

A method to help determine suitable water quality objectives was developed in this project. The DSS is the result of preliminary deliberations and needs verification by application to many wetlands. It is recognized that "expert knowledge" currently plays a large role in applying this protocol and that the process is not definitive. There is, however, intense pressure on wetlands and many licence applications have, and are being received by DWAF for the discharge of effluents, or for activities that might impact on the water quality of wetlands (R. Stassen, Directorate of Resource Directed Measures, *pers. com.* October 2003). Although not perfect, it is considered by the authors that DSS should at least help to set some limits to protect these assets. Wetlands have long been neglected in South Africa in terms of research and monitoring of all aspects, not just water quality. In a country that is limited in terms of freshwater it is important that attention now be directed towards these vitally important resources. Once more is known about these systems the methods of setting water quality objectives can be improved so that a greater confidence can be placed in the values obtained. Otherwise there is a very real danger of some wetlands being irretrievably damaged if steps are not taken to protect them.

In a similar vein eutrophication of all types of aquatic resources (not just wetlands, but also rivers and lakes), is an increasing problem both in South Africa and world-wide. Furthermore, because enhanced nutrient levels result in shifts in ecosystem functioning many aspects could potentially be measured to assess the trophic status of a water body. It is important that in order to protect aquatic resources the optimal variables are measured. This is further supported by the fact that monitoring of aquatic resources invariables involves expending considerable resources. The current method used to assess trophic status in this country appears to be on a sound footing. It is however important that measurements (even on a seasonal basis) of total nutrient concentration also be recorded.

The two major thrusts of this project are very different, the one directed at setting the water quality Reserve for wetlands, and the other for assessing nutrient levels (primarily in rivers). Nevertheless they are both concerned with managing water quality in aquatic resources. As water becomes even scarcer in this country, and pollution loads increase, managing water quality will become an ever-challenging concern. Sophisticated tools and new ways of tackling the problem will need to be engaged. The project team hopes that the products developed in the course of this project will go some way in helping to protect South Africa's vulnerable aquatic resources.

ASSESSMENT OF TROPHIC STATUS IN AQUATIC RESOURCES WITH PARTICULAR REFERENCE TO THE WATER QUALITY RESERVE

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

Chl *a* – chlorophyll *a*
DO – dissolved oxygen
DSS – decision support system
EC – electrical conductivity
EFA – Environmental Flow Assessment
EIS – ecological importance and sensitivity
EWR – Ecological/environmental water requirement
FRU – Freshwater Research Unit
RC – Reference condition
RDM – resource directed methods
RQO – resource quality objective
SASS – South African scoring system
Secc – secchi disk depth
STWs – sewerage treatment works
TDS – total dissolved solids
TIN – total inorganic nitrogen
TN – total nitrogen
TP – total phosphorus
TSS – total suspended solids
TWQR– target water quality range

CSIR – Council for Scientific and Industrial Research
DEAT – Department of Environmental Affairs and Tourism
DWAF – Department of Water Affairs and Forestry
UCEWQ-IWR – Unilever Centre for Environmental water quality – Institute for Water Research, Rhodes University
US EPA – United States Environmental Protection Agency
WRC – Water Research Commission

ACKNOWLEDGEMENTS

The authors of this report would like to thank the following people for either supplying, or giving permission to use, water quality data for the Wetlands Water Quality Database and/or the case-studies:

Helen James - Albany Museum, Grahamstown.
Noelline Kroon – Sasolburg.
Kate Snaddon and Ms Geordie Ratcliffe - Freshwater Consulting Group
Candice Haskins and Dirk van Driel – Cape Town Metropolitan Council.
Johan van Vuuren, Richard Greenfield, Wynand Vlok - Rand Afrikaans University
Wynand Vlok - University of the North.
Johan Wentzel – Department of Water Affairs and Forestry
Julian Conrad – Geoss

The authors would also like to thank the Members of the Steering Committee for their time and input:

Dr Steve Mitchell – Water Research Commission
Dr Jackie King – Freshwater Research Unit, UCT
Prof Tally Palmer – IWR, Rhodes University
Mr Nico Rossouw – Ninham Shand, Cape Town
Mr John Dini – Working for Wetlands
Ms Delana Louw – IWR Source-to-sea
Dr Cate Brown – Southern Waters
Ms Retha Stassen – DWAF
Dr Sebastian Jooste - DWAF
Dr Helen Dallas – Freshwater Research Unit, UCT
Mrs Podge Joska - Freshwater Research Unit, UCT
Ms Denise Schael - Freshwater Research Unit, UCT

Last, but not at all least, many thanks to the following people for help in various aspects of the project, Piet-Louis Grundling, Darragh Woodford, Jason Smit, Justine Ewart-Smith, and Dave Miller for ably performing the multivariate analyses. Especial thanks to Julian Conrad (GEOSS) and Johan Wentzel (DWAF) for making available documents arising from the Sandveld Reserve Determination project, and to the WRC for funding this project. Finally, to the late Bruce Davison for compiling maps of the sampling locations in the database.

CHAPTER 1.
INTRODUCTION: THE OVERALL PROJECT

1.1 OBJECTIVES OF THE PROJECT

This document forms part of the final report for Water Research Commission (WRC) project K5/1311 "Refinement of aspects of the Reserve determination methodology for water quality including the assessment of potential impacts to aquatic biota". The project lasted for three years, starting in April 2002 and was completed in Dec 2004. Two reports emanate from this work:

- Volume 1: "*Wetland water quality and the ecological Reserve*" (Malan and Day 2005), and
- Volume 2: "*Assessment of trophic status in aquatic resources with particular reference to the water quality Reserve*" (Malan and Day 2005).

The objectives of the project were as follows:

A. *assess the methodology and the availability of tools (and data) for carrying out water quality Reserve determinations in* ***wetlands*** *and where possible, to develop tools/methodology still outstanding;*

B. *refine existing Reserve protocols for* ***nutrients*** *by:*

i) *recommending the nutrient criteria (e.g. total phosphate, dissolved phosphate, total nitrogen or a ratio of two or more nutrients) that should be used to assess the nutrient status of a river or wetlands. A critique of the method now being used will be included;*

ii) *validating (or otherwise) the assumption in the Reserve methodology that the Reference Condition (i.e. the un-impacted state) levels of nutrients in all ecoregions are equal to or less than the Target Water Quality Ranges as given in the South African Water Quality Guidelines.*

The findings for **Objective A** are given in **Volume 1** "Wetland water quality and the ecological Reserve" (Malan and Day 2005). The findings for **Objective B** are presented in the current document (which forms **Volume 2**).

The above objectives were modified from those originally laid out in the project proposal. This topic is discussed further in Volume 1.

1.2 RATIONALE FOR THE PROJECT

The primary objective of this project is to fill in some gaps in the methodology for the determination of the water quality part of the Ecological Reserve. Although the basic ideas and concepts of determining the Ecological Reserve are documented in DWAF (1999a,b,c,d) "Resource directed measures for protection of aquatic resources" (referred to hereafter as the RDM manuals), there are some areas that require more attention. This may be either because a proper methodology for that step has not yet been developed (in the case of the water quality method for wetlands) or because it has, but it needs further evaluation (in the case of the nutrient assessment method).

Wetlands are an important, but neglected, component of the limited water resources in this country. The National Water Act (1998) recognises that both the water quantity and water quality aspects of the ecological Reserve need to be determined for this type of aquatic ecosystem. The method for water quality however, is rudimentary and procedures for determining this aspect of the Reserve need to be developed and refined. At the same time, there is considerable pressure on these systems with regard to development in the surrounding catchment, as well as with regard to the discharge of effluent into them (R. Stassen, *pers. com.*, DWAF RDM office, July 2003). Thus, addressing this deficiency, by setting realistic and sensible water quality specifications (objectives), is one of the major aims of the project. This part of the project is presented in Volume 1 ("Wetland water quality and the ecological Reserve" Malan and Day 2005) and is not discussed further in this document.

With regard to Objective B of the project ("Assessment of trophic status"), there are many different water quality variables that can be measured to describe the nutrient status of an aquatic ecosystem. These range in the case of phosphorus from total phosphorus (TP), to dissolved forms containing this element (soluble reactive phosphorus, ortho-phosphate). In the case of nitrogen there are also many different chemical species, all of which can be measured (examples are, nitrate, nitrite, ammonia/ammonium, total inorganic nitrogen (TIN)). Furthermore, biotic response variables such as the measurement of chlorophyll *a*, or the biomass of phytoplankton are also potentially useful assessment indicators. In the original RDM manual (DWAF 1999a) ratios of total inorganic nitrogen to total phosphate, or total phosphate to ortho-phosphate were used to describe the nutrient status of rivers. This was often problematic, since data on some of these variables (especially total phosphate) were often lacking at a site. Although this method has been superseded by a new approach, there is still a need to evaluate what criteria should be used to assess nutrient status, and the validity of the new method. At the same time, Reference conditions for nutrients are specified as being equivalent to a "natural", or "A class" (i.e. less than 0.005 mg/L for SRP, and less than 0.5 mg/L TIN (DWAF 1996a)). It is important to know if this assumption is valid for all Reference Sites in all ecoregions.

1.3 APPROACH USED IN THIS STUDY

Each section of the broad objectives stated in section 1.1 was sub-divided into small sub-objectives.

METHODS FOR ASSESSMENT OF NUTRIENTS IN RIVERS AND WETLANDS

B. *Refine existing Reserve protocols for* ***nutrients*** *by:*

B *i)* *recommending the nutrient criteria (e.g. total phosphate, dissolved phosphate, total nitrogen or a ratio of two or more nutrients) that should be used to assess the nutrient status of a river or wetlands. A critique of the method now being used will be included;*

B *ii)* *validating (or otherwise) the assumption in the Reserve methodology that the Reference Condition (i.e. the un-impacted state) levels of nutrients in all ecoregions is equal to or less than the Target Water Quality Range as given in the South African Water Quality Guidelines.*

This part of the project was addressed by:

1) under-taking a literature review to assess how the nutrient status of aquatic ecosystems is described internationally;

2) critically examining the latest method for assessing nutrients (DWAF 2002);

3) examination of reference condition values at different sites on rivers in different ecoregions. The sites were first screened for possible impacts by examining the land use in the catchment and using biomonitoring (SASS) data;

4) comparing reference condition values of nutrients obtained above and the South African Water Quality Guidelines for aquatic ecosystems;

5) drawing conclusions regarding the validity of the guidelines.

CHAPTER 2
ASSESSMENT OF TROPHIC STATUS

2.1 THE NEED FOR ASSESSMENT

Eutrophication, or the presence of excessive levels of nutrients in an aquatic water resource, is a form of pollution that is becoming increasingly problematic both locally and internationally (Chutter and Rossouw 1992; Sweeting 1994). The major consequence of elevated nutrient concentrations is the prolific growth of plants and the risk of algal blooms (Ridge, Pillinger and Walters 1995), including blooms of potentially toxic cyanobacteria (Dodds and Welch 2000; Lee and Jones-Lee 2002). The chemical species that are primarily responsible for excessive plant growth are the "macronutrients" (nitrogen and phosphorus), so called because they are taken up by plants and converted to biomass in large quantities in comparison to micronutrients such as sodium or potassium. The other chemical constituents taken up by plants in large amounts are water, carbon dioxide, and oxygen, but these are not commonly considered to be classified as "nutrients" (Noggle and Fritz 1976). Prolific plant growth in an aquatic resource can lead to major changes in the trophic status and consequently to the ecological functioning of an aquatic system. A review of the impact of nutrients on aquatic ecosystems, in general, can be found in Dallas and Day (2004). A discussion of the importance of cyanobacteria in South Africa is given in Harding and Paxton (2001), and a brief discussion of nutrient enrichment and wetlands is given in Volume 1 of this report (sections 2.4 and 2.6).

Nitrogen and phosphorus are natural (and essential) chemical constituents of rivers, lakes and wetlands and it is only at elevated concentrations that they begin to exert an impact. Yet at the same time, the generation of nutrients is a common feature of many anthropogenic activities, including disposal of sewerage, agriculture (utilizing livestock or crops) and several manufacturing industries (Dallas and Day 2004). Thus on-going monitoring and assessment of the concentrations and impacts of these constituents in aquatic systems is essential. Because both nitrogen and phosphorus are found in different chemical forms and can be found in the water column, in sediments (both in pore water and chemically or physically bound to particles) and within living organisms (Sweeting 1994), knowing exactly what should be measured to assess the nutrient status of a water body can be problematical. Furthermore, nutrients (with the exception of nitrite and ammonia) are not toxic to living organisms, but rather elicit a deleterious response through enhanced plant growth. Thus a potentially useful way of assessing the nutrient status of a water body is to measure some aspect of plant response. The chemical forms in which nutrients occur, as well as which aspects can most usefully be measured are discussed in the following section.

This part of the project is concerned with assessing nutrients in all types of freshwater aquatic resources and not just wetlands. The second part of this report is concerned with evaluating the validity of the nutrient target water quality range as defined in the South African Water Quality Guidelines for aquatic ecosystems (DWAF 1996a). As noted in Volume 1, although the guidelines are for all types of ecosystems (i.e. rivers, lakes and wetlands), they were derived primarily for, and using data from, riverine systems. As a result the emphasis in this report is largely on rivers.

CHAPTER 3

RECOMMENDATION OF THE NUTRIENT CRITERIA THAT SHOULD BE USED FOR ASSESSING TROPHIC STATUS

The first step of this part of the study was to examine the water quality guidelines used in other countries to see if further refinements should be made to the South African system. A short description of the different chemical forms in which nutrients occur and the water quality indicators typically implemented to ascertain the nutrient status of water bodies is included below. This is followed by a brief literature review of the nutrient water quality guidelines used in other countries. A section describing the two approaches that have been used in South Africa is then presented. Final recommendations are given at the end of this report.

3.1 GENERAL BACKGROUND ON NUTRIENTS

According to the South African Water Quality Guidelines for aquatic ecosystems (DWAF 1996a), inorganic nitrogen is seldom present in high concentrations in un-impacted rivers because it is rapidly taken up by the biota. Inorganic nitrogen concentrations in un-impacted aerobic systems are usually below 0.5 mg/L. Oxidised forms of inorganic nitrogen (usually nitrate) can sometimes be present naturally in groundwater and originate from mineral salts in rocks and soil. Occasional increases in inorganic nitrogen level above the target water quality range (TWQR) are not as critical as sustained elevated levels. Average summer inorganic nitrogen concentrations provide the best basis for estimating the risk of eutrophication to the biota, since it is during this time of the year that algae are likely to proliferate. The South African Water quality guidelines for aquatic ecosystems also suggest that average summer inorganic phosphorus concentrations be examined to see if they exceed the TWQR (this aspect is discussed further in section 4). But it is important to link the assessment of the two nutrients. In South Africa, as in many other countries, bioavailable phosphate in un-impacted waters is usually limiting to plant growth (Wiechers 1985) – see however, the paper by Dodds and Welch (2000) and Chessman *et al.* (1992) who contend that in other countries, at least, this may not always be the case. Note also that in unimpacted wetlands, phosphate levels can also reach high concentrations, especially in the sediments

(J. Day, FRU, UCT, *pers. com.* 2005). If phosphorus is no longer limiting, additional nitrogen, if required, can usually enter the system via nitrogen fixation. Thus considerable attention has been paid to phosphate levels in streams and rivers since it is thought that by controlling this nutrient, excessive algal growth may be limited (Cahill, Imperato and Verhoff 1974; De Jong, De Oude, Smits *et al.* 1989; Rossouw, Harding and Fatoki *in prep.*).

Phosphorus

Phosphorus is an essential macronutrient with a major role in the structure of nucleic acids, as well as in the storage and production of energy in cells. Natural sources of phosphorus include the weathering of rocks and leaching of phosphate salts into surface waters, as well as from decomposition of organic matter (DWAF 1996a This nutrient occurs in both dissolved and particulate forms. In the dissolved form it occurs most abundantly as the inorganic ortho-phosphate (PO_4^{3-}) ion, but also as poly-phosphates, meta-phosphates, pyro-phosphates and organic compounds (Holtan, Kamp-Nielsen and Stuanes 1988). Particulate forms include phosphorus bound up in organic compounds, in phytoplankton and phosphorus adsorbed to suspended particulate matter such as clays and detritus. Adsorbed phosphorus may be released from sediments under high flow conditions or when anoxic conditions prevail. The release and adsorption of soluble forms by mineral particles (e.g. clay or sand) plays an important role in influencing the bioavailability of phosphorus (Holtan *et al.* 1988). The above authors, citing Rigler (1973) define the fractions of phosphorus as shown below:

$$
\text{TP } (>0.45\ \mu m) \begin{cases} \text{PP} \\ \text{SP} \begin{cases} \text{SRP} \\ \text{SUP} \end{cases} \end{cases}
$$

Where: TP = total phosphorus
PP = particulate phosphorus (>0.45 μm)
SP = soluble phosphorus (<0.45 μm)
SRP = soluble reactive phosphorus
SUP = soluble unreactive phosphorus

Figure 1. *Fractions of phosphorus found in aquatic systems (from Holtan et al. 1988).*

Particulate P is composed of adsorbed/exchangeable P, organic P, precipitates with Ca, Fe and Al, and crystalline/amorphous P. Phosphorus in solution on the other hand (SP) is made up of ortho-phosphate, inorganic poly-phosphates and organic P compounds dissolved in the water phase. Soluble unreactive phosphorus can undergo enzymatic hydrolysis and become available for uptake by the biota (Holtan *et al.* 1988). The term "reactive" or "unreactive" refers to the fractions that respectively do, or do not, react with the molybdate reagent during the analysis procedure (EPA 1999a). The distinction between particulate and "dissolved" P is primarily a function of the filter used. Traditionally a 0.45um membrane filter has been used. Finally, organic phosphorus due to the action of bacteria is slowly converted to inorganic forms and thus becomes bioavailable again (EPA 1999a).

Nitrogen

Nitrogen is also a major component of all living organisms as it is an essential constituent of proteins. The forms of inorganic nitrogen found present in water are ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^{-2}). This includes the dissolved forms of inorganic nitrogen and those adsorbed onto suspended inorganic and organic matter. Both ammonia (also known as unionized ammonia) and ammonium (or ionized ammonia) are reduced forms of inorganic nitrogen. Water temperature and pH control the relative proportions in which they occur, both forms of which can exist as dissolved ions or adsorbed onto suspended material (DWAF 1996a). Most aquatic organisms are sensitive to the toxic effects of ammonia. Ammonium, together with nitrate, are the forms of nitrogen most readily assimilated by plants. Nitrite (NO_2^-) is the inorganic intermediate, and nitrate (NO_3^{-2}) the end product of the oxidation of organic nitrogen and ammonia. Nitrate is the most abundant form in aquatic systems as it is the more stable of the two forms. Nitrite and nitrate are generally measured together as a result of their co-occurrence and rapid inter-conversion (DWAF 1996a). Control of nitrogen is often more difficult than phosphorus because of the ability of some species, including some cyanophytes to utilize atmospheric nitrogen (EPA 1999a).

3.2 NUTRIENT INDICATORS

To assess the health of aquatic ecosystems, monitoring of a number of water quality indicators can be implemented. Indicators provide a measure of the input of pollutants to a system and from these potential impacts can be determined. Indicators ideally should be easily measured, scientifically credible and easy for non-scientists to understand. The trophic status of a water body can be expressed in many different ways. A useful approach is that used by the US EPA (EPA 2000; EPA 1999b), whereby a distinction is made between *causal indicators* (i.e. some measurement of nitrogen or phosphorus), *primary biological response indicators* (e.g. chlorophyll *a*, or biomass of periphyton) and *secondary response indicators* (e.g. dissolved oxygen concentration, pH). The secondary response indicators are impacts that are brought about primarily by the plants (macrophytes or algae). Some of the key nutrient indicators that are used internationally are described here, along with the potential strengths and weaknesses associated with each.

Total phosphorus (TP)

Total phosphorus (TP) is a measure of all the chemical species of phosphorus present in the water column. This includes dissolved forms, insoluble particulate forms and phosphorus already incorporated into phytoplankton (Liston and Maher 1997). Total phosphorus is considered to be a robust, reliable and comprehensive measurement, but does not reflect the actual proportion of phosphorus that is immediately available for uptake by aquatic plants and algae (the "bioavailable" fraction). Total phosphorus is, however, considered useful for determining trophic status because it represents the entire phosphorus content potentially available for incorporation into active biomass. In South Africa, TP is measured at a few sites, but by no means at all. Determination of TP is more difficult (and more expensive) than analysis of just the dissolved fraction because an additional digestion step is required to convert all phosphorus to the dissolved inorganic form, which is then measured (Dodds 2003).

Soluble forms of phosphate

Ortho-phosphate is the most common dissolved form of phosphorus and is that phosphorus immediately available for uptake by plants (DWAF 2002). Soluble reactive phosphorus (SRP) is the most commonly measured chemical species of phosphorus. It is generally acknowledged that SRP represents the amount of ortho-phosphate in the water plus some poly-phosphates (EPA 1999a). Dodds (2003), however, questions this practice saying that SRP represents an uncertain chemical fraction. The DWAF routinely measure soluble reactive phosphorus (SRP) which is commonly referred to as ortho-phosphate or just phosphate (DWAF 1999a; 2002).

"Filterable Reactive Phosphorus (FRP)" is used as an indicator in the Australian water quality guidelines (ANZECC/ARMCANZ 2000). Dissolved Inorganic Phosphorus (DIP) is another term also used in the literature (e.g. Harris 2001). From the above it can be seen that during analysis of phosphorus (as well as all the other indicators) it is essential that the laboratory procedures are consistent and standardized. Caution should also be observed when comparing data from several sources that use different techniques which may cause discrepancies (EPA 1999a).

Total Nitrogen (TN) and Dissolved Inorganic Nitrogen (DIN)

Dissolved inorganic nitrogen (DIN) is commonly measured as an indicator of trophic status (relative nutrient availability) since it is easier to measure than TN. As in the case of phosphorus, to determine total nitrogen an additional digestion step is required to convert all forms of N to the dissolved inorganic form. Furthermore, because of the many forms in which this element occurs in aquatic systems, several indicators are measured. The DWAF measure combined nitrate and nitrite, ammonium and (infrequently) Kjeldahl nitrogen. In terms of the Reserve methodology for assessing nutrient status (DWAF 2002), nitrogen levels are expressed as total *inorganic* nitrogen (TIN), which is the sum of the concentrations of nitrate, nitrite, ammonia and ammonium (DWAF 1996a). Total nitrogen (TN) on the other hand, is a measure of the all forms of this element and therefore also includes any nitrogen bound up in organic compounds. The total nitrogen concentration can be calculated by adding together the measured values of nitrate, nitrite, ammonia, ammonium and organic N. Where the organic fraction is given by Total Kjeldahl (TKN) which is the concentration of Kjeldahl N minus ammonia (EPA 1999a; EPA 1999b). Thus by combining measured values of nitrate + nitrite as well as kjeldahl N, the TN concentration can be determined (Roos, Pieterse and Prinsloo 1997).

Total nitrogen to total phosphorus ratio (TN: TP)

The total nitrogen to total phosphorus ratio (TN: TP) is often used as a measure of the tendency of a water body to support an algal bloom. Un-impacted rivers normally have an inorganic TN:TP ratio ranging between 25 to 40:1 whereas most impacted rivers have an inorganic TN:TP ratio of less than 10:1 (DWAF 1996a).

Chlorophyll a

Chlorophyll concentration is another commonly measured indicator of water quality and especially of eutrophication. Since all plants, algae and cyanobacteria contain approximately 2% (dry weight) of chlorophyll, the concentration of this chemical constituent serves as a general indicator of plant biomass. The term "chlorophyll" represents a family of molecules, chlorophyll *a*, *b*, *c*, and *d*. Chlorophyll *a* is, however, the primary photosynthetic pigment and a good indicator of plant biomass (EPA 1999a). Note though that the chlorophyll: carbon ratio in phytoplankton varies by about a factor of 5 depending on ambient light and nutrient levels (Laws and Chalup 1990 cited in EPA 1999a). An increase in chlorophyll *a* in the water column indicates that plants, algae or cyanobacteria are proliferating, and that a potential nuisance plant problem may exist requiring appropriate management action. Measurement of chlorophyll *a* together with nutrient measurements is a valuable means of assessing water quality.

Other variables used to assess trophic status

A useful review of all the variables that could be used to measure the trophic condition of a lake or reservoir is given in EPA (1999a). In addition to the nutrient criteria and measure of chlorophyll described above other potential variables are discussed. These include the extent (area) of macrophyte coverage, dissolved oxygen, organic carbon, biological community structure and land-use in the catchment of concern. A discussion of the factors affecting the measurement of dissolved oxygen and the TWQR for this variable are given in Dallas and Day (2004).

3.3 INTERNATIONAL WATER QUALITY GUIDELINES FOR NUTRIENTS

A review of the literature was undertaken to ascertain the approaches used to assess nutrient status in rivers and wetlands in other countries. The results from this survey are discussed below. The key nutrient parameters used to assess water quality are listed for each country that was reviewed. The international water quality guidelines for *wetlands* are discussed in Volume 1 (section 2.7.1.3 and 2.7.2).

Australia and New Zealand

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality have recently been revised by the Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ 2000). The general philosophy behind the guidelines is discussed in Volume 1 (section 2.7.2). Nutrient guidelines are tailored for different ecosystem types. Default nutrient guideline values based on suitable local reference waters are provided for up to 6 ecosystem types – upland rivers and streams, lowland rivers, freshwater lakes and reservoirs, wetlands, estuaries coastal and marine systems. The new default guidelines are based on regional data for five climatic/geographical regions across Australia and New Zealand. The nutrient parameters measured by the Australian States and Territories are: chlorophyll *a*, total phosphorus (TP), filterable reactive phosphate (FRP), total nitrogen (TN), oxides of nitrogen (Kn_{ox}) and ammonium (NH_4^+). The guideline trigger values for these parameters are based on condition 2 ecosystems i.e. substantially natural to slightly disturbed ecosystems.

United States of America

Currently the US Environmental Protection Agency (EPA) is focusing considerable resources on the problem of eutrophication as a result of the widespread occurrence of excessive fertilization of water bodies in the country (EPA 2002; Lee and Jones-Lee 2002). The ecoregional approach used by the US EPA to setting water quality objectives for wetlands and the values prescribed for lakes and reservoirs are discussed in Volume 1 (section 2.7.1). Guidance for assessing the trophic status of lakes and reservoirs is given in EPA (1999a) and for rivers and streams in EPA (2000). The variables recommended for *lakes and reservoirs* are: total phosphorus (TP), total nitrogen (TN), chlorophyll *a*, water clarity (as measured with a Secchi disc) and dissolved oxygen (EPA 1999a). The variables suggested for *rivers and streams* are the same as above, except that dissolved oxygen is not considered to be necessary (presumably because these are lotic systems). In addition, a distinction is made between benthic and planktonic algal biomass as indicated by chlorophyll *a* content.

The European Union

In countries within the European Union, the development of nutrient guidelines is set within the context of watershed management plans as stipulated in the Water Framework Directive. A watershed management plan sets out a common vision for identifying use-related objectives for water quality along with actions to achieve the objectives. For the Lake Peipsi catchment in Estonia, indicators were chosen of overall ecological condition. With regard to nutrient status, dissolved oxygen, ammonium, total P and total N were recommended as indicators (Noges 2003).

3.4 ASSESSMENT OF TROPHIC STATUS IN THE RESERVE METHODOLOGY

Various ways have been used to express the nutrient status of rivers in South Africa. In the context of setting water quality objectives for the ecological Reserve, a method was prescribed (termed Approach 1 in this report) in the Resource Directed Measures manual (DWAF 1999a). The ambient nutrient status of rivers (termed the "present state") was assessed by measuring various nutrient criteria (e.g. ammonia, total inorganic nitrogen, and SRP concentrations). The percentage of the total phosphorus concentration that was in the form of SRP was used to decide on whether a resource was oligo-, meso- or eutrophic and from there an assessment category (natural, good, fair etc.) was assigned. The N: P ratio was also calculated using either TP or if data for this variable were unavailable, SRP. The present state assessment and the setting of Resource Quality Objectives (i.e. target concentrations that should not be exceded) carried out as part of the process were based on a monthly timescale. This method was found to be cumbersome and often impracticable. One of the reasons being, that total phosphate concentrations are infrequently measured by DWAF in South African rivers.
The water quality assessment method (for all water quality variables, not just for nutrients) was revised in March 2002 and a new draft method (DWAF 2002) was introduced. This is termed "Approach 2" in this report and was refined at a workshop held in Grahamstown (21^{st} – 23^{rd} July 2003). Although not yet given official approval, this method is being used in ecological Reserve determinations for rivers (N. Rossouw, Ninham Sands, Cape Town, *pers. com.* Nov 2004).

In Approach 2, use is made of the absolute concentrations (rather than ratios) of TIN (Total inorganic nitrogen; i.e. NH_3 + NH_4^+ + NO_2^- + NO_3^-) and soluble reactive phosphorus (SRP). At this stage, TP is not included, although the authors state that future reviews of the method will consider this variable. The most recent 5 years of the data record is used to calculate the median value of TIN or SRP. This value is then compared with the default nutrient benchmark table (Table 1) to ascertain which category a river reach currently falls into. A mechanism has been included to take into account high background nutrient levels. Thus, if the Reference Condition level of a nutrient is *naturally* higher than the TWQR (as given in the South African Water Quality

Guidelines for Aquatic Ecosystems (DWAF 1996a)), this can be accommodated and the entire set of boundary values used to delineate management categories is adjusted accordingly. The Resource Quality Objectives (now termed ecospecifications) represent the desired "water quality standards" and in Approach 2 are set in terms of a single value rather than for each month of the year as in Approach 1.

Table 1. *The default benchmark category boundaries for median nutrient concentrations as used for setting the water quality component of the ecological Reserve (DWAF 2002).*

Category	Median SRP (mg/L)	Median TIN (mg/L)
Natural	≤ 0.005	≤ 0.25
Good	0.0051 – 0.025	0.251 – 1.0
Fair	0.0251 – 0.125	1.01 – 4.0
Poor	> 0.125	> 4.0

Furthermore, in Approach 2, use is made of chlorophyll *a* as an indicator of algal abundance. Inclusion of this variable in water quality assessments is necessary because the actual nutrient status may be eutrophic, resulting in excessive growth of nuisance algae or macrophytes, yet the levels of nutrients in the water might not reflect this, because the nutrients are bound up in plant biomass. Default benchmark boundary values are given for chlorophyll *a* extracted from phytoplankton or periphyton (DWAF 2002).

Consideration of which nutrient indicators should be used

There is considerable conflict in the literature as to whether total nitrogen (TN) and total phosphorus (TP) should be used as indicators of trophic status or whether the dissolved nutrient forms should rather be measured. For example, Dodds and Welch (2000) and Dodds (2003) state that with regard to surface waters in general, although dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) have been used by some to indicate the trophic status of waters, and the ratios of DIN: SRP concentration to indicate nutrient deficiency, the utility of such measurements should be questioned.

They state that DIN: SRP is a weak surrogate for TN: TP and should be used with caution to indicate nutrient limitation, and that the best values to use for indication of trophic state and nutrient limitation are TN and TP. On the other hand, Harris (2001) considers that in Australian waters, dissolved inorganic N (DIN) and DIP are better nutrient indicators than TN and TP and that the ratio of DIN: DIP is a good predictor of algal blooms. Furthermore, the dissolved forms are easier to measure than the total nitrogen or phosphorus content. He does conclude though that this does not preclude measurement of TN and TP in addition to the soluble forms.

The crux of the entire argument is whether it is better to assess the bioavailable nutrient concentration, or the total nutrient content, of which some potentially could become bioavailable. Dodds and Welch (2000) state that control based on measured levels of dissolved inorganic N and P may not be effective because these pools are replenished rapidly by remineralisation in surface waters. According to Lee and Lee-Jones (2002) phosphorus available for algal uptake in agricultural and urban runoff can be estimated as the soluble ortho-phosphate concentration, plus about 20% of the particulate phosphorus load. Algal-available nitrogen can be estimated as the concentrations of combined nitrate, nitrite and ammonia, plus some site-specific fraction of the organic nitrogen. The fraction of the organic nitrogen that is available depends on its source and age.

To some extent the most suitable indicator variable may depend on the type of ecosystem under consideration. According to Environment Australia (2002), in riverine systems, TP is often used as a primary water quality indicator because it represents the maximum amount of phosphorus that may ultimately become bioavailable and contribute to nutrient enrichment and algal blooms. In contrast, FRP (filterable reactive phosphorus) may be a more appropriate indicator in wetlands and estuarine ecosystems because it is a better measure of the availability of soluble forms of phosphorus, which may limit primary production and eutrophication in these systems. Note though that for wetlands, lakes, lowland and upland rivers, nutrient criteria in Australia are given both as TP and FRP, TN and NO_x (DEH 2004). In North America, on the other hand TP has been used as a basis for setting criteria for lake and reservoir management, whereas SRP has more often is used for setting criteria in rivers and streams (EPA 1999b). This is logical when it is considered that higher nutrient contents can be allowed in more hydrodynamically unstable systems (i.e. water quality criteria may be more lenient) because of regular scouring of algal biomass in rivers that flood frequently (Dodds and Welch 2000). Apart from the measurement of nutrient concentrations, it is equally important that attention is focussed on the biological effects of these nutrients (Lee and Jones-Lee 2002).

3.5 DISCUSSION

From the preceding discussion the following major points have emerged.

- Total N and TP should be used as indicators of rivers, streams, lakes and wetlands in addition to measures of dissolved nutrients. Scientific and technical issues should be balanced against practical considerations when deciding upon a water quality indicator and it would seem that both dissolve and total P and N measurements have their merits and if possible, both should be measured (EPA 1999b). It is recognised that measurement of TP and TN in addition to the dissolved nutrient forms would add to the financial cost of sampling. Samples would not have to be taken every month however, seasonal measurements could be taken.
- We concur with the authors of DWAF (2002) that, in line with the above, default boundary values between Reserve categories also need to be developed for TP and TN.
- Measurement of periphyton and phytoplankton chlorophyll *a* levels such as is now used in the determination of the trophic status of rivers in South Africa (DWAF 2002) is a useful addition to the assessment method for determining the ecological Reserve. Further research needs to be implemented, however, into the dynamics between nutrients and algal response in South African systems, in addition to the efficacy of sampling methods.

CHAPTER 4

VALIDATION OF THE TWQR FOR NUTRIENTS

4.1 INTRODUCTION

The aim of this part of the investigation is to check the validity of the Target Water Quality Range (TWQR) values for nutrients as they pertain to aquatic ecosystems (DWAF 1996a). In this sense, the aquatic environment can be considered to be a "water user" which has certain water quality requirements – i.e. ranges of physical variables such as pH, dissolved oxygen, or concentrations of chemical constituents required in order to protect the living organisms dependent on these systems. Other water uses for which guidelines have been drawn-up include; recreational use (DWAF 1993), industrial use (DWAF 1996b) and aquaculture (DWAF 1996c). The values for nutrients given in the guidelines for aquatic ecosystems represent the concentrations that should not be exceeded by these variables. These are the maximum concentration of nutrients that could be expected in non-impacted rivers. The values appear to have been derived from the literature and to some extent by expert judgment, but in the most part, do not seem to have been validated by a rigorous examination of measured water quality data from rivers around the country. Furthermore, these values are used to some extent as a basis for delimiting the boundary between the "natural" and "good" (or Class A and Class B) assessment classes in the Reserve methodology for nutrients (DWAF 1999a and 2002). A summary of the values of the TWQR and the associated criteria for nitrogen and phosphorus is presented in Table 2. Ammonia/ammonium was not considered in this project since the guidelines (DWAF 1996a) are stipulated in terms of ammonia, whereas ammonium is the chemical species that is measured by DWAF in rivers. Calculation of the percentage ammonia can be performed; however, this requires measurements of pH and temperature (DWAF 1996a). Temperature is not frequently measured by DWAF in rivers and therefore any calculations of ammonia levels would of necessity be estimates. Furthermore, ammonia is a toxic substance and therefore an ecotoxicological approach is probably more appropriate for setting guidelines for this chemical constituent.

Table 2. *Target Water Quality Ranges (TWQR) for nitrogen and phosphorus as defined in the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996a).*

Average summer inorganic *Nitrogen* conc.	**Target Water Quality Range**
< 0.5 mg/L	• Oligotrophic conditions < 0.5 mg/L: no nuisance growth of aquatic plants or the presence of blue-green algal blooms. • Inorganic N concentrations should not be changed by more than 15% from that of the water body under local unimpacted conditions at any time of the year. • The trophic status should not increase (although it can decrease). • The amplitude and frequency of natural cycles in inorganic nitrogen concentrations should not be changed.
Average summer inorganic *Phosphorus* conc.	**Target Water Quality Range**
< 0.005 mg/L	• Oligotrophic conditions < 0.005 mg/L: no nuisance growth of aquatic plants or the presence of blue-green algal blooms. • Inorganic P concentrations should not be changed by more than 15% from that of the water body under local unimpacted conditions at any time of the year. • The trophic status should not increase (although it can decrease). • The amplitude and frequency of natural cycles in inorganic nitrogen concentrations should not be changed.

4.2 METHOD

Selection of reference sites

The reference sites for the validation of the TWQR for nutrients were selected using the water quality data collected as part of the DWAF chemical monitoring programme. The criteria used to identify reference sites were; hydrology, water quality, SASS/ASPT score, and land-use. The method used is discussed below.

1. The reference sites were selected from DWAF gauging stations that were relatively un-impacted with regard to hydrology. Although the focus of this study is on aspects of water quality rather than flow, it was considered that sites where flow was

significantly altered were also likely to be sites exhibiting some degree of pollution. More importantly, the flow regime is a major factor in the mobility, availability and spatial distribution of phosphorus. For example, during periods of high flow adsorbed phosphorus may be released from the sediments (DWAF 1996a). Thus in order to try to eliminate the potentially confounding effect of altered flow regime, only sites exhibiting relatively natural hydrology were used. The DWAF gauging stations identified by Joubert and Hurly (1994) as being relatively natural with regard to hydrology (approximately 352 in total) were therefore used.

2. The above sites were then screened to exclude those that were heavily polluted. The criteria of Day, Dallas and Wackernagel (1998) were used to screen the data. Thus for each site, the percentage of samples for which combined nitrate and nitrite were ≥ 0.5 mg/L, SRP (soluble reactive phosphorus) ≥ 0.1 mg/L and electrical conductivity (EC) ≥ 500 mS/m was calculated. The percentages obtained for each of the three water quality variables were averaged to provide an indication of the overall level of impact at each site. These averages were used to rank sites according to their water quality and data for the three least impacted (in terms of nutrients) sites per drainage region were examined further. A list of all the sites, with their ranks, according to the above-defined water quality criteria can be found in Malan and Day (2002). The above list was then refined by examining the data values and excluding those sites for which the median SRP concentrations were elevated. The remaining stations were considered to be "minimally impacted" and are shown in Table 3. In some drainage regions, the majority of DWAF monitoring stations were impacted and thus no sites in the region satisfied the water quality criteria.

3. The minimally impacted sites (Table 3) were then screened further to confirm which of them were true reference sites (i.e. virtually natural). Two methods were used to achieve this. Firstly, by examining and comparing chemical monitoring data with biomonitoring data (if available) for the same reach of river. Secondly, by examination of land-use (and in particular the percentage area that was natural, or conversely transformed by agriculture, urbanisation etc.) in the catchment upstream of the site under consideration.

Table 3. *The list of DWAF water quality monitoring stations considered to be "minimally impacted". The code of the gauging station, place name and ecoregion are also recorded.*

Drainage region	**Gauging station**	**Place name**	**Ecoregion**
A	A6H018	Rasloop River, Sussensvale, Modderpoort	Central Highlands
	A6H021	De Wet Spruit, Groenvaley	Central Highlands
B	B4H005	Waterval River, Modderspruit	Central Highlands
	B6H003	Treur River, Willemsoord	Lebombo Uplands
	B7H004	Klaserie River, Fleur de Lys	Lebombo Uplands
E	E1H006	Jan Dissels River, Clanwilliam Commonage	Cape Fold Mountains
	E2H002	Doring River, Elands Drift, Aspoort	Cape Fold Mountains
	E2H003	Doring River, Melkboom	Western Coastal Belt
G	G1H016	Kasteelkloof Spruit, Zachariashoek, Kasteelkloof lower.	Cape Fold Mountains
H	H2H005	Rooi-Elskloof River, Roode Els Berg	Cape Fold Mountains
	H6H010	Waterkloof River, Waggensbooms Kloof	Cape Fold Mountains
J	J1H015	Bok River, Lot B	Cape Fold Mountains
L	L7H006	Groot River, Grootrivierspoort	Cape Fold Mountains
	L8H001	Wabooms River, Diepkloof	Cape Fold Mountains
N	N2H009	Volkers River	Eastern Uplands
Q	Q9H002	Koonap River, Adelaide	Eastern Uplands
	Q9H014	Koonap River, Frisch Gewaagd, Groenkop	Eastern Uplands
	Q9H016	Koonap River, Schurftekop	Eastern Uplands
S	S3H002	Klaas Smits River, Doornhoek, Wilgebosch	Eastern Uplands
U	U2H013	Mgeni River, Petrus Stroom	Eastern Uplands
V	V7H017	Boesmans River, Drakensberg Loc. 1	Great Escarpment
X	X2H010	North Kaap River, Bellevue	Lebombo Uplands
	X2H014	Houtbosloop, Sudwalaaskraal	Lebombo Uplands

4. The database of biomonitoring results for the River Health Programme (the "Rivers" database) was consulted to identify reference sites (i.e. least-impacted sites) by using the South African Scoring System (SASS). These data were used to confirm whether a site listed in Table 3 was indeed a reference site. The SASS score is a biotic index of riverine water quality that makes use of macroinvertebrates. The index is widely used in South Africa and is described in Chutter (1998) and Dallas (1997). Version 2 of the Rivers database (March 2003) was used, this being the most up to date available at the time (J. Ewart-Smith, Freshwater Consulting Group, *pers. com.* Dec. 2004). The water quality sites listed in Table 3 were investigated with regard to their proximity to River Health Programme (RHP) reference sites. Only RHP sites with SASS scores > 140 and Average Score Per Taxon (ASPT) ≥ 7.0 were considered to be reference sites. The value for ASPT was chosen from consideration of the values used in the revised water quality assessment method for establishing the boundary between "natural" and "good" condition (DWAF 2002). Table 4 shows the ASPT scores used to delineate each category. The SASS value of 140 was chosen because this was used as the boundary between Class A and B ecological status for biological integrity in the RDM manual for rivers (DWAF 1999a).

Table 4. *The default category boundaries for the biotic index, the South African Scoring System (SASS) - represented by the Average Score Per Taxon (ASPT) as given in DWAF (2002).*

Water quality Class	**Natural**	**Good**	**Fair**	**Poor**
ASPT Score	7	6	5	<5

Expert judgement was used to decide if a DWAF water quality monitoring station and RHP site were close enough to be considered to represent the water quality conditions in the same river reach. It was decided that the sites had to be within 5 km of each other on the same river, and that there should be no obvious major source of pollution (e.g. an urbanised region) or tributary between the two. All RHP reference sites were also examined for measurements of nutrient status that had been collected at the same time as macroinvertebrate samples. These data were also examined (in addition to the water quality data from DWAF monitoring stations) to see if they complied with the TWQR values for nutrients.

5. Land-use was another technique used to confirm which of the sites listed in Table 3 reflected natural water quality conditions with regard to nutrients. An arbitrary value of <5% was chosen as the area of the upstream catchment that could be transformed and still be considered to be natural. Therefore, for each of the minimally impacted sites, the proportion of the catchment upstream to the DWAF water quality monitoring station that was transformed from natural was calculated. The land-use coverage used to calculate these parameters was from CSIR (1997).

The sites that showed a land-use transformation of < 5% from natural were used as reference sites for further data analysis. The sites that exhibited greater modification than this value, were included only if biomonitoring data were also available and they satisfied the criteria detailed in the previous step.

6. The water quality data available for the sites identified as reference sites using either biomonitoring data or land-use were then manipulated according to the method described below.

<u>Data Analysis</u>

7. Time-series graphs were plotted for each reference site for combined nitrate and nitrite, soluble phosphate and total phosphate (if available) and the quality of the data was examined. It was found that measurements had been taken sporadically and a complete time series was unavailable for any of the reference sites. No positive trends in concentration (indicating a potential increase in nutrient loading) were exhibited at any of the sites, and thus the entire data set was used. The time period examined extended over at least 5 years.

8. Total inorganic nitrogen (TIN) for each sample was calculated by adding the ammonia and nitrite/nitrate values where both values were present. Where either value was not recorded, no value for TIN could be calculated. Only three of the sites had total phosphorus data. For each reference site, the number of data points, mean, median and standard deviation was calculated using the statistical functionality of Microsoft Excel. A test for "outliers" was performed on the data by comparing the minimum and maximum of the data set with the range of mean plus/minus three standard deviations. The data set was trimmed of "outliers" that fell significantly outside this range.

9. The TWQR for nitrogen and phosphorus in the South African Water Quality Guidelines (DWAF 1996a) is based on water column nutrient concentrations measured during the summer months. The "summer months" for this analysis were set as December, January and February. For the summer analysis, the data set was pruned to contain only samples from these months.

4.3 RESULTS

Selection of reference sites

The geographical distribution of minimally impacted sites (as listed in Table 3) and biomonitoring (RHP) reference sites (SASS >140 and ASPT >7) is shown in Figure 2. The RHP reference sites are subdivided into those with ASPT = 7 – 7.99 and those equal to or greater than 8. The localised nature of the present RHP sites can be seen. Most SASS sampling has been carried out in Limpopo/Mpumalanga, areas of KwaZulu/Natal and the Western Cape. The sites chosen as DWAF water quality monitoring stations and those used for biomonitoring are not usually the same, and this, coupled with the limited extent of the biomonitoring data that has been collected so far, meant that there was very little geographical overlap between the two data sets. Unfortunately, fewer than 7 of the minimally impacted sites, representing 5 primary drainage regions, were found to be close to RHP reference sites. These sites, together with their SASS and ASPT scores are shown in Table 5. It was found that for some RHP sites only one visit had been recorded, whereas for others, several values were given. In the case of the latter, the range of SASS parameters is given in the table. Overall, a wide range in scores was obtained (from 64 – 273 for SASS and from 4.27 – 9.21 for ASPT).

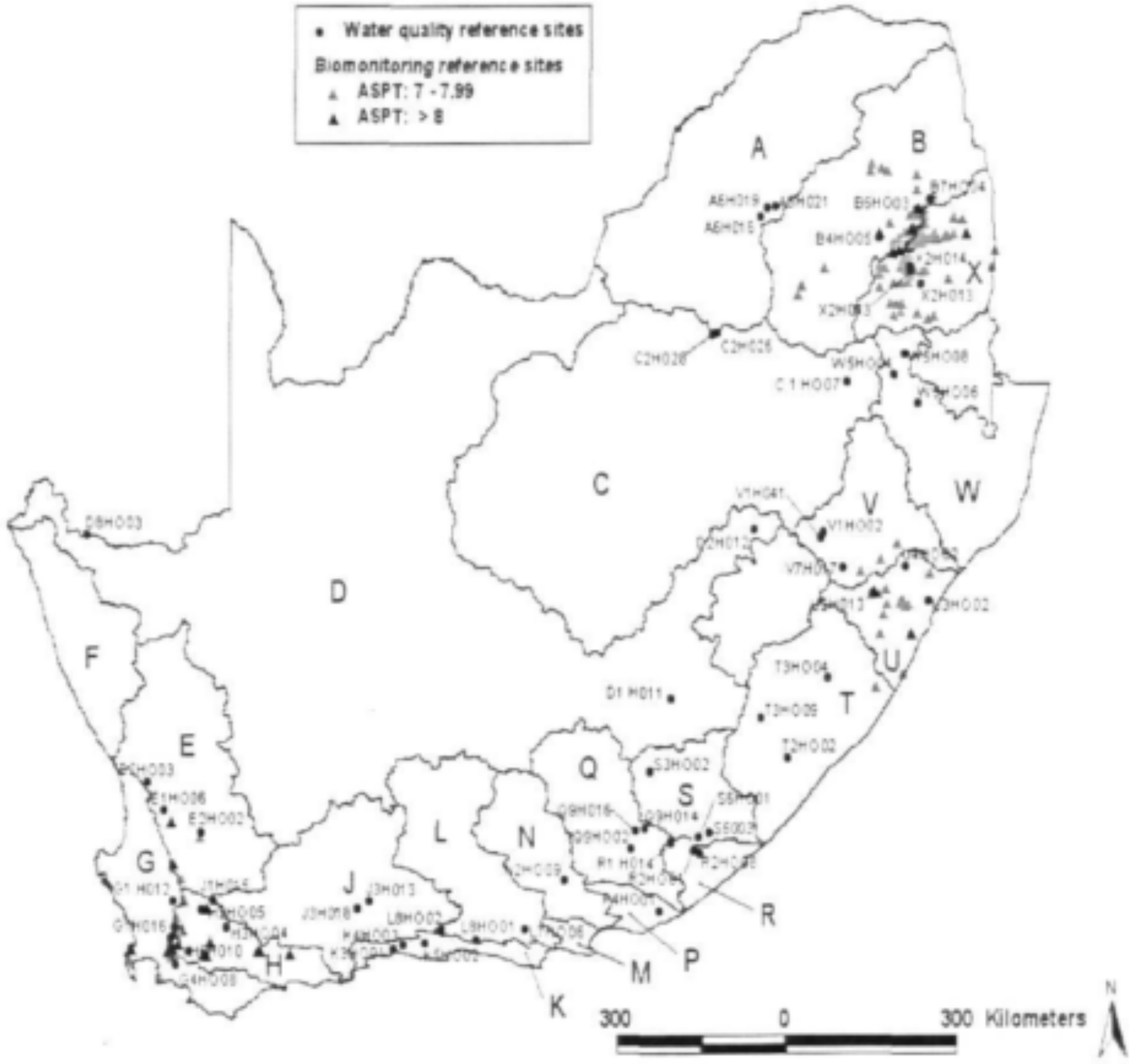

Figure 2. *Geographical distribution of the minimally impacted water quality sites (as listed in Table 3) and the River Health Programme (RHP) reference sites (SASS >140, ASPT >7).*

Table 5. *The list of "minimally impacted" sites as specified in Table 3, the SASS/ASPT scores and % upstream catchment transformed. Sites considered to be reference sites are shaded.*

Drainage region	Gauging station	Place name	Biomonitoring site	SASS	SASS ASTP	% Land Converted
A	A6H018	Rasloop River, Sussensvale, Modderpoort				0
	A6H021	De Wet Spruit, Groenvaley				0
B	B4H005	Waterval River, Modderspruit	B4WATE-TWEEF	214	8.23	7.01
	B6H003	Treur River, Willemsoord	B6TREU-R532B	209-273	7.38-7.74	28.5
	B7H004	Klaserie River, Fleur de Lys	B7KLAS-GEURN	164	7.13	35.6
E	E1H006	Jan Dissels River, Clanwilliam Commonage				3.9
	E2H002	Doring River, Elands Drift, Aspoort				4.8
	E2H003	Doring River, Melkboom	E2DORI-DEBRUG	64	5.82	4.3
G	G1H016	Kasteelkloof Spruit, Zachariashoek, Kasteelkloof Lower				0.9
H	H2H005	Rooi-Elskloof River, Roode Els Berg	H2UNSP-SANDD H2SAND-SANDD	129 129	9.21 8.6	11.4
	H6H010	Waterkloof River, Waggensbooms Kloof				3.5
J	J1H015	Bok River, Lot B				0
L	L7H006	Groot River, Grootrivierspoort				0.5
	L8H001	Wabooms River, Diepkloof				4.7
N	N2H009	Volkers River				0.7
Q	Q9H002	Koonap River, Adelaide				3.6
	Q9H014	Koonap River, Frisch Gewaagd, Groenkop				1.8
	Q9H016	Koonap River, Schurftekop				2.5
S	S3H002	Klaas Smits River, Doornhoek, Wilgebosch				2.1
U	U2H013	Mgeni River, Petrus Stroom	UU2MGEN-PETRU	141-167	7.04-7.95	30
V	V7H017	Boesmans River, Drakensberg Loc. 1				3.0
X	X2H010	North Kaap River, Bellevue				3.2
	X2H014	Houtbosloop, Sudwalaaskraal	X2HOUT-ELAND	160-190	6.88-7.31	69.4

The highest SASS score of 273 (37 families, ASPT = 7.38) was recorded on 19/1/99 for the Treur River which is a foothill/cobble bed river in the Mountain Escarpment ecoregion. For some sites there were anomalies and a very high ASPT score was recorded (e.g. for H2H005) in conjunction with a low SASS score. In such cases all the information recorded in the Rivers database for this site (e.g. site description, habitat index scores) were scrutinised and a decision made whether to include the site as a reference site or not.

A wide variation in the percentage catchment area that had been transformed by human activities was found (Table 5). These values ranged from 0 to nearly 70%. For some sites (e.g. B7H004) although the % land transformation was higher than 5% it was still considered to be a reference site because very high SASS scores were recorded. Other sites (e.g. E2H003) were discarded because of low SASS scores, even though the percentage transformation was less than 5%. The sites, considered for the purpose of this study to represent reference sites, are shown as shaded in grey in Table 5.

Compliance with the TWQR

Using the reference site selection criteria outlined above, 21 sites were selected for the analysis of TWQR for nutrients. A summary of the statistical parameters for all of these sites is given in the appendix to this document. Table 6 shows, using the entire dataset, what percentage of measurements exceed the Target Water Quality Ranges for total inorganic nitrogen (TIN = 0.5 mg/L) and Soluble Reactive Phosphorus (PO4 = 0.005 mg/L) respectively. The table shows that for TIN the TWQR was exceeded up to 50% of the time in some rivers (the Volkers River), but that for many rivers this value was never exceeded. For SRP, on the other hand, the water quality standard was exceeded at all sites for a large proportion of the time.

Table 6. *The percentage of records for each reference site that exceed the TWQR for total inorganic nitrogen (TIN) and soluble reactive phosphorus (SRP) respectively. Percentages calculated using the entire data-set. Values exceeding the TWQR are shaded.*

Drainage region	Gauging station	Place name	% TIN >0.5	% SRP>0.005
A	A6H018	Rasloop River, Sussensvale, Modderpoort	0.0	61.9
	A6H021	De Wet Spruit, Groenvaley	0.0	70.6
B	B4H005	Waterval River, Modderspruit	1.4	62.0
	B6H003	Treur River, Willemsoord	0.7	71.1
	B7H004	Klaserie River, Fleur de Lys	0.5	89.5
E	E1H006	Jan Dissels River, Clanwilliam Commonage	0.9	62.6
	E2H002	Doring River, Elands Drift, Aspoort	0.0	80.4
G	G1H016	Kasteelkloof Spruit, Zachariahshoek	0.0	43.3
	H6H010	Waterkloof River, Waggensbooms Kloof	0.0	58.1
J	J1H015	Bok River, Lot B	0.0	56.3
L	L7H006	Groot River, Grootrivierspoort	4.3	87.6.
	L8H001	Wabooms River, Diepkloof	0.5	89.3
N	N2H009	Volkers River	52.3	99.6
Q	Q9H002	Koonap River, Adelaide	5.5	93.0
	Q9H014	Koonap River, Frisch Gewaagd, Groenkop	8.9	80.3
	Q9H016	Koonap River, Schurftekop	7.7	79.9
S	S3H002	Klaas Smits River, Doornhoek, Wilgebosch	16.6	93.8
U	U2H013	Mgeni River, Petrus Stroom	3.6	54.6
V	V7H017	Boesmans River, Drakensberg Loc. 1	1.4	82.8
X	X2H010	North Kaap River, Bellevue	0.5	88.3
	X2H014	Houtbosloop, Sudwalaaskraal	0.0	72.0

Table 6 shows the results using the entire data-set (i.e. all months) whereas the TWQR as specified in the guidelines (DWAF 1996a) is for the summer months only. Table 7 shows the percentage of records that did not comply with the water quality specifications measured during the summer months (December – February).

Table 7. *The percentage of records for each reference site that exceed the TWQR for total inorganic nitrogen (TIN) and soluble reactive phosphorus (SRP) respectively. Percentages calculated using summer (December, January, February) data only. Values exceeding the TWQR are shaded.*

Drainage region	Gauging station	Place name	% TIN >0.5	% SRP>0.005
A	A6H018	Rasloop River, Sussensvale, Modderpoort	0.0	71.8
	A6H021	De Wet Spruit, Groenvaley	0.0	66.7
B	B4H005	Waterval River, Modderspruit	5.9	77.8
	B6H003	Treur River, Willemsoord	0.0	63.6
	B7H004	Klaserie River, Fleur de Lys	0.0	92.9
E	E1H006	Jan Dissels River, Clanwilliam Commonage	4.5	52.2
	E2H002	Doring River, Elands Drift, Aspoort	0.0	85.7
G	G1H016	Kasteelkloof Spruit, Zachariahshoek	0.0	16.7
H	H6H010	Waterkloof River, Waggensbooms Kloof	0.0	48.1
J	J1H015	Bok River, Lot B	0.0	63.6
L	L7H006	Groot River, Grootrivierspoort	9.9	87.3
	L8H001	Wabooms River, Diepkloof	1.9	89.8
N	N2H009	Volkers River	49.6	98.6
Q	Q9H002	Koonap River, Adelaide	4.5	95.5
	Q9H014	Koonap River, Frisch Gewaagd, Groenkop	16.3	73.9
	Q9H016	Koonap River, Schurftekop	7.7	74.5
S	S3H002	Klaas Smits River, Doornhoek, Wilgebosch	17.5	95.5
U	U2H013	Mgeni River, Petrus Stroom	1.7	47.3
V	V7H017	Boesmans River, Drakensberg Loc. 1	0.0	85.5
X	X2H010	North Kaap River, Bellevue	0.0	89.8
	X2H014	Houtbosloop, Sudwalaaskraal	0.0	71.7

Of these 21 sites, 6 sites exceeded the recommended TWQR for TIN in more than 5% of the records whilst only three sites exceeded the TWQR in more than 15% of the records. For phosphate, only one site (H1H016) met the recommended TWQR most of the time, whilst the TWQR was exceeded in 75% of the records for 11 sites.

From the above analysis of the water quality data, it was apparent that for SRP at least, the TWQR of 0.005 mg/L inorganic phosphate in summer was likely to be too stringent. It also appeared that the TWQR of 0.5 mg/L for TIN might be too lenient. Therefore, a more detailed analysis was carried out. The data-sets from each reference site were compared with the current recommended TWQR for nutrients by determining the percentage of records greater than 0.05, 0.1 and 0.5 mg/L for TIN and those greater than 0.005, 0.01 and 0.05mg/L for SRP. Once again the data were analysed first using the entire data-set, and then for measurements collected only during the summer. The results are summarised in Table 8 for the entire data-set, and for the summer data in Table 9.

The water quality guidelines specify that summer values should be used because this is the growing season and thus when any potential problems of excessive plant infestation are likely to occur. A comparison of Tables 8 and 9, however, shows that the median TIN and SRP concentrations do not differ greatly, whether all the data are analysed, or just the summer data. Although the median instream concentration of TIN was found, as expected to be higher than that of SRP, the difference was also not large (0.08 versus 0.01 mg/L respectively). With regard to TIN, the median percentage of measurements that exceeded the TWQR was only 0-1%, 32-36% of values were greater than 0.1 mg/L and 74-77% greater than 0.05 mg/L. For SRP on the other hand, 75-80 % of the values in general exceeded the TWQR, 53 – 58% were higher than 0.01mg/L and 3 – 4% greater than 0.05 mg/L.

Table 8. *A summary of the median and percentage measurements exceeding key values for all reference sites using all data. The percentage of values exceeding the TWQR values is shaded in grey.*

GAUGING STATION	PLACE NAME	TOTAL INORGANIC NITROGEN				SOLUBLE REACTIVE PHOSPHORUS			
		Median	% TIN >0.05	% TIN >0.1	% TIN >0.5	Median	% SRP >0.005	% SRP >0.01	% SRP >0.05
A6H018	Rasloop River, Sussensvale, Modderpoort	0.07	63.8	35.3	0.0	0.007	61.9	35.3	0.7
A6H021	De Wet Spruit, Groenvaley	0.08	72.0	24.0	0.0	0.007	70.6	29.4	0.0
B4H005	Waterval River, Moddersprult	0.11	79.2	52.8	1.4	0.009	62.0	43.0	0.0
B6H003	Treur River, Willemsoord	0.08	73.9	31.6	0.7	0.009	71.1	42.6	2.5
B7H004	Klaserie River, Fleur de Lys	0.08	65.5	31.6	0.5	0.015	89.5	70.3	4.6
E1H006	Jan Dissels River, Clanwilliam Commonage	0.07	64.0	26.3	0.9	0.007	62.6	33.9	1.7
E2H002	Doring River, Elands Drift, Aspoort	0.07	68.5	17.6	0.0	0.013	80.4	58.0	1.8
G1H016	Kasteelkloof Spruit, Zachariahshoek	0.07	75.6	17.1	0.0	0.005	43.3	16.7	0.0
H6H010	Waterkloof River, Waggensbooms Kloof	0.07	58.9	28.4	0.0	0.007	58.1	40.2	0.9
J1H015	Bok River, Lot B	0.06	60.2	23.5	0.0	0.007	56.3	29.1	1.0
L7H006	Groot River, Grootrivierspoort	0.08	72.4	28.0	4.3	0.013	87.6	63.4	4.6
L8H001	Wabooms River, Diepkloof	0.11	85.9	53.5	0.5	0.021	89.3	79.5	5.6
N2H009	Volkers River	0.53	95.0	85.3	52.3	0.087	99.6	98.0	59.8
Q9H002	Koonap River, Adelaide	0.14	89.7	64.4	5.5	0.0225	93.0	84.9	14.7
Q9H014	Koonap River, Frisch Gewaagd, Groenkop	0.15	85.5	60.5	8.9	0.014	80.3	61.3	8.0
Q9H016	Koonap River, Schurftekop	0.13	81.3	58.9	7.7	0.017	79.9	66.7	10.5
S3H002	Klaas Smits River, Doornhoek, Wilgebosch	0.17	86.1	67.5	16.6	0.022	93.8	84.5	23.6
U2H013	Mgeni River, Petrus Stroom	0.20	91.7	78.2	3.6	0.006	54.6	31.5	1.6
V7H017	Boesmans River, Drakensberg Loc. 1	0.07	67.8	23.7	1.4	0.013	82.8	60.5	4.2
X2H010	North Kaap River, Bellevue	0.07	72.2	23.5	0.5	0.014	88.3	63.2	7.2
X2H014	Houtbosloop, Sudwalaskraal	0.11	83.5	50.9	0.0	0.008	72.0	43.1	0.4
MEDIAN		**0.08**	**74**	**32**	**0.7**	**0.01**	**80**	**58**	**3**

Table 9. *A summary of the median and percentage measurements exceeding key values for all reference sites using summer data only. The percentage of values exceeding the TWQR values is shaded in grey.*

GAUGING STATION	PLACE NAME	TOTAL INORGANIC NITROGEN				SOLUBLE REACTIVE PHOSPHORUS			
		Median	% TIN >0.05	% TIN >0.1	% TIN >0.5	Median	% SRP >0.005	% SRP >0.01	% SRP >0.05
A6H018	Rasloop River, Sussensvale, Modderpoort	0.06	55.2	13.8	0.0	0.009	71.8	41.0	0.0
A6H021	De Wet Spruit, Groenvaley	0.08	66.7	27.8	0.0	0.007	66.7	29.2	0.0
B4H005	Waterval River, Moddersprult	0.09	76.5	41.2	5.9	0.013	77.8	61.1	0.0
B6H003	Treur River, Willemsoord	0.07	69.5	25.4	0.0	0.007	63.6	33.3	1.5
B7H004	Klaserie River, Fleur de Lys	0.10	75.5	45.3	0.0	0.015	92.9	76.8	3.6
E1H006	Jan Dissels River, Clanwilliam Commonage	0.06	63.6	18.2	4.5	0.008	52.2	47.8	4.3
E2H002	Doring River, Elands Drift, Aspoort	0.07	68.2	4.5	0.0	0.012	85.7	52.4	0.0
G1H016	Kasteelkloof Spruit, Zachariahshoek	0.07	80.0	20.0	0.0	0.0035	16.7	16.7	0.0
H6H010	Waterkloof River, Waggensbooms Kloof	0.05	47.4	15.8	0.0	0.005	48.1	29.6	3.7
J1H015	Bok River, Lot B	0.06	54.2	12.5	0.0	0.009	63.6	45.5	0.0
L7H006	Groot River, Grootrivierspoort	0.08	82.9	36.0	9.9	0.017	87.3	70.1	8.2
L8H001	Wabooms River, Diepkloof	0.10	94.2	42.3	1.9	0.018	89.8	71.2	0.0
N2H009	Volkers River	0.50	93.3	77.0	49.6	0.0605	98.6	97.9	52.1
Q9H002	Koonap River, Adelaide	0.15	86.4	66.7	4.5	0.026	95.5	94.0	16.4
Q9H014	Koonap River, Frisch Gewaagd, Groenkop	0.15	95.3	58.1	16.3	0.0135	73.9	58.7	4.3
Q9H016	Koonap River, Schurftekop	0.15	78.8	61.5	7.7	0.022	74.5	65.5	9.1
S3H002	Klaas Smits River, Doornhoek, Wilgebosch	0.17	90.0	67.5	17.5	0.0305	95.5	88.6	34.1
U2H013	Mgeni River, Petrus Stroom	0.22	91.4	79.3	1.7	0.005	47.3	27.0	5.4
V7H017	Boesmans River, Drakensberg Loc. 1	0.08	71.2	25.0	0.0	0.011	85.5	52.7	1.8
X2H010	North Kaap River, Bellevue	0.07	76.4	23.6	0.0	0.016	89.8	64.4	5.1
X2H014	Houtbosloop, Sudwalaaskraal	0.10	86.2	48.3	0.0	0.007	71.7	35.0	1.7
MEDIAN		**0.08**	**77%**	**36%**	**0%**	**0.01**	**75%**	**53%**	**4%**

Calculation of new TWQR

In section 2.7.1.3 of Volume 1 to this project, it was explained that the US EPA makes use of the 75th percentile of a distribution of nutrient measurements from *reference condition sites* as the recommended target concentration. This value was therefore calculated by combining all the data for reference sites from the same ecoregion. The calculated 75%iles for TIN and SRP are shown in Table 10. Measurements from all months of the year were used in the analysis.

Table 10. *Calculated 75%iles for TIN and SRP for each ecoregion in which a reference site was located.*

Ecoregion	Sites	75%ile TIN	75%ile SRP
Cape Fold Mountains	7	0.11	0.023
Central Highlands	3	0.15	0.013
Eastern Uplands	6	0.53	0.065
Great Escarpment	1	0.10	0.020
Lebombo Uplands	4	0.12	0.018
Median		**0.12**	**0.02**

Unfortunately, due to the stringent screening process, the number of ecoregions represented as well as the number of sites within each ecoregion is very limited. The values for the Eastern Uplands appear to be higher for both nutrients than the other ecoregions, but because of the limited data, this ecoregion was included. From the above it would appear that the TWQR for TIN should be around 0.12 mg/L and that for SRP equal to 0.02 mg/L. The detection limits for DWAF during the time period from which the data were extracted was 0.011 mg/L for SRP and 0.04 mg/L for combined nitrate and nitrite (T. Louw, DWAF, *pers. com.* 2004). This indicates that measurements of samples containing lower concentrations than the detection limit may be inaccurate.

Analysis of water quality data collected as part of the RHP

As part of the River Health Programme, water quality samples are sometimes collected at the same time as macroinvertebrate samples. The nutrient data available from this source were limited (a total of approximately 120 measurements each for TIN and SRP), with only one data point collected during the summer and three ecoregions represented (Central Highlands, Great Escarpment and Lowveld). For some ecoregions (e.g. Cape Folded Mountains), TIN could not be calculated because both combined nitrate/nitrite and ammonium had not been collected – nor had phosphate been recorded. A summary of the results is given in Table 11.

Table 11. *Summary of the nutrient concentration measurements collected as part of the River Health Programme.*

Total Inorganic Nitrogen				
Ecoregion	n	**Median**	**% TIN >0.5**	**75%**
Central Highlands	20	0.15	5.00	0.19
Great Escarpment	68	0.17	2.94	0.23
Lowveld	30	0.20	10.00	0.29
Median		0.17	5.00	**0.23**
Soluble Reactive Phosphorus				
Ecoregion	n	**Median**	**% SRP >0.005**	**75%**
Central Highlands	20	0.013	95.00	0.027
Great Escarpment	68	0.011	88.24	0.017
Lowveld	30	0.014	96.67	0.019
Median		0.01	95.00	**0.02**

There is some agreement between the two sources of water quality data (i.e. from the chemical monitoring programme and from the RHP). The median TIN value of 0.17 mg/L as shown in Table 11 for the RHP sites is higher than the value of 0.08 mg/L calculated from the DWAF monitoring data. On the other hand, the median value for SRP is identical (0.01 mg/L) with that obtained from the chemical monitoring programme. The 75%ile values calculated using the two data sources differ slightly for TIN (0.12 versus 0.23 mg/L) but are the same for SRP (0.02 mg/L).

4.4 DISCUSSION AND CONCLUSIONS

From the preceding results the following conclusions can be drawn.

- From the previous analysis, it would appear that the current TWQR of 0.005 mg/L for inorganic phosphate as specified in DWAF (1996a) is too conservative. From consideration of the 75%ile for the DWAF chemical monitoring data and from the data collected during biomonitoring, a more reasonable value would be around 0.02 mg/L (rather than 0.005mg/L). With regard to Total Inorganic Nitrogen, it would appear that the value of 0.5 mg/L is possibly too high and that a value of around 0.25 – 0.3 mg/L should be used. Because of the critical role that phosphate plays in limiting eutrophication, however, it is important that although realistic values be set, these should err on the side of conservatism (see below).

- The detection limits for DWAF during the time period from which the data were extracted was 0.011 mg/L for SRP and 0.04 mg/L for combined nitrate and nitrite Thus records with measurements lower than these values (roughly 42% of the SRP and 75% of TIN data points) may be unreliable in terms of the exact concentrations determined. Given this uncertainty, **the present TWQR values should be retained, especially with regard to SRP,** until the detection limits of routine sample analyses have been improved.
- The fact that there is little difference in the analysis of data using all months of the year or just the summer months may well be because these are oligotrophic systems. In such systems, the level of all nutrients is limiting, and excess are rapidly taken up by the biota.
- The screening method used in this study to identify reference sites is likely to be very stringent. For example, the fact that some sites for which there were biomonitoring data showed that the sites were unpolluted, even though the percentage land transformation was greater than 5%. This indicates that the 5% value may be too low. Furthermore the type of land transformation was not taken into account. Urbanisation for example is likely to have much more impact on rivers compared to, for example, agriculture or forestry. The value of SASS score > 140 is also possibly high. For example, Dallas, Day, Musibono and Day (1998) used a SASS (version 4) score = 140 (and ASPT = 7.5) to distinguish between impacted and non-impacted mountain streams in the Western Cape. Lower values were used for foothill (SASS =120), transitional (SASS = 85) and lowland rivers (SASS score = 50). Nevertheless, the aim of this procedure was to ensure that the sites analysed were near to natural.
- It should be noted that in the revised method for assessing the present state for nutrients (Approach 2, DWAF 2002), the default value of TIN used to differentiate between the Natural and Good categories is 0.25 mg/L (and 0.005 mg/L for SRP). A mechanism is included in the assessment method to take into account high nutrient levels. Thus, if the Reference Condition level of a nutrient is *naturally* higher than the TWQR, this can be accommodated and the entire set of boundary values used to delineate management categories is adjusted

accordingly. Nevertheless the results from the current project are useful in that it indicates that most values for SRP would need to be adjusted.

- It is important that there is integration between the water quality and River Health Programme monitoring systems. Collecting measurements of water quality as well as biological data (presence/absence of macroinvertebrate taxa and SASS scores) at the same time and same place maximises the usefulness of both. This enhanced usefulness is primarily because links between water quality and the presence or absence of specific taxa can then be made. The number and geographical distribution of the biomonitoring data is still rather limited and needs to be extended as soon as possible. Initiatives are currently being made to integrate the various DWAF monitoring systems (e.g. chemical, biomonitoring and microbiological) and to rationalize the choice of biomonitoring sites (H. Dallas, FRU, UCT, *pers. com.* Jan 2005).

4.5 RECOMMENDATIONS

The conclusions and recommendations arising from this part of the project are listed below.

- Total N and TP should be used as indicators of rivers, streams, lakes and wetlands in addition to measures of dissolved nutrients. Even seasonal measurements of TN and TP (in addition to more frequent measurement of dissolved nutrients) would be useful.
- Research needs to be carried out to draw up default boundary values between Reserve categories for TP and TN in order to demarcate the assessment categories.
- Measurement of periphyton and phytoplankton chlorophyll *a* levels (DWAF 2002) in rivers is a useful addition to the assessment method for determining the ecological Reserve.
- It is important that there is integration between the water quality and River Health Programme monitoring systems. Collecting measurements of water quality as well as biological data (presence/absence of macroinvertebrate taxa and SASS scores) at the same time and same place maximises the usefulness of both.

REFERENCES

ANZECC/ARMCANZ (2000) Australian and New Zealand guidelines for fresh and marine water quality (NWQMS4, 2000). Australian and New Zealand environmental and conservation council/ Agriculture and resource management council of Australia and New Zealand. Canberra, ACT, 2601.

Cahill, Imperato and Verhoff 1974; Cahill, T.H., Imperato, P. and Verhoff, F.H. (1974) Evaluation of phosphorus dynamics in a watershed. Journal of the environmental engineering division (EE2), 10445, 439-458.

Chessman, B.C., Hutton, P.E. and Burch, J.M. (1992) Limiting nutrients for periphyton growth in sub-alpine, forest, agricultural and urban streams. *Freshwater Biology* **28**: 349-361.

Chutter, F.M. (1998) Research on the rapid biological assessment of water quality impacts in streams and rivers. Water Research Commission Report No. 422/1/98, Pretoria.

Chutter, F.M. and Rossouw, N. (1992) The management of phosphate concentrations and algae in Hartebeespoort dam. Water Research Commission Report No. 289/1/92, Pretoria.

CSIR (1997) Digital CSIR/ARC National land-cover database as described in version 1.4 of the Data Users Manual of the National Land-Cover Database Project. CSIR, Pretoria, April 1997.

Dallas, H.F. (1997) A preliminary evaluation of aspects of SASS (South African Scoring System) for the rapid bioassessment of water quality in rivers, with particular reference to the incorporation of SASS in a national biomonitoring programme. *South African Journal of Aquatic Science* **23**: 79-94.

Dallas, H.F. and Day, J.A. (1993) The effect of water quality variables on riverine ecosystems: A review. Water Research Commission Report No. TT 61/93. Pretoria.

Dallas, H.F. and Day, J.A. (2004) The effect of water quality variables on riverine ecosystems: A review. 2nd Edition. Water Research Commission Report No. TT 224/04. Pretoria.

Dallas, H.F., Day, J.A., Musibono, D.E. and Day, E.G. (1998) Water quality for aquatic ecosystems: tools for evaluating regional guidelines. Water Research Commission Report No. 626/1/98. Pretoria.

Day, J.A., Dallas, H.F. and Wackernagel, A. (1998) Delineation of management regions for South African rivers based on water chemistry. *Aquatic Ecosystem Health and Management* **1**: 183-197.

De Jong, A.L., De Oude, N.T., Smits, A.H. and Volz, J. (1989) The phosphate load of the River Rhine 1975-1986. *Aqua* **38**: 76-188.

Dodds, W. (2003) Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface waters. *Journal of North American Benthological Society* **22**: 171-181.

Dodds, W.K. and Welch, E.B. (2000) Establishing nutrient criteria in stream. *Journal of the North American Bethological Society* **19**: 186-196.

DWAF (1993) South African Water Quality Guidelines (2nd Edition). Volume 2: Recreational Use. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (1996a) South African Water Quality Guidelines. Volume 7: Aquatic ecosystems. Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

DWAF (1996b) South African Water Quality Guidelines (2nd Edition). Volume 3: Industrial Use. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (1996c) South African Water Quality Guidelines (2nd Edition). Volume 6: Agricultural Use: Aquaculture. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (1999a) Resource directed measures for protection of water resources. Volume 3: Riverine ecosystems. Version 1.0. Institute for Water Quality studies, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

DWAF (1999b) Resource directed measures for protection of water resources. Volume 4: Wetland ecosystems. Version 1.0. Institute for Water Quality studies, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

DWAF (1999c) Resource directed measures for protection of water resources. Volume 6: Groundwater component. Version 1.0. Institute for Water Quality studies, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

DWAF (1999d) Resource directed measures for protection of water resources. Volume 5: Estuarine ecosystems. Version 1.0. Institute for Water Quality studies, Department of Water Affairs and Forestry, Private Bag X313, Pretoria 0001.

DWAF (2002) Methods for assessing water quality in Ecological Reserve Determinations for rivers. Draft document, Version 2. Department of Water Affairs and Forestry, Pretoria. Latest draft version: http://projects.shands.co.za/Hydro/hydro/WQReserve). Accessed November 2004.

Environment Australia (2002) Water quality targets: A handbook. Version 1.0. Available at http://www.ea.gov.au/water/quality/targets. Accessed December 2004.

EPA (1999a) Nutrient criteria technical guidance manual: lakes and reservoirs. Report no. EPA-822-D-99-001.

EPA (1999b) Protocol for developing nutrient TMDLs. Report no. EPA-841-B-99-007. Office of Water, 4503F, Washington DC.

EPA (2000) Nutrient criteria technical guidance manual: rivers and streams. Report no. EPA-822-B-00-002.

EPA (2002) Draft strategy: Proposed revisions to the "Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses." United States Environmental Protection Agency. Website: www.epa.gov/owow/wetlands/waterquality. Accessed June 2003.

Harding, W.R. and Paxton, B.R. (2001) Cyanobacteria in South Africa: A review. Water Research Commission Report No. TT 153/01, Pretoria.

Harris, G. (2001) A nutrient dynamics model for Australian waterways: Land use, catchment biogeochemistry and water quality in Australian rivers, lakes and estuaries. Australia State of the Environment Second Technical Paper Series (Inland Waters), Department of the Environment and Heritage, Canberra. Available at http://www.ea.gov.au/soe/techpapers/index.html. Accessed Sept 2004.

Holtan, H., Kamp-Nielsen, L. and Stuanes, A.O. (1988) Phosphorous in soil, water and sediment: an overview. *Hydrobiologia* **170**: 19-34.

Joubert, A.R. and Hurley, P.R. (1994) The use of daily flow data to classify South African rivers. pp 286-359 *in* King, J.M. and Tharme, R.E. *Assessment of the instream flow incremental methodology and initial development of alternative instream flow methodologies for South Africa.* Water Research Commission Report no. 295/1/94.

Lee, F.G. and Jones-Lee, A. (2002) Developing nutrient criteria/TMDLs to manage excessive fertilization of waterbodies. Proceedings of the Water Environment Federation TMDL conference, held in Phoenix, Arizona, USA, 2002.

Liston, P. and Maher, W. (1997) Water quality for maintenance of aquatic ecosystems: Appropriate indicators and analysis. Australia: State of the Environment Technical Paper Series (Inland Waters), Dept. Environment, Sport and Territories, Canberra.

Malan, H.L. and Day, J.A. (2002) Development of numerical methods for predicting relationships between stream flow, water quality and biotic responses in rivers. WRC Report no. 956/1/02.

Noges, T. (2003) Final report on the relevant system of indicators and criteria for evaluating the ecological status of a very large non-stratified lake and its river basin in WFD context. Deliverable D3b. Tartu University, Estonia.

Noggle, G.R. and Fritz, G.J. (1976) Introductory plant physiology. Prentice-Hall, INC. Englewood Cliffs, New Jersey, USA.

Ridge, T., Pillinger, P. and Walters, S. (1995) Alleviating the problems of excessive algal growth pp 211-218. *in* Harper, D.M. and Ferguson, A.J.D. (Eds.) The ecological basis for river management. John Wiley & Sons. Chichester.

Roos, J.C., Pieterse, A.J.H. and Prinsloo, J.F. (1997) Phytoplankton production and photosynthetic characteristics in relation to environmental variables in the Vaal River at Balkfontein. pp 3 – 24 *in* Pieterse, A.J.H. and Janse van Vuuren, S. (Eds.) An investigation into the phytoplankton blooms in the Vaal River and the Environmental variables responsible for their development and decline. Water Research Commission Report No. 359/1/97. Water Research Commission, Pretoria.

Rossouw, J.N., Harding, W.R. and Fatoki, O.S. (*in prep.*) A guide to conduct eutrophication assessments for rivers, lakes/reservoirs and lacustrine wetlands (in support of the water quality component of a catchment management strategy). Water Research Commission Report No. k5/1343/--- Draft version Jan 2005. Water Research Commission, Pretoria.

Sweeting, R.A. (1994) River Pollution. pp 23-32 *in* Calow, P. and Petts, G.E. (Eds.) *The Rivers Handbook*, Vol. 2. Blackwell Scientific Publications, Oxford.

Wiechers, H.N.S. (1985) Sources of phosphate which give rise to eutrophication in South African waters. Symposium on the impact of phosphate on South African Waters. CSIR Conference Centre, Pretoria, 22nd November 1985.

APPENDIX

Summary data for each reference site selected for validating the TWQR for nutrients

The data used to validate the TWQR for nutrients were retrieved from the DWAF chemical monitoring programme database for each of the reference sites selected for analysis (listed in Table A.1 below). The site selection procedure and method for data analysis is described in the main body of this report. A summary of the statistical parameters for the 21 sites considered to be "reference sites" is given in this appendix. One method of determining the TWQR used calls for the calculation of nutrient concentration based on the water quality variables in the summer months. The "summer months" for this analysis were determined to include December, January and February. The data set was pruned to contain only data points from these months for the summer analysis. The results of the analysis for the "summer data" for each reference site is presented in the second half of this appendix.

Table A.1 *The list of DWAF water quality monitoring stations considered to be reference sites.*

Drainage region	Gauging station	Place name
A	A6H018	Rasloop River, Sussensvale, Modderpoort
	A6H021	De Wet Spruit, Groenvaley
B	B4H005	Waterval River, Modderspruit
	B6H003	Treur River, Willemsoord
	B7H004	Klaserie River, Fleur de Lys
E	E1H006	Jan Dissels River, Clanwilliam Commonage
	E2H002	Doring River, Elands Drift, Aspoort
G	G1H016	Kasteelkloof Spruit, Zachariashoek, Kasteelkloof lower.
H	H6H010	Waterkloof River, Waggensbooms Kloof
J	J1H015	Bok River, Lot B
L	L7H006	Groot River, Grootrivierspoort
	L8H001	Wabooms River, Diepkloof
N	N2H009	Volkers River
Q	Q9H002	Koonap River, Adelaide
	Q9H014	Koonap River, Frisch Gewaagd, Groenkop
	Q9H016	Koonap River, Schurftekop
S	S3H002	Klaas Smits River, Doornhoek, Wilgebosch
U	U2H013	Mgeni River, Petrus Stroom
V	V7H017	Boesmans River, Drakensberg Loc. 1
X	X2H010	North Kaap River, Bellevue
	X2H014	Houtbosloop, Sudwalaaskraal

Summary data per reference site using data for all months

		NH4	NO2_NO3	TIN	PO4
A6H018Q01	n	147	123	116	139
	mean	0.05	0.05	0.10	0.009
	median	0.03	0.03	0.07	0.007
	standard deviation	0.05	0.06	0.08	0.008
	mean - 3SD	-0.11	-0.12	-0.13	-0.016
	mean + 3SD	0.21	0.22	0.34	0.035
	min	0.01	0.01	0.02	0.001
	max	**0.31**	**0.31**	0.33	**0.056**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	33.3	63.8	**%>0.005**	61.9
	%>0.1	15.4	35.3	**%>0.01**	35.3
	%>0.5	0.0	0.0	**%>0.05**	0.7
	Data Period	5-Dec-77	21-Jan-98		

		NH4	NO2_NO3	TIN	PO4
A6H021Q01	n	42	26	25	34
	mean	0.06	0.03	0.10	0.009
	median	0.04	0.02	0.08	0.007
	standard deviation	0.07	0.03	0.08	0.005
	mean - 3SD	-0.14	-0.07	-0.13	-0.008
	mean + 3SD	0.27	0.13	0.33	0.025
	min	0.01	0.01	0.02	0.001
	max	**0.3**	**0.13**	0.31	**0.025**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	11.5	72.0	**%>0.005**	70.6
	%>0.1	7.7	24.0	**%>0.01**	29.4
	%>0.5	0.0	0.0	**%>0.05**	0.0
	Data Period	26-Dec-77	27-Jan-82		

		NH4	NO2_NO3	TIN	PO4
B4H005Q01	n	81	76	72	79
	mean	0.04	0.10	0.14	0.012
	median	0.03	0.06	0.11	0.009
	standard deviation	0.02	0.15	0.15	0.011
	mean - 3SD	-0.03	-0.35	-0.31	-0.020
	mean + 3SD	0.11	0.55	0.58	0.043
	min	0.01	0.01	0.03	0.001
	max	**0.14**	**1.13**	**1.18**	**0.05**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	53.9	79.2	**%>0.005**	62.0
	%>0.1	32.9	52.8	**%>0.01**	43.0
	%>0.5	1.3	1.4	**%>0.05**	0.0
	Data Period	12-Oct-78	1-Dec-86		

B6H003Q01

	NH4	NO2_NO3	TIN	PO4
n	296	288	272	277
mean	0.04	0.06	0.10	0.012
median	0.03	0.04	0.08	0.009
standard deviation	0.03	0.08	0.08	0.018
mean - 3SD	-0.07	-0.19	-0.15	-0.042
mean + 3SD	0.14	0.31	0.34	0.066
min	0.001	0.001	0.01	0.001
max	**0.26**	**0.81**	**0.83**	**0.237**
	NO2_NO3	**TIN**		**PO4**
%>0.05	33.7	73.9	**%>0.005**	71.1
%>0.1	12.5	31.6	**%>0.01**	42.6
%>0.5	1.0	0.7	**%>0.05**	2.5
Data Period	5-Oct-76	26-Jan-98		

B7H004Q01

	NH4	NO2_NO3	TIN	KN
n	223	214	206	2
mean	0.04	0.05	0.09	0.17
median	0.03	0.03	0.08	0.17
standard deviation	0.04	0.07	0.08	0.01
mean - 3SD	-0.07	-0.15	-0.14	0.13
mean + 3SD	0.15	0.25	0.33	0.20
min	0.001	0.004	0.016	0.158
max	**0.2**	**0.712**	**0.753**	0.175
	NO2_NO3	**TIN**		
%>0.05	28.5	65.5		**%>0.005**
%>0.1	13.1	31.6		**%>0.01**
%>0.5	0.5	0.5		**%>0.05**
Data Period	6-May-77	13-Jan-98		

E1H006Q01

	NH4	NO2_NO3	TIN	PO4
n	130	118	114	115
mean	0.05	0.04	0.09	0.010
median	0.04	0.02	0.07	0.007
standard deviation	0.05	0.06	0.08	0.011
mean - 3SD	-0.10	-0.14	-0.15	-0.022
mean + 3SD	0.21	0.21	0.33	0.042
min	0.01	0.01	0.02	0.001
max	**0.26**	**0.55**	**0.59**	**0.083**
	NO2_NO3	**TIN**		**PO4**
%>0.05	12.7	64.0	**%>0.005**	62.6
%>0.1	5.9	26.3	**%>0.01**	33.9
%>0.5	0.8	0.9	**%>0.05**	1.7
Data Period	4-Jan-78	28-Sep-89		

E2H002Q01		NH4	NO2_NO3	TIN	PO4
	n	113	115	108	112
	mean	0.04	0.05	0.08	0.016
	median	0.03	0.03	0.07	0.013
	standard deviation	0.03	0.07	0.05	0.015
	mean - 3SD	-0.06	-0.15	-0.08	-0.028
	mean + 3SD	0.13	0.25	0.24	0.059
	min	0.004	0.001	0.019	0.001
	max	**0.283**	**0.46**	**0.363**	**0.114**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	23.5	68.5	**%>0.005**	80.4
	%>0.1	10.4	17.6	**%>0.01**	58.0
	%>0.5	0.0	0.0	**%>0.05**	1.8
	Data Period	1-Oct-79	17-Apr-97		

G1H016Q01		NH4	NO2_NO3	TIN	KN
	n	52	43	41	50
	mean	0.06	0.03	0.08	0.18
	median	0.05	0.02	0.07	0.17
	standard deviation	0.03	0.03	0.04	0.13
	mean - 3SD	-0.04	-0.05	-0.03	-0.20
	mean + 3SD	0.16	0.10	0.19	0.56
	min	0.01	0.002	0.02	0.033
	max	**0.2**	**0.17**	**0.2**	**0.7**
		NO2_NO3	**TIN**		
	%>0.05	4.7	75.6		**%>0.005**
	%>0.1	2.3	17.1		**%>0.01**
	%>0.5	0.0	0.0		**%>0.05**
	Data Period	27-Nov-75	5-Jun-90		

H6H010Q01		NH4	NO2_NO3	TIN	PO4
	n	128	102	95	117
	mean	0.05	0.04	0.09	0.011
	median	0.03	0.02	0.07	0.007
	standard deviation	0.05	0.05	0.07	0.012
	mean - 3SD	-0.10	-0.13	-0.12	-0.024
	mean + 3SD	0.20	0.20	0.30	0.046
	min	0.01	0.01	0.02	0.001
	max	**0.3**	**0.46**	**0.5**	**0.061**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	16.7	58.9	**%>0.005**	58.1
	%>0.1	5.9	28.4	**%>0.01**	40.2
	%>0.5	0.0	0.0	**%>0.05**	0.9
	Data Period	26-May-77	1-Dec-82		

Station		NH4	NO2_NO3	TIN	PO4
J1H015Q01	n	113	103	98	103
	mean	0.05	0.03	0.08	0.010
	median	0.03	0.02	0.06	0.007
	standard deviation	0.06	0.03	0.06	0.015
	mean - 3SD	-0.12	-0.05	-0.10	-0.035
	mean + 3SD	0.22	0.10	0.26	0.055
	min	0.001	0.003	0.017	0.001
	max	**0.39**	**0.18**	**0.41**	**0.138**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	7.8	60.2	**%>0.005**	56.3
	%>0.1	1.9	23.5	**%>0.01**	29.1
	%>0.5	0.0	0.0	**%>0.05**	1.0

Data Period 27-Jan-76 23-Apr-97

Station		NH4	NO2_NO3	TIN	PO4
L7H006Q01	n	566	526	514	571
	mean	0.05	0.08	0.12	0.020
	median	0.04	0.03	0.08	0.013
	standard deviation	0.03	0.17	0.17	0.031
	mean - 3SD	-0.04	-0.44	-0.40	-0.073
	mean + 3SD	0.13	0.59	0.64	0.113
	min	0.001	0.001	0.015	0.001
	max	**0.2**	**1.336**	**1.391**	**0.491**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	24.3	72.4	**%>0.005**	87.6
	%>0.1	13.3	28.0	**%>0.01**	63.4
	%>0.5	4.2	4.3	**%>0.05**	4.6

Note - Outliers have been removed from data set

Data Period 10-Nov-78 6-Mar-97

Station		NH4	NO2_NO3	TIN	PO4
L8H001Q01	n	219	243	213	234
	mean	0.05	0.08	0.13	0.023
	median	0.03	0.07	0.11	0.021
	standard deviation	0.07	0.07	0.09	0.018
	mean - 3SD	-0.16	-0.13	-0.14	-0.032
	mean + 3SD	0.25	0.30	0.40	0.078
	min	0.001	0.01	0.017	0.001
	max	**0.5**	**0.443**	**0.53**	**0.158**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	61.3	85.9	**%>0.005**	89.3
	%>0.1	28.8	53.5	**%>0.01**	79.5
	%>0.5	0.0	0.5	**%>0.05**	5.6

Data Period 17-Jul-73 16-Apr-97

N2H009Q01

	NH4	NO2_NO3	TIN	PO4
n	676	679	658	687
mean	0.07	0.46	0.54	0.098
median	0.05	0.46	0.53	0.087
standard deviation	0.10	0.36	0.37	0.084
mean - 3SD	-0.23	-0.62	-0.59	-0.155
mean + 3SD	0.38	1.54	1.66	0.351
min	0.001	0.003	0.006	0.001
max	**1.62**	**1.8**	**2.38**	**0.754**
	NO2_NO3	**TIN**		**PO4**
%>0.05	81.4	95.0	**%>0.005**	99.6
%>0.1	75.1	85.3	**%>0.01**	98.0
%>0.5	47.0	52.3	**%>0.05**	59.8

Note - Outliers have been removed from data set
Data Period 5-Oct-78 17-Apr-97

Q9H002Q01

	NH4	NO2_NO3	TIN	PO4
n	257	255	253	258
mean	0.07	0.14	0.20	0.033
median	0.05	0.07	0.14	0.023
standard deviation	0.08	0.18	0.19	0.040
mean - 3SD	-0.18	-0.40	-0.37	-0.086
mean + 3SD	0.32	0.67	0.77	0.152
min	0.001	0.002	0.014	0.001
max	**1.183**	**1.38**	**1.41**	**0.349**
	NO2_NO3	**TIN**		**PO4**
%>0.05	57.3	89.7	**%>0.005**	93.0
%>0.1	39.2	64.4	**%>0.01**	84.9
%>0.5	4.3	5.5	**%>0.05**	14.7

Note - Outliers have been removed from data set
Data Period 24-Jun-96 12-Nov-91

Q9H014Q01

	NH4	NO2_NO3	TIN	PO4
n	139	128	124	137
mean	0.04	0.17	0.22	0.020
median	0.04	0.09	0.15	0.014
standard deviation	0.04	0.25	0.25	0.024
mean - 3SD	-0.07	-0.58	-0.54	-0.051
mean + 3SD	0.16	0.92	0.97	0.092
min	0.01	0.01	0.03	0.001
max	**0.26**	**1.93**	**1.96**	**0.176**
	NO2_NO3	**TIN**		**PO4**
%>0.05	57.8	85.5	**%>0.005**	80.3
%>0.1	44.5	60.5	**%>0.01**	61.3
%>0.5	6.3	8.9	**%>0.05**	8.0

Note - Outliers have been removed from data set
Data Period 3-Dec-76 4-Mar-81

Q9H016Q01

	NH4	NO2_NO3	TIN	PO4
n	226	213	209	219
mean	0.07	0.14	0.20	0.034
median	0.04	0.06	0.13	0.017
standard deviation	0.17	0.20	0.24	0.133
mean - 3SD	-0.45	-0.46	-0.52	-0.365
mean + 3SD	0.59	0.73	0.92	0.432
min	0.01	0.01	0.02	0.001
max	**1.91**	**1.34**	**1.93**	**1.935**
	NO2_NO3	**TIN**		**PO4**
%>0.05	53.1	81.3	**%>0.005**	79.9
%>0.1	35.7	58.9	**%>0.01**	66.7
%>0.5	5.2	7.7	**%>0.05**	10.5

Note - Outliers have been removed from data set

Data Period 26-Nov-76 2-Mar-93

S3H002Q01

	NH4	NO2_NO3	TIN	PO4
n	165	154	151	161
mean	0.07	0.24	0.31	0.041
median	0.05	0.10	0.17	0.022
standard deviation	0.10	0.33	0.35	0.063
mean - 3SD	-0.22	-0.74	-0.74	-0.149
mean + 3SD	0.36	1.21	1.35	0.232
min	0.001	0.002	0.008	0.001
max	**0.79**	**2.31**	**2.32**	**0.671**
	NO2_NO3	**TIN**		**PO4**
%>0.05	64.9	86.1	**%>0.005**	93.8
%>0.1	49.4	67.5	**%>0.01**	84.5
%>0.5	12.3	16.6	**%>0.05**	23.6

Data Period 29-May-74 17-Apr-97

U2H013Q01

	NH4	NO2_NO3	TIN	KN
n	262	489	252	124
mean	0.05	0.18	0.22	0.39
median	0.05	0.16	0.20	0.29
standard deviation	0.03	0.17	0.17	0.29
mean - 3SD	-0.05	-0.32	-0.28	-0.49
mean + 3SD	0.16	0.68	0.73	1.26
min	0.01	0.01	0.02	0.036
max	**0.24**	**1.72**	**1.64**	**1.809**
	NO2_NO3	**TIN**		
%>0.05	74.6	91.7		**%>0.005**
%>0.1	63.4	78.2		**%>0.01**
%>0.5	2.9	3.6		**%>0.05**

Note - Outliers have been removed from data set

Data Period 18-Jul-77 29-Aug-95

V7H017Q01	NH4	NO2_NO3	TIN	PO4
n	243	215	211	238
mean	0.05	0.04	0.09	0.017
median	0.04	0.03	0.07	0.013
standard deviation	0.07	0.06	0.09	0.018
mean - 3SD	-0.15	-0.13	-0.18	-0.036
mean + 3SD	0.25	0.21	0.36	0.070
min	0.003	0.002	0.012	0.001
max	**0.784**	**0.7**	**0.818**	**0.153**
	NO2_NO3	**TIN**		**PO4**
%>0.05	16.7	67.8	**%>0.005**	82.8
%>0.1	5.1	23.7	**%>0.01**	60.5
%>0.5	0.5	1.4	**%>0.05**	4.2
Data Period	18-Jul-77	23-Apr-97		

X2H010Q01	NH4	NO2_NO3	TIN	PO4
n	216	196	187	223
mean	0.04	0.04	0.08	0.019
median	0.03	0.03	0.07	0.014
standard deviation	0.03	0.05	0.06	0.019
mean - 3SD	-0.05	-0.10	-0.09	-0.037
mean + 3SD	0.12	0.19	0.26	0.076
min	0.003	0.004	0.019	0.001
max	**0.3**	**0.479**	**0.522**	**0.106**
	NO2_NO3	**TIN**		**PO4**
%>0.05	26.5	72.2	**%>0.005**	88.3
%>0.1	6.6	23.5	**%>0.01**	63.2
%>0.5	0.0	0.5	**%>0.05**	7.2
Data Period	18-Oct-78	28-Apr-97		

X2H014Q01	NH4	NO2_NO3	TIN	PO4
n	247	223	218	225
mean	0.05	0.08	0.13	0.011
median	0.04	0.06	0.11	0.008
standard deviation	0.067	0.069	0.078	0.011
mean - 3SD	-0.15	-0.13	-0.11	-0.023
mean + 3SD	0.25	0.29	0.36	0.046
min	0.004	0.005	0.02	0.001
max	**0.78**	**0.299**	**0.5**	**0.127**
	NO2_NO3	**TIN**		**PO4**
%>0.05	52.9	83.5	**%>0.005**	72.0
%>0.1	30.0	50.9	**%>0.01**	43.1
%>0.5	0.0	0.0	**%>0.05**	0.4
Data Period	30-Jan-77	28-Apr-97		

Summary data per reference site for the establishment of TWQR for nutrients – Summer Dataset (December, January and February records).

A6H018Q01

	NH4	NO2_NO3	TIN	PO4
n	41	30	29	39
mean	0.04	0.03	0.08	0.009
median	0.03	0.02	0.06	0.009
standard deviation	0.04	0.05	0.06	0.006
mean - 3SD	-0.08	-0.11	-0.10	-0.007
mean + 3SD	0.17	0.18	0.25	0.026
min	0.01	0.01	0.02	0.001
max	**0.17**	**0.28**	**0.31**	0.025
	NO2_NO3	**TIN**		**PO4**
%>0.05	13.3	55.2	**%>0.005**	**71.8**
%>0.1	3.3	13.8	**%>0.01**	41.0
%>0.5	0.0	0.0	**%>0.05**	0.0
Data Period	5-Dec-77	21-Jan-98		

A6H021Q01

	NH4	NO2_NO3	TIN	PO4
n	28	19	18	24
mean	0.07	0.03	0.10	0.009
median	0.05	0.01	0.08	0.007
standard deviation	0.07	0.04	0.08	0.006
mean - 3SD	-0.14	-0.08	-0.13	-0.010
mean + 3SD	0.28	0.14	0.32	0.027
min	0.01	0.01	0.02	0.001
max	**0.3**	0.13	0.31	0.025
	NO2_NO3	**TIN**		**PO4**
%>0.05	15.8	66.7	**%>0.005**	**66.7**
%>0.1	10.5	27.8	**%>0.01**	29.2
%>0.5	0.0	0.0	**%>0.05**	0.0
Data Period	26-Dec-77	27-Jan-82		

B4H005Q01

	NH4	NO2_NO3	TIN	PO4
n	19	18	17	18
mean	0.04	0.15	0.17	0.018
median	0.04	0.06	0.09	0.013
standard deviation	0.02	0.27	0.27	0.014
mean - 3SD	-0.01	-0.65	-0.63	-0.025
mean + 3SD	0.09	0.96	0.98	0.061
min	0.01	0.01	0.03	0.001
max	0.07	**1.13**	**1.18**	0.05
	NO2_NO3	**TIN**		**PO4**
%>0.05	50.0	76.5	**%>0.005**	**77.8**
%>0.1	27.8	41.2	**%>0.01**	61.1
%>0.5	5.6	5.9	**%>0.05**	0.0
Data Period	7-Dec-78	1-Dec-86		

B6H003Q01		NH4	NO2_NO3	TIN	PO4
	n	69	67	59	66
	mean	0.05	0.04	0.09	0.010
	median	0.03	0.03	0.07	0.007
	standard deviation	0.05	0.05	0.06	0.014
	mean - 3SD	-0.11	-0.10	-0.09	-0.033
	mean + 3SD	0.20	0.18	0.27	0.053
	min	0.003	0.002	0.026	0.001
	max	**0.26**	**0.318**	**0.341**	**0.115**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	23.9	69.5	**%>0.005**	63.6
	%>0.1	7.5	25.4	**%>0.01**	33.3
	%>0.5	0.0	0.0	**%>0.05**	1.5
	Data Period	7-Dec-76	26-Jan-98		

B7H004Q01		NH4	NO2_NO3	TIN	PO4
	n	57	54	53	56
	mean	0.05	0.05	0.11	0.017
	median	0.04	0.03	0.10	0.015
	standard deviation	0.04	0.05	0.06	0.011
	mean - 3SD	-0.07	-0.11	-0.07	-0.017
	mean + 3SD	0.18	0.22	0.28	0.051
	min	0.001	0.01	0.02	0.001
	max	**0.19**	**0.221**	0.27	**0.064**
		NO2_NO3	**TIN**		**PO4**
	%>0.05	35.2	75.5	**%>0.005**	92.9
	%>0.1	18.5	45.3	**%>0.01**	76.8
	%>0.5	0.0	0.0	**%>0.05**	3.6
	Data Period	6-Dec-77	13-Jan-98		

E1H006Q01		NH4	NO2_NO3	TIN	PO4
	n	26	23	22	23
	mean	0.03	0.06	0.10	0.013
	median	0.03	0.03	0.06	0.008
	standard deviation	0.02	0.11	0.12	0.014
	mean - 3SD	-0.02	-0.27	-0.25	-0.029
	mean + 3SD	0.08	0.40	0.45	0.055
	min	0.01	0.01	0.02	0.001
	max	0.07	**0.55**	**0.59**	0.052
		NO2_NO3	**TIN**		**PO4**
	%>0.05	26.1	63.6	**%>0.005**	52.2
	%>0.1	13.0	18.2	**%>0.01**	47.8
	%>0.5	**4.3**	**4.5**	**%>0.05**	4.3
	Data Period	4-Jan-78	26-Jan-89		

E2H002Q01

	NH4	NO2_NO3	TIN	PO4
n	22	25	22	21
mean	0.03	0.07	0.07	0.013
median	0.03	0.03	0.07	0.012
standard deviation	0.02	0.11	0.05	0.008
mean - 3SD	-0.03	-0.27	-0.07	-0.012
mean + 3SD	0.10	0.41	0.22	0.037
min	0.006	0.001	0.023	0.001
max	0.09	**0.46**	**0.26**	0.029
	NO2_NO3	**TIN**		**PO4**
%>0.05	20.0	68.2	**%>0.005**	85.7
%>0.1	12.0	4.5	**%>0.01**	52.4
%>0.5	0.0	0.0	**%>0.05**	0.0
Data Period	2-Dec-79	4-Feb-97		

G1H016Q01

	NH4	NO2_NO3	TIN	KN	PO4	TP
n	11	11	10	12	6	12
mean	0.05	0.03	0.08	0.14	0.011	0.012
median	0.05	0.01	0.07	0.12	0.004	0.008
standard deviation	0.02	0.05	0.05	0.08	0.018	0.015
mean - 3SD	-0.02	-0.11	-0.06	-0.11	-0.044	-0.034
mean + 3SD	0.11	0.17	0.22	0.38	0.066	0.058
min	0.01	0.002	0.03	0.03	0.002	0.003
max	0.07	0.17	0.2	0.29	0.048	**0.06**
	NO2_NO3	**TIN**			**PO4**	
%>0.05	9.1	80.0		**%>0.005**	16.7	
%>0.1	9.1	20.0		**%>0.01**	16.7	
%>0.5	0.0	0.0		**%>0.05**	0.0	
Data Period	8-Dec-83	7-Dec-89				

H6H010Q01

	NH4	NO2_NO3	TIN	PO4
n	29	22	19	27
mean	0.03	0.03	0.07	0.010
median	0.02	0.02	0.05	0.005
standard deviation	0.02	0.03	0.04	0.013
mean - 3SD	-0.03	-0.07	-0.06	-0.028
mean + 3SD	0.10	0.14	0.19	0.048
min	0.01	0.01	0.02	0.001
max	0.08	0.12	0.18	**0.061**
	NO2_NO3	**TIN**		**PO4**
%>0.05	13.6	47.4	**%>0.005**	48.1
%>0.1	9.1	15.8	**%>0.01**	29.6
%>0.5	0.0	0.0	**%>0.05**	3.7
Data Period	7-Dec-77	1-Dec-82		

J1H015Q01

	NH4	NO2_NO3	TIN	PO4
n	27	25	24	22
mean	0.04	0.03	0.07	0.012
median	0.03	0.02	0.06	0.009
standard deviation	0.03	0.03	0.04	0.011
mean - 3SD	-0.06	-0.05	-0.05	-0.020
mean + 3SD	0.14	0.11	0.18	0.044
min	0.001	0.003	0.02	0.002
max	0.12	**0.14**	0.16	**0.046**
	NO2_NO3	**TIN**		**PO4**
%>0.05	4.0	54.2	**%>0.005**	63.6
%>0.1	4.0	12.5	**%>0.01**	45.5
%>0.5	0.0	0.0	**%>0.05**	0.0
Data Period	12-Feb-75	31-Dec-96		

L7H006Q01

	NH4	NO2_NO3	TIN	PO4
n	130	116	111	134
mean	0.05	0.13	0.18	0.026
median	0.05	0.03	0.08	0.017
standard deviation	0.03	0.26	0.27	0.046
mean - 3SD	-0.04	-0.64	-0.62	-0.113
mean + 3SD	0.14	0.90	0.98	0.165
min	0.002	0.004	0.015	0.001
max	**0.2**	**1.336**	**1.391**	**0.491**
	NO2_NO3	**TIN**		**PO4**
%>0.05	33.6	82.9	**%>0.005**	87.3
%>0.1	19.8	36.0	**%>0.01**	70.1
%>0.5	9.5	9.9	**%>0.05**	8.2
Data Period	21-Feb-84	20-Feb-97		

L8H001Q01

	NH4	NO2_NO3	TIN	PO4
n	53	63	52	59
mean	0.07	0.06	0.13	0.019
median	0.04	0.05	0.10	0.018
standard deviation	0.11	0.04	0.11	0.012
mean - 3SD	-0.26	-0.07	-0.20	-0.017
mean + 3SD	0.41	0.18	0.45	0.055
min	0.007	0.01	0.02	0.002
max	**0.5**	**0.242**	**0.53**	0.045
	NO2_NO3	**TIN**		**PO4**
%>0.05	49.2	94.2	**%>0.005**	89.8
%>0.1	12.7	42.3	**%>0.01**	71.2
%>0.5	0.0	1.9	**%>0.05**	0.0
Data Period	15-Jan-77	25-Dec-96		

N2H009Q01	NH4	NO2_NO3	TIN	PO4
n	137	145	135	142
mean	0.07	0.44	0.51	0.086
median	0.05	0.45	0.50	0.061
standard deviation	0.14	0.35	0.39	0.069
mean - 3SD	-0.36	-0.61	-0.66	-0.122
mean + 3SD	0.49	1.50	1.68	0.293
min	0.001	0.003	0.006	0.001
max	**1.62**	1.149	**2.38**	**0.295**
	NO2_NO3	**TIN**		**PO4**
%>0.05	75.2	93.3	**%>0.005**	98.6
%>0.1	71.7	77.0	**%>0.01**	97.9
%>0.5	46.2	49.6	**%>0.05**	52.1

Note - Outliers have been removed from data set
Data Period 7-Dec-78 6-Feb-97

Q9H002Q01	NH4	NO2_NO3	TIN	PO4
n	68	66	66	67
mean	0.06	0.12	0.19	0.042
median	0.05	0.07	0.15	0.026
standard deviation	0.05	0.16	0.16	0.051
mean - 3SD	-0.07	-0.35	-0.30	-0.110
mean + 3SD	0.20	0.59	0.67	0.194
min	0.002	0.003	0.014	0.003
max	**0.2**	**0.98**	**1.01**	**0.32**
	NO2_NO3	**TIN**		**PO4**
%>0.05	60.6	86.4	**%>0.005**	95.5
%>0.1	40.9	66.7	**%>0.01**	94.0
%>0.5	4.5	4.5	**%>0.05**	16.4

Note - Outliers have been removed from data set
Data Period 6-Feb-77 3-Feb-97

Q9H014Q01	NH4	NO2_NO3	TIN	PO4
n	48	43	43	46
mean	0.04	0.23	0.28	0.018
median	0.04	0.09	0.15	0.014
standard deviation	0.03	0.38	0.38	0.019
mean - 3SD	-0.03	-0.91	-0.86	-0.039
mean + 3SD	0.12	1.37	1.41	0.076
min	0.01	0.01	0.04	0.001
max	**0.13**	**1.93**	**1.96**	**0.101**
	NO2_NO3	**TIN**		**PO4**
%>0.05	60.5	95.3	**%>0.005**	73.9
%>0.1	44.2	58.1	**%>0.01**	58.7
%>0.5	11.6	16.3	**%>0.05**	4.3

Note - Outliers have been removed from data set
Data Period 3-Dec-76 25-Feb-81

Q9H016Q01

	NH4	NO2_NO3	TIN	PO4
n	57	53	52	55
mean	0.06	0.14	0.20	0.023
median	0.04	0.07	0.15	0.022
standard deviation	0.06	0.23	0.24	0.018
mean - 3SD	-0.11	-0.55	-0.52	-0.032
mean + 3SD	0.23	0.83	0.92	0.078
min	0.01	0.01	0.03	0.001
max	**0.3**	**1.34**	**1.41**	0.071
	NO2_NO3	**TIN**		**PO4**
%>0.05	54.7	78.8	**%>0.005**	**74.5**
%>0.1	35.8	61.5	**%>0.01**	65.5
%>0.5	5.7	7.7	**%>0.05**	9.1

Note - Outliers have been removed from data set

Data Period 10-Dec-76 5-Dec-89

S3H002Q01

	NH4	NO2_NO3	TIN	PO4
n	44	40	40	44
mean	0.07	0.26	0.33	0.048
median	0.05	0.09	0.17	0.031
standard deviation	0.11	0.35	0.39	0.040
mean - 3SD	-0.25	-0.79	-0.82	-0.071
mean + 3SD	0.39	1.31	1.49	0.166
min	0.005	0.002	0.008	0.004
max	**0.68**	**1.37**	1.46	0.156
	NO2_NO3	**TIN**		**PO4**
%>0.05	65.0	90.0	**%>0.005**	95.5
%>0.1	47.5	67.5	**%>0.01**	88.6
%>0.5	15.0	17.5	**%>0.05**	34.1

Note - Outliers have been removed from data set

Data Period 5-Dec-77 12-Dec-96

U2H013Q01

	NH4	NO2_NO3	TIN	KN	PO4	TP
n	60	101	58	34	74	72
mean	0.05	0.17	0.22	0.39	0.019	0.067
median	0.05	0.15	0.22	0.28	0.005	0.032
standard deviation	0.03	0.15	0.12	0.32	0.071	0.203
mean - 3SD	-0.04	-0.28	-0.15	-0.56	-0.196	-0.541
mean + 3SD	0.15	0.62	0.60	1.33	0.233	0.675
min	0.01	0.01	0.02	0.134	0.001	0.013
max	**0.22**	**0.86**	**0.71**	**1.809**	**0.606**	**1.74**
	NO2_NO3	**TIN**			**PO4**	
%>0.05	72.3	91.4		**%>0.005**	47.3	
%>0.1	63.4	79.3		**%>0.01**	27.0	
%>0.5	4.0	1.7		**%>0.05**	5.4	

Data Period 6-Dec-77 28-Feb-95

V7H017Q01

	NH4	NO2_NO3	TIN	PO4
n	59	53	52	55
mean	0.04	0.04	0.09	0.015
median	0.03	0.03	0.08	0.011
standard deviation	0.03	0.05	0.06	0.020
mean - 3SD	-0.06	-0.10	-0.09	-0.046
mean + 3SD	0.15	0.19	0.26	0.075
min	0.004	0.01	0.02	0.001
max	**0.19**	**0.21**	**0.296**	**0.153**
	NO2_NO3	**TIN**		**PO4**
%>0.05	20.8	71.2	**%>0.005**	85.5
%>0.1	9.4	25.0	**%>0.01**	52.7
%>0.5	0.0	0.0	**%>0.05**	1.8
Data Period	5-Dec-77	26-Feb-97		

X2H010Q01

	NH4	NO2_NO3	TIN	PO4
n	58	57	55	59
mean	0.04	0.05	0.09	0.020
median	0.03	0.03	0.07	0.016
standard deviation	0.03	0.05	0.05	0.019
mean - 3SD	-0.04	-0.10	-0.08	-0.036
mean + 3SD	0.12	0.19	0.25	0.075
min	0.01	0.005	0.03	0.003
max	**0.16**	**0.28**	**0.33**	**0.106**
	NO2_NO3	**TIN**		**PO4**
%>0.05	26.3	76.4	**%>0.005**	89.8
%>0.1	7.0	23.6	**%>0.01**	64.4
%>0.5	0.0	0.0	**%>0.05**	5.1
Data Period	6-Dec-78	24-Feb-97		

X2H014Q01

	NH4	NO2_NO3	TIN	PO4
n	65	59	58	60
mean	0.04	0.08	0.12	0.012
median	0.04	0.06	0.10	0.007
standard deviation	0.03	0.07	0.07	0.018
mean - 3SD	-0.06	-0.12	-0.09	-0.041
mean + 3SD	0.14	0.28	0.33	0.065
min	0.006	0.01	0.02	0.001
max	**0.19**	0.278	0.32	**0.127**
	NO2_NO3	**TIN**		**PO4**
%>0.05	55.9	86.2	**%>0.005**	**71.7**
%>0.1	28.8	48.3	**%>0.01**	35.0
%>0.5	0.0	0.0	**%>0.05**	1.7
Data Period	30-Jan-77	24-Feb-97		

Other related WRC reports available:

The effect of water quality variables on aquatic ecosystems: A Review

Dallas HF; Day JA

Water is a scarce resource in South Africa, and increasing population pressure has meant that the resource is heavily exploited and carries an increasing pollution load. Aquatic ecosystems are able to remediate a certain amount of pollution, but once this level has been exceeded then the ecosystem, together with its ability to remediate pollution declines.

Chapters 2 and 3 of the review provide a general introduction to the issue of water quality in relation to aquatic ecosystems. Chapters 4 to 12 synthesyse what is known about the effects on aquatic ecosystems of specific physical attributes and chemical constituents. Specifically, these include temperature, turbidity, pH, total dissolved solids and dissolved oxygen. Organic enrichment, including bacterial contamination, as well as the effects of enrichment by specific nutrients are covered, as are biocides and trace metals. The last eight chapters examine the effect of different types of whole effluents or other specific disruptions resulting from human activities, including agriculture, aquaculture, engineering and construction with specific reference to river regulation, forestry, industrial effluents, mining and urban runoff

Report Number: TT 224/04 **ISBN: : 1 77005 131 7**

TO ORDER: Contact **Publications** - Telephone No: 012 330 0340
Fax Number: 012 331 2565
E-mail: publications@wrc.org.za

1770053573

Water Research Commission
Private Bag X03, Gezina, 0031, South Africa
Tel: +27 12 330 0340, Fax: +27 12 331 2565
Web: http://www.wrc.org.za

Designed by The Kashan Group K-2102 (www.kashangroup.com)