A Guide to Catchment-Scale Eutrophication Assessments for Rivers, Reservoirs and Lacustrine Wetlands

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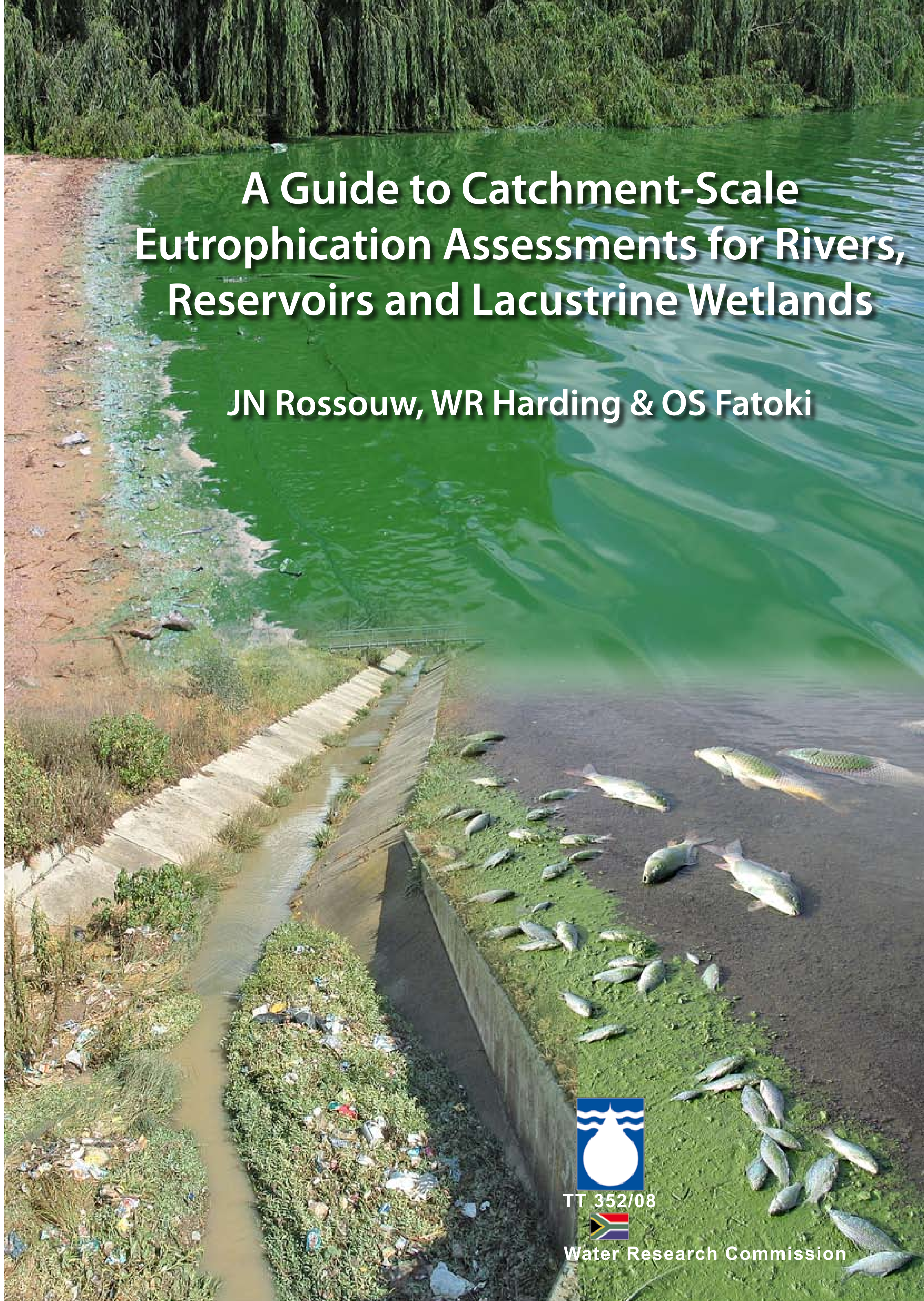

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Water Research Commission

A GUIDE TO CATCHMENT-SCALE EUTROPHICATION ASSESSMENTS FOR RIVERS, RESERVOIRS AND LACUSTRINE WETLANDS

by

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EXECUTIVE SUMMARY

A GUIDE TO CATCHMENT-SCALE EUTROPHICATION ASSESSMENTS FOR RIVERS, RESERVOIRS AND LACUSTRINE WETLANDS

Background to the study

Eutrophication is the enrichment of waters with plant nutrients which results in an array of symptomatic changes, namely increased production of algae and aquatic macrophytes, deterioration of water quality and other undesirable changes that interfere with water uses. In South Africa, eutrophication has been recognized as a priority water quality problem for over 30 years and in a study on the eutrophication status of a number of South African reservoirs, it was found that the extent of eutrophication had increased since the problem was first identified in the 1970s. A study commissioned in 2000 by the Water Research Commission (WRC) found that South Africa's policy and approach to eutrophication control has been inadequate over the last 20 years. A strong need was identified to remobilise and redevelop the WRC's capacity to manage eutrophication. A workshop followed in 2001, to discuss research and capacity building within the field of eutrophication and the assessment of the eutrophication problem was identified as the highest priority research area.

At the same time as the WRC eutrophication policy study was underway, the Department of Water Affairs and Forestry (DWAF) commissioned a project to develop a generic Guide to Conduct Water Quality Assessment Studies. The DWAF Guide suggested a protocol to undertake catchment scale water quality assessment studies to support the development of catchment management strategies.

The objective of the current WRC project was to use the DWAF protocol as the backbone for developing an Eutrophication Assessment Guide for Rivers, Reservoirs and Lacustrine Wetlands in Southern Africa. The guide would ensure that the development of eutrophication management strategies was aligned with current water resource management policies and procedures endorsed by DWAF.

Aims of the project

- To provide professional guidance to practitioners in using assessment protocols that were aligned with national catchment water quality assessment studies, to assess eutrophication-related catchment and receiving water body characteristics.
- To provide a means by which local and international best eutrophication assessment practice (methodologies and protocols) could be captured and made available to a wide range of catchment assessment practitioners in Southern Africa.
- To develop tools and course material that could be used to fast-track capacity building in eutrophication-related water quality assessment and management.

Output products of the project

Three products were produced as output from the project:

- A guide to assess eutrophication-related water quality for rivers, lakes/reservoirs and lacustrine wetlands,
- An internet-based Nutrient Enrichment Assessment Protocol (NEAP)
- A course outline and training material for a short course in eutrophication assessment.

These output products are described in more detail below.

A GUIDE TO ASSESS EUTROPHICATION-RELATED WATER QUALITY

Catchment management, catchment assessment studies and catchment water quality assessment studies

The National Water Act specifies that *catchment management strategies* (CMS) must be developed to manage water resources at a catchment scale. It goes on to describe, in broad terms, what a CMS should consider and what must be included in the strategy. A CMS is supported by a *catchment assessment study* (CAS) which deals with water-related natural resources in a catchment, including the human impacts on those resources, and the need to protect, use, develop, conserve, manage and control those resources. A *catchment water quality assessment study* is designed to assess water quality, at a catchment scale, in a systematic way and to develop integrated water quality management strategies. These topics are introduced in **Part 1** of the Guide document.

A Guide to assess eutrophication at a catchment scale

Eutrophication is one of the priority water quality problems in South Africa. **Part 2** of the Guide document describes, in detail, the key study components required to assess the eutrophication status of a catchment or sub-catchment and to develop management options that take into account the needs and aspirations of stakeholders and the constraints imposed on a particular catchment. The Guide is structured around six management questions:

- What is the eutrophication-related status of the study area and how did it get to this point?
- Who are the eutrophication-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?
- What are the study area's eutrophication-related issues, concerns, problems and opportunities?
- Where the eutrophication-related status of the study area might be heading in the future?
- What are the appropriate priority eutrophication management options?
- Has catchment management achieved its objectives?

For each management question, a management task has been formulated to provide the answers to the question (as illustrated in the table below). Each management task has a number of components or sub-tasks to collect the required information to answer the question.

Component	*Eutrophication Management Question 1:* **What is the eutrophication status of the study area and how did it get to this point?** *Eutrophication Assessment Task 1:* **Characterisation of the current eutrophication status and historical trends**
0	Inception summary of existing understanding, knowledge and past studies with regard to eutrophication related water quality in the catchment
1	Details of natural, developmental and administrative attributes and characteristics of the catchment relevant to the assessment of the eutrophication status
2	Requirements of the National Water Resource Strategy and Resource Directed Measures with regard to nutrient management
3	Water use and conservation related to eutrophication assessment
4	Overview of adequacy of water availability
5	User water quality requirements and constituents of concern relating to eutrophication
6	Eutrophication related water quality of streamflow, reservoirs, estuaries, wetlands and groundwater
7	Point source waste discharges and source characteristics relating to eutrophication
8	Non-point source water quality loadings and impacts relating to eutrophication

9	Configured and calibrated predictive tools/models with regard to eutrophication related water quality
10	Reconciliation: catchment nutrient sources and eutrophication related water quality patterns
11	Status reports on eutrophication monitoring, physical data and characterisation information
	Eutrophication Management Question 2: **Who are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages, and roles?** *Eutrophication Assessment Task 2:* **Engagement of water-related institutions and stakeholders in CAS process**
12	Stakeholder details and participation processes
13	Water-interest institutional arrangements and linkages
	Eutrophication Management Question 3: **What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?** *Eutrophication Assessment Task 3:* **Formulate and record eutrophication related water quality issues, concerns, problems, and opportunities**
14	Record of eutrophication related water quality issues and their origins
15	Catchment management implications of eutrophication related water quality issues
16	Vision (or long-term resource objectives) for eutrophication related water quality
	Eutrophication Management Question 4: ***Where the eutrophication related water quality status of the study area might be heading in the future?*** *Eutrophication Assessment Task 4:* ***Projection of eutrophication related water quality impacts of future water-related development scenarios***
17	National and regional plans and projections of future water demands and catchment development
18	Predicted future eutrophication related water quality at sites of management focus
	Eutrophication Management Question 5: **What are the appropriate (priority) eutrophication management options?** *Eutrophication Assessment Task 5:* **Formulate and prioritise eutrophication management options**
19	Eutrophication related management units and assessment of spatial and temporal resolutions
20	Prioritised eutrophication management options
	Eutrophication Management Question 6: **Have eutrophication management strategies achieved their objectives?** *Eutrophication Assessment Task 6:* **Monitoring and auditing of implementation of eutrophication management strategies**
21	Monitoring and auditing assessment of eutrophication management strategies

Links to the DWAF catchment water quality assessment guide

This guide document mirrors the key features of the DWAF *Catchment Water Quality Assessment Guide* document. This approach was adopted to ensure that the outputs of an eutrophication assessment study are compatible with the overall objectives of a catchment assessment study. The hypertext-enabled version of the Eutrophication Assessment Guide has live links to websites where background information, examples of good practice, etc., can be found.

Application of the eutrophication assessment guide

The application of the guide would help a user to undertake an eutrophication-related catchment water quality assessment study, which in turn, can be used to support the development and implementation of catchment management strategies to address the causes and consequences of eutrophication.

A WEB-BASED NUTRIENT ENRICHMENT ASSESSMENT PROTOCOL (NEAP)

What is NEAP?

NEAP is an internet-based phosphorus ((P)-based) nutrient loading tool for lakes and/or reservoirs which, depending on the level of information entered, allows the user to select one or more outputs that describe, for example, the P-load generated by the catchment, the trophic condition of the lake, and the lake's likely response to a change (increase or reduction) in phosphorus (P) loading.

NEAP is based on a range of existing phosphorus load: response relationships. Insofar as is possible, using available information, NEAP V1.0 has been calibrated for use under South African conditions, and in particular, for use in reservoirs as opposed to lakes.

NEAP development philosophy

NEAP has been purposefully designed as a simple, phosphorus-based, eutrophication screening tool. As such, it provides a non-data intensive means of determining the trophic status (degree of nutrient enrichment) of open-water environments. Once calibrated, it allows the user to determine the manner in which the annual mean concentration of phosphorus is likely to change in response to an increase or decrease in the loading of this element. Such determinations can be made with NEAP at a high (70%) level of confidence.

NEAP as a screening tool

The purpose of a screening tool, such as NEAP, is to provide management-related answers without having to resort to an extended period of data collection. In many cases, simple models such as NEAP target the key drivers that are essential for first-level appreciations. The underlying philosophy with NEAP has been to provide a fast and simple-to-use approximation of the level of eutrophication in a particular reservoir, and to inform options for management. Should more detailed examinations be required thereafter, more complex models can be employed as the required data becomes available.

Future developments

It is intended that subsequent releases of NEAP will incorporate a level of functionality that will support the integration of biogeochemical processes (fate and loss relationships), as well as refinements such as the inclusion of aquaculture impacts. Importantly, later versions will be able to include support for assessing 'virtual' nutrient load reductions relating to management approaches targeting 'top-down' foodweb manipulation. In the case of Hartbeespoort Dam, restructuring of the fishery is estimated to bring about a change in conditions equivalent to a reduction of some 25-40% in external phosphorus loading.

Knowledge of eutrophication to apply NEAP

It is extremely important that the NEAP user has a reasonable working understanding of what eutrophication is – i.e. that eutrophication is not simply a function of phosphorus loads and concentrations – and that a wide variety of biophysical and chemical factors can enhance or constrain the observed level of eutrophication in a particular waterbody. It is as important for the water resource manager to be able to determine whether or not a particular resource is eutrophic as it is to determine the likelihood of it becoming so, or where it lies on a trend towards an impaired trophic state. Unfortunately, appropriate management strategies directed against eutrophication are seriously constrained by a widespread lack of understanding of the problem – particularly at the decision-making level. Recent work carried out at Hartbeespoort Dam has suggested that with due attention, significant remedial changes are indeed possible, and not as insurmountable as has been the popular belief in South Africa for many years.

COURSE OUTLINE AND TRAINING MATERIAL FOR A SHORT COURSE IN EUTROPHICATION ASSESSMENT IN SOUTHERN AFRICAN WATER BODIES

Introduction

In the late 1990s, researchers felt that there was little effort made to review eutrophication policy in the light of the monitoring results and that the country regressed in terms of its capacity and ability to deal with eutrophication. This observation provided motivation to develop, as part of this project, the outline of a short eutrophication assessment course with the Eutrophication Assessment Guide document as the background document for the course. The primary target audience for the course material on the Southern African water resource practitioner, water resource manager and freshwater scientist. Students at tertiary training institutions would be a secondary audience.

A two-tiered training course

A need was identified for a two-tiered approach. The first tier would be an introductory course designed as a general introduction to eutrophication and its assessment at a catchment scale. The first tier course would be aimed at a person at management level who needs to understand the scope of catchment eutrophication assessment studies. The course would also serve as an introduction to the more detailed second tier short course designed for someone who would be responsible for undertaking a catchment scale eutrophication assessment study.

An introduction to eutrophication assessment

Focus and nature of the course

This short course introduces the topic of eutrophication and nutrient enrichment and what the basic steps are for assessing the problem at a catchment scale, to support the development of a catchment management strategy. Eutrophication is introduced by examining some of the key concepts, the causes, consequences and impacts of nutrient enrichment, and basic monitoring requirements. Catchment scale eutrophication assessment is then introduced along with the NEAP tools that were developed to support a first order assessment. The course is concluded with an overview of the different approaches to managing eutrophication.

This course is a prerequisite for the second short course that deals with the details of a catchment eutrophication assessment study.

Required outcomes

After completion of this short course, the student should be able to:

- Provide a broad overview of eutrophication and nutrient enrichment, the factors leading to eutrophication related problems and how these are manifested in rivers, reservoirs and lacustrine wetlands.
- Provide a time-line of eutrophication problems in South Africa (SA), measures to manage the negative impacts, the current situation in the country and approaches to deal with the problem under the National Water Act.
- Describe the basic steps to undertake a catchment scale eutrophication assessment study.
- Describe the basic approach to a first order assessment of eutrophication.
- Describe the main approaches to managing the negative impacts of eutrophication.

Catchment eutrophication assessment protocol

Focus and nature of the course

This two day short course introduces the topic of eutrophication and catchment eutrophication assessment during the first day (as described above). On the second day of the course, the context within which a catchment scale eutrophication assessment study is undertaken is discussed in more detail. The different tasks and sub-tasks of such a study are then discussed in detail using the eutrophication assessment guide (this document) as a manual. The NEAP web-based software is then used to undertake a hands-on assessment of a specific case study selected by the course leader. The purpose of the case study is to give students the opportunity to apply the concepts introduced during the preceding day and a half, to a specific case study.

Required outcomes

After completion of this short course, the student should be able to:

- Provide a broad overview of the key tasks in a catchment scale eutrophication assessment study.
- Decide on the scale and depth of the eutrophication assessment study for different parts of a catchment study area.
- Apply the NEAP suite of models and assessment tools to undertake a first order assessment of the scope of an eutrophication problem for a specific water body.
- Participate in a detailed eutrophication assessment study as part of a catchment assessment study.

CONCLUSIONS AND RECOMMENDATIONS

Catchment Eutrophication Assessment Guide

Discussion

The Catchment Eutrophication Assessment Guide mirrors the DWAF Water Quality Assessment Guide. The guide is a first attempt to identify those aspects that would differentiate an eutrophication assessment from an assessment of other water quality variables. It was often difficult to decide how much guidance should be given to water quality specialists undertaking an assessment study. The guide now needs to be applied to a number of real world eutrophication problems to identify aspects that need to be improved. A mechanism should also be developed to elicit feedback from users and to update the guide document from time to time.

Recommendations

1. That the WRC and DWAF should promote the use of the guide as a tool to support catchment water quality assessment studies.
2. That a mechanism be developed to obtain feedback from users and to update the knowledge base of the guide. An Internet based discussion forum may offer a way of capturing feedback from users.
3. That the integration of the eutrophication assessment with other water quality variables may require some investigation.
4. That similar guides should be developed for other priority water quality problems in the country. The two highest priority issues are probably salinisation and microbiological pollution.

NEAP (Nutrient Enrichment Assessment Protocol)

Discussion

The work undertaken for the NEAP component of this project has only established a platform for further development and application of subsequent releases of NEAP. The work undertaken will have been pointless if further in-depth analyses of the relevance of the models to a wider South African dataset are not undertaken. Only in this manner will the correct calibrations and application ranges relevant to NEAP become available.

There is no generic, NEAP-predictable eutrophication response applicable to all water supply reservoirs in the country. In many cases, the available water quality records contain few or no data for phosphorus. If the NEAP-based approach is to reach its full potential, the development of regional and/or special climate zone datasets need to be compiled and integrated as loadable calibration sets into future versions of NEAP.

Future versions of NEAP will need to incorporate increased flexibility for dealing with the manner in which phosphorus is assimilated within particular reservoir environments, and particularly with reference to the question of internal loading. The precise role and extent of internal phosphorus loading in highly flushed, shallow and warm South African reservoirs will only become apparent from a more detailed analysis of the available data.

Also critical to the value of NEAP is user-feedback. The developers of NEAP believe that use of this tool has been limited by (a) a general lack of understanding of what NEAP can do, and with this paucity underpinned by (b) inadequate understanding of eutrophication, and eutrophication in reservoirs, in particular.

Recommendations

1. That the value of NEAP be promoted through the convening of a small number of user-targeted workshops;
2. That the project be continued to further develop the local (South African) applicability and scope of NEAP – this by assessing all SA impoundments and their water quality databases through the same process used to select the models used in NEAP V1.0;
3. That the foregoing wider assessment include a catchment analysis and back-calibration of export coefficients in order to expand the relevance and local applicability of nutrient export coefficients by land-use type;
4. That NEAP V1.0 be expanded to include second and higher layers to accommodate biogeochemical processes;
5. That the NEAP V1.0 database and feedback system be maintained and used to both inform the user-friendliness of V1.0 and the relevance of the calibrations.

Eutrophication assessment training course outline and material

Discussion

The course material developed as part of this project was aimed at increasing the capacity to undertake eutrophication assessments at a catchment scale. There is a need to update the material from time to time to reflect advances in the knowledge base on eutrophication assessment. There is also a need to develop similar material to increase capacity to manage eutrophication in reservoirs and urban ponds, and to use more sophisticated assessment tools such as deterministic eutrophication models.

Recommendations

1. That a mechanism be found to update the training material based on feedback from users, updates to the presentations submitted by lecturers, and to keep up to date with advances in the knowledge base of eutrophication assessment methods.

2. That a training course be developed on the control and management of eutrophication in reservoirs and urban water bodies.
3. That a training course be developed on the use of more sophisticated assessment tools such as deterministic river and/or reservoir models.

Capacity building initiatives

Support for tertiary student training

Under the guidance of Prof Fatoki, the studies of two M.Sc students from the University of Venda, Ms M Mamali and Ms D Maluleke, were funded from this project. Ms Mamali undertook her MSc studies on the assessment of the eutrophication status of Vondo and Albasini Dams in Venda. She used the NEAP model during her studies and submitted her thesis during the first quarter of 2005. Ms Maluleke investigated the development of sustainable development indicators. She applied the indicators for case studies of Makhado and Thulamela municipalities. Some of the principles of eutrophication assessments were applied in her studies.

A short course, "Eutrophication Short Course and Modelling Workshop", was presented from 24-25 May 2005 to DWAF staff and others at Roodeplaat Dam. Mr Rossouw and Ms van Ginkel of DWAF presented the Eutrophication Assessment component on the 24th of May, and Prof Friedrech Recknagel from Adelaide University presented the Eutrophication Modelling component on the 25th of May.

Presentations at workshops and conferences

The work undertaken in this project was presented at the inaugural meeting of the WISA Nutrient Management Division, the joint ZSSA/SASAqS conference, and the annual conference of the North American Lake Management Society:

- Rossouw, J N, Harding, W R, Fatoki, O S (2003). Guide to Conduct Eutrophication Assessments for River, Lakes and Wetlands. WISA Nutrient Management Division seminar, Rand Water, 28 March 2003.
- Rossouw, J N and Harding, W R (2003). Bridging the gap between Science and Practice: Development of an Eutrophication Assessment Guide. Joint ZSSA/SASAqS Conference, Cape Town, 29 June to 4 July 2003.
- Rossouw, J N and W R Harding (2005). *Development of a Catchment Scale Eutrophication Assessment Guide to support catchment management in South Africa.* 25th Annual Conference of the North American Lake Management Society, November 9-11, 2005.

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A Guide to conduct Eutrophication Assessment Studies for Rivers, Lakes and Wetlands

The Steering Committee is thanked for contributing their knowledge and insights to the project and the content of this guide. The Steering Committee responsible for this project consisted of the following persons:

Mr H M du Plessis	Water Research Commission (Chairman)
Dr C Dickens	Institute for Natural Resources (previously with Umgeni Water)
Dr A H M Görgens	Ninham Shand Consulting Services
Dr H Malan	Freshwater Research Unit, University of Cape Town
Dr J Roos	Centre for Environmental Management, Free State University
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Ms L A Boyd	Department of Water Affairs and Forestry

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LIST OF ACRONYMS

CAS	-	catchment assessment study
CMA	-	catchment management agency
CMS	-	catchment management strategy
DWAF	-	Department of Water Affairs and Forestry
EIP	-	environmental implementation plan
EMF	-	environmental management framework
GIS	-	geographic information system
HIS	-	hydrological information system
HSPF	-	hydrological system program FORTRAN
IMPAQ	-	Impoundment/river management and planning assessment tool for water quality simulation
IWRM	-	integrated water resources management
NGO	-	non-governmental organisation
NWA	-	National Water Act (Act No 36 of 1998)
NWRS	-	national water resources strategy
POLMON	-	pollution monitoring system
QA/QC	-	quality assurance/quality control
RDM	-	resource directed measures
RQ	-	resource quality
RQOs	-	resource quality objectives
RWQOs	-	resource water quality objectives
TDS	-	total dissolved salts
WMA	-	water management area
WMI	-	water management institution
WMS	-	water management system
WQCAS	-	water quality catchment assessment study
WQCMS	-	water quality catchment management strategy
WSI	-	water services institution
WRC	-	water research commission
WRM	-	water resources management

WRPM	-	water resources planning model
WRYM	-	water resources yield model
WSA	-	water services authority
WSP	-	water services provider
WUA	-	water user association

PART 1

INTRODUCTION TO CATCHMENT-SCALE EUTROPHICATION ASSESSMENTS

1 INTRODUCTION

1.1 Background to the study

Eutrophication is the enrichment of waters with plant nutrients which results in an array of symptomatic changes, namely increased production of algae and aquatic macrophytes, deterioration of water quality and other undesirable changes that interfere with water uses. In South Africa, eutrophication has been recognized as a priority water quality problem for over 30 years and in a study on the eutrophication status of a number of South African reservoirs[1] (Van Ginkel *et al*., 2000), it was found that the extent of eutrophication had increased since the problem was first identified in the 1970s. A study commissioned by the Water Research Commission (WRC) (Walmsley, 2000) found that South Africa's policy and approach to eutrophication control has been inadequate over the last 20 years. A strong need was identified to remobilise and redevelop the capacity to manage eutrophication. The publication of this report was followed by a workshop to discuss research and capacity building within the field of eutrophication (Walmsley, 2001). Assessment of the eutrophication problem was identified as the highest priority research area.

At the same time as the WRC eutrophication policy study was underway, the Department of Water Affairs and Forestry (DWAF) commissioned a project to develop a generic *Guide to Conduct Water Quality Assessment Studies* (DWAF, 2003a, b, c). The Guide describes a protocol to undertake catchment scale water quality assessment studies to support the development of catchment management strategies.

The objective of this WRC project was to use the DWAF protocol as the backbone for developing a catchment-scale Eutrophication Assessment Guide for Rivers, Reservoirs and Lacustrine Wetlands in Southern Africa. The guide would ensure that the development of the eutrophication management strategies was aligned with current water resource management policies and procedures recommended by DWAF.

1.2 Aims of the project

- To provide professional guidance to practitioners in using assessment protocols that were aligned with national catchment water quality assessment studies to assess eutrophication-related catchment and receiving water body characteristics.
- To provide a means by which local and international best eutrophication assessment practice (methodologies and protocols) could be captured and made available to a wide range of catchment assessment practitioners in Southern Africa.
- To develop tools and course material that could be used to fast-track capacity building in eutrophication-related water quality assessment and management.

[1] In this document the terms reservoir, impoundment, and dam are deemed to be equivalent in the South African context and have been used interchangeably. All lakes in South Africa are dams or impoundments, in essence 'man-made' lakes. While in some countries the term 'dam' is used to refer to the wall structure alone, this distinction is not made here.

1.3 Description of the output products

Three products were produced as output from the project:

A Guide to Conduct Catchment-scale Eutrophication Assessments for Rivers, Reservoirs and Lacustrine Wetlands (This document)

This guide document describes, in detail, the key study components required to assess the eutrophication status of a catchment or sub-catchment and to develop management options that take into account the needs and aspirations of stakeholders and constraints imposed on a particular catchment. The application of the guide would help a user to undertake an eutrophication-related catchment water quality assessment study, which in turn, could be used to support the development and implementation of catchment management strategies to address the causes and consequences of eutrophication.

The Guide document was designed to mirror the key features of the DWAF *Catchment Water Quality Assessment Guide* document (DWAF, 2003c). This approach was adopted to ensure that the outputs of eutrophication assessment studies were compatible with the overall catchment water quality assessment objectives. The purpose was not to duplicate the text that appeared in the DWAF water quality assessment guide but to provide sufficient content and information from the DWAF document so that the eutrophication components could be integrated seamlessly into a water quality assessment study if so required. However, an eutrophication assessment study could also be undertaken as a stand-alone project. The user could select appropriate components from the guide to undertake a stand-alone eutrophication assessment study.

An internet-based Eutrophication Assessment Guide and Supporting Tools

The internet-based Eutrophication Assessment Guide consists of two parts. The first part is a hypertext enabled, interactive version of the Eutrophication Assessment Guide (on the report CD). The internet guide has live links to websites where background information, examples of good practice, etc., can be found. The second part is the Nutrient Enrichment Assessment Protocol (NEAP) toolbox that is a collection of simple database and modelling tools to support eutrophication assessment studies. The internet version was designed with easy maintenance in mind. The internet guide and toolbox are resources that can be used in catchment water quality assessment studies, which, in turn, form the basis for the development and implementation of catchment management strategies.

Course outline and training material for a short course in eutrophication assessment for Southern African water bodies

The outline of an eutrophication assessment short course used the Eutrophication Assessment Guide as the primary course material. This includes presentation material from which teaching resources such as handouts can be produced (on the report CD). Primary application is in building capacity amongst Southern African water resource practitioners, water resource managers and freshwater scientists.

1.4 Target audience of this guide document

This guide document is aimed at:

- Water resource managers responsible for managing eutrophication assessment studies or water quality assessment studies, to support the development catchment management strategies;
- Water quality specialists undertaking eutrophication assessment studies or water quality assessment studies where nutrient enrichment is a key concern;
- Lecturers compiling course material on nutrient enrichment or eutrophication related water quality problems, assessment and management.

1.5 Development philosophy of the Guide

The Guide document was designed to mirror the key features of the DWAF *Catchment Water Quality Assessment Guide* document (DWAF, 2003c). This approach was adopted to ensure that the outputs of eutrophication assessment studies were compatible with the overall catchment water quality assessment objectives. The purpose was not to duplicate the text that appeared in the DWAF water quality assessment guide but to provide sufficient content and information from the DWAF document so that the eutrophication components could be integrated seamlessly into a water quality assessment study, if so required.

However, an eutrophication assessment study could also be undertaken as a stand-alone project. The user could therefore select appropriate components from the guide to undertake a stand-alone eutrophication assessment study.

1.6 Layout of the Guide document

There are two parts to the Guide document:

Part 1 of the document, *Introduction to Catchment Scale Eutrophication Assessment*, is composed of a number of sections: the background to the project and the development of the guide; a brief introduction to eutrophication to introduce the most common terms used to describe nutrient enrichment and its impacts; an introduction to catchment eutrophication assessment; an introduction to the eutrophication assessment guide (Part 2 of this document), a description of the Nutrient Enrichment Assessment Protocol (NEAP), and a description of the eutrophication assessment training material. Part 1 is concluded with a short review of the conclusions and recommendations of the study and a description of the capacity building initiatives undertaken as part of this project.

Part 2 of the document, *A Guide to Conduct Catchment Scale Eutrophication Assessments for Rivers, Reservoirs and Lacustrine Wetlands*, is the procedural part of the document and details each component required to undertake an eutrophication assessment study in order to develop an eutrophication management strategy. The 21 components are grouped into six related activities; (1) activities that describe the current eutrophication status, (2) activities that describe the key stakeholders and how they are related, (3) activities that describe the eutrophication related issues, problems and concerns, (4) activities that project how the eutrophication status might change in future, (5) activities to prioritise eutrophication management strategies, and (6) activities relating to the monitoring and auditing of implementing management options.

2 INTRODUCTION TO EUTROPHICATION

2.1 Introduction and problem statement

This section is a brief introduction to the key concepts of eutrophication. More comprehensive descriptions of eutrophication are available and the reader is encouraged to carefully read the appropriate sections in Walmsley (2000, 2003) and DWAF (2002) for a more comprehensive introduction to the eutrophication situation in South Africa, as well as Harding and Paxton (2001) for a review of cyanobacteria in South Africa.

Eutrophication is a process whereby water bodies become progressively enriched with the plant nutrients, nitrogen and phosphorus. The process occurs naturally, over geological time, or may be accelerated due to allochothonous anthropogenic impacts, often termed 'cultural' eutrophication. Phosphorus, and to a lesser degree, nitrogen, have been identified as the major causes of eutrophication in surface waters (e.g. Rast and Thornton, 1996). Concentrations of total nitrogen, phosphorus, *chlorophyll-a*, together with values for optical (Secchi) transparency, have been grouped into a trophic classification system from oligotrophic, or nutrient-poor, to hypertrophic or excessively nutrient-enriched (OECD, 1982; **Table 1**). Terms to describe the state of enrichment are (Rast and Thornton, 1996, Walmsley, 2000):

- **Oligotrophic** indicating the presence of low levels of nutrients and no water quality problems,
- **Mesotrophic** indicating intermediate levels of nutrients, with emerging signs of water quality problems,
- **Eutrophic** indicating high levels of nutrients and an increasing frequency of water quality problems, and
- **Hypertrophic** indicating excessive levels where plant production is governed by physical factors. Water quality problems are almost continuous.

Table 1 OECD boundary values for open trophic classification system (annual mean values) (from Ryding and Rast, 1989)

Parameter	Statistic	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Total	mean (x)	8.0	26.7	84.4	-
Phosphorus	x + 1 SD	4.85-13.3	14.5-49	48-189	-
µg P $litre^{-1}$	x + 2 SD	2.9-22.1	7.9-90.8	16.8-424	-
	Range	3.0-17.7	10.9-95.6	16.2-386	75-1200
	n	21	19	71	2
Total	mean (x)	661	753	1875	-
Nitrogen	x + 1 SD	371-1180	185-1170	861-4081	-
µg N $litre^{-1}$	x + 2 SD	208-2103	313-1816	395-8913	-
	Range	307-1630	361-1387	393-6100	-
	n	11	8	37	
Chlorophyll-a	mean (x)	1.7	4.7	14.3	-
µg $litre^{-1}$	x + 1 SD	0.8-3.4	30.-7.4	6.7-31	-
	x + 2 SD	0.4-7.1	1.9-11.6	3.1-66	-
	Range	0.3-4.5	3.0-11	2.7-78	100-150
	n	22	16	70	2
Chlorophyll-a	mean (x)	4.2	16.1	42.6	-
peak value	x + 1 SD	2.6-7.6	8.9-29	16.9-107	-
µg $litre^{-1}$	x + 2 SD	1.5-13	4.9-52.5	6.7-270	-
	Range	1.3-10.6	4.9-49.5	9.5-275	-
	n	16	12	46	-
Secchi	mean (x)	9.9	4.2	2.45	-
depth, m	x + 1 SD	5.9-16.5	2.4-7.4	1.5-4.0	-
	x + 2 SD	3.6-27.5	1.4-13	0.9-6.7	-
	Range	5.4-28.3	1.5-8.1	0.8-7.0	0.4-0.5
	n	13	20	70	2

x = geometric mean, SD = standard deviation

The process of cultural pollution, or eutrophication, is no stranger to Africa. Some of the largest Central African lakes have been subject to anthropogenic impacts for some time, with the result that their ecological functioning and floral and faunal balances have become grossly disturbed (Marshall, 1997). Artisanal fishermen have abandoned Nigerian coastal lagoons for similar reasons (Ajao, 1994). The easily visible consequences of this, for example the spread of water hyacinth and the increasing incidence of cyanobacterial blooms, are all too apparent across the length and breadth of the continent (e.g. Ajao, 1994). During the past few years these noxious invasives have even spread to the acid, humic waters of the south-western tip of Africa, resulting in stock losses and disruption of the cage aquaculture of trout (e.g. Harding *et al*., 1995). Although there is little documented evidence, it is nevertheless clear that increasing levels of phosphorus are instrumental to the observed changes in trophic state of many of the surface waters of the African continent. In addition, the problem of nutrient enrichment is compounded by chemical and other pollutants, and/or the application of environmentally-unsound fishing practices (Van der Mheen, 1997).

The typical and immediately-apparent consequence of nutrient enrichment manifests as increased algal development and productivity. This phenomenon, in itself, can result in enhanced fish catches. Indeed the vast, man-made fish ponds of Eastern European countries such as the Czech Republic are purposefully-fertilized for this reason. However, progressive enrichment, and the exceedence of the ability of a waterbody to assimilate the primary pollution load, more often than not results in dominance of the phytoplankton assemblage by Cyanobacteria, or an increased incidence of algal population collapse and fish kills. Furthermore, and as the composition of the algal assemblage changes, the transfer of energy to higher levels within the aquatic food web is reduced or impaired.

Nutrient characteristics of shallow reservoirs

The nutrient dynamics in deep and shallow reservoirs (or lakes) are quite different (**Figure 1**) (Cooke *et al*., 2002).

In **deep lakes** (or reservoirs), the bulk of the nutrient rich sediments remain in the deepest portion of the lake. Nutrient cycling is limited to the upper water layers and macrophytes and bottom growing plants are limited to the small shallow areas of the dam or lake. The clear water of the dam is maintained by predatory fish (piscivores) keeping the numbers of the fish that feed on zooplankton low. Zooplankton feed on algae and this keeps the algal concentrations down.

In **shallow lakes** (or reservoirs) water is mixed throughout the water column and nutrients are easily mobilised from the sediments. This is referred to as internal loading. If sufficient macrophytes and submerged water plants are present, sediment re-suspension by wind action or by bottom-feeding fish (benthivores) is limited. Water plants support an abundant number of piscivores who in turn control the bottom and algal feeding fish. Zooplankton thrives by keeping the suspended algae low. Water is generally clear and plant and animal diversity is high.

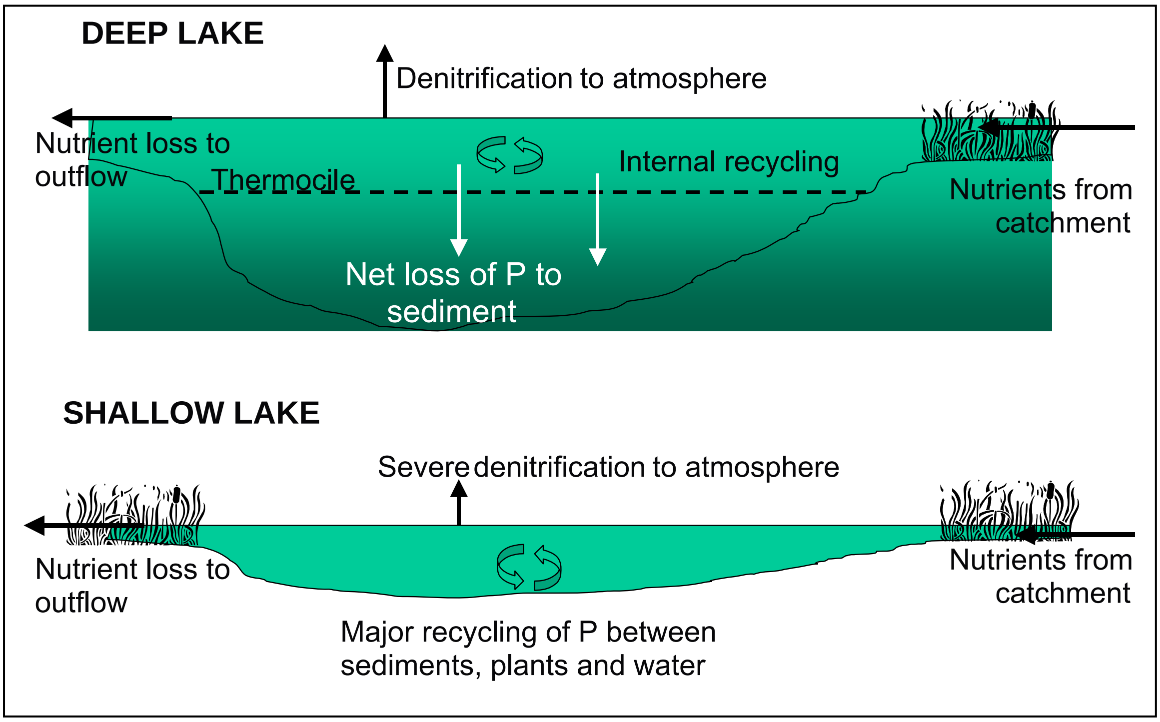


Figure 1 Differences in the nutrient dynamics of deep and shallow lakes

However, if enough nutrients and suspended sediment enters a shallow lake, suspended algae or turbidity may increase to a point where the lack of light in the deeper water could kill submerged water plants. Under these conditions, piscivores would be limited leaving planktivores and benthivores to thrive, resulting in a mechanism that reinforces high turbidity by high algal growth and by stirring of the sediment. Internal loadings become high and course fish (carp and other bottom feeders) and waterfowl lured by the open landscape surrounding a shallow lake, add to the problem. In the absence of rooted water plants, shoreline erosion and erosion of the reservoir bottom by wind or boat action helps to maintain the turbid state and high internal loadings.

Based on these observations, a theory was developed that shallow lakes and reservoirs can exist in two alternative stable states (see **Figure 2**) (Hosper, 1998, Moss, 1998, 2003).

The hypothesis of the alternative states model is that shallow lakes can exist, over a wide range of phosphorus concentrations, in either of two states, a plant-dominated clear-water system or an algal-dominated turbid-state. A change from a plant-dominated system to an algal-dominated system requires a switch such as the removal of water plants or the introduction of highly turbid inflow. The switch works better if it coincides with an increase in nutrient enrichment. The switch back to a clear water plant-dominated system is usually accomplished through biomanipulation and works well if it coincides with a reduction in nutrient concentrations.

There are also buffer mechanisms that maintain the stable state (Hosper, 1998). For example, a stable turbid state is often maintained by wind-induced re-suspension of sediment in plant-free lakes or reservoirs and by fish induced re-suspension of sediments by bottom feeding fish (benthivores), unhindered by plants. A forward switch to a clear-water stable state could be induced by maintaining a greater water depth to reduce wind exposure of bottom sediments, or by complete drawdown of the water level and consequent drying of exposed sediments, or possibly by reducing the population of bottom feeding fish. Hosper (1998) lists in greater detail the stable states, the buffer mechanisms and switches between the two states.

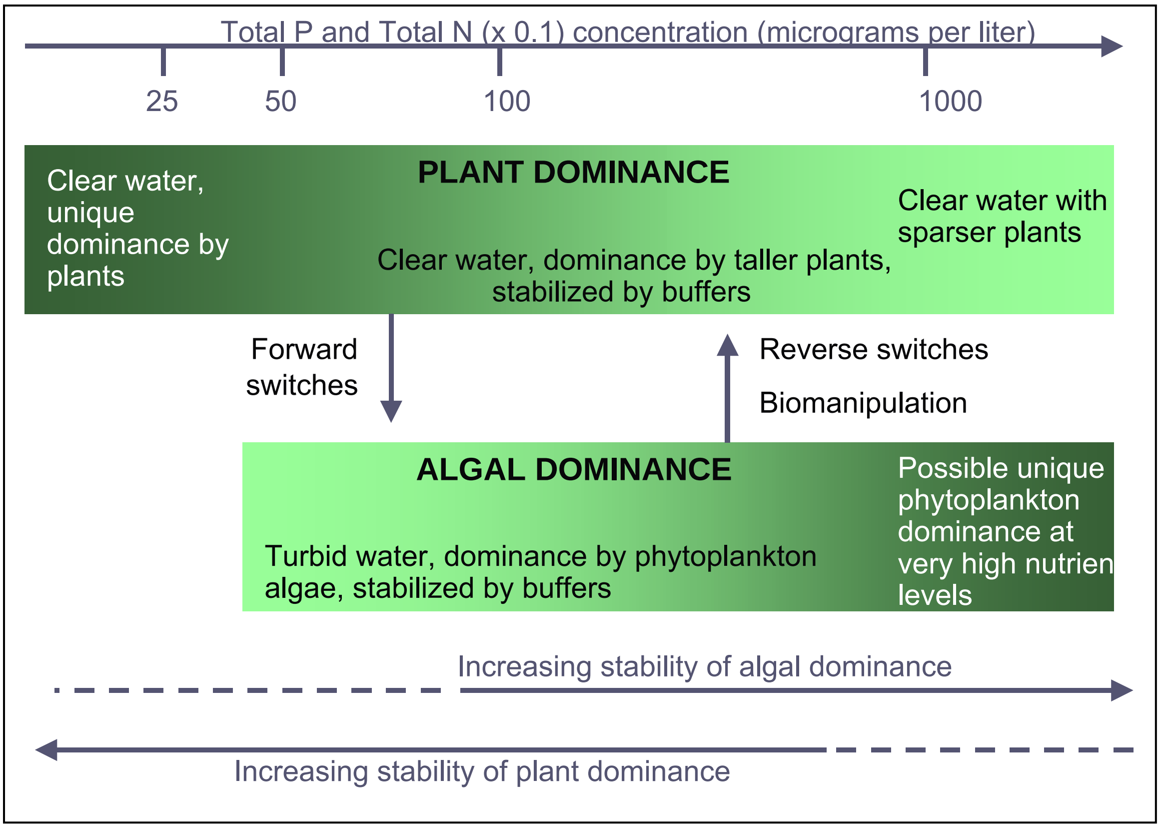


Figure 2 The alternative states model that summarises the current understanding of shallow lakes

2.2 Eutrophication status and trends in South Africa

Eutrophication, as a serious water quality problem, was first brought to the attention of water resource managers in the 1970s and since then it has been listed amongst the top three water quality problems in the country.

The 1970s – In the 1970s, research by the National Institute for Water Research (NIWR) resulted in the publication of the first review of eutrophication and initial guidelines for its control (Toerien, 1977). This was followed by an investigation into eutrophication problems in several South African reservoirs. This research resulted in a second report providing guidelines for the control of eutrophication in South Africa (Walmsley and Butty, 1980).

The 1980s – As part of the work of Walmsley and Butty, an important concept dealing with the impact of eutrophication, namely that of nuisance conditions varying in severity and frequency, was developed (Walmsley, 1984). These reports formed the basis of a decision by the Department of Water Affairs and Forestry in 1984 to implement a special phosphorus standard on effluent discharged into sensitive catchments (Taylor *et al*., 1984). A special 1 mg P/L standard was selected after an assessment of the technical and economic feasibility of phosphate removal technology available at the time the standard was promulgated. The introduction of the 1 mg P/L standard was criticised because the differences in phosphate assimilative capacity of reservoirs were ignored and in some catchments, the non-point source contribution to the phosphate load were equal to or greater than point source loads. These concerns led to projects by Grobler and Silberbauer (1984) and Rossouw (1990) to assess the impact of eutrophication control strategies on the trophic response of reservoirs in the sensitive catchments. In the 1980s the comprehensive study of Hartbeespoort Dam was undertaken by NIWR which furthered limnological research in South Africa (for example NIWR, 1985, Chutter and Rossouw, 1992).

The 1990s – After the termination of the Hartbeespoort Dam study and assessment of the special P standard, eutrophication was given a low status by government (Walmsley, 2000). DWAF initiated the trophic status project to monitor the impact of the 1 mg P/L standard on about 48 reservoirs and lakes (van Ginkel *et al*., 2000) but Walmsley (2000) felt that there was little effort to review eutrophication policy in the light of the monitoring results and that the country regressed in terms of its capacity and ability to deal with eutrophication (Moss, 1999).

2000 to present – Since 2000, eutrophication management has received considerable attention by DWAF supported by initiatives from the WRC. The interest in eutrophication management and research was revived with the publication of the WRC report on eutrophication related policy and research needs in South Africa (Walmsley, 2000). During this time, the National Eutrophication Monitoring Programme (NEMP) was designed in a joint initiative between DWAF and the WRC. NEMP was initiated with the publication of the Implementation Manual in 2002 (DWAF, 2002), and the directorate Resource Quality Services took on the responsibility of implementing the programme. This programme has been operational since then and is yielding data and information on the eutrophication status of a large number of water bodies in South Africa. The Department also recognised the need to develop a strategy and supporting policies to manage eutrophication and the first phase of a project to develop a strategy to control eutrophication in South Africa was completed in 2003 (Walmsley, 2003).

This project, development of an eutrophication assessment guide, builds on the initiatives that were undertaken between the WRC and DWAF in the late 1990s and early in 2000.

2.3 Causes of Eutrophication

Eutrophication is caused by an over-supply of nutrients to a waterbody, also referred to as nutrient enrichment (refer
Figure 3). A distinction is made between 'natural' and 'cultural' eutrophication. Natural eutrophication is related to the natural ageing of a lake or waterbody and depends on the geology and natural characteristics of its catchment. Cultural eutrophication refers to man-made activities that accelerate the eutrophication process. In most South Africa reservoirs, the causes of eutrophication can be traced to cultural eutrophication, i.e. man-made activities that lead to nutrient enrichment. Nutrient enrichment can originate from point sources such as discharges from wastewater treatment plants, and from non-point sources such as the wash-off of nutrients from fertilised agricultural lands.

Nutrients can also be released from in-lake sources, a process referred to as internal loading. The rate at which nutrients are released from the bottom sediments depend on a number of physical processes (re-suspension, mixing, bottom feeding fish, etc.) and chemical processes (e.g. low dissolved oxygen concentrations).

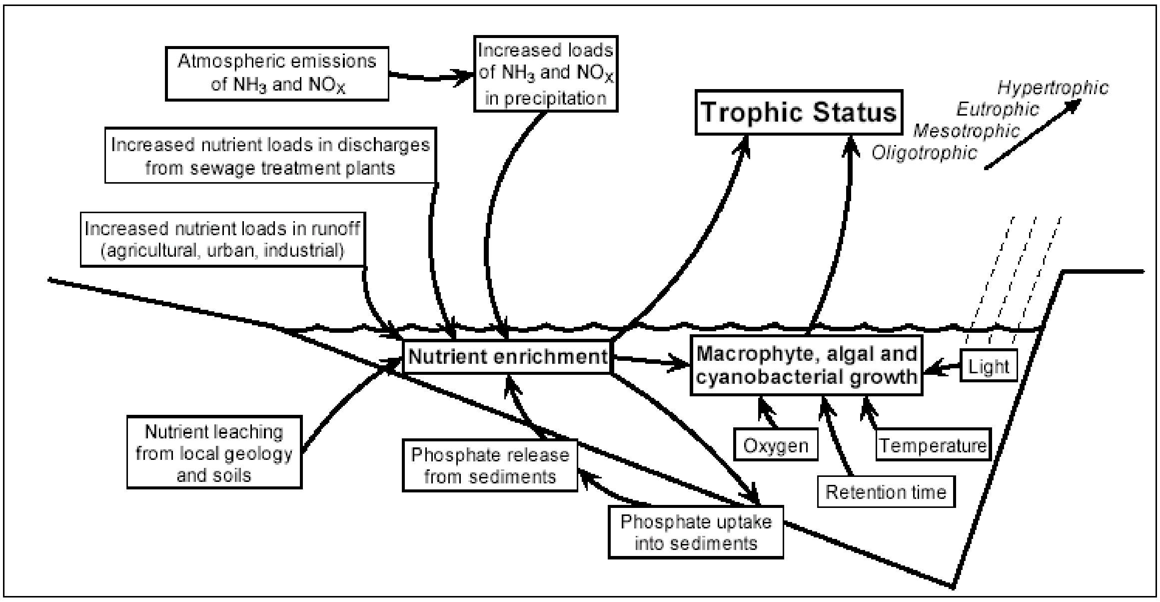


Figure 3 Diagram showing the main causes of eutrophication (from DWAF, 2002)

2.4 Impacts and consequences of Eutrophication

Nutrient enrichment causes numerous problems and they can be long- or short-term (Walmsley, 2000). These include (see Figure 4):

- Increased occurrence and intensity of nuisance algal blooms that in turn affects the treatment of the water for domestic water supplies and blocks irrigation equipment.
- An increasing dominance by cyanobacteria that sometimes result in unsightly and stinking algal scums in embayments of a reservoir.
- Increased occurrence of toxic algae that poses a health risk to domestic users and stock watering.
- Clogging of reticulation systems such as irrigation canals and dams by filamentous benthic algae.
- Increased occurrence of floating and rooted aquatic macrophytes such as water hyacinth, duckweed, red water fern, etc.
- Increased occurrence of taste and odour problems in drinking water due to the release of compounds such as geosmin during the treatment process.
- Increased occurrence of deoxygenation in bottom waters with associated chemical effects (formation of hydrogen sulphide and elevated levels of heavy metals in bottom waters).
- Changes to ecological community structure and loss of biodiversity.
- Increased water treatment costs through filter clogging in water treatment works and the need to include facilities to remove tastes and odours.
- Increased interference in recreation activities (boating, fishing, swimming).
- Increased occurrence of human health problems for contact recreation users (gastroenteritis, skin rashes).
- Loss of value of shorefront properties.
- Interference with irrigation and livestock agriculture (e.g. clogging of irrigation equipment/canals, mortality of stock).

- Undesirable aesthetic conditions (e.g. higher turbidity, foam, discolouration of the water, undesirable odours).

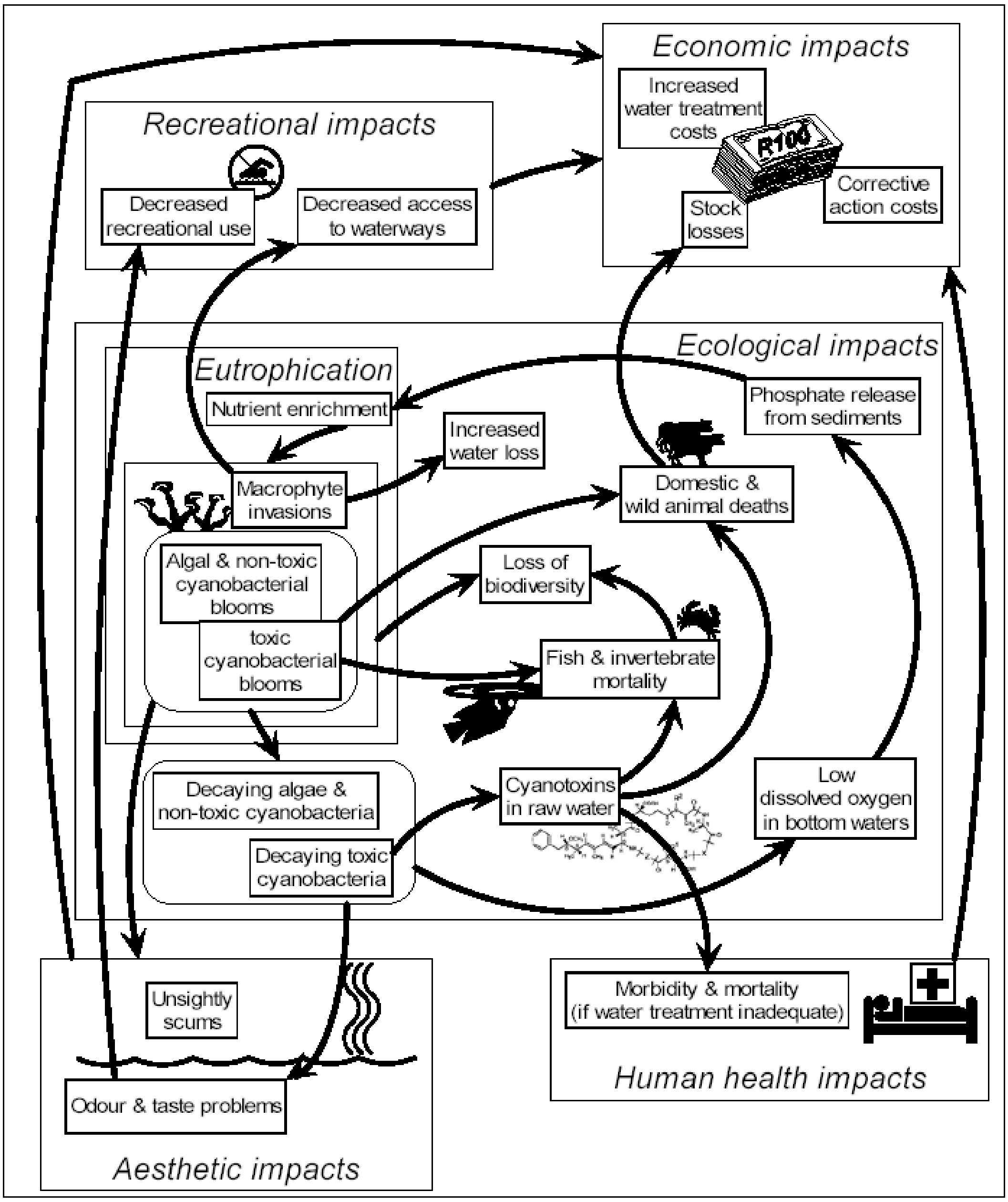


Figure 4 Diagram showing some of the negative impacts of eutrophication (DWAF, 2002)

2.5 Options to manage Eutrophication

The effective control of eutrophication in a waterbody is strongly linked to the control of the causes of eutrophication. Based on the limiting nutrient concept, most long-term eutrophication control measures are aimed at reducing the external loads of nutrients to a water body. In certain situations the reduction of external loads may not be feasible or cannot be reduced to sufficiently low levels to have the desired effect. In these cases, control programmes target the symptoms of eutrophication even though these do not eliminate the basic problem of nutrient enrichment (Ryding and Rast, 1989; Walmsley, 2000).

Measures to control the **external nutrient loads** include:

- Modification of products containing high levels of N and P to minimise nutrient inputs to the catchment, such as the replacement of phosphate-based detergents in the domestic and industrial cleaning sectors.
- Control of the load of nutrients discharged from wastewater treatment works by setting standards for N and P emissions.
- Control of non-point sources of nutrients in the catchment. The main source of non-point source of nutrients is agriculture and a change in agricultural practices and fertiliser application may be required to achieve the desirable reductions.
- Treatment of tributary influent water by means of in-stream removal techniques. These include passive or active treatment of inflows to a reservoir to reduce the nutrient loads or diversion of inflows with high nutrient concentrations.

In-lake management techniques to reduce the internal loads of nutrients to a water body include:

- Nutrient inactivation to bind nutrients to the sediments and allow them to settle out with the sediment.
- Selective discharge levels to withdraw nutrient rich bottom water.
- Aeration of the hipolimnion to reduce the release of nutrients from the bottom sediment.
- Sealing of the lake bottom with an agent like bentonite to prevent nutrient release from the bottom sediments.
- Manipulation of the food chain to, for example, remove bottom-feeding fish from the reservoir.
- Use of chemicals to control nuisance algal blooms or invasive plant growth.
- Dredging of the nutrient rich sediments and disposal of them outside of the reservoir basin.

Measures to control the symptoms of eutrophication are often short-term or emergency options. These include:

- Use of chemicals such as ferric sulphate to control algal blooms.
- Physical barriers such as floating screens to contain algal blooms or nuisance plants in a restricted area.
- For the treatment of eutrophied water for domestic water supplies, technologies such as dissolved air floatation and activated carbon are often included in the design of treatment plants.

3 INTRODUCTION TO CATCHMENT EUTROPHICATION ASSESSMENT

3.1 Introduction to catchment management

This section provides a brief introduction to the context within which a catchment eutrophication assessment study would be undertaken. For a more detailed description of catchment water quality management, the reader is encouraged to examine the following three documents that describes the water quality component of a catchment management strategy:

- A Conceptual Introduction to the Nature and Content of the Water Quality Management and Assessment Components of a Catchment Management Strategy (DWAF, 2003a)
- A Guideline to the Water Quality Component of a Catchment Management Strategy (DWAF, 2003b), and
- A Guide to conduct Water Quality Catchment Assessment Studies (Part 1 of the document) (DWAF, 2003c).

The reform of water resource management in South Africa that resulted in the National Water Act (Act No. 36 of 1998) were founded on a number of ***over-arching policy principles***. These policy principles also underlie the approach to water resource management on a catchment basis, and include:

- A requirement to ensure sustainable use of water resources,
- The equitable use of the resource for the "optimum social and economic benefit" of the country,
- A need for a transparent and participative approach to water resources management, and
- The redress of inequitable access to water resources caused by past policies.

The ***process of Catchment Management*** generally involves the following, often overlapping and iterative, stages (Görgens *et al.,* 1998):

- *Initiation*: of the catchment management process, triggered by one or more water-environment related issues;
- *Assessment*: to provide understanding of the water, social, economic and institutional environments;
- *Planning*: for catchment management in that area, resulting in a catchment management strategy;
- *Implementation*: of the actions and procedures detailed in catchment management strategy;
- *Administration:* of the catchment in terms of the catchment management strategy, including fine-tuning;
- *Monitoring*: and processing of data and information collected in the catchment; and
- *Auditing*: of catchment management against performance indicators, and regular review of the strategy.

Section 9 of the National Water Act (Act 36 of 1998) describes the requirements of a ***Catchment Management Strategy***. By reordering and paraphrasing Section 9, the requirements could read as follows:

Given the...:

- *Requirements and constraints of the national water resources strategy (Section 9b);*
- *Requirements of the water resources management class, resource quality objectives, the Reserve and international obligations (Section 9a);*

And considering the...:

- *Natural and anthropogenic character of a WMA, i.e. geology, land-use, etc (Section 9d);*
- *National and regional plans, including water services development plans (Section 9f);*
- *Needs and expectations of existing and future water users (Section 9h);*

The Catchment Management Strategy must set out the...:

- *Strategies, objectives, plans, guidelines and procedures of the CMA (Section 9c);*
- *Allocation plan, reflecting the principles for authorising water use (Section 9e);*
- *Institutions to be established (Section 9i);*

To enable the...:

- *Public to participate in managing water resources in their WMA (Section 9g);*

For water resource...:

- *Protection, use, development, conservation, management and control (Section 9c).*

These six requirements represent the main purpose of catchment management and are discussed in greater detail in DWAF (2003b).

A **framework for the water quality component** of a catchment management strategy was developed in DWAF (2003b). The framework recognises that a minimum level of protection is required to protect the resource, to meet basic human needs, and to meet the requirements of strategically important water users. Over and above these requirements, there is the need by stakeholders to use water resources and the framework describes four iterative and incremental steps to develop a catchment water quality management strategy and its component parts (DWAF, 2003b):

- Establish *resource water quality objectives* for use of the resource to dispose of water containing waste, based on the needs expressed by the stakeholders.
- Determine *source management objectives* to meet these needs.
- Formulate a WMA-wide *water quality management framework-plan* that indicates the management priorities, requirements, CMS linkages, sectoral responsibilities and programme to achieve these objectives.
- Develop individual *water quality management implementation plans*, which may be source-, issue- or sector-specific, or even, multi-sectoral, to give effect to the water quality management framework-plan.

This framework is supported by a catchment assessment study (CAS).

3.2 Introduction to catchment assessment studies

A Catchment Assessment Study (CAS) deals with water-related natural resources in a catchment, with human impacts on those resources, and with human needs regarding those resources (DWAF, 2003c). In more formal terms it can be stated that:

> a ***Catchment Assessment Study*** is the systematic assembly and processing of appropriate data and information, to yield a knowledge system, including predictive tools/models, with regard to all water-relevant physical, developmental and administrative attributes and characteristics and in consideration of all water-related issues and problems, to be used in integrated water resources management (IWRM) in a catchment.

The water quality component of a CAS therefore deals with the water quality characteristics of a catchment, with the human impact on water quality and with human needs regarding the water quality of the resources. The DWAF guide to conduct water quality assessment studies (DWAF, 2003c) was developed to help water quality specialists to undertake the catchment water quality assessment in a systematic way and to develop integrated water quality management strategies to address water quality related problems.

3.3 Eutrophication assessment as a component of a catchment assessment study

One of the key water quality problems experienced in South Africa is the effect of nutrient enrichment or eutrophication. This guide was designed to provide specific guidance to water quality specialists in undertaking a systematic catchment water quality assessment specifically related to eutrophication and its impacts and in developing catchment-scale eutrophication management strategies to address problems caused by nutrient enrichment.

The scale, timing and depth of the study are flexible, to adapt to the situation being investigated. A catchment scale eutrophication assessment study can generically be partitioned into two distinct phases, where:

- the first phase is about describing and understanding the catchment, and
- the second phase is about providing decision-support for catchment management.

In a catchment eutrophication assessment study, some of the components or sub-tasks (**Section 4**) relate to describing and understanding the eutrophication characteristics of the study area, while others are associated with support for decision-making and strategy development. However, in some tasks, short to medium actions can already be identified that can be implemented immediately to address specific eutrophication problems that require urgent attention. Little additional understanding is required to implement these corrective actions.

Some tasks, for example **Component 9** – "Configured and calibrated eutrophication models", can be undertaken at a coarse scale to understand the key management options to be undertaken. However, when developing action plans at a later stage to support decision-making, a more detailed model may be required to apportion loads between individual sources.

3.4 Eutrophication assessment as a discrete study

Eutrophication assessments are often undertaken as stand-alone projects without considering all the other water quality issues in a study area. These projects are often undertaken at a sub-catchment scale because eutrophication may be the dominant concern. This guide also provides guidance for the systematic assembly and processing of appropriate data and information for such a discrete study. The water quality specialist can select which components are important for a specific study and decide on the spatial and temporal extent at which these components should be investigated.

4 INTRODUCTION TO CATCHMENT-SCALE EUTROPHICATION ASSESSMENT GUIDE (PART 2 OF THIS DOCUMENT)

4.1 Introduction

Part 2 of this document was designed to mirror the key features of the DWAF *Catchment Water Quality Assessment Guide* document. This approach was adopted to ensure that the outputs of eutrophication assessment studies are compatible with the overall water quality assessment objectives of a catchment assessment study. The purpose was not to duplicate the text that appeared in the DWAF water quality assessment guide but to provide sufficient content and information from the DWAF document so that the eutrophication assessment components could be integrated seamlessly in a water quality assessment study if it was required.

The layout and components of **Part 2** of the guide mirrors the layout of the *Catchment Water Quality Assessment Guide* (DWAF, 2003b) to enable a user of the Guide to switch and cross-reference between the two documents. This document does not replicate the text that appears in the *Assessment Guide* (DWAF, 2003b) but provides more detail for the eutrophication part of an assessment. This document therefore needs to be read in conjunction with the *Catchment Water Quality Assessment Guide* (DWAF, 2003b), especially when undertaking catchment scale studies.

4.2 Primary management questions and assessment tasks

The primary building blocks of **Part 2** of this document (the step-by-step guide) are six generic questions about the eutrophication related water quality status in a catchment or the study area. This concept is illustrated on the right. See **Table 1** for the full text of the questions. For each question, an assessment task is formulated to answer the question. Each primary task is then sub-divided into a number of sub-tasks or output components that need to be completed in order to satisfy the requirements of the task.

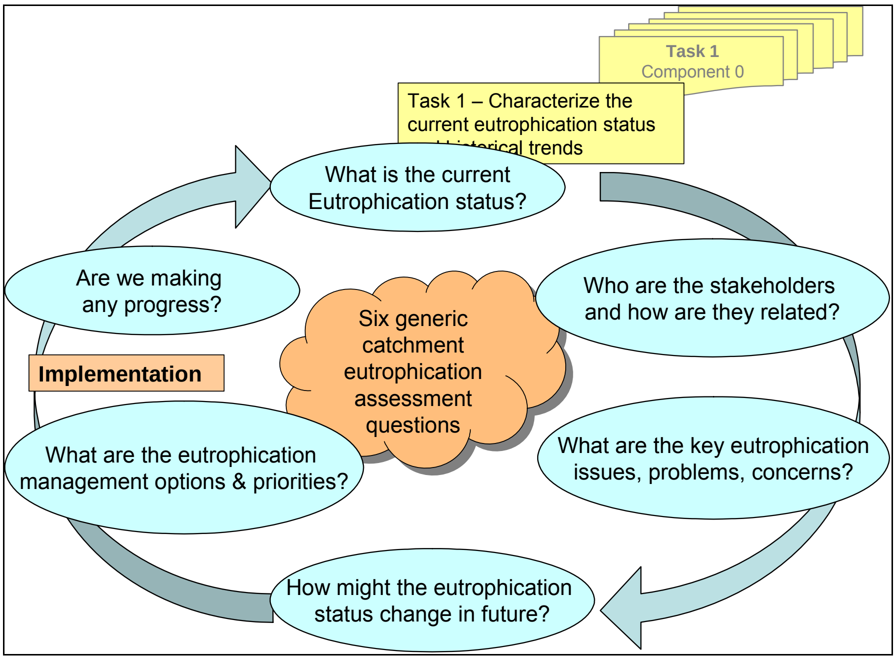


Figure 5 **This Guide is designed to answer six generic questions about eutrophication in a catchment. Each question has an associated task and sub-tasks to gather the required information**

A Catchment scale eutrophication assessment study can generically be partitioned into two distinct phases (as is the case for a generic catchment water quality assessment study), where:

- the first phase is about "describing and understanding the catchment", and
- the second phase is about "providing decision-support for catchment management".

Phase One: Describing and understanding the eutrophication status of the catchment is about providing answers for the following questions:

- What is the eutrophication-related status of the study area and how did it get to this point?
- Who are the eutrophication-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?
- What are the study area's eutrophication-related issues, concerns, problems and opportunities?
- Where might the eutrophication-related status of the study area be heading in the future?

It also supports the *eutrophication management strategy* process by providing answers to the following two questions:

- "What are the goals for eutrophication management?" – Resource Water Quality Objectives, and
- "How must nutrient loads change to achieve the goals?" (partly) – Source Management Objectives.

Phase Two: Supporting catchment management decision-making is about providing answers for the following two questions:

- What are the appropriate priority eutrophication management options?
- Has catchment management achieved its objectives?

It also supports the eutrophication management strategy process by providing answers to:

- "How must nutrient loads change to achieve the goals?" (rest of) – Source Management Objectives, and
- "How will this be managed across the WMA?" – Water Quality Management Framework-Plan
- "How, where, by whom and when will this be implemented?" – Water Quality Management Implementation Plans.

In a catchment eutrophication assessment study, some of the components have elements in Phase 1 and in Phase 2 due to the iterative nature of assessment studies. The early tasks clearly have to do with describing and understanding the eutrophication characteristics of the study area. The later tasks clearly have to do with the supporting decision-making and strategy development. However, in some tasks, short to medium actions can already be identified that can be implemented to address eutrophication problems that require urgent attention and for which actions are clearly evident. Little additional understanding is required to implement these corrective actions.

Table 2 Major components of the Eutrophication Assessment Guide document (Part 2 of this document)

Component	*Eutrophication Management Question 1:* **What is the eutrophication status of the study area and how did it get to this point?** *Eutrophication Assessment Task 1:* **Characterisation of the current eutrophication status and historical trends**
0	Inception summary of existing understanding, knowledge and past studies with regard to eutrophication related water quality in the catchment
1	Details of natural, developmental and administrative attributes and characteristics of the catchment relevant to the assessment of the eutrophication status
2	Requirements of the National Water Resource Strategy and Resource Directed Measures with regard to nutrient management
3	Water use and conservation related to eutrophication assessment
4	Overview of adequacy of water availability
5	User water quality requirements and constituents of concern relating to eutrophication
6	Eutrophication related water quality of streamflow, reservoirs, estuaries, wetlands and groundwater
7	Point source waste discharges and source characteristics relating to eutrophication
8	Non-point source water quality loadings and impacts relating to eutrophication
9	Configured and calibrated predictive tools/models with regard to eutrophication related water quality
10	Reconciliation: catchment nutrient sources and eutrophication related water quality patterns
11	Status Reports on eutrophication monitoring, physical data and characterisation information
	Eutrophication Management Question 2: **Who are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages, and roles?** *Eutrophication Assessment Task 2:* **Engagement of water-related institutions and stakeholders in CAS process**
12	Stakeholder details and participation processes
13	Water-interest institutional arrangements and linkages
	Eutrophication Management Question 3: **What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?** *Eutrophication Assessment Task 3:* **Formulate and record eutrophication related water quality issues, concerns, problems, and opportunities**
14	Record of eutrophication related water quality issues and their origins
15	Catchment management implications of eutrophication related water quality issues
16	Vision (or long-term resource objectives) for eutrophication related water quality

	Eutrophication Management Question 4: ***Where the eutrophication related water quality status of the study area might be heading in the future?*** *Eutrophication Assessment Task 4:* ***Projection of eutrophication related water quality impacts of future water-related development scenarios***
17	National and regional plans and projections of future water demands and catchment development
18	Predicted future eutrophication related water quality at sites of management focus
	Eutrophication Management Question 5: **What are the appropriate (priority) eutrophication management options?** *Eutrophication Assessment Task 5:* **Formulate and prioritise eutrophication management options**
19	Eutrophication related management units and assessment spatial and temporal resolution
20	Prioritised eutrophication management options
	Eutrophication Management Question 6: **Has eutrophication management strategies achieved its objectives?** *Eutrophication Assessment Task 6:* **Monitoring and auditing of implementation of eutrophication management strategies**
21	Monitoring and auditing assessment of eutrophication management strategies

Each of the above components has eight sub-sections:

- The title of the component
- An overview of the context and purpose of the component. Links with other components are listed here
- A description of the outputs to be produced and how this can be attained
- A more detailed description of methods or tools that are available to produce the output
- A description of possible sources of information
- Checklists or reminders that can be consulted in the preparation of the outputs
- Some options on how the output results can be displayed
- A bibliography of references referred to in the component

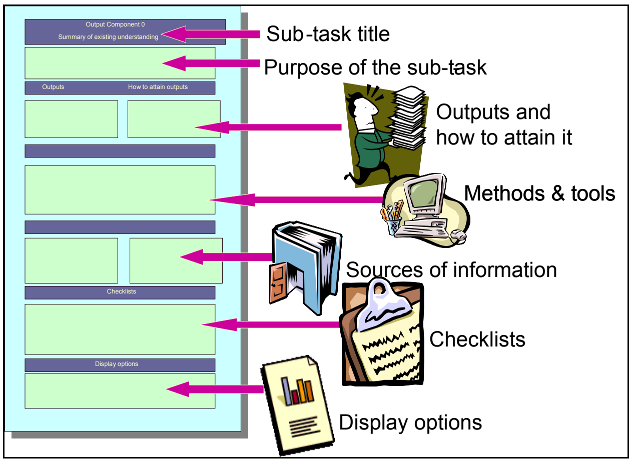


Figure 6 Generic layout of each study component

Some of the components have been modified very little from what appears in the DWAF assessment guide and only key concepts were repeated in the eutrophication assessment guide. This is because they *inform* the process of developing a catchment management strategy and are not specific to the type of problem under investigation. For example, **Components 12** and **13** deal with stakeholder details and institutional arrangements and these Components are generic to the development of catchment management strategies and largely independent of the type of water quality problem. Other Components were developed quite extensively, i.e. **Component 15** – Catchment management implications of eutrophication relating to water quality issues.

5 NUTRIENT ENRICHMENT ASSESSMENT PROTOCOL (NEAP)

5.1 What is NEAP?

NEAP is an internet-based phosphorus (P)-based nutrient loading tool for lakes and/or impoundments (= reservoirs) which, depending on the level of information entered, allows the user to select one or more outputs that describe, for example, the P-loading generated by the catchment, the trophic condition of the lake, and the lake's likely response to a change (increase or reduction) in phosphorus (P) loading (http://www.dhec.co.za/neap\).

NEAP is based on a range of existing phosphorus load: response relationships. Insofar as is possible, using available information, NEAP V1.0 has been calibrated for use under South African conditions, and in particular for use in reservoirs as opposed to lakes.

5.2 The NEAP Development philosophy

NEAP has been purposefully designed as a simple, phosphorus-based, eutrophication screening tool. As such, it provides a non-data intensive means of determining the trophic status (degree of nutrient enrichment) of lacustrine environments. Once calibrated, it allows the user to determine the manner in which the annual mean concentration of phosphorus is likely to change in response to an increase or decrease in the loading of this element. Such determinations can be made with NEAP at a high (70%) level of confidence.

In most cases, the calibration of dynamic models is severely limited by the availability of data, or the quality thereof. Increasing model complexity also often renders the model lake-specific. The purpose of a screening tool, such as NEAP, is to provide management-related answers without having to resort to an extended period of data collection. In many cases, simple models such as NEAP target the key drivers that are essential for first-level appreciations. The underlying philosophy with NEAP has been to provide a fast and simple to use approximation of the level of eutrophication in a particular reservoir, and to inform options for management. Should more detailed examinations be required thereafter, more complex models can be employed as the required data becomes available.

It is intended that subsequent releases of NEAP will incorporate a level of functionality that will support the integration of biogeochemical processes (fate and loss relationships), as well as refinements such as the inclusion of aquaculture impacts. Importantly, later versions will be able to include support for assessing 'virtual' nutrient load reductions relating to management approaches targeting 'top-down' foodweb manipulation. In the case of Hartbeespoort Dam, restructuring of the fishery is estimated to bring about a change in conditions equivalent to a reduction of some 25-40% in external phosphorus loading.

5.3 What is nutrient enrichment?

Nutrient enrichment, commonly known as eutrophication, is simply an oversupply (= in excess of natural) of plant nutrients into an environment such that the growth of certain plants, typically phytoplankton but also reeds and floating species such as water hyacinth, becomes excessive, or 'weedy'. The process, apparent since the 1950s, frequently encompasses a decline in ecosystem health and biodiversity and increasing dominance by undesirable species of flora, typically cyanobacteria (= blue-green algae). In fact, most of the work relating to eutrophication has been in response to the development of noxious algal blooms posing major environmental and user (drinking water) problems.

Eutrophication is a global phenomenon now regarded as being the most significant water quality threat to both freshwater and marine resources.

Note: It is not the purpose of NEAP to provide a detailed background to eutrophication. Should the NEAP user wish to source further information on this topic it is recommended that Harding and Paxton (2001) and Walmsley (2000 and 2003) be consulted.

5.4 Why focus on phosphorus?

The principal elements associated with nutrient enrichment are phosphorus, nitrogen and, to a lesser degree, carbon. Oversupply of these elements is directly related to human (anthropogenic) activities. Of the three, phosphorus is the only element that may be directly attenuated through the management of land-use practices or point source controls. In the majority of cases, phosphorus is the key element that regulates primary production in lacustrine environments - i.e. there exists a direct relationship between the concentration of total phosphorus (TP) and the photosynthetic pigment *chlorophyll-a* (*Chl-a*). It is for these reasons that eutrophication management tools focus fundamentally on phosphorus.

5.5 Where does phosphorus come from?

5.5.1 Is nutrient enrichment the sole cause of eutrophication?

Absolutely not. Increased nutrient availability is but one component in a complex array of causal factors that ultimately present, in one way or another, as eutrophication. The often-singular focus on nutrient loading as the cause of eutrophication has more often than not led to the implementation of costly and unsuccessful management decisions.

An increase in trophic state is not only the product of a multivariate suite of biophysical (waterbody morphology, geology, retention time, water temperature, light, mixing, turbidity) and chemical (fluxes of micro- and macronutrients) factors, but crucially also a loss in the level of biostability that underpins the lake foodweb. The central implication of this is that ecologically-sound environments can exist, despite high levels of nutrient enrichment, but that once the structural stability is lost then the waterbody is likely to swing to one dominated almost solely by phytoplankton.

5.5.2 Trophic state

It should be clear from the foregoing that the concept of trophic state is a multi-variate, and encompasses both plant nutrients and foodweb stability and interactions. The use of trophic state definitions arose from a need to be able to classify lakes for management purposes. Two approaches have arisen, *viz*:

- The use of fixed-boundary conditions (e.g. those set by the OECD);
- The use of indices (e.g. the TSI approach developed by Carlson).

It is important to realize that trophic states exist along a continuum of conditions ranging from oligotrophic (poorly enriched with nutrients), through meso- (moderately enriched) and eutrophic (highly enriched) to hypertrophic (grossly enriched with nutrients). Accordingly, it must be accepted that there will be considerable overlap between these arbitrary conditions. It is acknowledged that the use of indices, while facilitating rapid relative comparison, excludes any measure of productivity (dynamics).

The most commonly used boundary descriptors of trophic state are those defined by the Organization for Economic Co-operation and Development (OECD) in their 1982 review of monitoring, assessment and control measures for enriched waters. With minor alterations these have been shown to be applicable to South African waters. The OECD Co-operative Programme on Eutrophication showed that:

- In the majority of cases, phosphorus determined the extent of eutrophication development;
- Even when another nutrient such as nitrogen was the limiting growth factor, phosphorus could still be successfully used as the limiting nutrient for management purposes.

With respect to the use of indices, NEAP has recognized that for any index to be useful, it has to be as simple as possible, i.e. it should be based on the fewest possible variables. In this regard, the log2-based approach used by Carlson has been employed. NEAP generates trophic state conditions that are comparable with the OECD boundaries, and a range of indices, based on the Carlson approach, that have been calibrated using known South African best (oligotrophic) and worst case (hypertrophic) conditions - for both shallow and deep systems. This affords NEAP users the opportunity to position their assessments against these extremes.

5.5.3 Lakes vs. reservoirs

With a single exception South Africa has no naturally formed lakes. All of our large bodies of freshwater are man-made bulk-storage reservoirs (dams or impoundments). South Africa has approximately 240 large dams, as well as thousands of smaller dams of various sizes.

Reservoirs differ fundamentally from lakes in that they are artificial, and typically lack many of the dynamic features associated with a naturally formed ecosystem. They are obviously much younger (historical vs. geological age) than reservoirs, and consequently may be expected to respond more rapidly than lakes to the pressures of eutrophication. Reservoirs occupy a position intermediate between rivers and lakes, and exhibit characteristics of both. Their character is determined by the degree of influence driven by the river, and the rate at which they are flushed through during each hydrological cycle.

As water enters a lake or reservoir, the structure of the system changes progressively from one that supports organisms suited to lotic (flowing) systems, to those adapted to lentic (standing) aquatic environments. Water quality changes occur as sedimentation takes place, and a greater propensity for eutrophication and the development of algae comes into play. It is important to note that different zones of an impoundment may display different eutrophication characteristics that are morphologically dependent.

In reservoirs, the ratio of inflow to storage capacity is greater than in lakes, consequently the amount of material transferred into dams or impoundments is disproportionately higher. This may be offset by a higher net flushing rate depending on the morphology of the dam. Shallow reservoirs do not benefit from sedimentation losses to deep water that prevail in deeper systems, and are prone to re-suspension of sediments by wind, current and cavitation forces. Accordingly, while water quality conditions generally improve from shallow to deeper waters in deep lakes, a more homogenous condition of poorer quality may be expected to prevail in shallower bodies of water.

5.6 What is NEAP's level of resolution?

NEAP is a First Level tool, with its central value in its simplicity. NEAP is an annual time-step (dT = 1 year) model, i.e. it requires the minimum level of data for all parameters. Notwithstanding this, the model is robust and allows for relatively rapid screening and classification of individual systems, as well as providing indications of how each assessed waterbody will respond to a change in phosphorus loading.

Once NEAP has been used to classify and rank systems, more sophisticated predictive tools, requiring monthly, weekly or daily data for a wide range of parameters may be employed, if a higher level of confidence, not otherwise obtainable from expert assessment, is required. Decisions to rehabilitate a lake or reservoir should not be made on the basis of NEAP alone, nor should higher level predictive modelling necessarily have to follow the use of NEAP. For this reason, a Risk Assessment component has been integrated into NEAP, providing an indication of the confidence with which the final output is made.

It should be noted that estimates of catchment nutrient loading can contain errors as high as 50% - therefore accuracy requires a comprehensive assessment process.

5.7 Introduction to the model base of NEAP

NEAP is a single layer, single variable (total phosphorus) empirical model that incorporates simple allowances for aspects that are essentially features of multi-layer models, for e.g. the very important need to include sediment loading sub-models. There is currently an absence of detailed information on internal loading in South African reservoirs, precluding the development of a more detailed sediment sub-model at this point in time.

Several single layer, single variable models have been developed to study the behaviour of phosphorus in hydrodynamically-different reservoirs. Internationally, the Vollenweider General Lake Model relationship provides the best generic starting point for modelling phosphorus in lakes (Vollenweider, 1975). Previously, work conducted on a limited number of South and southern-African reservoirs showed that the OECD-type models (OECD, 1982) provided the closest relationship between predicted and observed conditions (Walmsley and Thornton, 1984, Thornton and Harding, 2003). This study, which examined 12 models, confirmed that the OECD relationship for phosphorus loading provided a generic fit for South African conditions. However, a predominant characteristic of South African impoundments and shallow lake/vlei environments is a high rate of water exchange (low hydraulic retention times). A more detailed comparison of these models on specific reservoirs indicated that the use of the Walker Reservoir Model (Walker, 1985), a relationship derived for systems with high flushing rates, was more appropriate. Both models have been incorporated and NEAP makes the appropriate selection based on the lake flushing rate determined from the hydrological information that is entered.

NEAP is an annual, single time-step model, i.e. it produces outputs based on annual total or mean values for each parameter.

Models used in NEAP, compared with the Vollenweider General Lake Model:

1. Vollenweider General Lake Model

   $P = L_p / q_s (1 + T_w^{0.5})$

2. OECD (Combined Data Set)

   $P = 1.55([P\}_j / (1+ \sqrt{T_w}))^{0.82}$

3. Walker Reservoir Model

   $P = L*T_w (1\text{-}R) / z$

   $R = 1 + [1\text{-}(1 + 4Nr)^{0.5}] / 2Nr$

   $Nr = (K_2*L*T_w^2)/z$

   $K_2 = 0.17q_s / (q_s + 13.3)$

Where: P = average in-lake total phosphorus (mg ℓ^{-1})
$[P]_j$ = annual mean inflow of phosphorus (mg m^{-3})
L_p = annual total phosphorus areal loading (mg m^{-2} y^{-1})
q_s = annual areal water loading rate (m y^{-1})
T_w = hydraulic retention time, years
z = mean depth, m

5.8 Features of NEAP

NEAP V1.0 is a modular, web-based tool incorporating the following components:

1. A user login and registration module;
2. An "About NEAP" section that describes what NEAP can be used for;
3. A "How-to" section that provides a step-by-step explanation, supported by worked examples, of how NEAP can be used, and which allows the user to download a checklist of requirements that can be completed, and the correct units established, prior to entering data into NEAP;
4. Six calculation modules that allow the user to determine one or more of the following:

An estimation of the total phosphorus load back-calculated from the observed in-lake condition;

A phosphorus loading module that allows for the aggregation of phosphorus loads from multiple sources, and which outputs a predicted in-lake mean annual phosphorus concentration. This module includes allowance for internal loads from sediments to be added;

A *chlorophyll-a* prediction module – generating an annual mean and peak concentration for *chlorophyll-a* based on the calculated in-lake phosphorus concentration;

A trophic state prediction module, with output in two formats;

A load-reduction module that outputs the change in condition in response to a selected reduction in phosphorus loading;

A risk assessment, based on the concentration at which problematical levels of bloom development (expressed as *chlorophyll-a*) are likely to be encountered.

5. A user feedback section that allows the user to post queries to the NEAP developers, or to request assistance or advice for a particular problem.

5.9 User understanding of eutrophication

It is extremely important that the NEAP user has a reasonable working understanding of what eutrophication is – i.e. that eutrophication is not simply a function of phosphorus loads and concentrations – and that a wide variety of biophysical and chemical factors can enhance or constrain the observed level of eutrophication in a particular waterbody. It is as important for the water resource manager to be able to determine whether or not a particular resource is eutrophic as it is to determine the likelihood of it becoming so, or where it lies on a trend towards an impaired trophic state. Unfortunately appropriate management strategies directed against eutrophication are seriously constrained by a widespread lack of understanding of the problem – particularly at the decision-making level. Recent work carried out at Hartbeespoort Dam has suggested that with due attention significant remedial changes are indeed possible, and not as insurmountable as has been the popular belief in South Africa for many years (Harding *et al*., 2004).

6 INTRODUCTION TO THE EUTROPHICATION ASSESSMENT TRAINING MATERIAL

6.1 Introduction

In the late 1990s, Walmsley (2000) and Moss (1999) felt that there was little effort to review eutrophication policy in the light of the monitoring results and that the country regressed in terms of its capacity and ability to deal with eutrophication. This observation provided motivation to develop, as part of this project, the outline of an eutrophication assessment short course with the *Eutrophication Assessment Guide* document as the background document for the course. The course material prepared as part of this project includes presentations from which supplementary material such as handouts can be produced.

6.2 Target audience

The primary target audience for the course material is Southern African water resource practitioners, water resource managers and freshwater scientists. A secondary audience is students at tertiary training institutions.

6.3 Guiding principles in developing the training material

The following principles guided the development of the course outline and the training material:

- Qualifications of the attendees - It was assumed that the course attendees would at least have a matric level qualification or, preferably, some tertiary level qualification.
- Accommodate both managers and practitioners – The course outlined below describes an introductory course that is aimed at persons at a management level and an intermediate level course aimed more at knowledge workers who will be responsible for eutrophication assessments.
- Flexible course outline - The course outlined in this document is a suggested outline of topics and a timetable. The course topics and schedule should be customised to suit a specific target audience.
- Presentations should be easy to update – The supporting presentations were developed with Microsoft PowerPoint so that presenters can customise the material to suit their target audience.
- Web-based presentations – The presentations should be developed in such a way that it should be relatively easy to convert it to web-based material that can be accessed via an Internet browser.

6.4 Outline of two eutrophication assessment short courses

6.4.1 Introduction

A need was identified for a two-tiered approach to developing capacity in eutrophication assessment. The first tier is an introductory course that is designed as a general introduction to eutrophication, and its assessment at a catchment scale. Such a short course would be suitable for a person at management level who needs to understand the field of eutrophication better and understand the scope of a catchment eutrophication assessment. The course also serves as an introduction to the more detailed second tier short course designed for someone who would be responsible for undertaking a catchment scale eutrophication assessment study.

The one and two-day courses described below can be integrated into a more comprehensive course on eutrophication assessment and management. It is up to the course leader to customise the course for a specific audience. This document only includes presentations to support the two courses described below.

6.4.2 An introduction to eutrophication assessment

Focus and nature of the course

This short course introduces the topic of eutrophication and nutrient enrichment and what the basic steps are for assessing the problem at a catchment scale. Eutrophication is introduced by examining some of the key concepts, the causes, consequences and impacts of nutrient enrichment, and basic monitoring requirements. A historical overview of the eutrophication in South Africa is also provided to establish the context within which certain decisions have been made in the past leading to where we are today. Catchment scale eutrophication assessment is then introduced along with the NEAP toolbox which was developed to support a first order assessment. The course is concluded with an overview of the different approaches to managing eutrophication.

This course is a prerequisite for the second short course that deals with the details of a catchment eutrophication assessment study.

Required outcomes

After completion of this short course, the student should be able to:

- Provide a broad overview of eutrophication and nutrient enrichment, the factors leading to eutrophication related problems and how these are manifested in rivers, reservoirs and lacustrine wetlands.
- Provide a time-line of eutrophication problems in South Africa, measures to manage the negative impacts, the current situation in the country and approaches to dealing with the problem under the National Water Act.
- Describe the basic steps in undertaking a catchment scale eutrophication assessment study.
- Describe the basic approach to a first order assessment of eutrophication.
- Describe the main approaches to managing the negative impacts of eutrophication.

Example of a course timetable

Short course – An introduction to eutrophication assessment	
Time	Topic
8:30-9:00	Welcome Administrative matters Overview of course objectives and expectations Overview of the course programme and method of presentation
09:00-10:30	**An introduction to eutrophication and nutrient enrichment** • Eutrophication concepts o Natural and cultural eutrophication o Trophic states o Limiting nutrient concept o Nutrient ratios • Causes of eutrophication o Origin of phosphate o Origin of nitrogen o Nutrient cycles

	o Key catchment processes • Symptoms of eutrophication o Algal blooms o Toxic cyanobacteria o Secondary symptoms • Impacts of eutrophication o Ecosystem impacts o Drinking water, human health, agricultural, industrial, recreational effects • Monitoring eutrophication o Minimum monitoring requirements o Desired monitoring requirements o Specialist studies • Eutrophication terms and terminology
10:30-11:00	Refreshments
11:00-11:30	**Historical overview of eutrophication in South Africa** • The 1970s – nutrient enrichment identified as a problem • The 1980s – eutrophication research and first control measures • The 1990s – new water laws and maintaining the status quo • 2000-present – renewed interest in research and management
11:30-13:00	**Introduction to catchment scale eutrophication assessment** • Introduction to catchment management in South Africa • Catchment assessment studies to support catchment management • Introduction to catchment eutrophication assessment studies • Eutrophication assessment study tasks and sub-tasks • Scheduling eutrophication assessment tasks
13:00-14:00	Lunch
14:00-14:30	**NEAP – Nutrient enrichment assessment protocol** • Estimating nutrient loads to a waterbody o Point sources o Non-point sources o Diffuse internal loads • Estimating in-lake nutrient and algal concentrations o Empirical waterbody models o Deterministic waterbody models
14:30-15:15	**Introduction to web-based NEAP software** Example application using NEAP
15:15-15:30	Refreshments
15:30-16:00	Example application continues.
16:00-16:30	**Managing eutrophication** • Establish management goals • External nutrient source control strategies • In-lake eutrophication control strategies
16:30-17:00	Closing statements on eutrophication and nutrient enrichment Review of course objectives, expectations and comments from the attendees Closure

Resources

- Rossouw, J.N., Harding, W.R. & Fatoki, O.S. (2005). *A guide to conduct eutrophication assessments for rivers, reservoirs and lacustrine wetlands*. Water Research Commission, Pretoria.
- Presentations on the CD included with this document

6.4.3 A catchment eutrophication assessment protocol

Focus and nature of the course

This short course introduces the topic of eutrophication and catchment eutrophication assessment during the first day (as described above). On the second day of the course the context within which a catchment scale eutrophication assessment study will be undertaken is discussed in more detail. The different tasks and sub-tasks of such a study are then discussed in detail using the eutrophication assessment guide (this document) as a manual. The NEAP web-based software is then used to undertake a hands-on assessment of a specific case study selected by the course leader. The purpose of the case study is to give students the opportunity to apply the concepts introduced during the preceding day and a half to a case study.

Required outcomes

After completion of this short course, the student should be able to:

- Provide a broad overview of the key tasks in a catchment scale eutrophication assessment study.
- Be able to decide on the scale and depth of the eutrophication assessment study for different parts of a catchment study area.
- Apply the NEAP suite of models and assessment tools to undertake a first order assessment of the scope of an eutrophication problem for a specific water body.
- Participate in a detailed eutrophication assessment study as part of a larger catchment water quality assessment study.

Example of a course timetable

Short course: A catchment eutrophication assessment protocol	
Time	Topic
Day 1 08:30-17:00	**An introduction to eutrophication assessment**
Day 2 8:00-8:30	Welcome Administrative matters Overview of course objectives and expectations Overview of the course programme and method of presentation Brief review of the Introduction to Eutrophication Assessment short course
8:30-9:00	**Review of catchment management and assessment** • Review of the principles of catchment management • Review of water quality assessment studies to support catchment management • Review of catchment eutrophication assessment studies • Introduction to the eutrophication assessment guide document
9:00-10:30	**Detailed description of the eutrophication assessment components** • Component 0 – Current eutrophication status • Component 1 – Catchment description relevant to eutrophication • Component 2 – NWRS and RDM requirements • Component 3 – Water use and conservation • Component 4 – Water availability • Component 5 – Users requirements • Component 6 – Eutrophication description • Component 7 – Point sources • Component 8 – Non-point sources

10:30-11:00	Refreshments
11:00–13:00	**Detailed description of the eutrophication assessment components** • Component 9 – Eutrophication models • Component 10 – Reconciling sources and effects • Component 11 – Status of eutrophication monitoring • Component 12 – Stakeholder details and participation • Component 13 – Institutional arrangements • Component 14 – Record of eutrophication issues and origins • Component 15 – Eutrophication management options • Component 16 – Vision for eutrophication • Component 17 – Catchment development plans and eutrophication • Component 18 – Predicted eutrophication status • Component 19 – Eutrophication management units and spatial scale • Component 20 – Prioritised eutrophication management options • Component 21 – Monitoring implementation of eutrophication management
13:00-14:00	Lunch
14:00-14:30	**NEAP software review** • Instructions on using the software • Example application
14:30-16:00	**NEAP application project** • Class divide into teams to undertake a catchment scale eutrophication assessment using the *Eutrophication Assessment Guide* document and the NEAP software. Refreshments available (no formal break for refreshments)
16:00-16:30	Team report back, discussion and comments on NEAP software and Guide document
16:30-17:00	Short course wrap-up Concluding remarks Course evaluation Closure

Resources

- Rossouw, J N, Harding, W R and Fatoki, O S. (2007). *A guide to conduct eutrophication assessments for rivers, lakes/reservoirs and lacustrine wetlands*. Water Research Commission, Pretoria.
- Department of Water Affairs and Forestry (2003c). *A Guide to conduct Water Quality Assessment Studies: In support of the Water Quality Management component of a Catchment Management Strategy.* Water Quality Management Series, Sub-series No. MS 8.3. Pretoria
- Presentations on the CD included with this document

6.5 Inventory of Eutrophication Assessment training material

The CD included with this report contains the following PowerPoint presentations:

- Introduction to eutrophication assessment short course
- Introduction to eutrophication
- Historical overview of eutrophication in South Africa
- Catchment scale assessment of eutrophication
- Introduction to modelling eutrophication
- Introduction to the Nutrient Enrichment Assessment Protocol (NEAP)

The PowerPoint presentations can be used to produce handouts using the Print/Handouts facility of PowerPoint. The presentation can also be converted to a web-based presentation that can be added to a company Intranet or the worldwide web.

6.6 Concluding remarks on the building of eutrophication assessment capacity

The one and two-day short courses described above should be customised to suit the needs of the target audience. The details of each lecture can be increased or shaped to emphasise specific aspects that may be of value to the target audience. The lecturer can also decide to select only one or two topics from the course and use it to support for example, a course on water quality assessment and management.

7 CONCLUSIONS, RECOMMENDATIONS AND CAPACITY BUILDING INITIATIVES

7.1 Conclusions and recommendations: *Catchment Eutrophication Assessment Guide*

The *Catchment Eutrophication Assessment Guide* mirrors the DWAF *Water Quality Assessment Guide* to make certain that the outputs from an eutrophication assessment can be integrated into a catchment water quality strategy. The guide is a first attempt to identify those aspects that would differentiate an eutrophication assessment from an assessment of other water quality variables. It was often difficult to decide how much guidance should be given to water quality specialists undertaking an assessment study. The guide now needs to be applied to a number of real world eutrophication problems to identify aspects that should be improved. A mechanism should also be developed to elicit feedback from users and to update the guide document from time to time.

Accordingly it is recommended that:

1. The Water Research Commission promotes the use of the guide as a tool to support catchment water quality assessment studies.
2. A mechanism be developed to obtain feedback from users and to update the knowledge base of the guide from time to time. An Internet based discussion forum may offer a way of capturing feedback from users.
3. The integration of the eutrophication assessment with other water quality variables may require some investigation.
4. Similar guides should be developed for priority water quality issues in the country. The two highest priority issues are probably salinisation and microbiological pollution.

7.2 Conclusions and recommendations: NEAP (Nutrient Enrichment Assessment Protocol)

The work undertaken for the NEAP component of this project has only established a platform for further development and application of subsequent (to be developed), versions of NEAP. The work undertaken will have been pointless, if further in-depth analyses of the relevance of the models to a wider South African dataset are not undertaken. Only in this manner will the correct calibrations and application ranges relevant to NEAP become available.

South Africa is hugely dependent on raw potable water provided from man-made storages, some 250 impoundments scattered across the length and breadth of this country. There is no generic, NEAP-predictable eutrophication response applicable to all of them. In many cases, the available water quality records contain few or no data for phosphorus. If the NEAP-based approach is to reach its full potential, the development of regional and/or special climate zone datasets need to be compiled and integrated as loadable calibration sets into future versions of NEAP.

Future versions of NEAP will need to incorporate increased flexibility for dealing with the manner in which phosphorus is assimilated within particular reservoir environments, and particularly with reference to the question of internal loading. The precise role and extent of internal phosphorus loading in highly flushed, shallow and warm South African reservoirs will only become apparent from a more detailed interrogation of the available data – an option not available to the development of NEAP V1.0.

Also critical to the value of NEAP is user-feedback. The developers of NEAP believe that use of this tool has been limited by (a) a general lack of understanding of what NEAP can do, and with this paucity underpinned by (b) inadequate understanding of eutrophication, and eutrophication in reservoirs in particular.

Accordingly, it is recommended that:

1. The value of NEAP be promoted through the convening of a small number of user-targeted workshops;
2. The project be continued, to further develop the local (South African) applicability and scope of NEAP – this by assessing all SA impoundments and their water quality databases through the same process used to select the models used in NEAP V1.0;
3. That the foregoing wider assessment include a catchment analysis and back-calibration of export coefficients in order to expand the relevance and local applicability of nutrient export coefficients by land-use type;
4. NEAP V1.0 be expanded to include second and higher layers to accommodate biogeochemical processes;
5. That the NEAP V1.0 database and feedback system be maintained and used to both inform the user-friendliness of V1.0 and the relevance of the calibrations.

7.3 Conclusions and recommendations: Eutrophication assessment training course outline and material

The course material developed as part of this project was aimed at increasing the capacity to undertake eutrophication assessments at a catchment scale. There is a need to update the material from time to time to reflect advances in the knowledge base on eutrophication assessment. There is also a need to develop similar material to increase capacity in the management of eutrophication in reservoirs and urban ponds, and in the use of more sophisticated assessment tools such as deterministic eutrophication models.

Accordingly, it is recommended that:

1. A mechanism be found to update the training material based on feedback from users, updates to the presentations submitted by lecturers, and to keep up to date with advances in the knowledge base of eutrophication assessment methods.
2. A training course be developed on the control and management of eutrophication in reservoirs and urban water bodies.
3. A training course be developed on the use of more sophisticated assessment tools such as deterministic river and/or reservoir models.

7.4 Capacity building initiatives

7.4.1 Support for tertiary student training

Under the guidance of Prof Fatoki, the studies of two M.Sc students from the University of Venda, Ms M Mamali and Ms D Maluleke, were funded from this project. Ms Mamali undertook her MSc studies on the assessment of the eutrophication status of Vondo and Albasini Dams in Venda. She used the NEAP model during her studies and submitted her thesis during the first quarter of 2005. Ms Maluleke investigated the development of sustainable development indicators. She applied the indicators to case studies of Makhado and Thulamela municipalities. Some of the principles of eutrophication assessments were applied in her studies.

A short course, "Eutrophication Short Course and Modelling Workshop", was presented from 24-25 May 2005 to DWAF staff and others at Roodeplaat Dam. Mr Rossouw and Ms van Ginkel of DWAF presented the Eutrophication Assessment component on the 24th of May and Prof Friedrech Recknagel from Adelaide University presented the Eutrophication Modelling component on the 25th of May.

7.4.2 Presentations at workshops and conferences

The work undertaken in this project was presented at the inaugural meeting of the WISA Nutrient Management Division, the joint ZSSA/SASAqS conference that was held in Cape Town in June 2003, and at the Annual Conference of the North American Lake Management Society that was held in Madison, Wisconsin, in November 2005:

- Rossouw, J N, Harding, W R, Fatoki, O S. (2003). *Guide to Conduct Eutrophication Assessments for River, Lakes and Wetlands.* WISA Nutrient Management Division seminar, Rand Water, 28 March 2003.

- Rossouw, J N and Harding, W R. (2003). *Bridging the gap between Science and Practice: Development of an Eutrophication Assessment Guide*. Joint ZSSA/SASAqS Conference, Cape Town, 29 June to 4 July 2003.

- Rossouw, J N and W R Harding. (2005). *Development of a Catchment Scale Eutrophication Assessment Guide to support catchment management in South Africa.* 25th Annual Conference of the North American Lake Management Society, November 9-11, 2005

Copies of the abstracts and PowerPoint presentations are available on the CD.

8 REFERENCES FOR PART 1 OF THE GUIDE DOCUMENT

Ajao, E J. (1994). *Coastal Aquatic Ecosystems, Conservation and Management Strategies in Nigeria*. South African Journal Aquatic Science 20:3-22.

Department of Water Affairs and Forestry (2002). *National Eutrophication Monitoring Programme: Implementation Manual*. South African National Water Quality Monitoring Programme Series. Pretoria.

Department of Water Affairs and Forestry (2003a). *A Conceptual Introduction to the Nature and Content of the Water Quality Management and Assessment Components of a Catchment Management Strategy.* Water Quality Management Sub-series No. MS 8.1. Pretoria.

Department of Water Affairs and Forestry (2003b). *A Guideline to the Water Quality Management Component of a Catchment Management Strategy*. Water Quality Management Series, Sub-series No. MS 8.2. Pretoria.

Department of Water Affairs and Forestry (2003c). *A Guide to conduct Water Quality Assessment Studies: In support of the Water Quality Management component of a Catchment Management Strategy.* Water Quality Management Series, Sub-series No. MS 8.3. Pretoria.

Department of Water Affairs and Forestry (2003d). *Towards a Strategy for a Waste Discharge Charge System.* 1st Edition. Water Quality Management Series. Sub-series No. MS11. Pretoria.

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

Cooke, G D, Lombardo, P and Brant, C. (2001). Shallow and deep lakes: determining successful management options. *Lakeline*, 22(1): 42-46

Grobler, D C and Silberbauer, M J. (1984). *Impact of eutrophication control measures on South African impoundments.* WRC Report No. 130/1/84. Water Research Commission, Pretoria.

Görgens, A H M and Pegram, G C. (1998). *Guidelines for catchment management to achieve integrated water resources management in South Africa.* WRC Report No. KV 108/98. Water Research Commission.

Harding, W R, Rowe, N, Wessels, J C, Beattie, K A and Codd, G A. (1995). *Death of a Dog attributed to the Cyanobacterial Hepatotoxin Nodularin in South Africa*. J SA Vet Assoc. 66:256-259.

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

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R. (2004). *Hartbeespoort Dam Remediation Project (Phase 1)*. Volume 1. Report to the North West Department of Agriculture, Conservation, Environment and Tourism.

Hosper, S H. (1998). Stables states, buffers and switches: an ecosystem approach to the restoration and management of shallow lakes in the Netherlands. Water Science and Technology, 37(3): 151-164

Marshall, B E. (1997). *Eutrophication in African lakes and its impact on fisheries*. In: African Inland Fisheries: Aquaculture and the environment. K Remane (ed). Oxford. Fishing News Books.

Moss, B. (1998). *Shallow lakes biomanipulation and eutrophication*. *Scope Newsletter* No 29.

Moss, B. (1999). *Eutrophication and eutrophication research in South Africa – an independent view.* Report to Lever Pond's. Durban.

Moss, B. (2003). *Cinderella goes to the ball*. A story of shallow lakes. *Lakeline,* 23(1): 11-16.

National Institute for Water Research (1985). *The Limnology of Hartbeespoort Dam.* S A National Scientific Programmes Report No 110, Foundation for Research Development.

Rast, W and Thornton, J A. (1996). Trends in eutrophication research and control. *Hydrological Processes*, Vol 10, 295-313.

Ryding, S-O and Rast, W. (1989). *The control of eutrophication of lakes and reservoirs.* Man and the Biosphere Series, Volume 1. UNESCO and The Parthenon Publishing Group.

Rossouw, J N. (1990). *The development of management orientated models for eutrophication control*. WRC Report No. 174/1/90. Water Research Commission, Pretoria.

Taylor, R, Best, H J and Wiechers, H N S. (1984). *The effluent phosphate standard in perspective: Part 1. Impact and management of eutrophication*. *IMIESA*, 9:43-56

Toerien, D F. (1977). *A review of eutrophication and guidelines for its control in South Africa.* Special Report WAT. 48. National Institute of Water Research, CSIR, Pretoria.

Van der Mheen, H. (1997). *Mitigation of small reservoir environmental degradation through communicty-based management*. In African Inland Fisheries: Aquaculture and the environment. K Remane (ed). Oxford. Fishing News Books.

Van Ginkel, C E, Hohls, B C, Belcher, A, Vermaak, E and Gerber, A. (2000). *Assessment of the Trophic Status Project.* Internal Report No. N/0000/00/DEQ/1799. Institute for Water Quality Studies. Department of Water Affairs and Forestry, Pretoria.

Walmsley, R D. (1984). *A chlorophyll-a trophic status classification system for South African impoundments*. *J. environ. Qual*., 13:97-76

Walmsley, R D. (2000). *Perspectives on Eutrophication of Surface Water: Policy/research needs in South Africa.* WRC Report No. KV 129/00. Water Research Commission, Pretoria.

Walmsley, R D. (2003). *Development of a Strategy to Control Eutrophication in South Africa: Phase 1. A review and discussion document.* Water Quality Management Series. Report No. U 2.1, Department of Water Affairs and Forestry, Pretoria.

Walmsley, R D and Butty, M. (1980). *Guidelines for the control of eutrophication in South Africa.* Collaborative report by Water Research Commission and National Institute of Water Research, CSIR, Pretoria.

PART 2

A GUIDE TO CONDUCT CATCHMENT SCALE EUTROPHICATION ASSESSMENTS FOR RIVERS, RESERVOIRS AND LACUSTRINE WETLANDS

Chronology of a catchment scale eutrophication assessment as part of a catchment water quality assessment

A catchment scale eutrophication assessment study can generically be partitioned into two distinct phases (as is the case for a generic catchment water quality assessment study), where:

- the first phase is about "describing and understanding the catchment", and
- the second phase is about "providing decision-support for catchment management".

Phase One: Describing and understanding the eutrophication status of the catchment is about providing answers to the following questions:

- *What is the eutrophication-related status of the study area and how did it get to this point?*
- *Who are the eutrophication-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?*
- *What are the study area's eutrophication-related issues, concerns, problems and opportunities?*
- *Where the eutrophication-related status of the study area might be heading in the future?*

It also supports the *eutrophication management strategy* process by providing answers to the following two questions:

- *"What are the goals for eutrophication management?" – Resource Water Quality Objectives, and*
- *"How must nutrient loads change to achieve the goals?" (partly) – Source Management Objectives.*

Phase Two: Supporting catchment management decision-making is about providing answers to the following two questions:

- *What are the appropriate priority water-related management options?*
- *Has catchment management achieved its objectives?*

It also supports the eutrophication management strategy process by providing answers to:

- *"How must nutrient loads change to achieve the goals?" (rest of) – Source Management Objectives, and*
- *"How will this be managed across the WMA?" – Water Quality Management Framework-Plan*
- *"How, where, by whom and when will this be implemented?" – Water Quality Management Implementation Plans.*

In a catchment eutrophication assessment study, some of the components have elements in Phase 1 and in Phase 2, due to the iterative nature of assessment studies. The early tasks clearly have to do with describing and understanding the eutrophication characteristics of the study area. The later tasks clearly have to do with the supporting decision-making and strategy development. However, in some tasks, short to medium-term actions can already be identified that can be implemented to address eutrophication problems that require urgent attention and where actions are clearly evident. Little additional understanding is required to implement these corrective actions.

Some tasks, for example **Component 9** – Configured and calibrated eutrophication models, can be undertaken at a coarse scale to understand the key management options to be undertaken. However, when developing action plans at a later stage to support decision-making, a more detailed model may be required to apportion loads between individual sources.

TABLE 1 CHRONOLOGY OF AN EUTROPHICATION ASSESSMENT AS PART OF CATCHMENT WATER QUALITY ASSESSMENT

COMPONENT NO.	COMPONENT TITLE	PHASE NO.**	TIMING OF ACTIVITIES LEADING TO OUTPUT (DURING NOMINAL INCREMENTS OF 10% OF TOTAL DURATION)									
Eutrophication Management Question 1: What is the Eutrophication Status of the Study Area and how did it get to this Point? Eutrophication Assessment Task 1: Characterisation of the Current Eutrophication Status and Historical Trends												
0	Inception summary of existing understanding, knowledge and past studies with regard to eutrophication related water quality in the catchment	One										
1	Details of natural, developmental and administrative attributes and characteristics of the catchment relevant to the assessment of the eutrophication status	One										
2	Requirements of the National Water Resource Strategy and Resource Directed Measures with regard to nutrient management	One										
3	Water use and conservation related to eutrophication assessment	One										
4	Overview of adequacy of water availability	One & Two										
5	User water quality requirements and constituents of concern related to eutrophication	One & Two										
6	Eutrophication related water quality of streamflow, reservoirs, estuaries, wetlands and groundwater	One										
7	Point source waste discharges and source characteristics related to eutrophication	One										
8	Non-point source water quality loadings and impacts related to eutrophication	One										
9	Configured and calibrated water quality predictive tools/models with regard to eutrophication related water quality	One & Two										
10	Reconciliation: catchment nutrient sources and eutrophication related water quality patterns	One & Two										
11	Status Reports on eutrophication monitoring, physical data and characterization information	One & Two										

COMPONENT NO.	COMPONENT TITLE	PHASE NO.**	TIMING OF ACTIVITIES LEADING TO OUTPUT (DURING NOMINAL INCREMENTS OF 10% OF TOTAL DURATION)										
Eutrophication Management Question 2: Who are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages, and roles? Eutrophication assessment task 2: Engagement of water-related institutions and stakeholders in CAS process													
12	Stakeholder details and participation processes	One											
13	Water-interest institutional arrangements and linkages	One & Two											
Eutrophication management question 3: what is the study area's eutrophication related water quality issues, problems, concerns and opportunities? Eutrophication assessment task 3: formulate and record eutrophication related water quality issues, concerns, problems, and opportunities													
14	Record of eutrophication related water quality issues and their origins	One & Two											
15	Catchment management implications of eutrophication related water quality issues	One & Two											
16	Vision (or long-term resource objectives) for eutrophication related water quality	One & Two											
Eutrophication management question 4: Where might the eutrophication related water quality status of the study area be heading in the future? Eutrophication assessment task 4: Projection of eutrophication related water quality impacts of future water-related development scenarios													
17	National and regional plans and projections of future water demands and catchment development	One & Two											
18	Predicted future eutrophication related water quality at sites of management focus	Two											
Eutrophication management question 5: what are the appropriate (priority) eutrophication management options? Eutrophication assessment task 5: formulate and prioritise eutrophication management options													
19	Eutrophication related management units and assessment spatial and temporal resolution	One & Two											
20	Prioritized eutrophication management options	One & Two											**Etc.**
Eutrophication management question 6: Has water quality management achieved its objectives? Eutrophication assessment task 6: Monitoring and auditing of implementation of water quality management options													
21	Monitoring and auditing assessment of eutrophication management options	One & Two											**Etc.**

** **Phase One**: *Describing and understanding the catchment*

Phase Two: *Supporting catchment management decision-making*

Route Map of the Guide

You are here

Eutrophication Management question 1

What is the eutrophication status of the study area and how did it get to this point?

Output 0: Summary of existing understanding, knowledge and past studies with regard to eutrophication related water quality in the catchment

Output 1: Details of natural, developmental and administrative attributes and characteristics of the catchment relevant to the assessment of the eutrophication status

Output 2: Requirements of the National Water Resource Strategy and Resource Directed Measures with regard to nutrient management

Output 3: Water use and conservation related to eutrophication assessment

Output 4: Overview of adequacy of water availability

Output 5: User water quality requirements and constituents of concern related to eutrophication

Output 6: Eutrophication related water quality of rivers, lakes (reservoirs) and wetlands

Output 7: Point source waste discharges and source characteristics related to eutrophication

Output 8: Non-point source water quality loadings and impacts related to eutrophication

Output 9: Configured and calibrated water quality predictive tools/models with regard to eutrophication related water quality

Output 10: Reconciliation: catchment nutrient sources and eutrophication related water quality patterns

Output 11: Status Reports on eutrophication monitoring, physical data and characterisation information

Eutrophication Management question 2

What are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?

Eutrophication Management question 3

What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?

Eutrophication Management question 4

Where might the eutrophication related water quality status of the study area be heading in the future?

Eutrophication Management question 5

What are the appropriate (priority) eutrophication management options?

Eutrophication Management question 6

Have the eutrophication management strategies achieved their objectives?

Eutrophication Management Question 1:

WHAT IS EUTROPHICATION STATUS OF THE STUDY AREA AND HOW DID IT GET TO THIS POINT?

Eutrophication Assessment Task 1:
Characterisation of the current eutrophication status and historical trends

COMPONENT 0

Inception Summary of Existing Understanding, Knowledge and Past Studies with Regard to Eutrophication Related Water Quality in the Catchment

RATIONALE

Generic catchment assessment context

No catchment is a clean slate in terms of information or knowledge about it. Some experienced-based understanding of the functioning of at least some parts of a catchment is usually present among some of the long-standing inhabitants of a catchment, as well as among state officials or professionals active in water-related matters. Similarly, the existence of water-related issues and problems is often common knowledge. In many instances, particular water-related studies have historically been conducted in the catchment under consideration.

Eutrophication assessment context

Eutrophication knowledge and information about eutrophication related water quality problems are often available:

From catchment reports, basin studies, water quality assessment studies, effluent discharge investigations, waste load allocation studies, reports dealing with drinking water treatment, water use licence applications and research reports, or

Reside in long-standing inhabitants of an area, state officials such as water bailiffs or water/wastewater treatment plant operators or professionals active in water-related matters.

Similarly, the existence of eutrophication related issues and problems is often common knowledge and can be brought to the fore through an initial public participation process.

Purpose

The purpose of this component is to provide the eutrophication assessment study at an early stage with a provisional overview of readily available eutrophication related knowledge and information, and of existing issues, concerns, problems and opportunities related to eutrophication. Such an overview can be used as an inception report to bring all stakeholders and interested parties to a similar level of understanding of the overall problem, to identify key issues (symptoms and causes) and to provide an early focus on acute eutrophication problems that may require urgent attention.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Two outputs are produced in a generic catchment water quality assessment study; a summary document providing an overview of known water quality characteristics, and a summary report on existing water quality problems and issues.	The generic outputs are produced using information that is readily available at the start of a catchment assessment study.
Eutrophication assessment outputs	
A brief overview document giving a summary of eutrophication related characteristics of the study area.	Assemble readily available reports on relevant past technical and scientific studies and summarise the primary aspects mentioned under Checklists below. Identify persons with knowledge of eutrophication (causes or consequences) in the study area and capture their knowledge through interviews and/or correspondence.

<table>
<tr><td>An initial report on real or perceived eutrophication related problems and issues, and challenges and opportunities to mitigate its impacts. [Refer to Component 15 for a Checklist of typical eutrophication issues]</td><td>Summarise the eutrophication concerns, issues, challenges and opportunities that are contained in reports on past studies. Be specific about spatial and temporal extent of problems.
Obtain further inputs from knowledgeable persons through interviews (telephone or personal) and/or correspondence.</td></tr>
<tr><th colspan="2">METHODS AND TOOLS</th></tr>
<tr><td colspan="2">Compile a bibliography of previous studies, investigations, papers and journal articles, etc.
Use standard research protocols to synthesise the available information and to identify eutrophication concerns, issues, challenges and opportunities.
Compile a contact database of persons with experience in eutrophication in the study area or being affected by eutrophication symptoms.
Use standard referral techniques to identify persons with knowledge of eutrophication related water quality in the study area.</td></tr>
<tr><th colspan="2">SOURCES</th></tr>
<tr><td>Reports of the study area with the following themes:
Catchment Description; Hydrology; Land-use; Water Resources; Water Quality Situation Analysis; System Analysis; etc.</td><td>DWAF: Directorates responsible for water resources management, water quality planning and management, setting resource water quality objectives, and resource protection
Catchment Management Agencies
Water Service Providers
Local Authorities</td></tr>
<tr><td>Reports with the following themes:
Water Quality Situation Analysis/ Study; Waste Load Allocation; Water Quality Management Plan, etc.</td><td>DWAF: Directorates responsible for water quality management, resource protection, and scientific support
Catchment Management Agencies
Water Service Providers
Local Authorities</td></tr>
<tr><td>Reports with the following themes:
Catchment Management; Catchment Management Plans; etc.</td><td>DWAF: Directorates responsible for Catchment Management
Catchment Management Agencies
Water Service Providers
Local Authorities (district municipalities and local councils)</td></tr>
<tr><th colspan="2">CHECKLISTS</th></tr>
<tr><td colspan="2">The generic water quality overview reports should typically <u>summarise</u> the following, at coarse scales, with a focus on the following general water resource issues (if appropriate): climate, surface water and groundwater resources; demography; water use and demands; land-use; water quality; return flows; Environmental Reserve, water balance, water-related infrastructure; water management institutions; water-related issues, problems and opportunities.</td></tr>
</table>

The ***eutrophication assessment overview*** should typically summarise the following, *at coarse scale*, with a focus on eutrophication related water quality: *water quality (e.g. nutrient concentrations, chlorophyll-a concentrations, benthic algae, water clarity); water quantity (e.g. flow rates, residence times, flushing rates); physical characteristics (e.g. temperature regime, dissolved oxygen regime) reservoir morphology (e.g. mean depth, shape, thermal stratification) return flows (e.g. treated wastewater effluent, irrigation); agricultural runoff (e.g. fertilized lands, feedlots), Ecological Reserve, known eutrophication-related issues, problems and opportunities (e.g. what? where? when? how severe? who affected?)*.
DISPLAY AND PRESENTATION OPTIONS
The format of the output would typically be similar to that of a scoping report and the focus would be on factors that affect nutrient enrichment and eutrophication. Information should preferably be presented graphically or in map form (with GIS support), while text should be limited to significant observations or concerns only. Any changes required to the study brief as a result of the preliminary findings should be included in the initial overview report. The overview report should include a complete bibliography of previous studies and reports consulted, as well as relevant reports and journal articles that need to be consulted during further phases of the study. The contact details of persons consulted for this component should also be included.

COMPONENT 1

Details of Physical, Developmental and Administrative Attributes and Characteristics of the Catchment Relevant to the Assessment of the Eutrophication Status

RATIONALE

Generic catchment assessment context

Every human being lives in a catchment. Therefore, one of the challenges of integrated water resource management at the catchment scale is to be able to identify the natural characteristics of the water resource and the degree to which these have been modified by developments in the catchment. A description of these natural and human-related elements and their linkages is therefore a fundamental prerequisite of a catchment assessment study.

Eutrophication assessment context

Eutrophication is the enrichment of water bodies leading to excessive production of organic materials by algae and/or aquatic plants. The symptoms of eutrophication (e.g. high algal biomass, reduced water transparency, hypolimnetic oxygen depletion) are related to external nutrient loadings, hydrology and river and reservoir morphometric characteristics. External nutrient loads of nitrogen and phosphorus are mobilised by rain and transported to rivers and reservoirs through processes such as overland flow, groundwater seepage, drainage networks, and urban and industrial wastewater. Once in the rivers and reservoirs, the nutrients can be taken up by algae, macrophytes and micro-organisms, it can be adsorbed onto organic or inorganic particles in the water and sediments, it can be accumulated and recycled in the sediments, or transformed and released as a gas from the water body (denitrification).

In order to understand the process of eutrophication, it is important to understand where and how nutrients are produced in the catchment, how these are mobilised and transported to a water body, and their fate once in a river or reservoir. It is therefore important to identify those characteristics of the catchment that promote nutrient production, enrichment and contribution to nuisance algal growth. Some of the features identified in this component are investigated in greater detail in later components (e.g. point and non-point sources, etc).

Purpose

The purpose of this component is to identify and describe those features of the catchment that lead to elevated nutrient concentrations in rivers, reservoirs and wetlands, the water body characteristics that promote algal growth, and identification of the users that are negatively affected by nuisance algal growth. This component informs the eutrophication assessment study of the following generic aspects:

- Natural attributes of the catchment or study area (e.g. what would the nutrient status have been under natural conditions given the natural geomorphological template of the catchment?)
- Extent of human development and impacts (e.g. what were the modifications to the catchment that would effect changes to the nutrient status?)
- Socio-economic profile (e.g. what socio-economic developments have contributed to nutrient enrichment and which were negatively affected by eutrophication?)
- Water-related infrastructure and monitoring (e.g. has water-related infrastructure contributed to or mitigated eutrophication in the catchment, what monitoring is done?)
- Administrative arrangements (e.g. which organisations are responsible for managing water quality and eutrophication and what is their area of jurisdiction?)
- These catchment characteristics are relevant to water resources management in general but the descriptions should focus on those aspects that relate to eutrophication in the study area.

Prerequisite Components

The outputs from **Component 0** should guide the data and information collection for this component.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic Catchment Assessment Outputs	
For a generic catchment water quality assessment, georeferenced data and information are required on the following land-use aspects: • Natural attributes (e.g. geology or land cover) • River system details (e.g. river channels and tributaries) • Location of monitoring points • Infrastructure (e.g. dams, irrigation schemes, WWTWs, etc.) • Current and past land-use • Socio-economic profile • Areas of jurisdiction • Boundaries of water resource management units	Sources of this data are listed in the *Catchment Water Quality Assessment Guide*[2].
Eutrophication Assessment Outputs	
User-friendly GIS coverages and tables, as well as detailed database storage sets of the following information: • Natural attributes with special attention on geological formations, soil types, vegetation and sediment production potential.	Method of information assembly to attain the corresponding outputs in the left-hand column: • Use available GIS coverages or digitise from available maps or aerial photos.
• River system details such as main stem channels and tributaries, wetlands and reservoirs and catchment boundaries (primary, secondary, tertiary, and quaternary, as the need arises).	• Use available national coverage from DWAF, CMA, or local authority, or digitise from existing maps.
• Monitoring locations, type and responsible organisation; this would include stations for water quality sampling of rivers, reservoirs, and effluent discharges, and flow gauging points (also see **Component 11** for more information).	• Locate via latitudes and longitudes obtained from data custodians, or determine with the aid of maps, aerial photos or a GPS.
• Infrastructure locations and dimensions with specific attention to locating return flow points from wastewater treatment works, irrigation schemes, urban stormwater, etc.	• Locate via latitudes and longitudes, obtained from scheme or infrastructure owners, or their consultants, or digitise from maps or aerial photos.
• Land-use (current and past), with specific attention to human settlements with different degrees of sanitation services; commercial and industrial areas; dryland agriculture; mining areas and solid waste sites.	• Use existing GIS coverages available from custodians of remotely sensed data, based on interpretation of satellite imagery, aerial photographs and orthophotos; alternatively, perform land-use identifications from aerial photographs supported by ground-truthing in the field.

[2] Department of Water Affairs and Forestry (2003c). *A Guide to conduct Water Quality Assessment Studies: In support of the Water Quality Management component of a Catchment Management Strategy.* Water Quality Management Series, Sub-series No. MS 8.3. Pretoria.

• Boundaries and *areas of jurisdiction* of water management institutions and service providers.	• Use existing GIS coverages available from DWAF, CMAs and municipalities, or digitise from appropriate maps.
• Boundaries of water resource *management units* (see **Component 19**).	• This is one of the outputs from the consultative tasks in a catchment assessment (see **Component 14**) and would usually follow physiographic boundaries; digitised from maps.

METHODS AND TOOLS

The information collated in this component serves as a baseline for both the technical assessment tasks as well as the consultative/public participation tasks. The information needs to be spatially organised, with three levels of output:

- In map form for easy visualisation (for consultative tasks).
- In numerical/ tabular form with explanatory text (for consultative and technical tasks).
- In database storage form (for technical tasks).

SOURCES

Maps, aerial photographs and orthophotos	• Chief Directorate: Surveys and Mapping, Department of Land Affairs. • Map Office – all major cities.
GIS coverages	• Directorate: Geomatics, DWAF, Pretoria • CSIR, Pretoria • District municipalities and local authorities • Catchment Management Agencies • Large Water Service Providers • Water Users Associations
Institutional boundaries	• Directorate: Geomatics, DWAF, Pretoria

CHECKLISTS

Refer to the *Catchment Water Quality Assessment Guide* for the checklists for human settlements, irrigation activities, afforestation and plantations, dryland agriculture, and institutional boundaries.

In terms of eutrophication, the following catchment characteristics should be considered (location and aerial extent):

- *Eco- and water quality regions* – Level 1 and Level 2 eco-regions that were derived from terrain and vegetation, with some consideration of altitude, rainfall, runoff variability, air temperature, geology and soil (Available online at www.dwaf.gov.za) and water quality regions (Day *et al*, 1998).
- *Human settlements*: High, medium and low-density urban areas (stormwater runoff), high-density settlements (stormwater runoff), urban areas or settlements with poor sanitation services (stormwater runoff, surcharging sewers and dry weather flow in stormwater system), Smallholdings (stormwater and irrigation runoff).
- *Irrigation activities*: Irrigation schemes, crop types, type of irrigation practices, location of return flows, fertilizer application practises (Non-point source nutrient loads).

- *Dryland agriculture*: Summer crops; winter crops; perennial crops, subsistence crops and fertilizer application practises (non-point source nutrient loads, sediment loads, turbidity).
- *Infrastructure:* wastewater treatment plants (effluent volume & nutrient concentrations, location of discharge points), water treatment plants and abstraction points (abstraction volumes).
- *Institutional boundaries*: Water Management Areas, Magisterial districts, district councils, metropolitan councils, TLCs, TRCs, water boards, government water control areas, provincial and international boundaries (required to identify, for example, institutions responsibilities for the management of water quality in a region).

The following water body characteristics should be collected during the execution of this component for use in later components of the assessment:

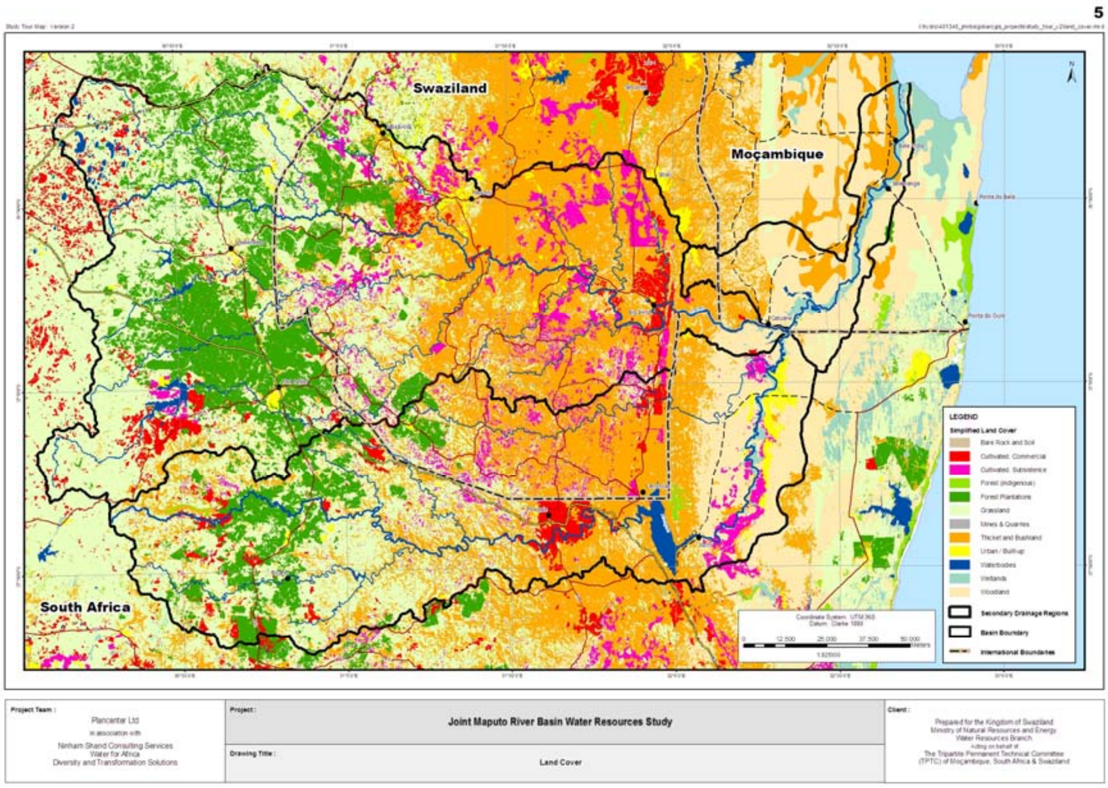
Reservoirs	Full supply volume* and area*, maximum depth and mean depth*, catchment area and mean annual runoff*, longitude and latitude coordinates, height above mean sea level, reservoir form and bathymetric information, precipitation and evaporation*, reservoir operating rules, abstraction/release depth at reservoir outlet. ** = inputs needed for the NEAP model*
Rivers	Stream order, mean flow.
Wetlands	Aerial extent, wetland type

The most common source of land-use information is the CSIR's South African Land Cover Database (www.csir.co.za) that was mapped from a series of 1:250 000 scale satellite images captured primarily during 1994 and 1995. Land cover was mapped using 31 land-cover classes. The land-cover generally of concern for eutrophication assessments includes Urban/Built-up land (urban runoff concerns), Bare Rock and Soil – erosion surfaces, and Degraded Lands (high suspended sediment load concerns), Cultivated lands – irrigated (high nutrient return flow concerns), and Cultivated lands – temporary crops – commercial – dryland (wash-off of fertiliser concerns).

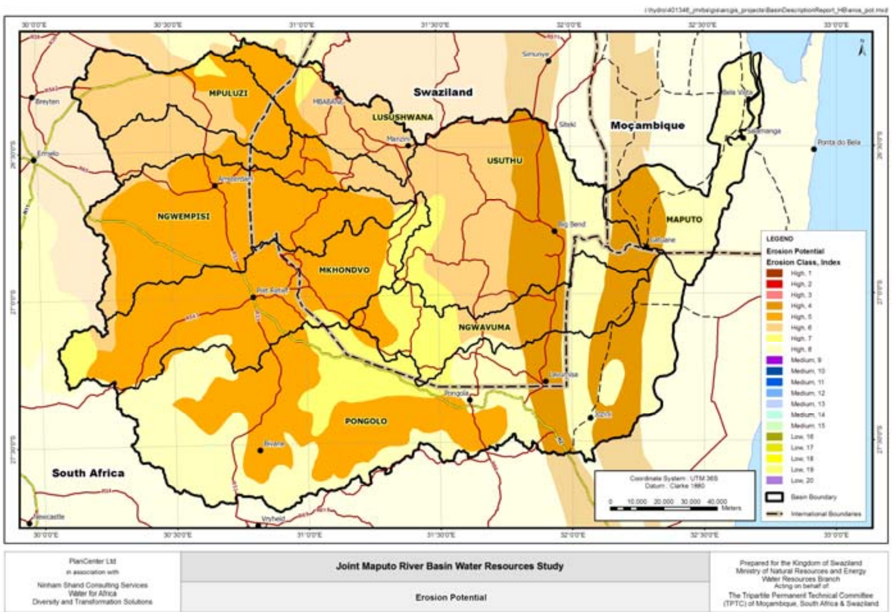
NEAP requires catchment areas matching the following land-use types for which TP export coefficients have been developed: High, medium and low density urban, smallholdings, horticulture, grasslands/pastures, row crops, and forestry. It is recommended that professional judgement and knowledge of the study area be used to match CSIR land-cover information to the land-use data required for NEAP.

DISPLAY AND PRESENTATION OPTIONS

An example of a catchment scale map[3] showing land-uses that could potentially affect eutrophication related water quality such as irrigation areas, degraded lands, urban areas, commercial forestry, etc.



An example of a catchment scale map showing erosion potential.



3 Examples of maps are presented in this report to illustrate how information can be presented using maps. The above map is a generic example (for conceptual purposes only) illustrating how this information can be presented in a visual format. For the purposes of this guide document, the detail contained within the examples is not necessarily intended to be presented at a legible scale.

REFERENCES

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

COMPONENT 2

Requirements of the National Water Resource Strategy and Resource Directed Measures with regard to Nutrient Management

RATIONALE

Generic catchment assessment context

The National Water Resource Strategy (NWRS) and Resource Directed Measures (RDM) can place specific constraints on the development of catchment water quality management strategies and plans. The ***National Water Resource Strategy*** (NWRS) provides the framework for the implementation of the National Water Act, 1998 (No. 36 of 1998). The first edition was published for comment in August 2002 (DWAF, 2002a) and the revised NWRS is due for completion in 2004. The national strategy is being progressively developed to set out policies, strategies, objectives, plans, guidelines, procedures and institutional arrangements for the protection, use, development, conservation, management and control of the country's water resources. The NWRS identifies, *inter alia*, development opportunities and constraints with respect to water availability (quantity and quality). The NWRS was given further impetus through the development of ***Internal Strategic Perspective*** (ISP) documents for the 19 water management areas (for example DWAF, 2003). These documents present more detail on the Department's strategic perspective on how it wishes to protect, allocate usage, develop, conserve, manage and control water resource in the WMA's until the functions have been delegated to Catchment Management Agencies (CMAs). ***Resource-Directed Measures*** (RDM) focus on the quality and the overall health of water resources (DWAF, 1999, DWAF, 2002b, Kleynhans *et al*, 2005). Resource quality includes water quantity and water quality, the character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota. Resource-directed measures include a National Classification System; determination of the Management Class of specific water resources; and the establishment, for each significant water resource, of resource quality objectives and determination of the Reserve in accordance with the Management Class of the resource.

Eutrophication assessment context

Examination of the ***NWRS and ISPs*** within the context of an eutrophication assessment should focus on strategies and plans that would affect the nutrient status of the catchment. For example, in a specific catchment, effluent return flows may be viewed as an important water resource for downstream users or for transfer between river basins. The high nutrient concentrations in the return flows result in eutrophication related water quality problems in the receiving rivers and reservoirs. However, due to the strategic importance of the return flows, management options that would affect the return flow volume would be constrained (e.g. effluent diversion or irrigation options) and consideration be given to managing the causes (e.g. limiting the discharge nutrient concentrations) and the consequences in the receiving waters. In some international agreements such as the Incomaputo Agreement between South Africa, Swaziland and Mozambique, water quality targets are specified and eutrophication management strategies need to consider these targets.

The ***Reserve*** includes the water quantity and quality required to meet basic human needs, and to protect aquatic ecosystems. The Reserve specifies, amongst others, the nutrient concentrations required to maintain a resource in a specific Management Class. It should be noted that reservoirs were specifically excluded from ecological Reserve determinations due to their artificial nature.

Purpose

The purpose of this component is to identify and document the:

- Strategies and plans in the NWRS and ISP's that would affect the nutrient status in a catchment as well as the constraints imposed by these strategies on options to manage eutrophication.
- Management objectives and actions described in the ISP documents that address issues relating to nutrient enrichment and its impacts.
- Nutrient objectives contained in the Resource Directed Measures for a specific catchment or water resource unit.
- Nutrient objectives specified in international agreements with co-basin states.

Prerequisite Components

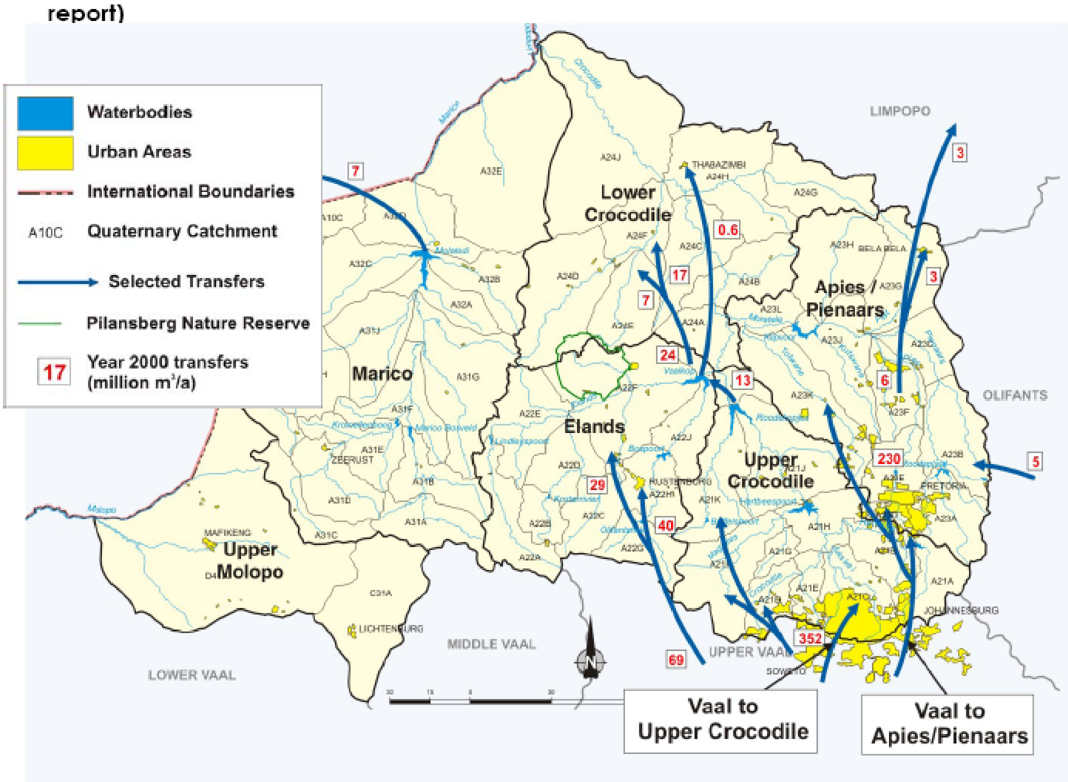
Geographical boundaries of the study area (**Component 1**).

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Description of the NWRS and ISP strategies, and resource directed measures (class, reserve and resource quality objectives) that would affect the development of a catchment water quality management strategy.	Examine the NWRS, ISP and Reserve documents and summarise the aspects relevant to a catchment water quality strategy.
Eutrophication assessment outputs	
Description of NWRS and ISP constraints that would affect the nutrient status or the selection of nutrient management options for the study area.	Use the checklist below as a guide to extract information relevant to the nutrient status and management strategies in the study area.
Description of the management class and nutrient objectives that has been set for water resources in the study area. GIS Map showing river reaches where Reserve determinations have been done, indicating nutrient objectives.	Use the **checklist** below as a guide to collate nutrient water quality Reserve information from Reserve study documents.
SOURCES	
Information on the National Water Resources Strategy can be obtained from the Directorate: Policy and Strategy Co-ordination.	Director: Policy and Strategy Coordination Website: www.dwaf.gov.za
Information on the ISPs for the study area can be obtained from the Directorate: National Water Resource Planning.	Director: National Water Resource Planning Website: www.dwaf.gov.za
Information on international agreements can be obtained from the Directorate: International Development Co-operation.	Director: International Development Co-operation Website: www.dwaf.gov.za
Information on Reserve determinations that have been undertaken in the study area can be obtained from the RDM Directorate.	Director: Resource Directed Measures Website: www.dwaf.gov.za

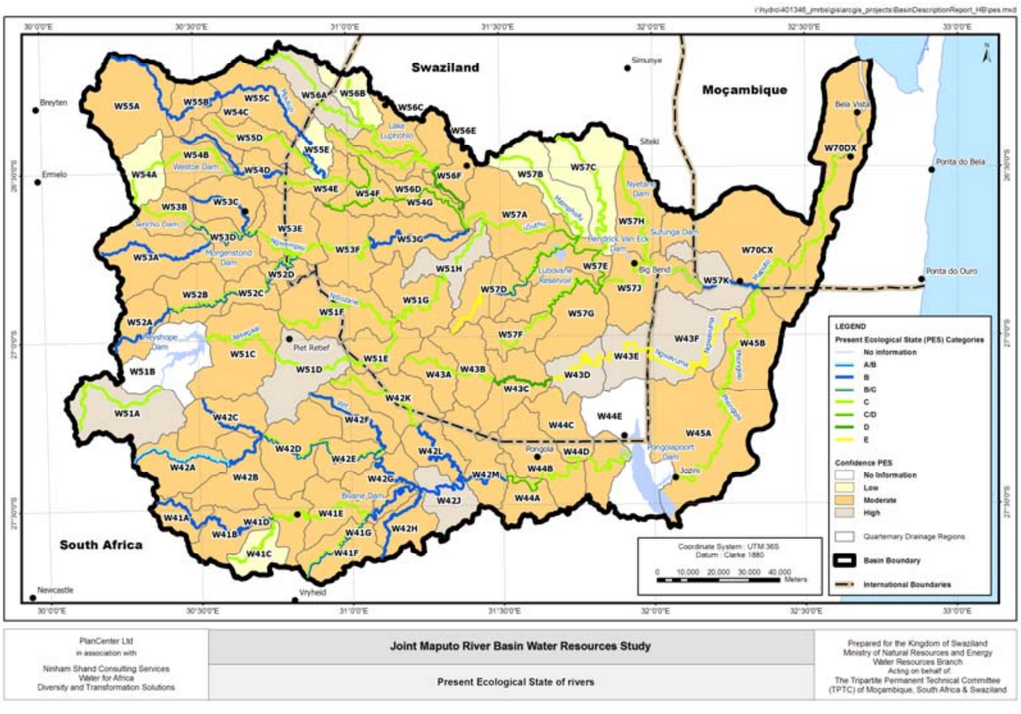
CHECKLISTS	
National Water Resource Strategy Information on usable return flows, balancing supply and demand, resource protection and water quality management can be found in the following sections of the NWRS.	Chapter 2: South Africa's water situation, and strategies to balance supply and demand 2.3 Water Resources 2.5 Strategies to balance supply and demand (Reconciliation) Chapter 3: Strategies for Water Resources Management Part 1 – Protection of Water Resources Part 3 – Water conservation and water demand management Part 6 – Monitoring and information systems
Internal Strategic Perspective Information on strategies, management objectives, strategic approaches and management actions relating to nutrient management can be found in the following sections if an ISP document.	Part 2 – Strategies Strategic area 1: Yield, water balance and reconciliation (requirements and availability) Strategic area 2: Water resource protection (Reserve and resource quality objectives, water quality) Strategic area 3: Water use management (pollution control) Strategic area 9: Monitoring and information
International agreements The Incomaputo agreement that was signed between South Africa, Swaziland and Mozambique has a resolution on the exchange of information and water quality. Similar agreements are being considered for other shared rivers like the Orange River.	Copies of international agreements are available on the DWAF website at www.dwaf.gov.za The Incomaputo agreement provides, for example, guidelines for nitrogen and phosphorus concentrations at borders between the basin countries as well as guidelines for sample analysis, monitoring and information exchange.
Reserve Information The Reserve describes the quality and quantity of water required to maintain a water resource in a specific ecological management class and is set for rivers, wetlands, groundwater and estuaries. Information on the water quality components of the Reserve can be obtained from Reserves signed off by the Director-General of DWAF and in the supporting documentation for a Reserve determination.	The water quality component of the Reserve for river ecosystems is set in terms of: • Inorganic salts • *Nutrients such as ortho-phosphate and total inorganic nitrogen* • Physical variables such as pH, temperature, dissolved oxygen and turbidity • Toxic substances, and • Response variables such as *algal abundance*, a biotic invertebrate index and toxicity *Note*: The revised documentation for the water quality component of the Reserve was due for release towards the end of 2003 (Jooste and Rossouw, 2002).

DISPLAY AND PRESENTATION OPTIONS
Maps can be used to illustrate existing and envisaged water resource development options (for example DWAF, 2004).

Figure 3.1: Transfers in and out of the Crocodile River (West) catchment (Source: WMA report)



Example of a map showing the Present Ecological Status of rivers.



Tables can be used to quantify available water resources such as urban return flows which can be high in nutrient content (for example DWAF, 2004).

Table 3c: Available Yield in the Year 2000 (million m³/annum)

Component / Sub-area	Natural Resource		Usable Return Flow			Total Local Yield
	Surface Water (1)	Groundwater	Irrigation	Urban	Mining & Bulk	
Upper Crocodile	111	31	21	158	15	336
Apies/Pienaars	38	36	4	106	2	186
Elands	30	29	3	10	14	86
Lower Crocodile	7	29	14	1	8	59
Total for Catchment	**186**	**125**	**42**	**275**	**39**	**667**

REFERENCES

Department of Water Affairs and Forestry (1999). *Resource Directed Measures (RDM) for protection of water resources*. Department of Water Affairs and Forestry, Pretoria (Various volumes for river, wetland, groundwater and estuarine ecosystems).

Department of Water Affairs and Forestry (2002a). *National Water Resource Strategy* (Proposed first edition). , Pretoria.

Department of Water Affairs and Forestry (2002b). *Manual for Assessing the Ecological Reserve for Rivers*. Report No. RDM 000-01-COM-Meth-0102. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (2003). *Gouritz WMA: Internal Strategic Perspective*. Draft 1. Prepared by Ninham Shand (Pty) Ltd on behalf of the Directorate: Resource Planning (South). DWAF Report No. P WMA 16/HJK/0303.

Department of Water Affairs and Forestry (2004). *Crocodile River (West) and Marico Water Management Area: Internal Strategic Perspective of the Crocodile River (West) Catchment* : Prepared by Goba Moahloli Keeve Steyn (Pty) Ltd, Tlou & Matji (Pty) Ltd and Golder Associates (Pty) Ltd, on behalf of the Directorate: National Water Resource Planning. DWAF Report No. 03/000/00/0303.

Jooste, S and Rossouw, J N. (2002). *Hazard-based Water Quality EcoSpecs for the Ecological Reserve in Fresh Surface Water Resources*. Report No. N/0000/REQ0000. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kleynhans, C J, Louw, M D, Thirion, C, Rossouw, J N and Rowntree, K. (2005). *River Ecoclassification: Manual for Ecostatus Determination. Version 1*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

COMPONENT 3
Water Use and Conservation relating to Eutrophication Assessment

PURPOSE

Generic catchment assessment context

One of the reasons why water resource management has a high priority in South Africa is the rapid increase in water use which in turn results in effluents and return flows that reduces the assimilative capacity in streams, rivers and reservoirs. Section 21 of the National Water Act defines a wide range of activities as water use.

An inventory of water uses, both current and historical, provides one of the basic templates for structuring the water quality assessment of a catchment. Historical water use trends are important to help explain the current water quality status, and provides crucial input data to enable the calibration of water quality models. A description of water conservation measures and their outcomes helps explain historical water use trends and to assess the impacts on the water quality status.

Eutrophication assessment context

The focus in an eutrophication assessment study is to identify water use activities that affect the nutrient status of the catchment and receiving streams, rivers and reservoirs. The key activities that should be considered are all aspects of discharging wastes into water resources:

Section 21(f) discharging waste or water containing waste into a water resource – many waste streams are high in nutrients,

Section 21(g) disposing of waste in a manner which may detrimentally impact on a water resource – improper disposal of waste high in nutrients (e.g. manure, wastewater sludge, etc.) can result in high nutrient loadings to streams through leaching or direct wash-off,

Section 37.1(a) the disposal of wastewater by irrigation – improper disposal of wastewater high in nutrients can also result in high nutrient loadings through processes such as wash-off,

Section 21(a) and (b) abstracting water from a water resource (and storing it) affects capacity of the resource to assimilate waste,

Section 21(c) making changes to the physical structure of rivers and streams (impeding or diverting the flow of water in a watercourse – affects the assimilative capacity of the resource,

Section 21(j) altering the bed, banks, course or characteristics of a watercourse – these activities often affect water clarity during construction and can expose nutrient rich sediments thereby increasing nutrient loads.

Purpose

For eutrophication assessment, the objective is to identify and list those activities described in Section 21 of the NWA that affect the nutrient status of the catchment and receiving water bodies.

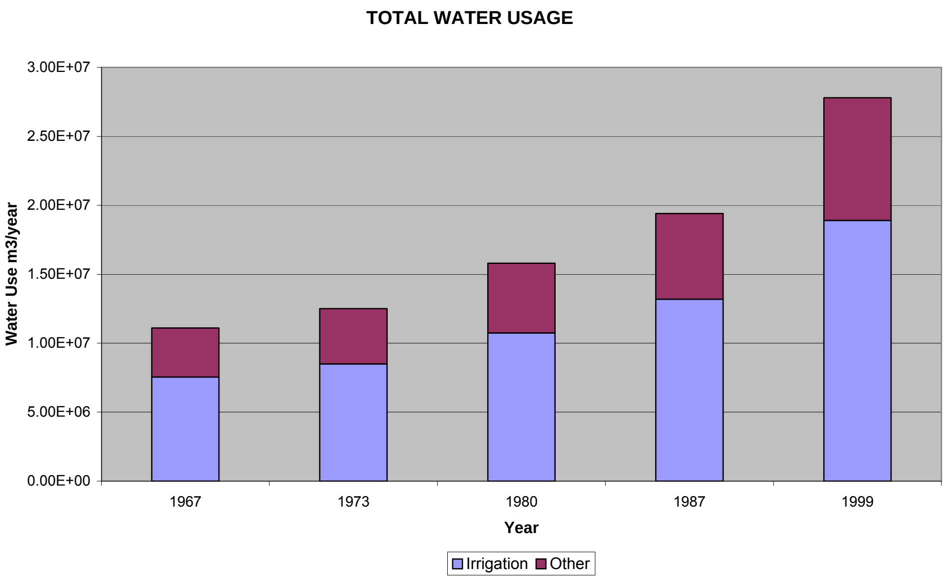
The output from this component should help focus the activities undertaken in **Component 4** – Overview of water availability, **Component 7** – Point source discharges, and **Component 8** – Non-point source loadings. The primary output is what activities are taking place where and who are the primary stakeholders involved in those activities. These are investigated in greater detail in **Components 4**, **7** and **8**.

Prerequisite Components

Component 1 – Description of the study area.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The generic catchment water quality assessment study requires an inventory of all effluents and return flows, effluent irrigation activities, water abstractions, stream flow reduction or alteration activities, and water conservation measures.	These activities are assembled by examining records at DWAF, CMAs, WUAs, and local authorities.

Eutrophication assessment activities	
Geo-referenced inventory of all effluent discharges and return flows, arranged by sub-catchment and by type.	Assemble water use licence information from DWAF or the licensees. Point source discharges are unpacked in **Component 7**.
Geo-referenced inventory of effluent irrigation activities arranged by sub-catchment.	Assemble licence information from DWAF or the licensee
Geo-referenced inventory of all water abstractions summarised by sub-catchment and by water use category (see **Checklist** below).	Assemble a list all water abstractions or bulk water suppliers and their locations from relevant sources (DWAF, CMAs, WSPs, WUAs).
Geo-referenced database of all streamflow reductions or alteration activities summarised by sub-catchment unit and by category.	Identify the type of streamflow reduction activities (see **Checklist** below) and their locations from maps and other relevant sources.
SOURCES	
Controlled activity licences WARMS database (Water use licensing, registration and revenue collection database).	Available from DWAF (Chief Directorate: Water Use and Conservation), Regional Office, or CMAs. Website: www.dwaf.gov.za.
Water abstraction or delivery records.	Available from DWAF (Directorates: Water Utilisation; Hydrology), WUAs, CMAs, Water Boards, mines and municipalities.
Database on SFRAs such as afforested, alien infested and sugarcane areas.	**Component 1**
CHECKLISTS	
• *Water use categories*: domestic; irrigation; industrial; power generation; mining; livestock. • *Streamflow reduction categories*: commercial timber plantations (pines, eucalypts, wattles); range of classes of alien vegetation; dryland agricultural crops (at least sugar cane).	
DISPLAY AND PRESENTATION OPTIONS	
The graph below shows an example of how the growth in water usage in a catchment can be displayed using a stacked bar graph.	



COMPONENT 4
Overview of Adequacy of Water Availability

PURPOSE

Generic catchment water quality assessment context

A sound understanding of the adequacy of water quantity availability in a catchment is a prerequisite to the understanding of water quality issues and appropriate management responses to them. At the heart of certain water quality issues lie inadequate or unreliable supplies of fresh water, needed for dilution, flushing, assimilative capacity, river channel maintenance, or as alternative supplies to existing supplies that have problematic quality. This component provides an integrated picture of how much water is available *at particular assurances/reliabilities* at key locations in the catchment, and how this availability balances the demand for water. The water balance assessment should include not only the current water use situation, but also projected future water demands. Water quality issues that arise in areas of potential supply shortfall obviously need different management responses to those in areas of supply surplus.

Eutrophication assessment context

Eutrophication problems can be alleviated or exacerbated by dilution or over-exploitation of water resources in parts of the study area.

Purpose

This component provides the catchment management strategy development process with an integrated picture of how much surface water and groundwater is available at particular assurances/ reliabilities at key locations in the catchment, and how this availability balances the demand for water (Output **Component 3**). The assessment should include potential future impoundments or groundwater development schemes.

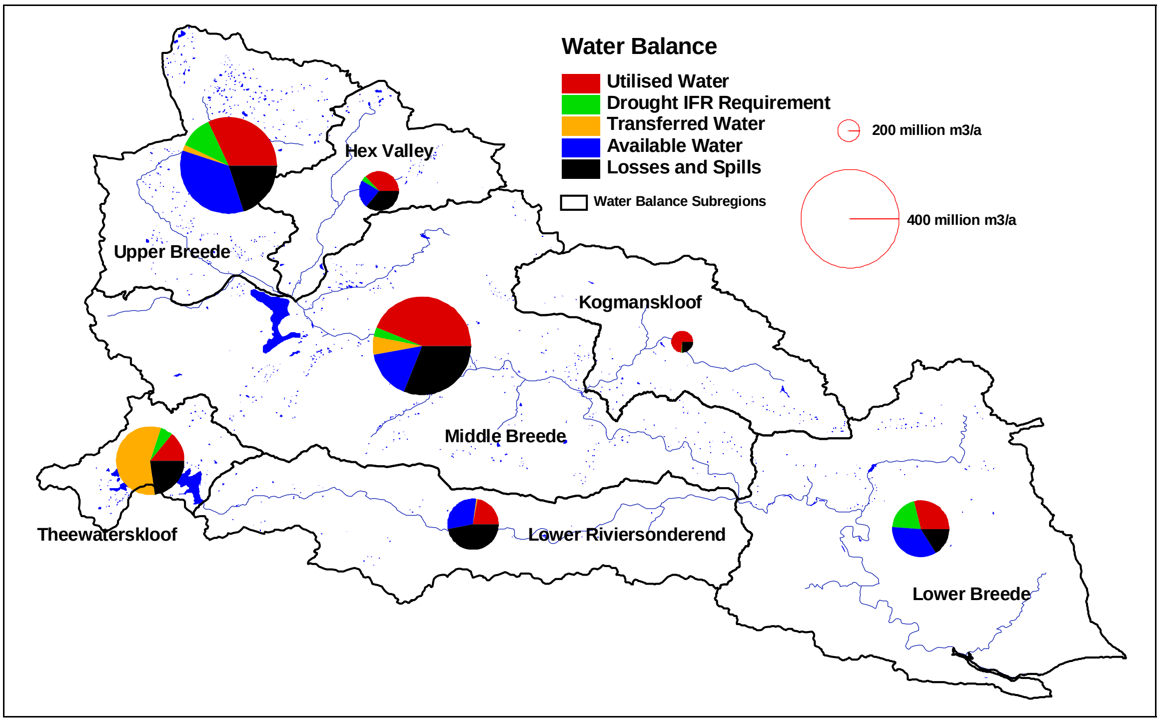
Prerequisite Components

Component 3 (Water use and Conservation) and the provisional version of **Component 20** (Management Options).

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Overview chapters on surface and groundwater availability-reliability characteristics at key locations in catchment, and a description of the balance of available water supplies and demands.	A detailed water resources analyses does not usually form part of a water quality management assessment, and should precede or be conducted simultaneously to it. Refer to the *Catchment Water Quality Assessment Guide* for a description of how to produce this output.
Eutrophication assessment outputs	
This component would not be undertaken differently from that of a generic catchment assessment study. The outputs are therefore the same as the ones described in the *Catchment Water Quality Assessment Guide.*	Refer to the *Catchment Water Quality Assessment Guide* for a description of how to produce the outputs.
SOURCES	
Planning or Design Reports with the following themes: *Hydrology; Water Resources; System Analysis; Water Demands; Water Supply Augmentation Scheme Design*; *Groundwater Studies; Geohydrology; Demand Management*; etc.	DWAF - Directorates of National Water Resources Planning or Geohydrology, or Relevant Metropolitan or Local Councils.
Reports with the following themes: *Catchment Management; Catchment Management Plans*; etc.	DWAF – Regional Offices Catchment Management Agencies.

CHECKLISTS
Apply checklists of **Components 3** and **20**.
DISPLAY AND PRESENTATION OPTIONS

Example of a map showing a water balance in different sub-catchments of the Breede River basin.



Example of a table listing a water balance for a water management area (DWAF, 2004).

Table 3d: Reconciliation of Water Requirements and Available Water for the Year 2000 (million m³/annum)

Component/Sub-area	Local Yield	Transfers In (2)	Local Requirements	Transfers Out (2)	Balance (1)
Upper Crocodile	336	279	556	17	42
Apies/Pienaars	186	182	280	87	1
Elands	86	71	113	24	20
Lower Crocodile	59	112	171	0	0
Total for Catchment	**667**	**519**	**1120**	**3**	**63**

COMPONENT 5
Water Quality Requirements, and Constituents of Concern relating to Eutrophication

PURPOSE
Generic catchment assessment context
Section 9(h) of the National Water Act specifies that the "Needs and expectations of existing and future water users" be taken into account when developing a catchment management strategy. Not all the users have the same water quality requirements, are not concerned about the same water quality constituents, and have different tolerances for changes in water quality. This component is aimed at identifying the water quality required by different user groups because it provides one of the measures against which the present water quality can be assessed.
Eutrophication assessment context
In the context of an eutrophication assessment, the objective is to identify the primary and secondary variables of concern. Primary variables of concern are often related to the symptoms of eutrophication (nuisance or toxic algae, unpleasant odours etc.) while secondary variables of concern are more related to the causes (elevated nutrient concentrations, improvement in water clarity, etc.). The implication in terms of eutrophication related water quality is that the constituents of concern regarding nutrient enrichment be identified and that the requirements for these constituents be documented.
Purpose
The purpose of this component is to describe the water quality requirements for each water user. The default water quality requirements should at least be the Target Water Quality Range for nutrients and eutrophication related variables as specified in the South African Water Quality Guidelines. However, where appropriate, the requirements should be made site specific to account for local conditions.
Prerequisite components
To undertake this component, the following information should be available: Initial scoping (**Component 0**), Reserve water quality requirements (**Component 2**), Water users in the study area (**Component 3**), draft Water quality issues (**Component 15**).

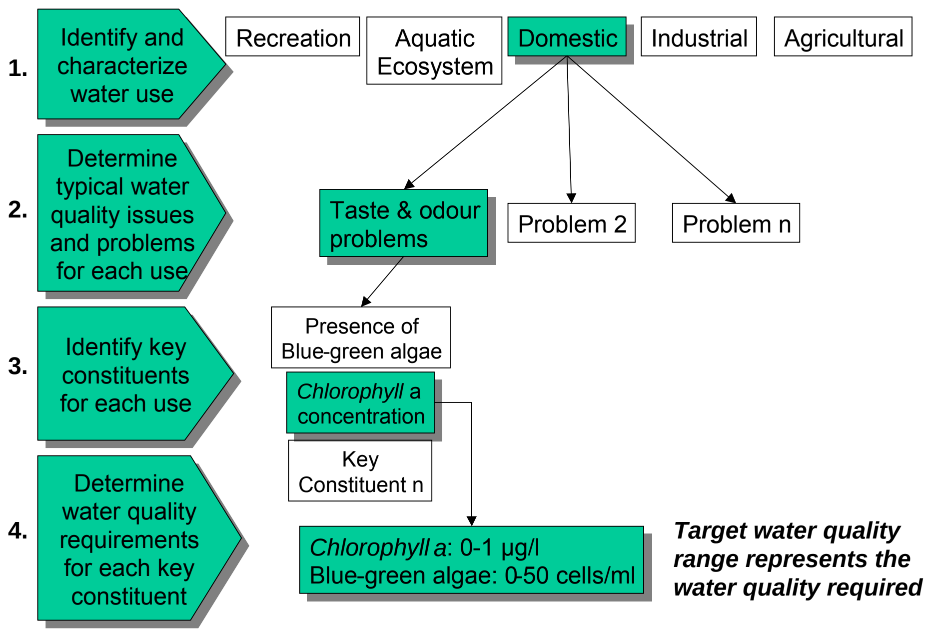
OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The Catchment Water Quality Assessment Guide describes two outputs, an inventory of water quality issues and an inventory of water quality constituents.	Refer to *Catchment Water Quality Assessment Guide* for a description of how to develop the two inventories.
Eutrophication assessment outputs	
Inventory of the eutrophication related water quality issues and problems that concern different water users in the study area.	Public participation process or specialist knowledge and insights of the study area. Use the checklist as a guide to identify the water quality variables of concern. Also refer to the checklist of **Component 14** for a list of typical eutrophication related water quality issues and concerns and the variables associated with it.
Inventory of eutrophication related water quality constituents and target water quality ranges for different water uses.	Summarize the target water quality guidelines for the eutrophication related water quality constituents for the different water uses using the South African Water Quality Guidelines. Develop site-specific guidelines where the SA Water Quality Guidelines are not appropriate for local conditions.

	Summarize the water quality reserve requirements for aquatic ecosystems. If a water quality reserve for aquatic ecosystems does not yet exist, use the default "natural" range values for nutrients and *chlorophyll-a* as an initial target for aquatic ecosystem requirements.
Inventory of resource water quality objectives for nutrients.	Document any resource water quality objectives that have been set for nutrients and other eutrophication related water quality variables.

DETAILED METHODS

The steps to identify site specific water quality requirements are (see example below):

- Identifying and characterising the main water uses for a specific water resource,
- Determining the water quality issues or problems experienced by the main water users,
- Identifying the water quality constituents associated with the each problem or issue, and
- Specifying a target water quality range for each of the key constituents.



SOURCES

The primary sources of information on user requirements for water uses in South Africa are the South African Water Quality Guidelines, the Assessment Guide for Domestic Water Supply, and the SABS specifications for drinking water.

South African Water Quality Guidelines, Vol 2 (1996): Volume 1: Domestic water use Volume 2: Recreational water use Volume 3: Industrial water use Volume 4: Agricultural water use: Irrigation Volume 5: Agricultural water use: Livestock watering	Can be obtained from the DWAF (hard copy or on CD): Director: Water Quality Management Web page: www.dwaf.gov.za

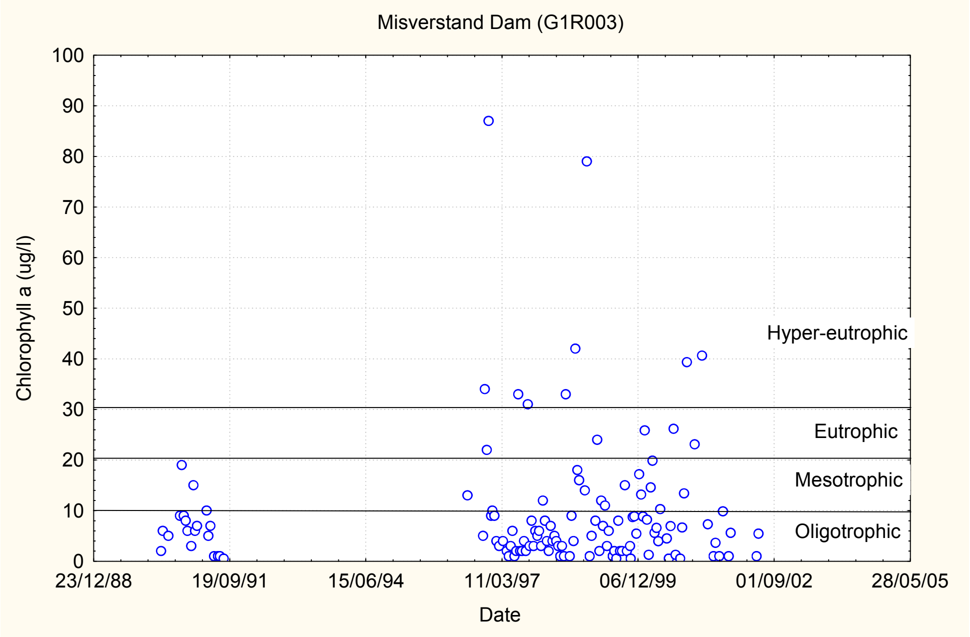
Volume 6: Agricultural water use: Aquaculture Volume 7: Aquatic ecosystems Volume 8: Field guide	
Quality of domestic water supplies. Volume 1: Assessment Guide. Second edition. Water Research Commission Report TT 101/98.	Can be obtained from: Water Research Commission Web page: www.wrc.org.za
South African Bureau of Standards 241-2001 *Specifications for drinking water.*	Can be obtained from: South African Bureau of Standards Web page: www.sabs.co.za
Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems.	Can be obtained from the DWAF: Director: Resource Directed Measures Web page: www.dwaf.gov.za
Manual for Ecostatus Determination (Version 1).	Kleynhans *et al.* (2005) Can be obtained from the Water Research Commission. Web page: www.wrc.org.za
Guideline for Determining Resource Water Quality Objectives (RWQOs), Water Quality Stress and Allocatable Water Quality.	DWAF (2006) Can be obtained from the DWAF. Web page: www.dwaf.gov.za
Local sources of information that can be used to supplement the Guidelines are:	
Site specific nutrient or chlorophyll management objectives for specific catchments or sub-catchments.	Contact the Regional Office of DWAF responsible for water quality management in the area under consideration. Contact the local authorities or Water Service Providers in the area under consideration.
Eutrophication related water quality guidelines and criteria that have been developed and applied in South Africa.	Consult the following publications: Walmsley and Butty (1980) Walmsley (1984) DWAF (2002) Van Ginkel *et al*., (2000)
International sources that can be used to supplement the South African Water Quality Guidelines include (only those which can be accessed via the Internet are listed here):	
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (1999)	Australian and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand http://www.deh.gov.au/water/quality/nwqms/index.html#quality
USEPA Water Quality Criteria	USEPA Water Quality Standards Section http://epa.gov/waterscience/criteria/nutrient/index.htm
Canadian Water Quality Guidelines	Environment Canada http://www.ec.gc.ca/CEQG-RCQE/English/Ceqg/Water/
Guidelines for Drinking Water Quality	World Health Organisation http://www.who.int/water_sanitation_health/dwq/guidelines2/en/

CHECKLISTS	
Key water uses that are affected by eutrophication related water quality problems	
Water use	***Typical variables of concern***
Domestic water use • Drinking water (health and aesthetic considerations) • Food preparation • Bathing	Algae (taste and odours) Cyanobacteria (toxicity, taste and odours) THMs
Agricultural water use • Irrigation water supply • Livestock watering • Aquaculture	Cyanobacteria (toxicity, taste and odours) Algae (phytoplankton, filamentous algae) Low dissolved oxygen concentrations Nutrients (excess fertilizer application)
Recreational use • Full contact recreation • Limited contact recreation • Non-contact recreation	Algae (phytoplankton, filamentous algae) Algal scums Water clarity Aesthetic appeal (visual impairment, odours) Anoxic products (odours)
Aquatic ecosystem health • Habitat impacts	Algae (periphyton, filamentous algae) Low dissolved oxygen Anoxic products (odours)
Industrial water use	Biofilms (biofouling) Algae (toxicity, taste and odours) Nutrients (biofouling)
Water quality constituents of concern relating to eutrophication	
Algae • Phytoplankton, periphyton Physical properties • pH, temperature, suspended solids, turbidity, water clarity Nutrients • Total and dissolved phosphorus, total and dissolved nitrogen	Metals • Copper (Cu) Other inorganic constituents • Silica (Si), total dissolved solids Organic constituents and compounds
Water quality problems or concerns and problems associated with eutrophication	
Refer to ***Component 14*** (Record of water quality issues) for a discussion of water quality concerns, problems and variables of concern that are associated with eutrophication.	

DISPLAY AND PRESENTATION OPTIONS

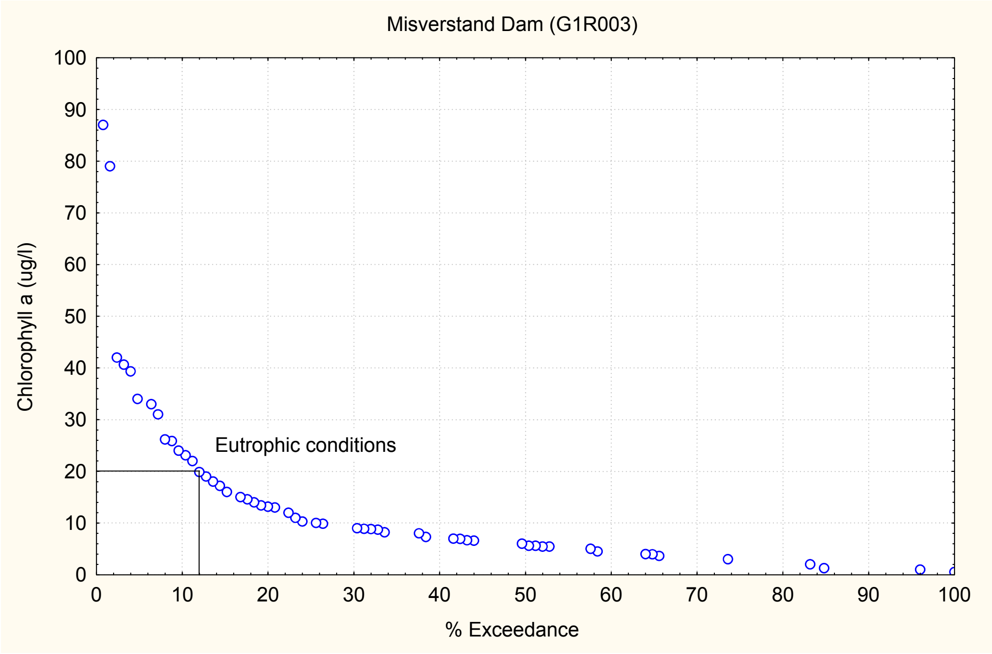
Time series plot

A time series plot like the example shown here can be used to indicate the eutrophication status at one location, over time. The example shows a time series of *chlorophyll-a* concentrations measured as Misverstand Dam on the Berg River as well as the DWAF boundary concentrations for oligotrophic, mesotrophic, eutrophic and hypertrophic conditions.



Exceedence diagram

An exceedence diagram can be used to illustrate the percentage of observations that exceeded a specific value. In the example below it can be seen that at Misverstand Dam, about 12% of the observations exceeded the 20 µg/l Chl, a eutrophic boundary value.



Summary Tables of water quality guidelines and objectives

The example below shows the water quality guidelines that were developed for the Modder/Riet Catchment Management Strategy (DWAF, 2006b).

Table 7.5: Proposed water quality guidelines

Variable	Unit	Upper Bound of Water Quality Guideline Boundary														
		Domestic			Agriculture			Recreation			Ecosystem			Combined		
		Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable
Electrical Conductivity	mS/m	70	150	370	40	90	270	X	X	X	X	X	X	40	90	270
pH Upper	units	9.0	9.5	10.0	8.4	X	X	8.5	9.0	X	8.5	9.0	9.5	8.4	9.0	9.5
pH Lower	units	6.0	5.0	4.0	6.5	X	X	6.5	5.0	X	6.5	5.5	5.0	6.5	5.5	5.0
Nitrate	mg/l N	6	10	20	5.0	30.0	X	X	X	X	0.5	2.5	10.0	0.5	2.5	10
Fluoride	mg/l F	0.70	1.00	1.50	2.00	4.00	6.00	X	X	X	0.75	1.50	2.00	0.70	1.00	1.50
Sulphate	mg/l S	200	400	600	1000	1500	2000	X	X	X	52.0	100.0	200.0	52	100	200
Sodium	mg/l Na	100	200	400	70	115	230	X	X	X	31.0	60.0	120.0	31	60	120
Potassium	mg/l K	25	50	100	X	X	X	X	X	X	X	X	X	25	50	100
Magnesium	mg/l Mg	30	70	100	X	X	X	X	X	X	23.0	50.0	100.0	23	50	100
Calcium	mg/l Ca	32	80	150	X	X	X	X	X	X	348.0	700.0	1400.0	32	80	150
Chloride	mg/l Cl	100	200	600	100	175	350	X	X	X	537.0	1000.0	2000.0	100	175	350
Ammonia	mg/l N	X	X	X	5.0	30.0	X	X	X	X	0.057	0.121	0.650	0.057	0.121	0.65
Orthophosphate	mg/l P	X	X	X	X	X	X	X	X	X	0.005	0.025	0.050	0.005	0.025	0.050
Total Hardness	mg/l $CaCO_3$	100	200	300	X	X	X	X	X	X	X	X	X	100	200	300
Sodium Adsorption Ratio	units	X	X	X	2	8	15	X	X	X	X	X	X	2	8	15
Faecal Coliforms	CFU/100 ml	X	X	X	1.0	1000.0	X	130	600	2000	X	X	X	1	600	2000

The example below shows water quality objectives, including objectives for nutrients, which were developed for the Modder/Riet system (DWAF, 2006b).

Table 7.6: Water Quality Objectives (95TH percentile values) For the Modder and Riet River Catchment

Variable	Unit	Objective
Electrical Conductivity	mS/m	90
pH Upper	units	9
pH Lower	units	5
Nitrate	mg/l N	2.5
Fluoride	mg/l F	1
Sulphate	mg/l S	100
Sodium	mg/l Na	100
Potassium	mg/l K	50
Magnesium	mg/l Mg	50
Calcium	mg/l Ca	150
Chloride	mg/l Cl	150
Ammonia	mg/l N	0.3
Nitrite	mg/l N	0.25
Orthophosphate	mg/l P	0.025
Total Hardness	mg/l CaCO3	300
Sodium Adsorption Ratio	units	6
Faecal Coliforms	CFU/100ml	600

REFERENCES

Department of Water Affairs and Forestry (2002). *National Eutrophication Monitoring Programme: Implementation Manual*. [Online]. South African National Water Quality Monitoring Programmes Series.

Available: http://www.dwaf.gov.za/IWQS/eutrophication/NEMP/NEMP_implementation.htm

Department of Water Affairs and Forestry (2006a). *Resource Directed Management of Water Quality Series: Management Instruments. Volume 4.2: Guideline for Determining Resource Water Quality Objectives (RWQOs), Water Quality Stress and Allocatable Water Quality.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.2, Edition 2. ISBN No. 0-621-36793-1. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (2006b). *Development of a Catchment Management Strategy for the Modder and Riet Rivers in the Upper Orange Catchment Management area: Catchment Management Strategy*. Report prepared by BKS for the DWAF Free State Regional Office.

Kleynhans, C J, Louw, M D, Thirion, C, Rossouw, J N and Rowntree, K. (2005). *River Ecoclassification: Manual for Ecostatus Determination. Version 1*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Van Ginkel, C E, Hohls, B C, Belcher, A, Vermaak, E and Gerber, A. (2000). *Assessment of the Trophic Status Project*. Internal Report No. N/0000/00/DEQ/1799. Institute for Water Quality Studies. Department of Water Affairs and Forestry. Pretoria.

Summary available online: http://www.dwaf.gov.za/IWQS/eutrophication/NEMP/default.htm

Walmsley, R D. (1984). *A chlorophyll-a trophic status classification system in South Africa*. Special report, Water Research Commission.

Walmsley, R D and Butty, M. (1980). *Guidelines for the Control of Eutrophication in South Africa*. Water Research Commission, National Institute for Water Research, CSIR.

COMPONENT 6
Eutrophication Related Water Quality for Streamflow, Reservoirs and Wetlands

PURPOSE

Generic catchment assessment context

The present water quality status needs to be described in order for the CMA and/or the Department and other stakeholders to make informed decisions on how to manage water quality in a specific catchment. An analysis of water quality data needs to provide information on the present water quality status, how the status may possibly change over time if current trends continue and, by comparing it to the user water quality requirements, determine whether user requirements are met or not.

Eutrophication assessment context

The present eutrophication status needs to be described to determine by how much water quality has deteriorated in a study area and to focus the development of management options on those variables and "hot spots" where the desirable uses of water are compromised. An analysis of water quality data needs to provide information on the present eutrophication status, how the status has changed over time and whether user water quality requirements are being met or not.

Purpose

The purpose of this component is to obtain eutrophication related water quality data and information for the study area from appropriate sources and to analyse the data to describe:

- Eutrophication related water quality in the catchment at an overview level
- Spatial trends for the water quality variables of concern
- Temporal trends for the water quality variables of concern
- The fitness of water resources for the key water uses in the study area

Prerequisite Components

To undertake this component, the following information should be available:

Component 1 – Details of physical, developmental and administrative attributes and characteristics of the catchment relevant to water resources management, **Component 3** – Water use and conservation and **Component 5** – User water requirements, constituents of concern and water quality management objectives.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
For a generic catchment assessment study, the outputs would include an inventory of water quality data sources and a description of the temporal and spatial trends in water quality, summarised in a water quality assessment report.	The methods for attaining the output are described in the Catchment Water Quality Assessment Guide document (DWAF, 2003) and are similar to the methods described for eutrophication below.
Eutrophication assessment outputs	
Inventory of eutrophication related water quality data sources for the study area. *Note: A detailed assessment of different monitoring programmes are undertaken in **Component 11**.*	Identify the key sources of data and information for the study area using the national, provincial and local authorities, water service providers, and other institutions listed in the checklist below. For each data source, list the name of the monitoring program, name of the institution responsible for the monitoring programme, and key objectives of their monitoring programme.
Inventory of key water quality reaches in the study area where eutrophication interferes with the desirable water uses.	• Define the geographical boundaries and describe the key water quality reaches. • Compile a GIS map showing the location of the water quality reaches. *Also refer to **Component 1**.*

<table>
<tr><td>Temporal trends in eutrophication related water quality variables</td><td>• Describe and illustrate the temporal trends, at specific points in the study area, for eutrophication related water quality constituents, using the presentation and display options listed below. Use statistical procedures to determine whether the trends are significant.
• Use a statistical software package (such as WQStat or Statistica) and the Kruskal-Wallis test for seasonality, to determine whether there is seasonality in the data. Seasonality can be illustrated with monthly box-and-whisker plots (see display options below).</td></tr>
<tr><td>Spatial trends in key water quality variables</td><td>• Describe and illustrate spatial trends, in eutrophication related water quality, along the length of key water quality reaches.
• Use statistical procedures to confirm the statistical significance of spatial trends.</td></tr>
<tr><td>Eutrophication assessment report</td><td>Compile an eutrophication assessment report which addresses the following aspects:
• A summary of the affected water users in the study area (refer to detailed descriptions in Component 12).
• A summary of the eutrophication problems experienced by users (refer to detailed descriptions in Components 4 and 15).
• List of the eutrophication related water quality variables investigated (refer to detailed descriptions in Components 4 and 15).
• A description of the temporal trends determined.
• A description of the spatial trends determined.</td></tr>
<tr><th colspan="2">METHODS AND TOOLS</th></tr>
<tr><td colspan="2">Standard methods for the analysis of water quality data applies. Graphical and statistical procedures for analysing and reporting on water quality data are described in the document Conceptual design report for a National River Water Quality Assessment Programme (Harris et al., 1992). Other detailed descriptions of water quality data analysis can be found in Gilbert (1987) and Ward et al. (1990). See also the display options below.</td></tr>
<tr><th colspan="2">SOURCES</th></tr>
<tr><td colspan="2">Eutrophication related water quality data and information are generally collected as part of monitoring water quality in a catchment. The Department of Water Affairs and Forestry probably operates the most inclusive water quality monitoring programme in the country. Other potential sources include Water Service Authorities (local authorities, metropolitan councils, etc.), Water Service Providers such as water boards, as well as research institutions. The list of potential data sources is by no means complete and is presented here to serve as a guide to the types of organizations involved in collecting water quality data. It is up to the study team to identify the key sources of water quality data and information in the catchment under investigation.</td></tr>
</table>

National government department data sources	
Department of Water Affairs and Forestry • National Eutrophication Monitoring Programme • National chemical water quality monitoring programme • Groundwater quality	Director: Resource Quality Services Private Bag X313 Pretoria 0001 Website: www.dwaf.gov.za
DWAF Regional Offices Regionally, offices often monitor specific water quality variables as part of their water quality management activities.	Contact details of regional offices available on the DWAF website Website: www.dwaf.gov.za
Catchment Management Agencies	Catchment Management Agencies may in future be delegated the responsibility of monitoring in their Water Management Area. The DWAF Regional office is the de facto CMA until a CMA has been established.
Provincial government sources	
Provincial nature conservation departments mostly participate in the River Health Programme that collects information on the ecosystem health of rivers. Some observations might be available about excessive periphyton growth at survey sites.	Contact the relevant provincial nature conservation department about eutrophication related water quality data that may be available from them, or Visit the River Health Programme website Website: www.csir.co.za/rhp
Examples of Water Service Providers and Water User Associations involved in water quality monitoring	
Most Water Service Providers have extensive monitoring networks in their area of operation and often collect specialist eutrophication data such as algal species composition.	Rand Water Website: www.randwater.co.za Umgeni Water Website: www.umgeni.co.za
Water user associations (WUAs), such as former Irrigation Boards or Water Conservation Boards, may be a source of qualitative observations on eutrophication, such as excessive filamentous algae in canals or nuisance algal blooms in irrigation dams.	WUA's are too numerous to list in this document and it is recommended that WUA's in the study area be identified and contacted about the availability of water quality data. *Refer to **Component 12**.*
Examples of Water Service Authorities data sources	
City of Cape Town	City of Cape Town Scientific Services Website: www.capetown.gov.za
Durban Metropolitan Council	Durban Metro Water Services Laboratory Website: www.durban.gov.za

Examples of other organizations involved in eutrophication studies and monitoring	
Universities and Technikons sometimes collect project specific water quality data.	Contact the natural sciences departments at Universities and Technikons in the study area to find out whether they have undertaken any project-specific water quality data collection that would be relevant to an eutrophication assessment study.

DISPLAY AND PRESENTATION OPTIONS

Summary statistics

Summary statistics provide a good overview of the order of magnitude of concentrations recorded for different variables in the study area. Summary statistics can include the average, median, minimum, maximum, standard deviation and number of samples over a specified period of time. The example below shows the summary statistics output of statistical analysis of PO_4-P concentrations measures in the Pongola River catchment.

MONITORI	PO4_P Means	PO4_P N	PO4_P Std.Dev.	PO4_P Variance	PO4_P Minimum	PO4_P Maximum	PO4_P Q25	PO4_P Median	PO4_P Q75	PO4_P 10%tile	PO4_P 90%tile
W4H003Q0	0.021	261	0.024	0.001	0.003	0.329	0.011	0.017	0.026	0.003	0.038
W4H004Q0	0.022	326	0.039	0.001	0.003	0.458	0.008	0.014	0.025	0.003	0.043
W4H006Q0	0.026	604	0.077	0.006	0.003	1.770	0.010	0.018	0.027	0.003	0.042
W4H007Q0	0.018	41	0.022	0.000	0.003	0.148	0.009	0.013	0.019	0.007	0.027
W4H008Q0	0.067	113	0.065	0.004	0.003	0.456	0.025	0.049	0.097	0.011	0.140
W4H009Q0	0.027	262	0.037	0.001	0.003	0.438	0.011	0.019	0.029	0.003	0.047
W4H010Q0	0.013	39	0.008	0.000	0.003	0.049	0.007	0.013	0.015	0.005	0.020
W4H011Q0	0.028	56	0.048	0.002	0.003	0.285	0.003	0.012	0.033	0.003	0.070
W4H012Q0	0.014	3	0.007	0.000	0.009	0.022	0.009	0.010	0.022	0.009	0.022
W4H013Q0	0.016	280	0.013	0.000	0.003	0.117	0.009	0.013	0.020	0.006	0.027
W4H014Q0	0.020	251	0.034	0.001	0.003	0.434	0.009	0.013	0.020	0.006	0.032
W4R001Q0	0.020	244	0.047	0.002	0.003	0.671	0.008	0.012	0.018	0.003	0.033
W4R001Q1	0.024	4	0.004	0.000	0.021	0.030	0.021	0.023	0.028	0.021	0.030

The example below demonstrates how a colour coding system can be used to illustrate the fitness for use (from DWAF, 2006). For example, blue indicates ideal water quality, green is acceptable water quality, and orange is tolerable water quality.

Table 6.4: Water quality assessment results for Recreation, Ecology and Industry

(Values shown are 75th percentile values)

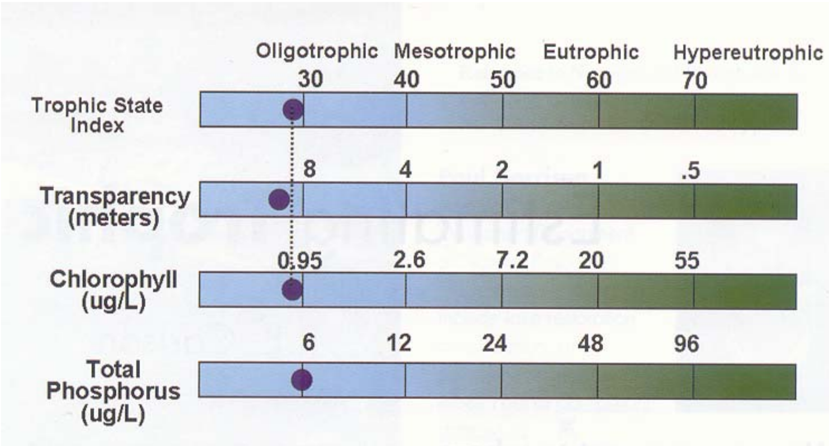
	SUB-CATCHMENT	DESCRIPTION	STATION	RECREATION	ECOLOGY				INDUSTRY		
				pH	pH	Ammonia (mg/l N)	Flouride (mg/l)	Phosphorous (mg/l)	Silica	Sulphate (mg/l)	Chloride (mg/l)
1	Upper Modder	Rustfontein Dam	C5R003	8.37	8.37	0.06	0.30	0.04	2.59	13.7	7.10
2	Middle Modder	Krugersdrift Dam	C5R004	8.61	8.61	0.06	0.31	0.09	2.35	24.7	36.6
3	Lower Modder	Tweerivier	C5H018	8.35	8.35	0.05	0.27	0.02	8.16	113	159
4	Upper Riet	Tierpoort Dam	C5R001	8.36	8.36	0.07	0.40	0.21	6.32	23.3	12.7
5	Middle Riet	Kalkfontein Dam	C5R002	8.52	8.52	0.08	0.54	0.03	1.51	43.8	53.7
6	Lower Riet	Aucampshoop	C5H016	8.31	8.31	0.05	0.25	0.02	7.61	147	200

Trophic State Index

The trophic state index developed by Carlson can be used to assess the current (or historical) state of eutrophication (Carlson, 1977, 2007; Carlson and Havens, 2005). The index is based on water clarity (measured as the Secchi disk depth), the algal concentration (measured as the *chlorophyll-a* concentration) and the nutrient concentration (measured as the total phosphorus concentration). Below is an example of how the results can be displayed graphically (Carlson, 2007).

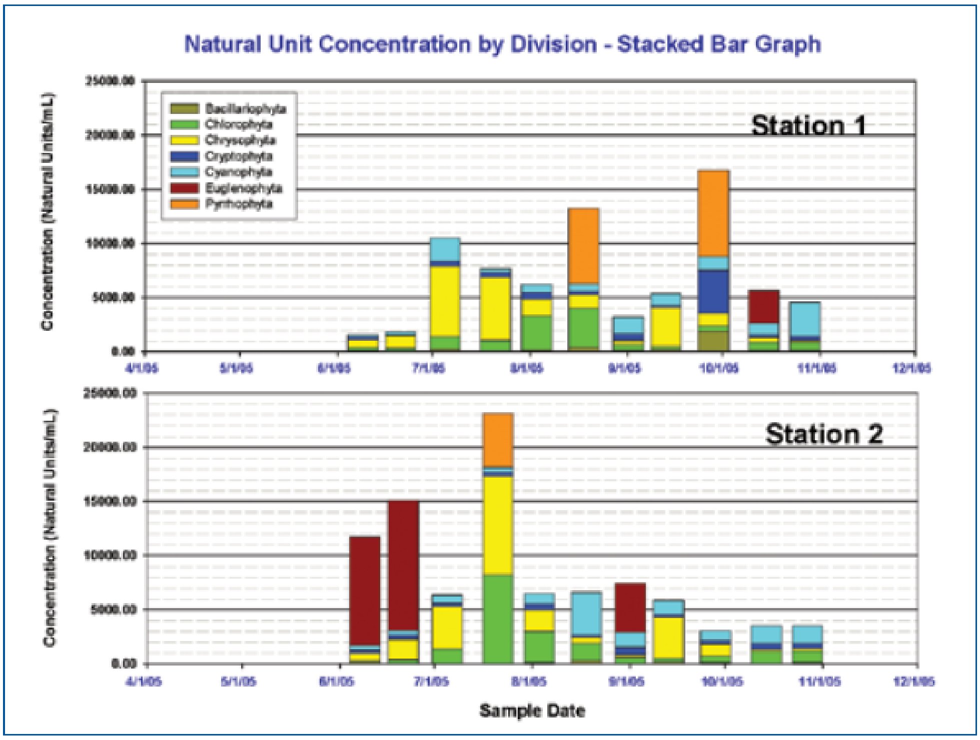
The following equations are used to calculate the three indices:

Transparency	TSI = 60 – 14.41 ln (SD)	SD = Secchi disk depth (m)
Chlorophyll	TSI = 9.81 ln(CHL) + 30.6	CHL = *Chlorophyll-a* (µg/l)
Total-P	TSI = 14.42 ln(TP) + 4.15	TP = Total phosphorus (µg/l)



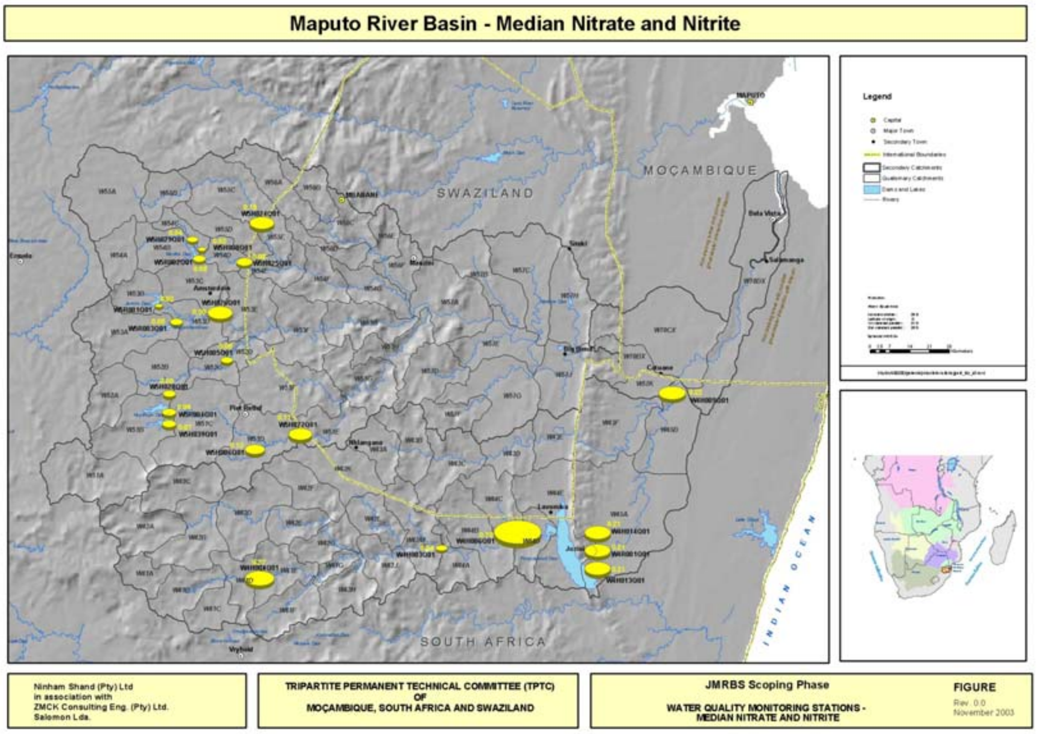
Displaying algal data

The figure below demonstrates how stacked box plots can be used to illustrate the algal species composition of different samples (St. Amand and Chapman, 2007).



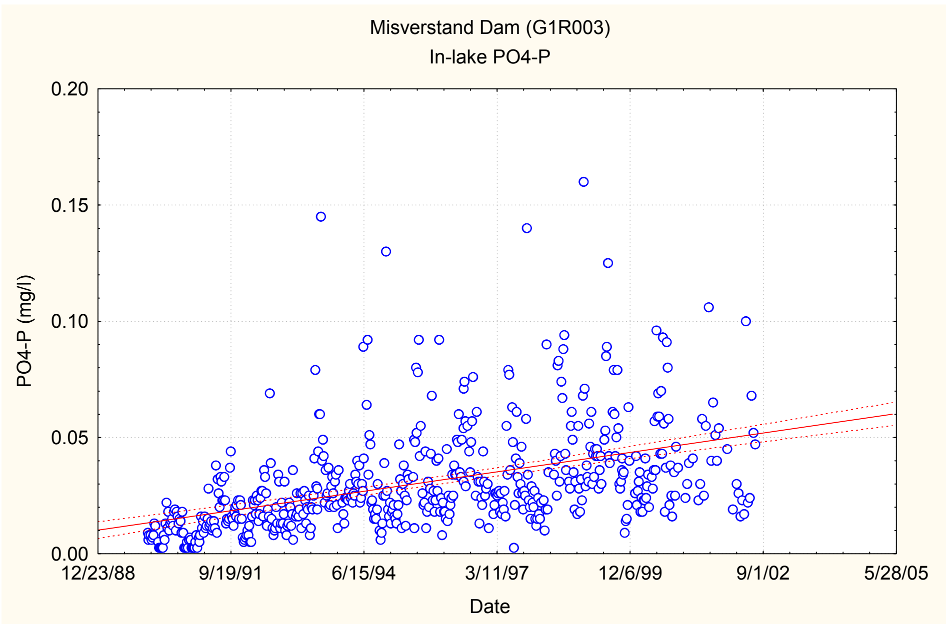
GIS maps for synoptic overviews

GIS maps of the study area can provide a good spatial overview of eutrophication related water quality in a catchment. The maps are used to illustrate spatial trends in water quality rather than actual values. In the example below the size of the circles are proportional to the median concentration.



Time series plot

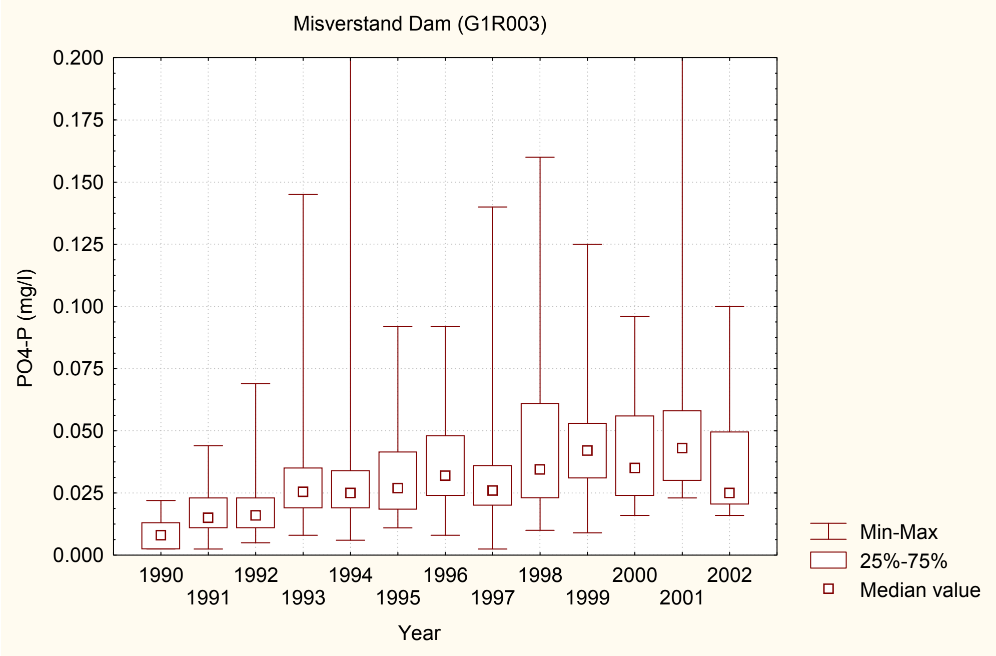
A plot of the water quality variable against time. A visual examination of the time series plot can show suspect outliers as well as some indication of seasonal or longer-term trends. In the example below there appears to be an increase in PO_4-P concentrations over time as well as some seasonal differences in quality. Fitting a linear line through the points provides some indication of a long-term trend.



Annual box-and-whisker plot

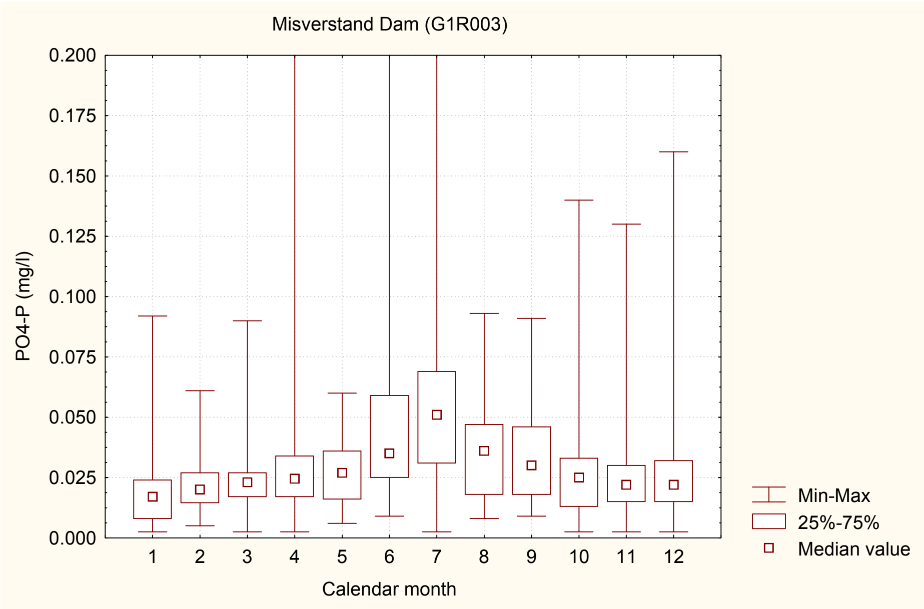
A box-and-whisker plot is based on a five number summary consisting of the 95th (or maximum), 75th, 50th, 25th and 5th (or minimum) percentiles. The box is enclosed by the 75th and 25th percentile and contains the 50th percentile (also called the median). The whiskers join the box to 95th and 5th percentiles or maximum or minimum depending on the software being used.

An annual box-and-whisker plot is obtained by plotting the data collected during a specific year as a box-and-whisker plot. An examination of the annual box-and-whisker plot of PO_4-P concentrations indicates that there has been an increase in concentrations since the early 1990's.



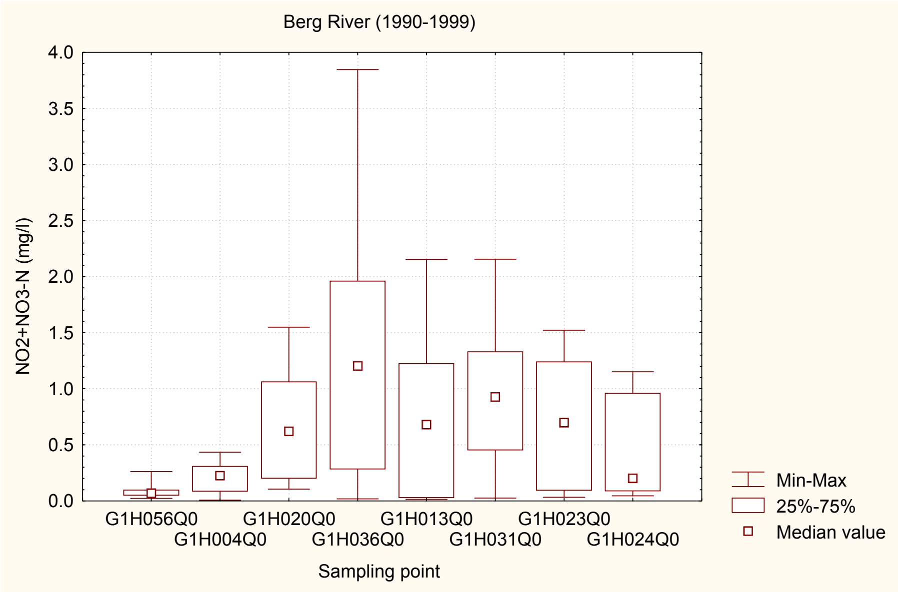
Seasonal box-and-whisker plot

A seasonal box-and-whisker plot is obtained by plotting all the data collected during a specific month as a box-and-whisker graph. An examination of a monthly box-and-whisker plot can give an indication of seasonal differences in the data. This can be confirmed with statistical tests for seasonality. For example, this box-and-whisker plot shows some seasonality with higher PO_4-P concentrations occurring during the early and mid-winter months in a winter rainfall region.



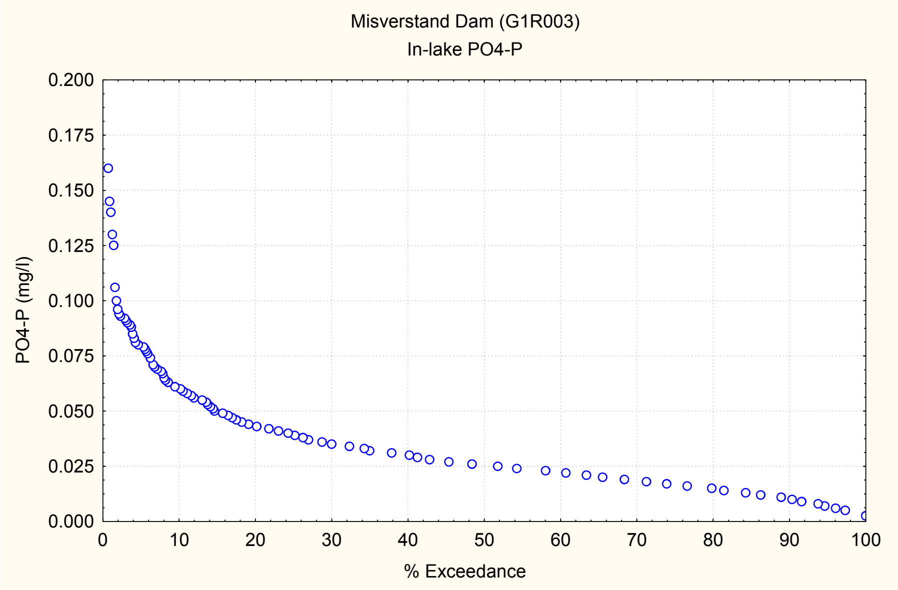
Spatial box-and-whisker plot

A spatial box-and-whisker plot is compiled by arranging the sampling stations according to their downstream position in the river. An examination of a spatial box-and-whisker plot can give an indication of the water quality changes along the length of a river. For example, this spatial box-and-whisker plot of NO_2+NO_3-N concentrations along the Berg River shows a sharp increase in the Paarl/Wellington area (G1H020 and G1H036) and a gradual decrease in a downstream direction even though the concentrations remain relatively high.



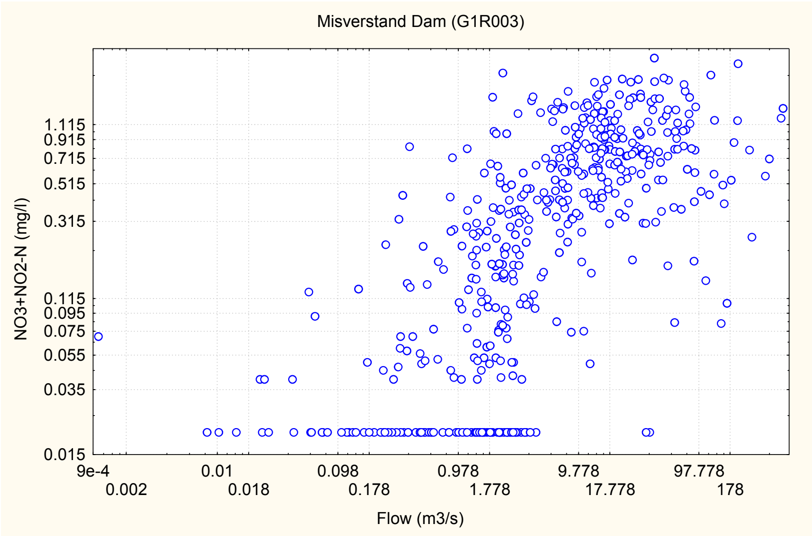
Exceedence diagram

An exceedence diagram shows the percentage of time a specific concentration was exceeded in the data recorded. This is obtained by ranking the data from large to small and calculating the plotting position as the rank divided by the total number of data+1.



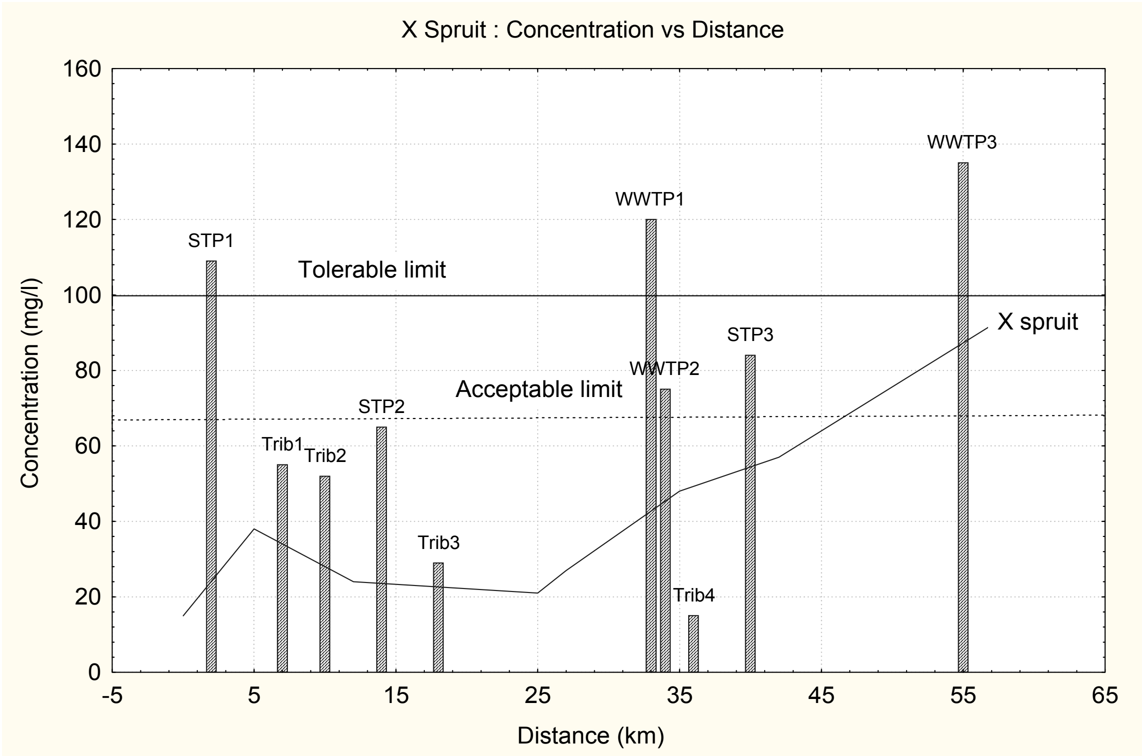
Concentration *vs* Flow plot

A plot of nutrient concentration against flow can be used to illustrate the relationship with flow. For example, it may illustrate that there are sufficient nutrients available on the catchment surface to be washed off during rainfall events, that is, the nutrient concentration increases as flow increases, as illustrated in the log-log plot below.



Concentration *vs* Distance Diagram

A concentration vs. river distance diagram can provide valuable information on spatial changes in water quality especially when reconciling source water quality data with in-river data. The example below illustrates the effect of sampling the river, tributaries and point sources on a specific day and then plotting the concentrations as a function of river distance. This type of graph can be used to assess whether the changes concentration can be explained with data from the known point sources in the catchment. A more accurate estimate can be obtained for catchment processes if concentrations are replaced with constituent loads.



REFERENCES

Carlson, R E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, 22:361-369.

Carlson, R E and Haven, K E. (2005). Graphical methods for the interpretation of relationships between trophic state variables. *Lake and Reservoir Management*, 21:107-118.

Carlson, R.E. (2007). Estimating Trophic State. *Lakeline*, 27(1): 25-28.

Department of Water Affairs and Forestry (2006). *Development of a Catchment Management Strategy for the Modder and Riet Rivers in the Upper Orange Catchment Management area: Catchment Management Strategy*. Report prepared by BKS for the DWAF Free State Regional Office

Gilbert, R O. (1987). Statistical *Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York, NY, USA

Harris, J, Van Veelen, M and Gilfillan, T C. (1992). *Conceptual design report for a National River Water Quality Assessment Programme*. Water Research Commission, Report No. 204/1/92, Pretoria, South Africa.

St. Amand, A and Chapman, A. (2007). Using plankton data. *Lakeline,* 27(1):34-40.

Ward, R C, Loftis, J C and McBride, G B. (1990). *Design of Water Quality Monitoring Systems*. Van Nostrand Reinhold, New York, NY, USA.

COMPONENT 7

Point Source Waste Discharges and Source Characteristics relating to Eutrophication

PURPOSE	
Generic catchment assessment context	
Wastewater treatment works or industrial plants usually discharge their effluents to stream channels or surface water bodies through conduits such as outfall pipes, ditches or canals. Such "end-of-pipe" sources of pollutant loading of surface water bodies are known as point sources. The quality of effluent discharges must conform to standards prescribed in licences or other forms of authorisations. Such effluent quality standards are intended to safeguard the fitness-for-use of the receiving waters. Point source assessment does not only comprise the processing of available effluent stream records, but may also include scrutiny of streamflow water quality records to identify unknown contaminant loadings, which may signify unauthorised discharges.	
Eutrophication assessment context	
In South Africa, many of the eutrophication related water quality problems are related to the cumulative effects of point source discharges of nutrient rich effluents that in turn contribute to deteriorating fitness-for-use in terms of the requirements of specific water users (e.g. Van Ginkel *et al*, 2000, Walmsley, 2003). Consequently, the assessment of point source nutrient contaminant loads to streams, rivers and reservoirs is a prerequisite for understanding the eutrophication patterns and problems in a catchment. Point source data are also essential inputs for the configuration and calibration of eutrophication simulation models for use in water quality assessments (see **Component 9**) and the investigation of eutrophication management options. It is not only the present day point source waste discharges, but also historical waste discharge records or trends that are required for proper calibration of the models.	
Purpose	
The purpose of this component assists in understanding the eutrophication characteristics and patterns in a catchment by examining both the detailed information of the location and magnitude of individual nutrient sources but also the cumulative nutrient loads and impacts. For instance, by subtracting known point source nutrient loadings from cascading incremental load balances at flow gauging/ water quality observation (or simulation) points in a river, non-point loadings, and unauthorised point sources, can be identified and quantified.	
Prerequisite Components	
Component 1- Description of the study area.	
OUTPUTS	**HOW TO ATTAIN OUTPUTS**
Generic catchment assessment outputs	
An inventory of individual point sources in the study area listing the location, discharge volume, constituent loads, source type, primary activity involved, contact details, etc.	The inventory information can be compiled from the register of water use licences and compliance monitoring records.
Database of compliance monitoring data (sample analyses and flow rate data).	This raw data can be assembled from the records kept by DWAF (or a CMA) as responsible authority, or from the discharger's own monitoring data.
Monthly time series of historical waste discharge volumes and constituent loads.	These time series can be infilled or extrapolated from compliance monitoring data.

Eutrophication assessment outputs	
An inventory of point sources contributing high nutrient loads in the study area. The type of information to be captured includes the location and point of discharge, effluent volume, nutrient loads, type of source, and contact information of the accountable person.	Specific attention should be given to sources that are high in nutrients (see **checklist**). Current annual discharge volumes and loads are based on the monthly time series of historical discharges (the third output); and other information can be sourced from the register of water use licences.
Database of historical data of nutrient concentrations and flow rates for individual sources.	The historical data can be assembled from the records kept by DWAF as the licensing authority, or from the discharger's own monitoring data. Some additional monitoring may be required if a previously unknown point source is identified during the assessment.
Monthly time series of historical nutrient loads and effluent volumes.	These monthly nutrient time series can be developed by infilling or extrapolating the grab sample nutrient data (second output) using appropriate infilling methods (refer to **methods and tools**).

METHODS AND TOOLS

Load calculations

Generally, some effluent flow and nutrient concentration data are available for wastewater treatment discharges because monitoring requirements of the effluent discharge is specified in the water use licence issued by the DWAF.

Nutrient loads can be calculated by multiplying the concentration by the flow. The effluent discharge volume and nutrient concentrations are generally not as variable as those observed in rivers. Using discrete flow and concentration observations for estimating average loads is therefore adequate to estimate point source loads.

Two terms are generally encountered when calculating loads namely "Flux" and "Load". "Flux" is the rate at which a pollutant load passes a given point in a river or stream at a given moment. The integral of flux over time is the load. The flux is equal to the concentration multiplied by the flow at the time of the sample. "Load" is the mass of a chemical substance which passes a given point in a river or stream in a given period of time, a total quantity. The load for an entire period of interest, usually a month or a year is the sum of the daily loads in the period, or the product of the average daily load and the number of days.

SOURCES

Generic catchment assessment outputs	
DWAF pollution and other monitoring data on Water Management System (WMS).	Directorate: Resource Quality Services, DWAF Website: www.dwaf.gov.za
Water quality-focused reports or chapters in previous basin – or system analysis studies.	Director: Water Resources Planning, DWAF Website: www.dwaf.gov.za
Reports on assimilative capacity or waste load allocation studies for particular licence applications.	Director: Water Quality Management, DWAF Website: www.dwaf.gov.za
Reports on environmental management or impact assessment in urban rivers.	Metropolitan councils or local authorities

Eutrophication assessment outputs	
Nutrient data for point source stored on WMS. Old POLMON data that have not yet been imported. WMS can be obtained from the DWAF regional offices.	WMS: Director: Resource Quality Services. POLMON: Deputy-Director: Water Quality Management, any Regional Office of DWAF.
Nutrient and flow data for effluent discharges directly from the effluent producing facility.	An inventory of the licences can be obtained from the Deputy Director: Water Quality Management at the Regional Office of DWAF.
The nutrient components of water quality-focused reports or chapters in previous basin studies or system analysis studies.	Director: Water Resources Planning, DWAF Website: www.dwaf.gov.za
The nutrient components of reports on assimilative capacity or waste load allocation studies for particular licence applications.	Director: Water Quality Management, DWAF Website: www.dwaf.gov.za

CHECKLISTS

- *Source Types with high nutrient concentrations*: Wastewater and wastewater treatment plants, animal feeding lots, canning and food-processing factories, wineries and breweries, and dairy-related factories.
- *Other source types not known for high nutrient concentrations:* pulp and paper mills, textile factories, tanneries, petro-chemical plants, mine de-watering sites, ore processing plants, quarries, etc.

DWAF uses a source classification system that classifies activities and processes on a first tier assessment of the level of threat to a water resource (DWAF, 2003). The classification system describes the sector, sub-sector and activities, a class, and a threat level. Using the classification system, the following point sources probably affect the nutrient status in the catchment (DWAF, 2003):

Sector	**Class**	**Threat level**	**Sub-sector**	**Activities**
Industry	A	High	Paper, pulp or pulp products industries	Industries that manufacture paper, paper pulp or pulp products
	B	Medium	Breweries or distilleries	Produce alcohol or alcoholic products
			Chemical industries	Agricultural fertilizers
				Explosive or pyrotechnics industries that manufacture explosives.
				Soap or detergent industries (including domestic, institutional or industrial soaps or detergent industries)
			Dredging works	Materials obtained from the bed, banks or foreshores of many waters.
Agriculture	A	High	Intensive livestock operations	Feedlots that are intended to accommodate in a confined area and rear or fatten (wholly or substantially) on prepared or manufactured feed (Piggeries, Poultry, Dairies, Saleyards)
			Livestock processing industries	Slaughter animals (including poultry), Manufacture products derived from the slaughter of animals including tanneries or fellmongeries or rendering or fat extraction plants, scour, top or carb onise greasy wool or fleeces with an intended production capacity.
	B	Medium	Agriculture	Industries that process agricultural produce including dairy, seeds, fruit, vegetables or other plant material.
			Aquaculture or mariculture	Commercial production (breeding, hatching, rearing or cultivation) of marine, estuarine or freshwater organisms, including aquatic plants or animals (such as fin fish, crustaceans, mollusks or other aquatic invertebrates) but not including oysters.
	C	Low	Other farming	All other farming and agricultural activities
Settlements urban	A	High	Wastewater treatment plants	Including the treatment works, pumping stations, wastewater overflow structures and the reticulation system (> 250 kiloliters/day)
	B	Medium	Wastewater treatment plants	Including the treatment works, pumping stations, wastewater overflow structures and the reticulation system (< 250 kiloliters/day)
			Composting	And related reprocessing or treatment facilities (including facilities that mulch or ferment organic waste, or that are involved in the preparation of mushroom growing substrate, or in a combination of any such activities).
Settlements, rural/dense	A	High	All	Wastewater, waste and water supply activities in areas outside designated urban settlements

DISPLAY AND PRESENTATION OPTIONS

Tables summarising point source information

Point source information can be summarised in table format as illustrated below (from DWAF, 1998).

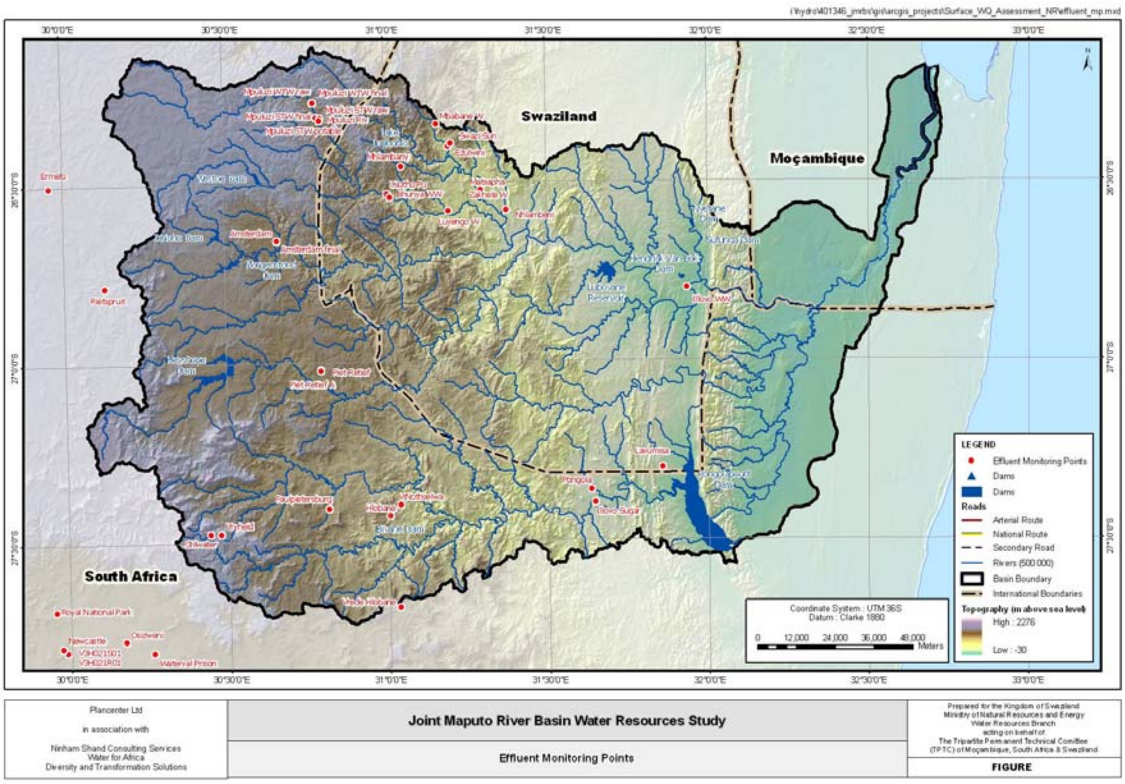
Table 5.8 Mean monthly loads from point sources in the Buffalo & Yellowwoods Catchments (for 1990 - 1996)

Point Source	TDS Load (ton/month)	PO_4 Load (ton/month)	SS Load (ton/month)
KWT STW	32.48	0.125	**0.842**
Zwelitsha STW	85	**0.345**	1.935
King Tanning	21	0.008	0.130
Da Gama Textiles	**104**	0.042	1.073
Bisho STW	22.43	0.124	1.0
Breidbach STW	6.53	0.037	0.448
Ilitha STW	8.25	0.058	0.411

Note: the highest loads are shown as bold values

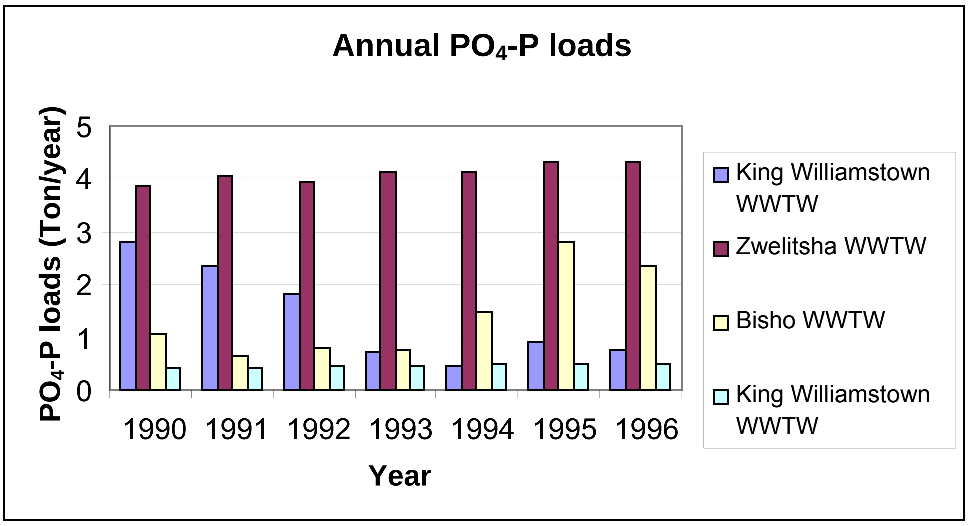
Catchment scale maps showing the location of point sources

Example of a catchment scale map showing the location of wastewater discharges and effluent monitoring points.



Graphs showing point source loads

The bar graph below illustrates the change in annual phosphate loads from four wastewater treatment works in the Buffalo River system (data from DWAF, 1998).



REFERENCES

Department of Water Affairs and Forestry (DWAF) (1998). Amatole Water Resource System Analysis Phase II. Volume 3: *Water quality Modelling. Part 1: Monthly model configuration*. DWAF Report No. PR 000/00/1798.

Department of Water Affairs and Forestry (DWAF) (2003). *Source management in South Africa* [online]. First edition for comment. Department of Water Affairs and Forestry, Pretoria.

Available: http://www.dwaf.gov.za/dir_wqm/docsframe.htm

COMPONENT 8
Non-Point Source Water Quality Loadings and Impacts relating to Eutrophication

PURPOSE

Generic catchment assessment context

Non-point sources (or diffuse sources) represent *land-use types, areas and activities* that result in the mobilisation and discharge of contaminants in any manner other than through a well defined point such as discharge pipe or group of pipes. In South Africa, non-point source pollution of surface waters is largely caused by rainfall and the associated surface runoff or groundwater discharge. Non-point sources are generally diffuse and intermittent, contributing to contamination of water resources over a widespread area, such as storm washoff and drainage from urban or agricultural areas. Alternatively, they may be concentrated, associated with localized high activity areas, such as mines, feedlots, landfills and industrial sites.

Non-point source contributions are generally not monitored directly but are inferred using techniques such as experience-based interpretation, mass balances against measured point source loadings, or simulation modelling. The nature of impacts determines spatial and temporal scale at which non-point sources need to be assessed which in turn determines the range of techniques that can be used for the analysis. Short-term, event-driven problems occurring at a local scale requires analysis at finer spatial and temporal resolutions than what is required for longer term or relatively constant problems with regional scale impacts.

Understanding point and non-point sources helps with the interpretation of water quality characteristics and patterns in a catchment because it yields both detailed and cumulative information on the location and magnitude of primary impactors on ambient water quality. Non-point source assessments can be very complex because they relates to the whole hydrological cycle. This Component can be undertaken at different levels of interest, each with a different suite of assessment tools. At a *scoping* level, it may simply determine whether, in a particular sub-catchment, non-point sources contribute more to water quality concerns than point sources, or which sub-catchment in a basin has the highest non-point loadings. At an *evaluation* level individual non-point source impacts are distinguished at the catchment level. At a *prioritisation* level the key source types, areas and activities are identified which require management attention.

Eutrophication assessment context

Non-point sources of nutrients are generally associated with surface runoff and sediment washoff from fertilised agricultural fields, atmospheric deposition of nitrogen compounds, and washoff from urban residential, commercial and industrial areas. Leaking sewers in poorly serviced dense settlements and poor or non-existent sanitation in informal settlements also represent important sources of diffuse nutrient loadings. Poor runoff control from concentrated sources such as feedlots and waste disposal sites can also contribute significantly to diffuse source nutrient loads.

Purpose

The purpose of this Component, together with the point source information from **Component 7** provides an overall understanding and interpretation of the nutrient dynamics in a catchment or study area by identifying and estimating the magnitude of the primary nutrient sources. The document, *A Guide to Non-point Source Assessment* (Pegram and Görgens, 2001) describes a protocol (scoping, evaluation and prioritisation levels) and a suite of predictive tools that can be applied to assess non-point source loadings and impacts. The configuration and calibration of these water quality predictive tools (see **Component 9**) require land-use and water use information as essential inputs. Not only the current day information, but also historical land-use and water use trends are required for proper calibration of the models over a representatively long time period.

NB: ***Component 9*** *and* ***Component 8*** *should be considered and developed simultaneously, as there is a strong overlap between them and their underlying processes.*

Prerequisite Components

Components 1, 3, 4, 5, 6, 7, and **9** need to be substantially completed and **14**, **15** and **16** reasonably progressed before this Component can be finalised.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Catchment Water Quality Assessment Guide* describes methods to assess non-point source (NPS) impacts at a *coarse scoping* level, more detailed *evaluation* level, and detailed *prioritisation* level. This approach has also been adopted for eutrophication assessment studies.	
Eutrophication assessment outputs	
Scoping level: Aggregated (e.g. mean annual) nutrient loadings at a relatively coarse scale, such as quaternary catchments, or coarser. *Note: the assessment tools referred to in this section are outlined in* ***Component 9*** *(Predictive tools)*	Refer to Pegram and Görgens (2001) (Part 3c) for guidelines on assessing the relative contribution from NPS and the importance of NPS in a study area. Assessment tools include: • knowledge based approaches • data analysis techniques • potential and hazard maps • unit area loading/export coefficients
Evaluation level (depending on the resolution required): Either time series or aggregated nutrient loadings for individual land and water use categories at the scale of quaternary catchments.	Refer to Pegram and Görgens (2001) (Part 3d) for guidelines on assessing the contributions from NPS, the impacts and important processes. Assessment tools include • unit area loading/export coefficients • loading functions and potency factors • simple process models • detailed process models
Prioritisation level: Identification of those non-point nutrient sources that have the greatest existing or potential future impacts, the main processes causing the impacts from these priority nutrient sources, and how manageable the priority nutrient sources are.	Refer to Pegram and Görgens (2001) (Part 3e) for guidelines on how to determine priority nutrient sources and key sources requiring control. The *Evaluation* task will indicate what resolution is required and which of the following techniques are needed. • data analysis techniques • unit area loading/export coefficients • loading functions and potency factors • simple process models • detailed process models

METHODS AND TOOLS

Calculating nutrient export from non-point sources

Accurate estimates of nutrient loads on receiving water bodies are essential to understand the functioning of the receiving water body and to predict the response of the water body to changes in the nutrient loads. There are two methods for estimating nutrient loads (Grobler, 1985):

- If simultaneous flow and concentrations data are available, ***direct methods*** can be used to estimate nutrient loads.
- In the absence of observed flow and concentrations records, ***indirect methods*** can be used to estimate loads.

In practice, both direct and indirect methods are employed to assess the impacts of alternative nutrient control strategies.

Direct load calculation methods

Direct methods are subdivided into averaging, flow-interval and regression methods.

- Averaging methods refer to those in which loads are calculated as the sum of the products of the total flow and the average nutrient concentration that was obtained from fixed time interval sampling. Grobler *et al*. (1982) evaluated six different averaging methods for calculating chemical loads in South Africa and found large uncertainties were associated with estimating phosphate loads by all the methods tested. They concluded that averaging methods should not be used to calculate phosphate loads in event-response rivers.

- Flow-interval and regression methods make use of concentration: flow or load:flow relationships to calculate nutrient loads. These methods do not require as intensive monitoring as do averaging methods. Grobler (1985) evaluated flow-interval and regression methods in South Africa and found log load:log flow regression models were best for calculating phosphate loads and for estimating annual P loads. Once the regression models was calibrated for a particular river, it could be used to estimate loads for periods when no sampling occurred. The FLUX program developed by Walker (1996) provides a convenient toolbox for determining the relationship between nutrient loads and flow and for estimating time series of nutrient loads (Grobler and Rossouw, 1988).
- Herold and Görgens (1991) also developed a good algorithm for infilling DWAF grab sample data and this method is often used in estimating TDS and nutrient time series in water resource assessment studies.

Indirect load calculation methods

Indirect methods can be used to calculate nutrient loads from catchments where no or very limited observed data are available. Loads are usually estimated as a function of catchment properties such as land-use, land form and runoff and nutrient export coefficients or loading functions for different types of land-use. The general procedure is to divide a catchment up into point and non-point sources. The non-point source contribution is then estimated by dividing the catchment up into different source areas and to estimate the load from each source area using a nutrient export coefficient characteristic of that source area. This is the approach followed in the NEAP model described in **Part 1** of this report.

More complex rainfall:runoff that simulates catchment processes can also be used to estimate nutrient loads. These include models such as SWAT (Neitsch *et al*., 2005) and ACRU-NP (Campbell *et al*., 2001). It is usually not practical to use complex models to predict nutrient loads due to the difficulty of applying them and their intensive data requirements.

SOURCES

The FLUX program is available from the US Army Corps of Engineers.	Available online: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual
Current and historical land-use and water use information.	**Components 1**, **3, 5, 6** and **7**.
Water quality and flow data.	Refer to **Component 4**.
A description of non-point source assessment methodologies.	Refer to Pegram and Görgens (2001).
A synthesis of non-point source assessment case studies in South Africa.	Refer to Quibell *et al.* (2003).

CHECKLISTS

The non-point *source areas* can be determined by separating a catchment or sub-catchment into areas with relatively homogeneous non-point source characteristics, based on:

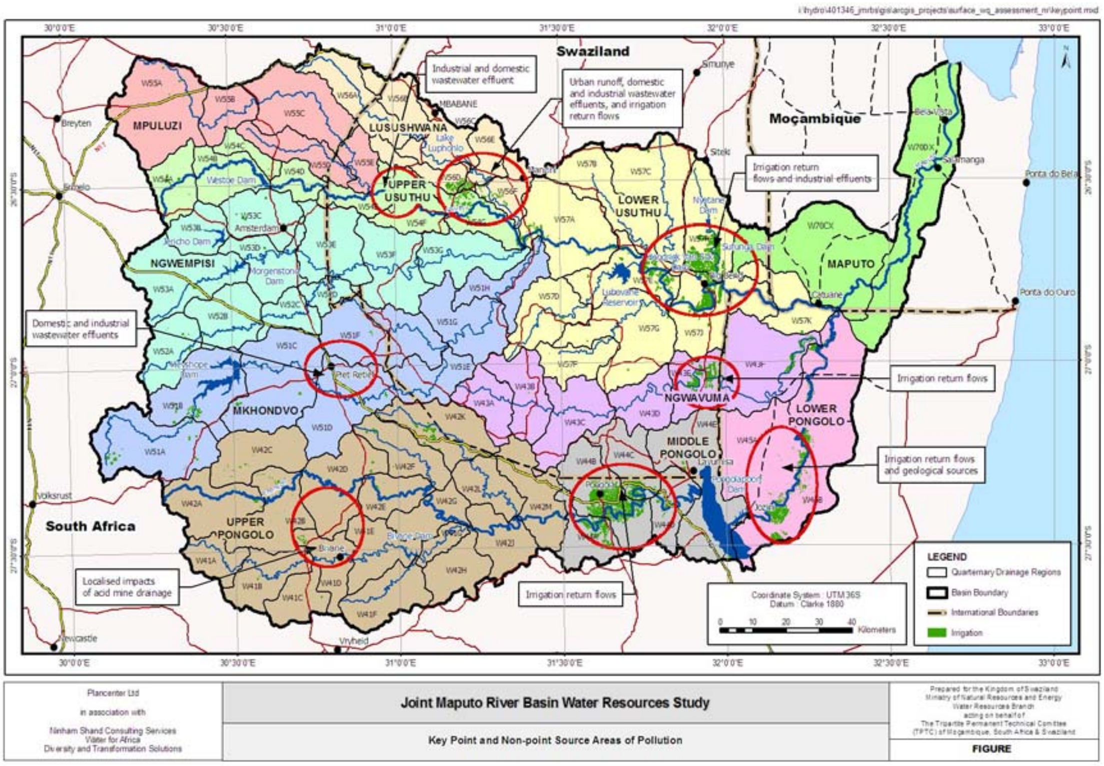
- *Land-use*: natural, different types of agricultural, different types of human settlement, CBD, different types of industrial, etc;
- *Natural features*: soils, topography, geology, natural vegetation, etc; and
- *Climate*: rainfall, temperature, evaporation, seasonality, etc.

Use **checklists** under **Component 1** as a guide.

DISPLAY AND PRESENTATION OPTIONS

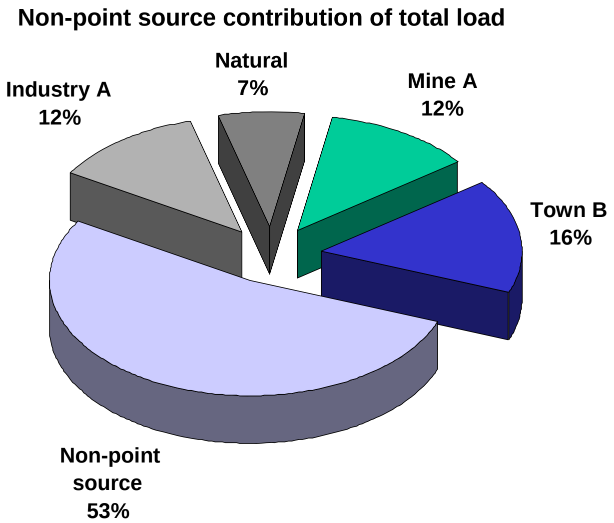
Catchment map showing location of known point and non-point sources

A catchment scale map of the study area can be used to indicate locations of known point and non-point sources. The example below illustrates areas of concern and whether these are related to point sources, non-point sources or a combination of the two.



Non-point source contribution to observed nutrient loads

Nutrient loads can be calculated at a known location in the study area (e.g. water quality monitoring point). If the known point source loads and natural background loads can be accounted for, the remainder can be assumed to originate from non-point sources. This information can then be displayed in a pie diagram as displayed in the example below or on a map of the study area.



REFERENCES

Campbell, K L, Kiker, G A and Clark, D L. (2001). *Development and testing of a nitrogen and phosphorus process model for Southern African water quality issues*. ASAE Annual International Meeting, Sacramento, CA, July 30-August 1, 2001. Available online:

http://www.beeh.unp.ac.za/acru/

Grobler, D C. (1985). *Management-oriented eutrophication models for South African Reservoirs*. PhD Thesis, University of the Orange Free State, Bloemfontein.

Grobler, D C, Bruwer, C A, Kemp, P J. (1982). *A comparison of chemical load estimation algorithms using data obtained by sampling four South African rivers at varying frequencies*. Water SA, 8(2): 121-129.

Grobler, D C and Rossouw, J N. (1988). *Non-point source derived phosphorus export from sensitive catchments in South Africa*. Confidential Report to the Department of Water Affairs, Pretoria.

Herold, C E and Görgens, A. (1991). *Vaal Dam salinity assessment with particular reference to atmospheric deposition*. Stewart Sviridov & Oliver in co-operation with Ninham Shand Inc. Report No. NC120/13/DEQ0391, Hydrological Research Institute, Department of Water Affairs and Forestry.

Neitsch, S L, Arnold, J G, Kiniry, J R, and Williams, J R. (2005). *Soil and Water Assessment Tool (SWAT): Theoretical documentation (Version 2005).* Grassland, soil and water research laboratory, Agricultural Research Service, Temple, Texas.

Pegram, G and Görgens, A. (2001). *A Guide to Non-point Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa.* WRC Report No. TT 142/01, Water Research Commission, Pretoria.

Quibble, G Pegram, G C, Moolman, J, Matji, M P, Hohls, B and Görgens, A H M. (2003). *Development of a guide to assess non-point source pollution of surface water resources in South Africa.* WRC Report No. 696/2/03. Water Research Commission, Pretoria.

Walker, W W. (1996). *Simplified procedures for eutrophication assessment and prediction: User manual,* Instruction Report W-96-2, U S Army Engineer Waterways Experiment Station, Vicksburg, MS.

COMPONENT 9

Configured and Calibrated Water Quality Predictive Tools/ Models with regard to Eutrophication Related Water Quality

PURPOSE

Generic catchment assessment context

The key to the water quality component of a catchment management strategy is the water quality use allocation strategy. That is the allocation of the available constituent load, defined by management objectives, to different water user groups, sectors and sources in order to meet the management objectives. Management plans relate to point source discharges, non-point source discharges and in-stream management, and include appropriate reservoir release operations, in-stream rehabilitation and environmental needs. A toolbox of predictive models is a key technology for the development of a water quality use allocation strategy and the applications of predictive models can serve to:

- Indicate which of point or non-point source pollution is dominant, or which sub-catchments in a basin are dominant water quality load contributors, etc; in turn, this would help to prioritise certain types of management actions
- Estimate water quality constituent loadings from a range of land-uses and water uses that result in non-point source pollution, and indicate which non-point sources are dominant
- Indicate the likely effects of pollution load increases or decreases on downstream water quality, or receiving waters
- Simulate water quality constituents at key points in river-reservoir systems in response to particular system operating rules
- Simulate water quality variables at points of concern for different future scenarios of land-use and water use
- Support prioritisation and appropriate selection of competing management options
- Extend, infill or simulate time series of water quality variables at points of concern.

Eutrophication assessment context

Eutrophication models relate the consequences of nutrient enrichment (excessive algal growth) to it's causes (elevated nutrient concentrations, improved underwater light climate) and the models range from very simple, empirical models to very complex catchment and water body process models. The NEAP model described in this document is an example of a simple empirical eutrophication model.

In the context of an eutrophication assessment, eutrophication models support the following components:

- The development of catchment nutrient management objectives, i.e. nutrient and algal targets that balance the national needs outlined in the NWRS and in RDM with the needs of stakeholders for disposing of wastewater with elevated nutrient concentrations.
- Development of nutrient management objectives, i.e. nutrient load reductions in stressed catchments, maintenance of nutrient loads in threatened catchments, or increases in nutrient loads in unstressed catchments.
- Development of the water quality use allocation strategy, i.e. allocating nutrient loads to different sectors or groups.
- Development of the individual sectoral or source-based nutrient management plans that form the heart of the allocation strategy.
- Development of suitable interventions where a single nutrient source (rather than a whole catchment) has been identified as the cause of eutrophication problems.

Application of some of the predictive tools listed in this Component requires a reasonable degree of technical and scientific understanding of the models, application procedures, dependence on other supporting tools or software, limitations and data preparation requirements. This Guide is not designed to educate users in modelling protocols and users are encouraged to consult the original source material listed in the "**Sources**" section below.

Purpose

The outputs that are specified in this section are predictive methods or tools, which have been applied to the particular catchment and constituents of concern.

*NB: It is recommended that **Component 9** and **Component 8** be considered and developed simultaneously because there is a strong overlap between them and their underlying processes.*

Prerequisite Components

Components 1, **2**, **3**, **5**, **6** and **7** should be completed, or at least, well advanced, before substantial progress becomes possible with this Component.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment water quality assessment outputs	
The *Catchment Water Quality Assessment Guide* lists models or predictive tools for non-point sources, simple water quality process models, detailed process models, systems analysis models, and hydrodynamic models for rivers and reservoirs. Only models or methods that have been applied operationally in South Africa have been listed. Systems analysis models, commonly used to generate flow and demand sequences, often provide these flow sequences to water quality models as inputs. These are hydrological tools and are not discussed in this document.	
Eutrophication assessment outputs	
Not all the outputs listed here are applicable to a specific catchment or study area. The user needs to select the appropriate model or suite of models for the assessment based on the level of stress of the catchment (unstressed, threatened, or stressed) in terms of eutrophication problems and the availability of data to calibrate the model(s).	
Export coefficients and loading functions	
Export coefficients (also referred to as unit area loads), are empirical estimates of the mass of pollutant exported (usually annually) per unit area per unit time for a particular land-use. Export coefficients are reported as mass of pollutant per unit area per year (annum), with units of kg/ha/yr or kg/ha/a. Loading functions on the other hand, calculate constituent loads by multiplying the estimated runoff by their empirically determined parameters that describe the relationship between the constituent (e.g. nutrient concentration) and flow.	
Parameterised non-point source *Scoping* tools: • knowledge based approaches • data analysis techniques • potential and hazard maps • unit area loading/export coefficients	Follow the *Non-Point Source Assessment Guide* (Pegram and Görgens, 2000) (see “**Sources**” section below).
Calibrated and verified non-point source *Evaluation* and *Prioritisation* tools that produce aggregate loads (e.g. mean annual): • unit area loading/export coefficients • loading functions and potency factors	Follow the *Non-Point Source Assessment Guide* (Pegram and Görgens, 2000) (see “**Sources**” section below).
Simple empirical and semi-empirical reservoir models	
Simple, empirical nutrient budget models relate the in-reservoir nutrient concentrations to nutrient loads. These models are based on the principle of conservation of mass and are used to simulate the change in nutrient concentration stored in a water body at any time.	Identify an appropriate nutrient budget model and calibrate it against observed in-reservoir nutrient concentrations.

<table>
<tr><td>Empirical and semi-empirical models are simple equations that generally relate algal concentrations to in-lake nutrient concentrations. These are based on theoretical considerations and observed/ experimental data.</td><td>Identify an appropriate Chlorophyll-a – Nutrient model and calibrate/verify it against observed in-reservoir chlorophyll and nutrient data.</td></tr>
<tr><td colspan="2">Simple catchment process models</td></tr>
<tr><td>Simple, mass balance catchment models link different empirical models that simulate different catchment processes. These include (1) the washoff of nutrients from different catchment sources using export coefficients and/or loading functions, (2) routing the loads through the river network and estimating in-river losses, (3) estimating the in-reservoir nutrient concentrations using nutrient mass balance models, and (4) relating the in-reservoir nutrient concentrations to chlorophyll-a concentrations. These models run at different time scales.</td><td>Calibrate and verify the appropriate catchment water quality simulation tools so that load and concentration time series can be produced at all points of management interest.</td></tr>
<tr><td colspan="2">Monthly: IMPAQ. This is a medium-to-fine-scaled model for salinity, sediment and phosphate production and transport in large multi-use catchments, specially designed to be driven by the same natural flows that drive the water resources yield model (WRYM) and the water resources planning model (WRPM) system analysis models. It has a washoff routine that uses SCS Curve Numbers to allow any mix of land-uses to affect sediment and phosphate production, which are derived from a combination of loading functions, potency factors and the USLE approach. Non-conservative processes are allowed to play a role in a channel transport module and a simple mixed reactor reservoir module. IMPAQ is used in conjunction with WRYM to generate very long sequences of monthly loads/concentrations of selected constituents in large river systems.</td></tr>
<tr><td colspan="2">Daily: ACRU-NP. This is a fine-scaled model for sediment and phosphate production from individual small catchments with a limited range of agricultural land-uses. It is driven by daily rainfall and uses soil-moisture budgeting according to a discretisation based on soil texture classes and agricultural practices. It is recommended to investigate localised impacts of land-use and their related management options.

Sub-hourly to daily: HSPF. This is a medium-to-coarse-scaled model for production and transport of salinity, temperature, sediment and a range of non-conservative constituents in medium-to-large multi-use catchments. Its water quality chemical simulation components are comprehensive and it uses relatively black-box rainfall-runoff functions, different forms of hydrological channel routing and treats reservoirs as simple mixed reactors. It may be used to assess water quality outcomes of management and operational options in medium-to-large catchments.</td></tr>
<tr><td colspan="2">Detailed Process Models</td></tr>
<tr><td>Detailed process models incorporate sophisticated processes, such as adsorption-desorption, decay and plant uptake, into the simulation of contaminant movement and transformation in soil and water. These contaminant processes are integrated with relatively complex hydrological and sediment models.

NB: These models require specialised support and are not recommended for general use in catchment assessments. Their main function would be to optimise management options for site-specific water quality issues.</td><td>These models tend to be very data intensive and limited to areas where there has been intensive data collection. The uncertainty of a-priori parameter estimates can lead to highly inaccurate output estimates in unmonitored catchments where calibration and verification are not possible. However, the model parameters often have physical interpretations and can be linked to observed catchment characteristics. The requirements of these models are not usually warranted in urban situations, so detailed process models are generally oriented towards rural, waste-related and agricultural land-uses.</td></tr>
</table>

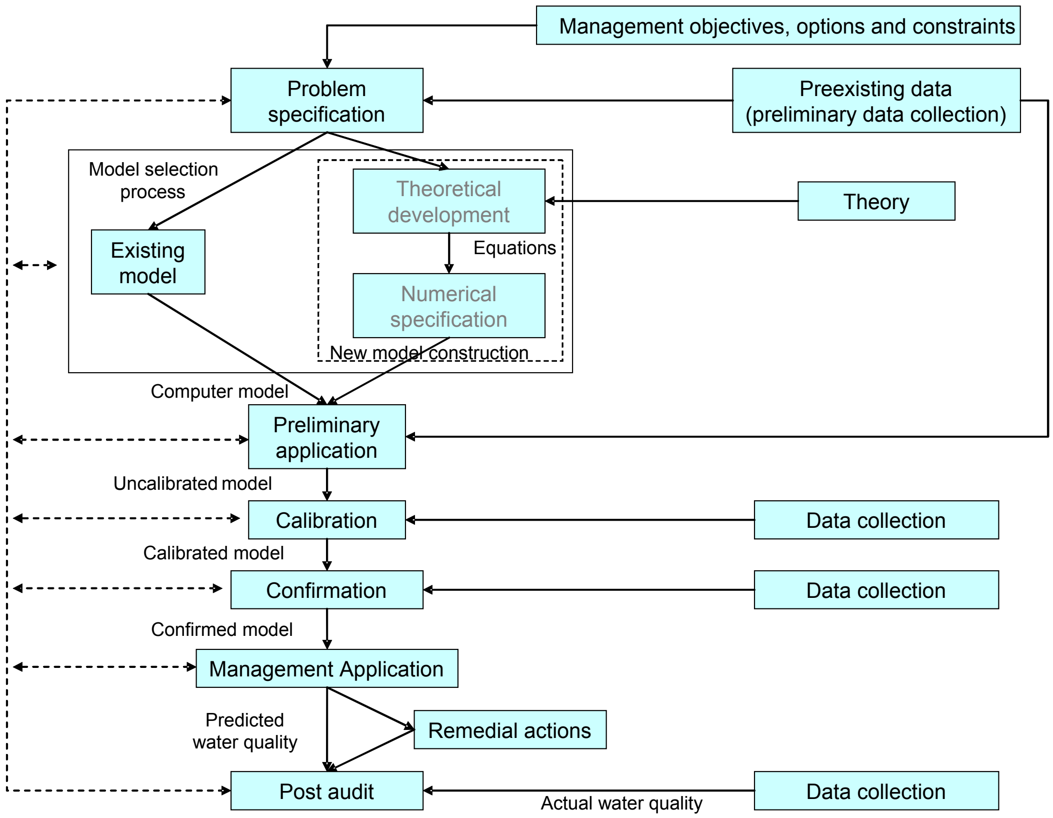
<table>
<tr><td colspan="2">Daily Reservoir Hydrodynamics and Water Quality Models</td></tr>
<tr><td>The following daily reservoir hydrodynamic and water quality models have seen operational use in South Africa:

CE-QUAL-W2 – a 2-D finite difference model that incorporates all primary hydrodynamic processes as well as a range of conservative and non-conservative water quality processes.

DYRESM – a 1-D finite difference model using LaGrangian principles to simulate all energy and kinetic exchanges as well as salinity processes.</td><td>The models are configured according to the reservoir's specific depth-area-volume, spillway, and off-take characteristics. Daily inflow and relevant water quality values need to be provided, as well as a range of meteorological variables. The hydrodynamics of these models require no calibration and are completely deterministic. The water quality process parameters of CE-QUAL do require calibration. If the primary interest of the simulation is stratification, then DYRESM is the more complete model in an energy balance sense. It should be noted that CE-QUAL does not perform its own mass balance, and needs outflows and spills as input.</td></tr>
<tr><td colspan="2">Sub-daily River Hydrodynamics Models</td></tr>
<tr><td>Three 1-D river hydrodynamics models have seen operational use in South Africa: MIKE11, ISIS and DUFLOW. All three models are based on a finite difference application of the full St Venant's flow equations to a series of cross-sections of the river channel and flood-plain. A range of conservative and non-conservative water quality routines are incorporated into all three models.</td><td>The basic requirements for applying these models are regular cross-sections of the river channel and its flood-plains, boundary conditions in the form of upstream and tributary inflow series (including water quality), and certain meteorological time series. Friction loss factors and water quality parameters are derived by calibration. This means that reasonable flow and water quality records of in-channel conditions are required. These models are useful to assess short-term downstream water quality impacts of upstream operations, or to examine management options relating to localised water quality issues.</td></tr>
</table>

METHODS AND TOOLS

The water quality modelling process is illustrated below (from Chapra, 1997) showing the modelling process along with the necessary information that is required for its effective implementation.



Good modelling practices should be followed to identify suitable models, configuring and applying them, calibrating the models, confirming the models, and then applying the confirmed models to predict the potential outcome of different eutrophication management interventions. Good modelling practices are described in Chapra (1997, 2003) and Pascual *et al*. (2003).

SOURCES

Non-point Source Scoping and Evaluation Tools	*A Guide to Non-point Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa*. WRC Report by G Pegram and A Görgens, 2000. Water Research Commission, Pretoria.
Empirical models (examples)	
REMDSS	Rossouw, J N. (1990). *The development of management orientated models for eutrophication control*. WRC Report No. 174/1/90. Water Research Commission, Pretoria.
NEAP	• **Part 1** of this document. • Harding, W R. (2007). *The determination of annual phosphorus loading limits and land-use-based phosphorus loads for 30 key South African dams in relation to their present and likely future trophic status*. WRC Report. Water Research Commission.

Empirical equations	A large number of empirical equations exist in the literature that relate nutrient loadings to algal concentrations. Examples include: • Walmsley, R D and Butty, M. (1980). *Guidelines for the control of eutrophication in South Africa.* Collaborative report by Water Research Commission and National Institute of Water Research, CSIR, Pretoria. • Walker, W W. (1996). *Simplified procedures for eutrophication assessment and prediction: User manual,* Instruction Report W-96-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS. • Cooke, G D, Welch, E B, Peterson, S A and Nichols, S A. (2005). *Restoration and management of lakes and reservoirs*. Third edition. Taylor & Francis, Boca Raton.
Simple Catchment Process Models (examples)	
IMPAQ	Bath A, Reid C and Görgens A (1997). Amatola Water Resource System Analysis: *Water Quality Modelling*. DWAF Report No. PR 000/00/1798
ACRU-NP (Water Quality)	ACRU - Schulze, R E (1995). Hydrology and Agrohydrology: A text to accompany ACRU 3.00 agrohydrological modelling system, WRC Report No. TT 69/95 ACRU2000 – Kiker, G A and Clark, D J. (2001). *The development of a Java-based, Object-oriented Modelling System for Simulation of Southern African Hydrology*. ASAE Paper No. 012030, St. Joseph, MI.
Reservoir Hydrodynamics Models (examples)	
DYRESM and CE-QUAL-W2	Görgens A, Bath, A. Venter, A, De Smidt, K and Marais, G. (1994). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa.* WRC Report No. 304/1/93. Bath A, De Smidt, K, Görgens, A and Larsen, E J. (1997). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa: Application of DYRESM and CE-QUAL-W2* . WRC Report No. 304/2/97.
River Models (examples)	
QUAL2K	Chapra, S, Pelletier. G and Tao, H. (2006). *QUAL2K: A modelling framework for simulating river and stream water quality (Version 2.04). Documentation and Users Manual.* Civil and Environmental Engineering Department, Tufts University, Medford, MA.
MIKE11	DHI (1992) *Mike11 Version 3.01. A micro-computer based modelling system for rivers and channels, Reference Manual*, Danish Hydraulic Institute Software.
ISIS	HR (1997) *ISIS Flow, User Manual.* Halcrow/HR Wallingford, UK.
DUFLOW	STOWA/EDS (1998). *DUFLOW for Windows, Version 3.0.* EDS, Leidschendam, The Netherlands.

REFERENCES

Bath, A, De Smidt, K, Görgens, A and Larsen, E J (1997). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa*: *Application of DYRESM and CE-QUAL-W2* . WRC Report No. 304/2/97.

Bath A, Reid, C and Görgens, A (1997). *Amatola Water Resource System Analysis: Water Quality Modelling.* DWAF Report No. PR 000/00/1798.

Bricknell, B R, Imhoff, J C, Kittle, J L, Donigan, A S and Johanson, R C (1993). *Hydrological Simulation Program-Fortran: Users Manual, Release 10*, EPA Report 600/R-93/174, Athens.

Chapra, S C (1997). *Surface water-quality modelling*. McGraw-Hill Companies, Inc., New York.

Chapra, S C (2003). *Engineering water quality models and TMDLs*. Journal of Water Resources Planning and Management, 129(4): 247-256.

DHI (1992) Mike11 Version 3.01. A micro-computer based modelling system for rivers and channels, Reference Manual, Danish Hydraulic Institute Software.

DWAF (1994). Vaal River System Analysis: Analysis procedures manual Addendum A. DWAF Report No PC000/00/6986 by BKS Inc, Pretoria.

Görgens, A, Bath, A, Venter, A, De Smidt, K and Marais, G (1994). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa*. WRC Report No. 304/1/93.

HR (1997) ISIS Flow, User Manual. Halcrow/HR Wallingford, UK.

Kiker, G A and Clark, D J (2001). *The development of a Java-based, Object-oriented Modelling System for Simulation of Southern African Hydrology*. ASAE Paper No. 012030, St. Joseph, MI.

Pegram, G and Görgens, A (2001). *A Guide to Non-point Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa*. WRC Report No. TT 142/01, Water Research Commission, Pretoria.

Pascaul, P, Stiber, N and Sunderland, E (2003). *Draft guidance on the development, evaluation, and application of regulatory environmental models*. Prepared by The Council for Regulatory Environmental Modeling.

Rossouw, J N (1990). *The development of management orientated models for eutrophication control*. WRC Report No. 174/1/90. Water Research Commission, Pretoria.

Schulze, R E (1995). Hydrology and Agrohydrology: A text to accompany ACRU 3.00 agrohydrological modelling system, WRC Report No. TT 69/95.

STOWA/EDS (1998). DUFLOW for Windows, Version 3.0. EDS, Leidschendam, The Netherlands.

Walker, W W (1996). *Simplified procedures for eutrophication assessment and prediction: User manual,* Instruction Report W-96-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

COMPONENT 10
Reconciliation: Catchment Sources and Eutrophication Related Water Quality Patterns

PURPOSE

Generic catchment assessment context

The patterns of water quality changes through space (say, along a river) are related to (a) the spatial variability of the natural background soil and geological materials and rainfall, and (b) the spatial location of point and non-point anthropogenic sources. Similarly, sustained temporal trends in water quality, over and above the usual "noise" caused by hydrometeorological variability, indicate that such anthropogenic sources have "kicked in" and/or are growing in impact. **Component 6** (water quality data review) provides the basic information on patterns and trends.

Eutrophication assessment context

Spatial and temporal patterns in nutrients are complicated due to the non-conservative behaviour of nutrients in rivers, reservoirs and wetlands. Nutrients exhibit losses due to uptake by plants in these water bodies and/or adsorption onto suspended sediment particles and co-settling with these particles. They can also exhibit gains due to resuspension of bottom sediment or disassociation from sediments due to anaerobic conditions. Many of these processes are light and temperature dependent and the rate of change therefore exhibits seasonal differences.

Purpose

The purpose of this Output is diagnostic: it provides a knowledge-based interpretation and reconciliation of all spheres of information - land-use, water samples, model findings - relating to known sources or sinks that contribute to our understanding of nutrient loads. This interpretation represents a final "sweep" through the catchment to spot hitherto unsuspected sources or sinks of nutrients. An easy example is as follows: if **Component 6** shows that phosphorus concentrations at low flows jumps between Point X and Point Y (10 km apart) along a river, and no major tributary enters that reach, then a clandestine effluent discharge or previously unsuspected irrigation return flow might need to be investigated, which would require management attention. A more complex example is: checking the presence of observed nutrients against expected background nutrient concentrations, or the expected impacts of known land-uses, and finding them discrepant.

Prerequisite Components

This Component can only be substantially completed if **Components 1** and **6** have already been completed and **Components 7** and **8** are quite advanced.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Catchment Water Quality Assessment Guide* describes three outputs that document discrepancies in spatial water quality patterns and in temporal water quality patterns, and unexpectedly high concentrations.	Refer to the *Catchment Water Quality Assessment Guide* for a description of how to examine the data and information for spatial and temporal discrepancies, and unexpectedly high concentrations.

Eutrophication assessment outputs	
Diagnostic table of discrepancies in spatial patterns in terms of nutrient concentrations.	Discrepant *point* discharges can be detected from (a) same-day sampling of low flows at sequential locations, (b) consistent differences between low flow concentrations at sequential locations from routine grab sampling over longer periods, (c) extraordinary model parameter values/settings required in order to achieve reasonable simulations, (d) systematic deviations of calibrated model outputs from observed values. Discrepant *non-point* contributions are more difficult to ascertain, as they are driven by rainfall-runoff events, which are highly variable and seasonal by nature. A powerful clue can be found in consistent under-estimation of spatially sequential concentrations or loads during simulation modelling of rainfall-runoff events in that catchment.
Diagnostic table of discrepancies in temporal trends in terms of particular constituent concentrations.	Abrupt steps or sustained trends in observed constituent values not explained by known trends in land- or water uses, provide a first clue. Trends in *moving averages* over a number of months or years smooth out the variability caused by climate and seasonality and buoy the underlying tendency. A powerful clue is offered when simulation modelling reveals a *systematically changing deviation* between observed and simulated concentrations or loads on a moving average basis. Trends in the *lowest few concentrations* per *wet* season would indicate non-point source change trends, while trends in the *highest few concentrations* per *dry* season would indicate point source change trends.
Diagnostic table of water quality constituents with unexpectedly high concentrations.	Interpret, on the basis of experience, values in grab-sample records in terms of the effluent constituents that might usually be associated with the known land- or water uses.

METHODS AND TOOLS

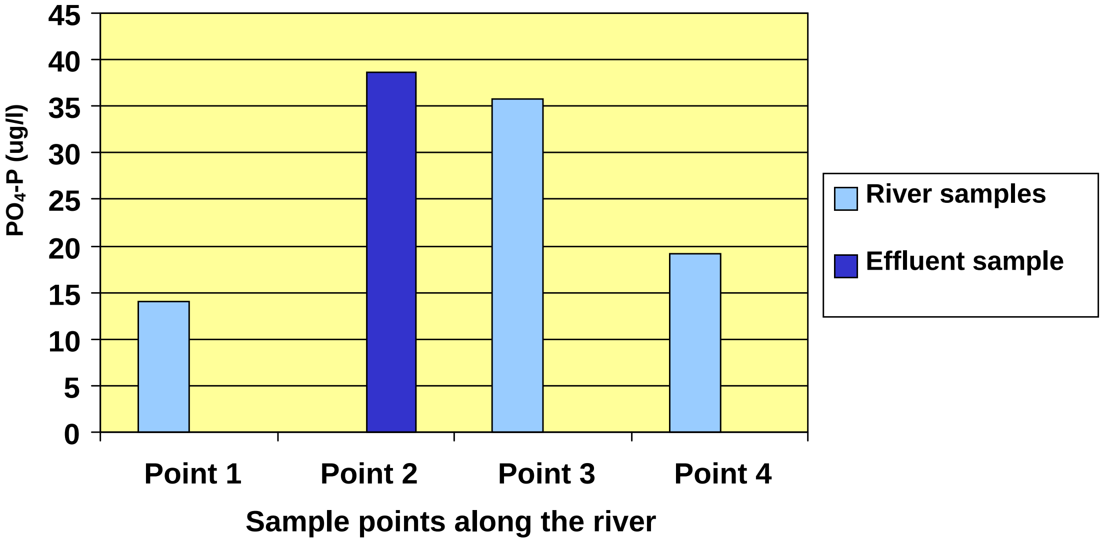
Diagnose against temporal trends or steps in nutrient concentrations (sometimes, loads) as follows:

- Dry season flow – flow-weighted mean per season, as well as moving average
- Monthly flow-weighted means and their moving averages
- Trends in lowest few wet-season values/season
- Trends in highest few dry-season values/season
- Trends against modelled values.

Diagnose against spatial steps or spatial trends in nutrient concentrations (sometimes, loads) as follows:

- Same-day nutrient concentrations at different locations along the river
- Consistent deviations between sequential spatial values over time with simulated values
- Spatial trends in lowest few wet-season values/season
- Spatial trends in highest few dry-season values/season
- Spatial trends against modelled values.

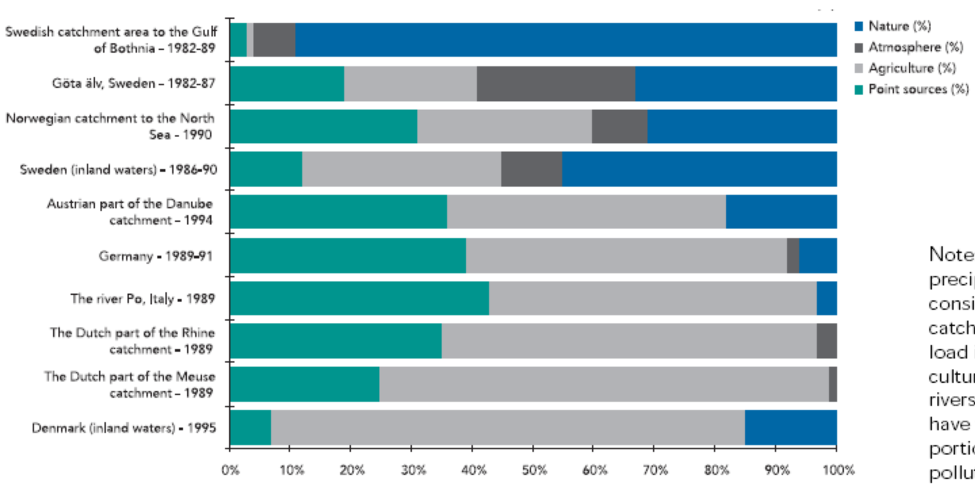
SOURCES
Information for these outputs is sourced from the prerequisite Components mentioned in the "**Purpose**" section above.
CHECKLISTS
None
DISPLAY AND PRESENTATION OPTIONS
An example of how same day monitoring of a point source and river samples can explain temporal trends.



The example below shows the apportionment of nitrogen loads to different sources. These can be compared to know data from those sources to determine if the know loads match apportionment.

Source apportionment of nitrogen load. Source: compiled by ETC/IW from state of the environment reports: Windolf, 1996; Swedish EPA, 1994; Umweltbundesamt, 1994; BMLF, 1996; Ibrekk *et al.*, 1991; Italian Ministry of the Environment, 1992; RIVM, 1992; Löfgren and Olsson, 1990

Figure 3.14



Notes: Atmospheric precipitation only considered for some catchments. Natural load included in agriculture for the Dutch rivers. The lower bars have the highest proportion of agricultural pollution

COMPONENT 11
Status Report on Eutrophication Monitoring, Physical Data and Characterization Information

PURPOSE

Generic catchment assessment context

A Catchment Management Agency may have to rely on a number of water quality data sources to assess the water quality status in the study area. The purpose of this component is to provide guidance on methods to assess the suitability of the data for a catchment water quality assessment.

Eutrophication assessment context

In an eutrophication assessment study, data may be sourced from a number of sources. The assessment team needs to assess whether:

- The spatial and temporal distribution of nutrient and other data is adequate to describe the eutrophication dynamics of the study area,
- The appropriate nutrients fractions have been measured using appropriate detection limits, and
- Data from different sources are compatible.

Purpose

The purpose of assessing the status of monitoring systems in the study area is to address the problems associated with the location of sampling points, sampling frequency, variables monitored, detection limits, and data compatibility. This component includes a checklist that alerts the user to some of the common problems and shortcomings of water quality monitoring programmes.

Prerequisite Components

To undertake this component, information from the following Components are required:

Component 6 (Water quality of streamflow, reservoirs, estuaries, wetlands and groundwater), **Component 7** (Point source waste discharges), and **Component 9** (Non-point source water quality contributions and impacts).

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
GIS map showing the location of monitoring points in the study area	Compile a GIS map of the study area and plot the location of all the water quality monitoring points.
Monitoring system evaluation report for each of the key data sources used in the assessment.	Use the checklist and evaluation information described below to compile the monitoring system evaluation reports.
Monitoring data assessment report	Summarise the key findings of this component into a short data assessment report.
Eutrophication assessment outputs	
GIS map showing monitoring points	Use different symbols or colours to differentiate between different monitoring programmes (or organisations). Indicate which sampling points were used in the study to characterise the present eutrophication status.
Monitoring system assessment report for each of the data sources used in the assessment.	Use the checklist and evaluation guidelines described below to compile the monitoring programme assessment report. Give specific attention to the laboratory detection limits for nutrient concentrations used by different

	programmes as well as the way in which the concentrations are reported (for example reporting nitrate concentrations (NO_3) (uncommon) or as nitrate-nitrogen (NO_3-N) (common).
Monitoring assessment report	Conclude this component with an overall evaluation of the suitability of the monitoring programmes and motivate why some monitoring points or data sets were not used in the assessment. Identify any additional short-term monitoring that might be required to fill data gaps for the eutrophication assessment.

METHODS AND TOOLS

Examples of techniques to evaluate the suitability of monitoring data for a water quality assessment, are described in the following publications:

- Ward, R C, Loftis, J C and McBride, G B (1990). *Design of Networks for Monitoring Water Quality.* Van Nostrand Reinhold, New York, NY, USA 231pp.
- Harris, J M, Van Veelen, M and Gilfillan, T C (1992). *Conceptual Design Report for a National River Water Quality Assessment Programme*. Water Research Commission. Report No. 204/1/92. Available from the Water Research Commission. Website: www.wrc.org.za

SOURCES

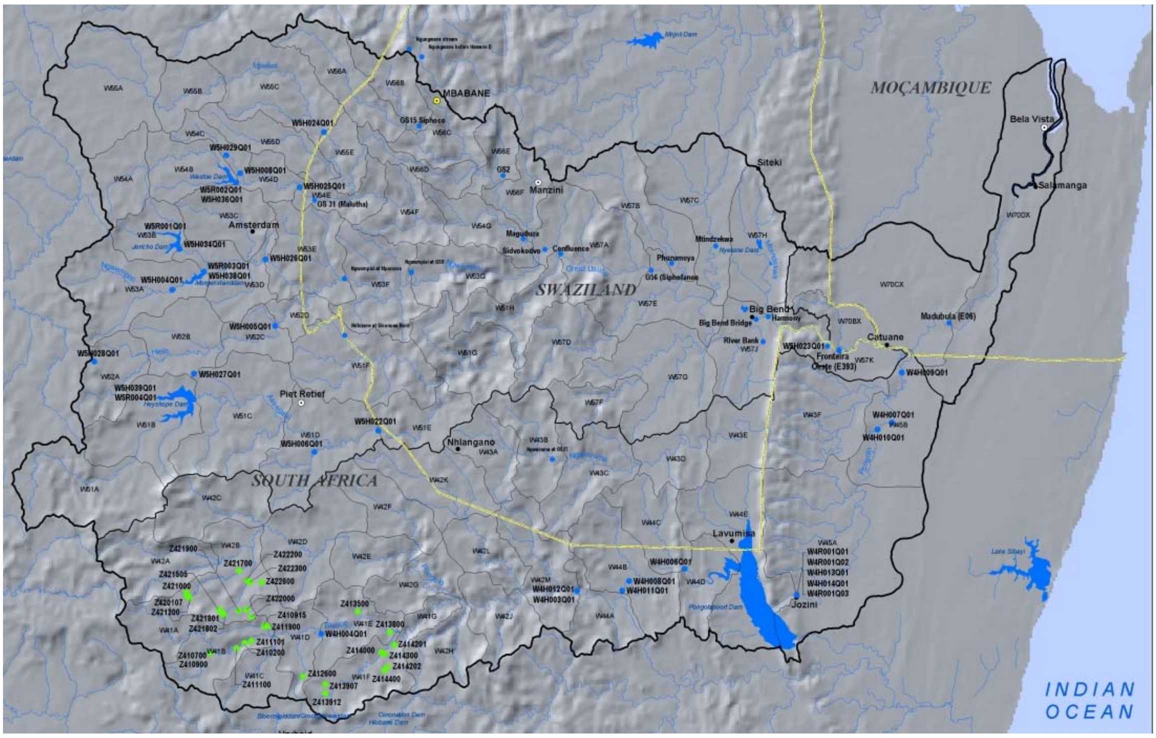
Contact the organisations responsible for operating the monitoring programmes for information on the design and operation of the monitoring programme.	Typical monitoring design and operation information includes : • Georeferenced location of monitoring points (e.g. name, description, geographic coordinates, etc) • Sampling frequency (daily, weekly, monthly, ad hoc) • Sampling procedures (e.g. grab or integrated samples, sample preservation, transport procedures, sampling bottle preparation) • Quality control/quality assurance procedures in the field and analysing laboratory • Nutrient analysis detection limits • Data storage and manipulation procedures

<table>
<tr><th colspan="2">CHECKLISTS</th></tr>
<tr><td colspan="2">Limitations to monitoring data can generally be divided into two groups, namely limitations to the design of the monitoring system, and limitations to the data records. The Catchment Water Quality Assessment Guide (DWAF, 2003b) describes the limitations in the design of monitoring systems under the following headings:
• Monitoring system design documentation,
• Spatial distribution of sampling points,
• Sampling frequency,
• Sampling depth,
• Sample preservation,
• Quality assurance/quality control,
• Analysing laboratory,
• Data storage,
• Data conversions,
• Data availability and security, and
• Flow measurements.
Some of the limitations associated with monitoring eutrophication related water quality are discussed below.</td></tr>
<tr><td colspan="2">Limitations in the design of the monitoring system</td></tr>
<tr><td>Spatial distribution of sampling points
Ideally, monitoring points should be distributed over the catchment to provide a balanced view of water quality changes. However, nutrients are non-conservative substances and the location of a monitoring point in relation to a point or non-point source can be quite important. If the monitoring point is located close to a source in can potentially lead to an over-estimation of the impacts, or alternatively, an under-estimation if located far downstream from a point source.</td><td>Plot the monitoring points on a GIS map and examine the distribution of monitoring points in relation to major features which impact on the nutrient concentration such as major point and non-point sources.</td></tr>
<tr><td>Sampling depth
The depth of sample collection in stratified reservoirs is important because vertical differences in nutrient concentrations occur. Water samples are generally collected as grab samples from just below the water surface. However, in deep water bodies samples can be collected at specific depths or a depth-integrated sample can be collected using a hosepipe.</td><td>Examine the data record for an indication of sampling depth, or contact the data supplier for information on the sampling depth.</td></tr>
<tr><td>Sample preservation
Water quality samples for nutrient analysis should be preserved with a preservative like mercury chloride (HgCl) to prevent biological growth in the sampling bottle from modifying the nutrient fractions in the samples.</td><td>Examine the data records for an indication whether individual samples were preserved or not, or contact the data suppliers for information on sample preservation.</td></tr>
<tr><td>Analysing laboratory
Nutrient concentrations, especially phosphorus, often occur in ppb (μg/l) concentrations in natural waters. Some laboratories, for example municipal laboratories, use nutrient analysis methods that detect in the ppt (mg/l) range of concentrations because they mostly analyse samples from wastewater treatment works.</td><td>Contact the analysing laboratory to find out what the detection limits are for their nutrient analysis methods.</td></tr>
</table>

<table>
<tr><td>They then report phosphorus concentrations in rivers in streams as less than 1 mg/l or less than 0.25 mg/l, depending on their detection limit.</td><td></td></tr>
<tr><td colspan="2">Limitations to data records</td></tr>
<tr><td colspan="2">The Catchment Water Quality Assessment Guide (DWAF, 2003b) describes the limitations to data records under the following headings:
• Outliers
• Non-detects
• Laboratory duplicates, and
• Missing data.
Some of the limitations associated with eutrophication related water quality data records are discussed below.</td></tr>
<tr><td>Outliers
Nutrient data records often have a few very high observations. Outlying values can occur due to analysis errors or when conditions in the water body changes in a dramatic way.</td><td>Outlying values should be removed from the data set. Diagnosing a value as an outlying value can be complex. The publication of Harris et al (1992) provides a comprehensive method for identifying outlying values.</td></tr>
<tr><td>Non-detects
Non-detects refers to cases where values are less than (or exceed) the detection limit of the analytical technique used in the laboratory. These are then recorded as less than the detection limit.</td><td>For data analysis, it is standard convention to change values reported as less than the detection limit, to half the detection limit. However, this practice can pose a problem in cases where the detection limit is high, say 1 mg/l for PO_4-P. Replacing the observation with 0.5 mg/l may lead to the wrong conclusion of the trophic status of a water body.</td></tr>
<tr><td>Derived data
Some data is derived from other observations. For example, particulate P is sometimes calculated by subtracting the PO_4-P from the TP concentrations. In the water quality database, derived data should be clearly distinguished from the raw data.</td><td>Contact the data supplier to determine whether there are nutrient fraction data that are calculated from other observations and how these are calculated.</td></tr>
</table>

DISPLAY AND PRESENTATION OPTIONS

Example of mapping the location of sampling points



Monitoring Programme Evaluation

A monitoring evaluation sheet should have the following information on each monitoring programme in the study area:

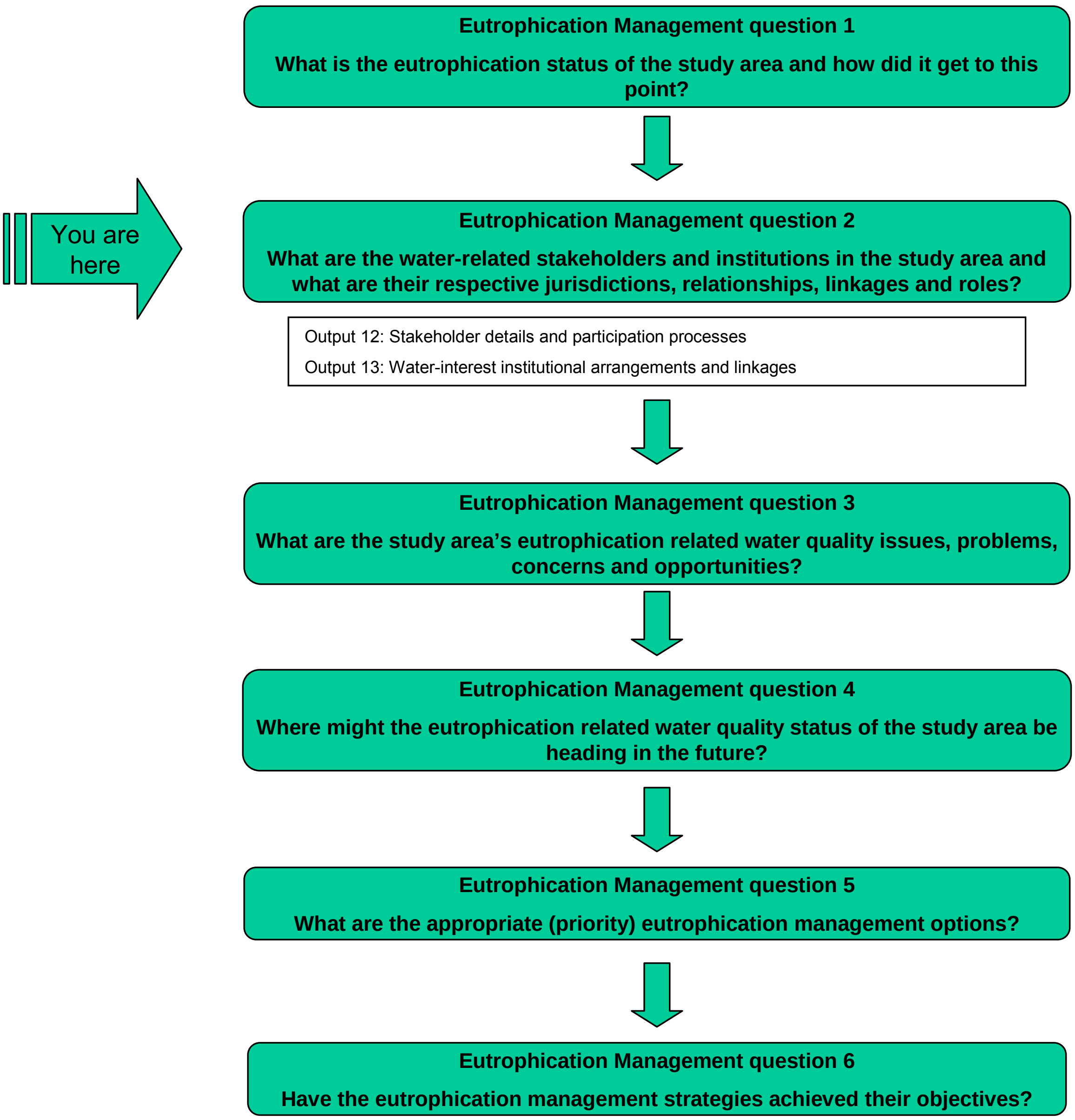
- The name of the monitoring programme
- Contact details of the owner of the monitoring programme
- Contact details of the analysing laboratory
- Information about the purpose of the programme and quality assurance procedures
- Location of sampling points and length of data records at each sampling point
- A qualitative assessment of the suitability of the data for assessing the water quality status

Example of a monitoring programme evaluation sheet.

Monitoring Programme Evaluation Sheet (Example)

Name of monitoring programme								
	Data source				Analyzing laboratory			Date
Organization				Organization				
Contact person				Contact person				
Postal address				Postal address				
Tel #				Tel #				
Fax #				Fax#				
Email				Email				
Web site				Web site				
Brief description of the objectives of the monitoring programme								
Documentation for the monitoring system			Yes/No/Unknown		Comments			
Quality assurance / Quality control procedures			Yes/No/Unknown		Comments			
Data security			Public domain / Restricted / No access / Unknown		Comments			
For each sampling point in the study area, list the following								
Station number	Description		Longitude	Latitude	Total number of samples	Date of first sample	Date of latest sample	Sampling frequency
For each sampling point used in the analysis, list the following								
Station number	Assessment Good/Moderate/Poor		Comments					

Route Map of the Guide



Eutrophication Management Question 2:

WHO ARE THE WATER-RELATED STAKEHOLDERS AND INSTITUTIONS IN THE STUDY AREA AND WHAT ARE THEIR RESPECTIVE JURISDICTIONS, RELATIONSHIPS, LINKAGES, AND ROLES?

Eutrophication Assessment Task 2:
Engagement of water-related institutions and stakeholders in CAS process

COMPONENT 12
Stakeholder Details and Participation Processes

PURPOSE
Generic catchment assessment context
The National Water Act requires that a CMS must "…enable the public to participate in managing the water resources within its water management area" [*s9(g)*] and "…take into account the needs and expectations of existing and potential water users" [*s9(h)*]. In a generic catchment water quality assessment, the purpose of this component is to identify the "water quality stakeholders" and to engage them in the catchment management strategy process. These are *any people* or institutions interested in water quality, or affected by water quality and the way it might be managed. One of the best ways of understanding water quality issues in catchments is by engaging the people and the institutions who perceive them, or who are affected by them.
Eutrophication assessment context
In the context of an eutrophication assessment it is important to engage with stakeholders that are involved in the sources of nutrient enrichment (e.g. an effluent discharger) or those affected by the negative effects of eutrophication (e.g. domestic or recreational water users).
Purpose
This component will ensure that the primary groupings of people and institutions that have an interest in eutrophication in the study area are recognised and given the opportunity to make inputs into the assessment. The output from this Component is not only *stakeholder information*, but should also be viewed as a *process*; i.e. the first stage of a stakeholder engagement and participation process.
Prerequisite Components
This component starts simultaneously with **Component 0** (inherent knowledge), as well as **Component 5**, but requires crucial information from **Components 1, 5, 6** and **7** before it can be regarded as reasonably advanced.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Stakeholder database, organised by sector and/or sub-catchment and cross-referenced for individuals' technical or scientific specialities.	Compile a stakeholder database using the stakeholder groupings listed in the checklist. This is generally an iterative process.
First stage of catchment management–related stakeholder participation processes.	For the catchment description phase, the minimum required output from the process is the identification of water quality issues and concerns. The formulation of a vision and management objectives for the catchment belongs to the management support phase of the catchment assessment study.
Eutrophication assessment outputs	
Same as the generic catchment assessment outputs.	Compile a stakeholder database using the checklist below to identify those stakeholders associated with the causes of eutrophication or affected by the symptoms of eutrophication.
SOURCES	
In many catchments, the process of establishing a Catchment Management Agency is well advanced and the regional DWAF office would have a good stakeholder database.	Regional CMA manager DWAF Regional offices Website: www.dwaf.gov.za

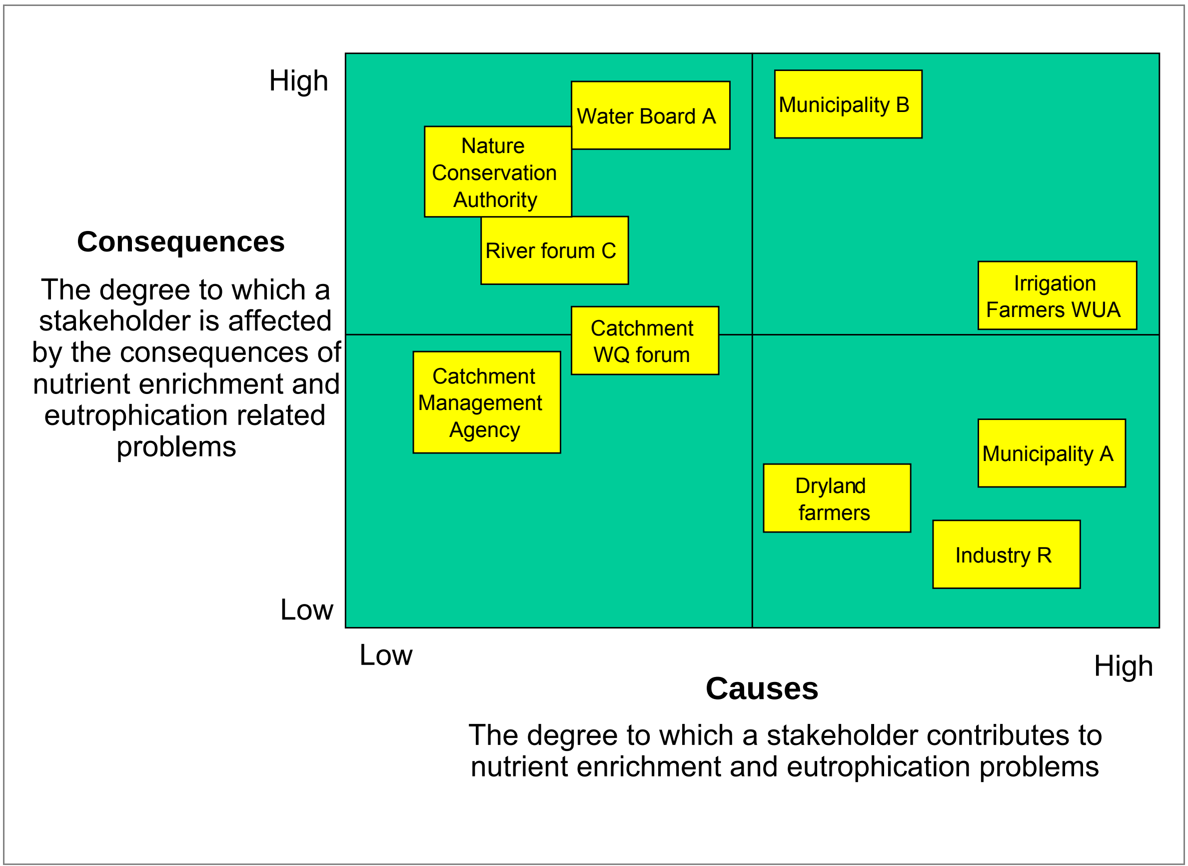
Technical Guide for public participation to support Integrated Water Resources Management.	Greyling, T and Manyaka, S (1999). *Appropriate Public Participation for Catchment Management Agencies and Water User Associations: Towards Co-operative Governance.* Technical Report to Directorate: Catchment Management, DWAF, Pretoria.
CHECKLISTS	
Water Management and Water Services Institutions	CMAs, catchment management committees, WUAs, and Water Boards are often affected by the symptoms of eutrophication and would therefore have knowledge of eutrophication problems in the study area.
Existing Forums and Steering Committees	Forums or Forum Committees, involved in aspects such as Water Quality, Irrigation, Environment, Catchment Management, Conservancies, Land Care, Green Belts, Wetlands, Wildlife, Coastline and Bays, Estuaries, can have specific knowledge of nutrient sources or eutrophication effects.
Civil Society	Community-based organisations (CBOs), residential organisations, traditional leaders, scientific organisations, professional organisations may have knowledge of specific eutrophication problems in the study area.
Agriculture	Sector organisations and *relevant* individual professionals, researchers and academics in this sectors often have knowledge of, for example, fertilizer use and possible load estimates from agricultural sources, eutrophication symptoms such as excessive nuisance algal growth in canals or algal blooms in irrigation dams.
Conservation, Environment and Health	Sector organisations and *relevant* individual professionals, researchers and academics in these sectors often have specialist knowledge of nuisance algal blooms in rivers (River Health Programme) or taste and odour problems in treated drinking water.
Government: Central, Provincial and Local	Government officials with responsibilities for water quality management often have specialist knowledge of eutrophication causes and symptoms in their area of jurisdiction.
Researchers and technical specialists	Relevant individuals who have local scientific and technical experience with eutrophication problems and who may have gathered local eutrophication related data and information.
DISPLAY AND PRESENTATION OPTIONS	

Stakeholder table

See the example in the *Catchment Water Quality Assessment Guide* (DWAF, 2003b).

Stakeholder Analysis Matrix

The stakeholder profile of a study area can be analysed in different ways. For example, one way may be to assess the stakeholders on a two by two matrix where one axis could be the degree to which a stakeholder contributes to the causes of eutrophication, and the second axis could be the degree which a stakeholder is affected by the consequences of eutrophication. The study team can then develop different strategies for interacting with clusters of similar stakeholders. This example is illustrated below. Another possible two by two matrix would be to examine stakeholders and how they would be affected by proposed management strategies, against the power they have to influence strategy development process.


High
Consequences
The degree to which a stakeholder is affected by the consequences of nutrient enrichment and eutrophication related problems
Low
Water Board A
Municipality B
Nature Conservation Authority
River forum C
Irrigation Farmers WUA
Catchment WQ forum
Catchment Management Agency
Municipality A
Dryland farmers
Industry R
Low
High
Causes
The degree to which a stakeholder contributes to nutrient enrichment and eutrophication problems

COMPONENT 13
Water-Interested Institutional Arrangements and Linkages

PURPOSE

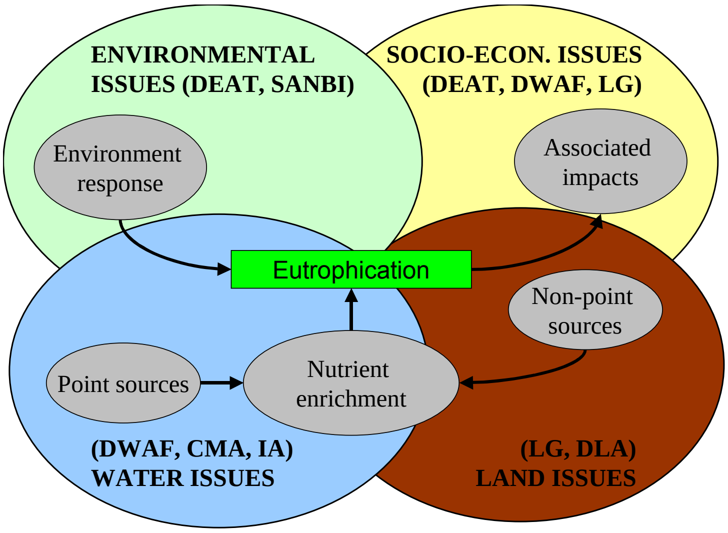
Generic catchment assessment context

Water quality in a catchment is an expression of the degree to which land-use and other physical developments have modified the terrestrial phase of the hydrological cycle. However, control over many land-uses and other physical developments lies outside the statutory domain of the National Water Act. Other laws and government institutions control many of the activities that affect catchment water quality. Against this fragmented background, the development and implementation of a catchment management strategy will be highly dependent on a process of co-operative governance. It is therefore important that a catchment water quality assessment study identifies and describes the water-interest institutions in a catchment and clarifies the linkages between them.

Eutrophication assessment context

The focus in an eutrophication assessment is to identify and describe the institutions that would have control over nutrient loads generated in the catchment and its fate in different components of the hydrological cycle.

Eutrophication has distinct water, land, environmental and socio-economic elements (as illustrated below) and institutional role players range from central government (DWAF, DEAT, DLA) to regional (CMA) to local government (LG)[4].



Water issues - Eutrophication is commonly perceived as a water quality problem because the environmental response to eutrophication occurs within water bodies and follows from the enrichment with nutrients. However, eutrophication is not only a water quality problem. In terms of nutrient enrichment, the point-source discharge of nutrient-rich effluent from, importantly, wastewater works but also from bulk industry (pulp and paper, textiles, agro-industry) and from intensive animal husbandry, is defined as a water use under the National Water Act (Section 21). Such enrichment therefore falls within the institutional realm of the Department of Water Affairs and Forestry (DWAF), the Catchment Management Agency (CMA) and the Infrastructure Agency (IA), where it influences the ability of the IA to recover costs.

Land issues - Nutrient enrichment also occurs from a number of non-point sources (NPS). Under some circumstances, these NPS are the dominant contributors to the eutrophication problem (see **Component 8**). These sources of nutrient enrichment are associated with issues of land-use and the management of these sources are based on the management of land and land-based activities.

[4] Extracted from documents prepared by C. von der Heyden of Pegasus Strategic Management for Operational Guideline for Best Eutrophication Management Practices.

The NPS fall within the institutional remit of either Local Government (LG) as the service provider and as the local development planner, or of the Department of Land Affairs and Agriculture (DLA). Relevant legislation in terms of the agricultural NPS includes the Conservation of Agricultural Resources Act (CARA) which describes the measures required to prevent the wash-off of soil and sediment, and to limit the return-flow of irrigation water.

Environmental issues - Eutrophication has a very clear environmental element, namely the environmental response to the increased availability of nutrient. The Environmental Conservation Act (ECA) and the National Environmental Management Act (NEMA) are key pieces of legislation that describe how, *inter alia*, eutrophication is governed. For example, Section 20 of the ECA provides for the licensing of waste disposal sites and affords protection to underground water resources from polluted seepage. The purpose of NEMA is to give effect to the Constitutional rights to an environment that is not harmful to health or well-being, and that is protected. The National Environmental Management: Biodiversity Act operates within the framework provided by NEMA. The Act is significant to eutrophication governance as Section 52 creates a mechanism for protecting ecosystems that are threatened or in need of protection. Chapter 5 deals with, *inter alia*, alien species that threaten water resources, such as the macrophytes associated with eutrophication. These issues fall within the mandate of the Department of Environmental Affairs and Tourism (DEAT). However, other statutory institutions, such as the South African National Botanical Institute (SANBI) and South African National Parks (SANParks), and the civil society conservation organisations, such as the Wildlife and Environment Society of South Africa (WESSA) and the conservancies, are intricately associated with the governance of the environment and with the ecological change inherent in eutrophication.

Socio-economic issues - The socio-economic issues of eutrophication are cross-cutting, in that eutrophication has some significant socio-economic impacts, while some of the causes of eutrophication (particularly nutrient enrichment) are related to socio-economic factors. Eutrophication results in increased costs to society and changes in social behaviour, both as a result of the enrichment of water bodies with nutrients and through the ecological response to such enrichment. As the socio-economic issues relating to eutrophication are diverse, so the institutional responsibilities for such issues are similarly diverse. Water quality for use is the responsibility of the DWAF, of Water Boards and of the service providers (LG). Changes in non-consumptive use of a resource and associated change in recreational and tourism revenue are the concern of DEAT, while the health effects and the poverty effects discussed are the mandate of LG. Clearly, civil society is involved in the governance frameworks at various points, for example community based organisation (CBO), community health organisation and recreational user associations.

Purpose

The purpose of this component is to compile an information base on water-related statutory institutions, their jurisdictions, functions, administrative structures and inter-institutional relationships, that have control over the production and delivery of nutrients in a study area as well as the impacts on water users.

Prerequisite Components

Components 0, 1 and **12** are prerequisites for this Component.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The catchment water quality assessment guide (DWAF, 2003b) lists three outputs: • An outline of all statutory water management and water services institutions in the catchment, • A description of *internal and external* institutional relationships, and • A schematic description of *internal* and *external* "voluntary" relationships with stakeholders and other interested parties.	Refer to the *Catchment Water Quality Assessment Guide* (DWAF, 2003b).

Eutrophication assessment output	
The outputs for an eutrophication assessment are similar to outputs required for a generic catchment assessment study.	Identify and describe the institutions that have control over the production and delivery of nutrients in the study area using the guidelines provided in the *Catchment Water Quality Assessment Guide* (DWAF, 2003b).

SOURCES

Pegram, G C (1999). The Catchment Management Agency Establishment Process, Report to Directorate: Catchment Management, DWAF, Pretoria.

Görgens, A H M (1999). Catchment Management Agency Functions and Organizational Considerations, Report to Directorate: Catchment Management, DWAF, Pretoria.

Peart, R and Masia, M (1999). Relationship between Catchment Management Agencies and Other Institutions. Report to Directorate: Catchment Management, DWAF, Pretoria.

Pegram, G C and Palmer Development Group (2000). Guidelines for Financing Catchment Management. Report to the Water Research Commission, Pretoria.

Pegram, G and Mazibuko, G. (2003). Evaluation of the role of Water User Associations in water management in South Africa. Report to the Water Research Commission, Report No. TT 204/03.

Pegram, G, Mazibuko, G, Hollingworth, B and Anderson, E (2006). Strategic review of current and emerging governance systems related to water in the environment in South Africa. WRC Report No. 1514/1/06, Water Research Commission.

CHECKLISTS

Refer to checklists for **Components 12** and **17**.

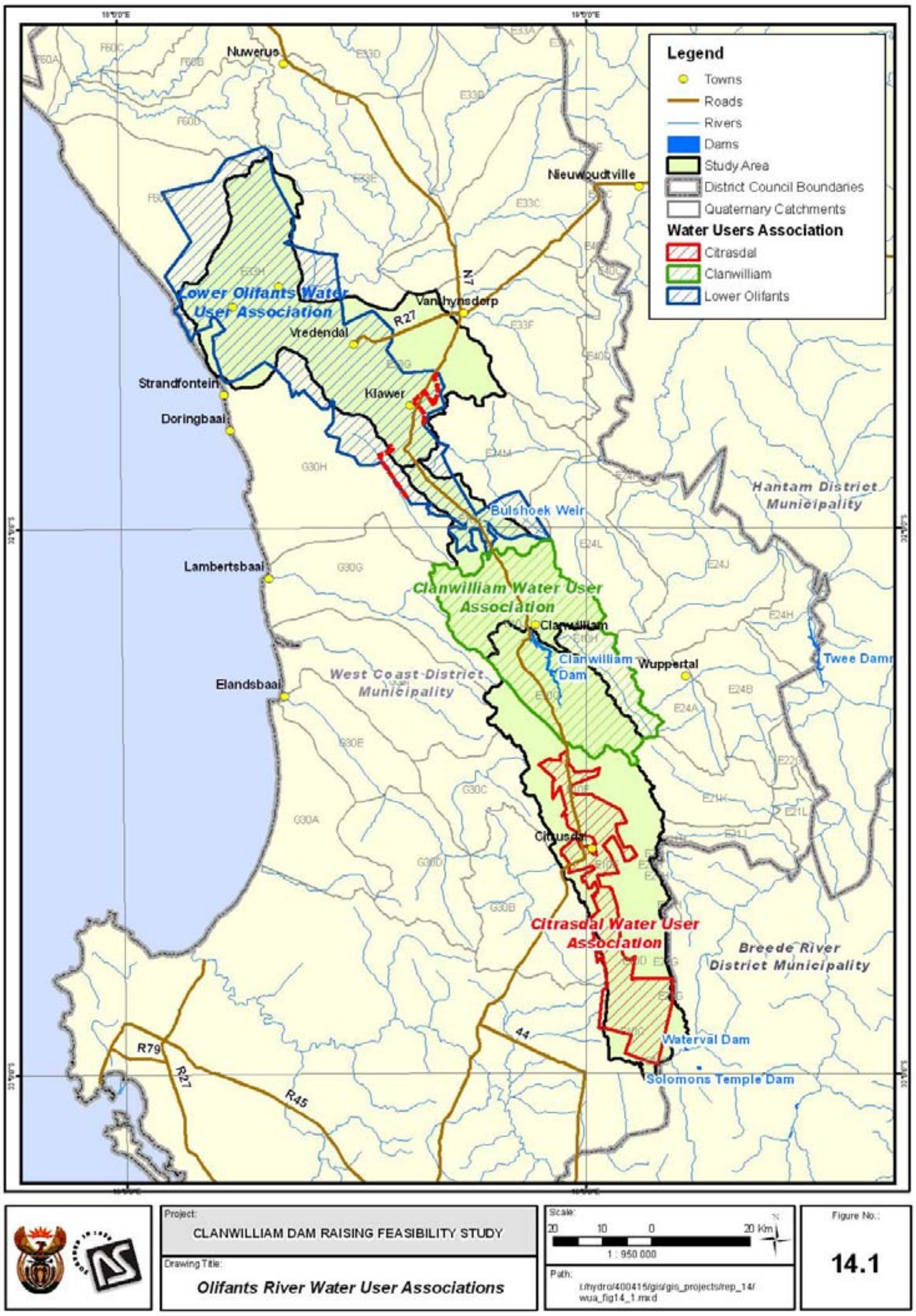
Relationships between institutions

The nature of the relationships between institutions can be described as:

- Statutory (powers and duties assigned or delegated under an Act)
- Regulatory (one monitors and audits the other)
- Co-operative governance based (collaboration amongst various organs of state with differing competencies and jurisdictions)
- Contractual (performing catchment management functions (not statutory) on behalf of each other in return for a management or service fee)
- Representative (between stakeholders - particularly water user sectors – and their representative water management structures, as well as politically accountable spheres of government.

DISPLAY AND PRESENTATION OPTIONS

Example of a map showing the geographic boundaries of different water user associations and district councils.



Route Map of the Guide

Eutrophication Management question 1

What is the eutrophication status of the study area and how did it get to this point?

Eutrophication Management question 2

What are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?

You are here

Eutrophication Management question 3

What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?

Output 14: Record of eutrophication related water quality issues and their origins

Output 15: Catchment management implications of eutrophication water quality issues

Output 16: Vision (or long-term resource objectives) for eutrophication related water quality

Eutrophication Management question 4

Where might the eutrophication related water quality status of the study area be heading in the future?

Eutrophication Management question 5

What are the appropriate (priority) eutrophication management options?

Eutrophication Management question 6

Have the eutrophication management strategies achieved their objectives?

Eutrophication Management question 3:

WHAT ARE THE STUDY AREA'S EUTROPHICATION RELATED WATER QUALITY ISSUES, PROBLEMS, CONCERNS AND OPPORTUNITIES ?

Eutrophication Assessment Task 3:
Formulate and record eutrophication related water quality issues, concerns, problems, and opportunities

COMPONENT 14
Record of Eutrophication Related Water Quality Issues and their Origins

PURPOSE

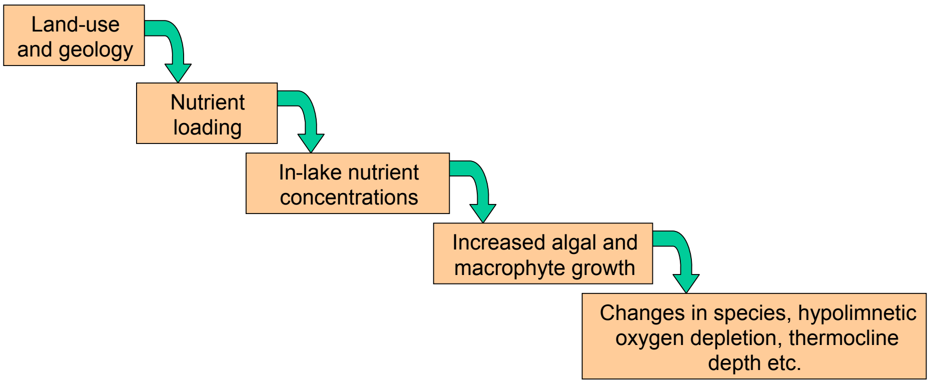
Generic catchment assessment context

Water quality issues are water quality related problems that users experience. These problems are based on perceptions of water users and may therefore be real problems or perceived problems. Real water quality issues and problems can be identified by determining if the observed water quality is poorer than the user water quality requirements, and by how much. The link between causes and consequences or symptoms can then be investigated in more detail.

Eutrophication assessment context

The cause-effect chain in eutrophication can be quite complex and in an eutrophication assessment study, the problems experienced by users are often far removed from its causes. It is therefore important to identify those water quality issues, concerns and problems that can be traced back to nutrient enrichment.

The components of reservoirs, rivers and lakes are interconnected. Increased nutrient loadings generally affect plants (algae etc.) directly but other components of the system are affected indirectly through various pathways. This is referred to as the trophic causal chain and is illustrated below (Gibson *et al*., 2000).



Stakeholders often raise the symptoms of eutrophication as a water quality concern and one needs to step back through the trophic causal chain to identify the origins of the concern.

Purpose

The first objective of this component is to identify the water quality concerns relating to eutrophication (e.g. taste and odour problems in drinking water) and then to identify and understand the processes that contribute to the causes of the problem (e.g. presence of nuisance blue-green algae in the raw water as a result of high nutrient concentrations). The last step is to identify all the relevant water quality constituents that should be managed to alleviate the symptoms of the problem. This approach will also ensure an integrated approach to managing the physical, chemical and biological factors contributing to eutrophication problems.

Prerequisite Component

To undertake this Component, Task 1: Characterization of the current situation and historical trends must be completed.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Inventory of eutrophication related water quality problems, issues and the factors contributing to the problems.	Integration of eutrophication related water quality problems raised by stakeholders, water user requirements, and observed water quality status and trends.

SOURCES

The primary sources of generic information on water quality problems in South Africa and the water quality constituents associated with them, are the *South African Water Quality Guidelines* and the *Assessment Guide for Domestic Water Supply*.

South African Water Quality Guidelines (1996) Volume 1: Domestic water use Volume 2: Recreational water use Volume 3: Industrial water use Volume 4: Agricultural water use: Irrigation Volume 5: Agricultural water use: Livestock watering Volume 6: Agricultural water use: Aquaculture Volume 7: Aquatic ecosystems Volume 8: Field guide	*The South African Water Quality Guidelines* can be obtained from the Directorate of Water Quality Management, DWAF. Website: www.dwaf.gov.za
Quality of domestic water supplies. Volume 1: *Assessment Guide*. Second edition. Water Research Commission Report TT 101/98	*The Assessment Guide* can be obtained from Water Research Commission, Pretoria. Website: www.wrc.org.za

CHECKLISTS

The following is a range of common eutrophication related water quality issues that have been grouped per water use sector. The list can be used as a checklist to guide the identification of water quality issues in a catchment assessment study.

***Note: only the problems and constituents relating to eutrophication have been identified below. Other constituents associated with the problem are listed in the* Catchment Water Quality Assessment Guide.**

Domestic water supply

Water used for domestic purposes includes water for drinking, food & beverage preparation, hot water systems, bathing and personal hygiene, washing, laundry and gardening. Domestic water users can experience a wide range of water quality problems. These can be categorized as impacts on the health of consumers, aesthetic impacts and economic impacts.

Concerns	***Eutrophication related constituents***
Health impacts that includes short and long-term effects on the health of consumers. This includes the effect of toxic substances that can be harmful even at low concentrations.	Toxic algae, ammonia, trihalomethanes
Aesthetic impacts that include changes in water taste, odour or colour or staining of laundry or household fittings and fixtures.	Algae, dissolved organic carbon, nitrate, odour, suspended solids, turbidity
Economic impacts that include increased treatment costs.	Algae, taste and odours.

Industrial water supply

The eutrophication related water quality problems experienced in industries can be categorized in the following groupings:

- Potential damage to equipment, for example biofouling.
- Potential problems in the manufacturing process, for example precipitates and colour changes, and
- Impairment of product quality, for example taste or discolouration.

The eutrophication related water quality constituents generally associated with these industrial water quality problems are listed below.

Concern	***Eutrophication related constituents***
Biofouling	Nutrients, chemical oxygen demand, biochemical oxygen demand
Blockages	Algae (filamentous or free floating), chemical oxygen demand, biochemical oxygen demand
Discolouration	Algae, chemical oxygen demand
Foaming	Algae, chemical oxygen demand
Sediment	pH, total hardness, Iron, Manganese, Sulphate, suspended sediment
Gas production	Chemical oxygen demand
Taste and/or odours	Algae
Turbidity	Algae, Chemical oxygen demand
Colour	Algae, Chemical oxygen demand
Biological growth or biofouling	Algae, nutrients, suspended sediment, chemical oxygen demand
Agricultural water supply: Irrigation	
Irrigation water users experience a range of impacts as a result of changes in water quality. These include:	The key water quality constituents which can be linked to these water quality problems include:
Concern	***Eutrophication related constituents***
Nuisance filamentous algae or blue-green algal scums in irrigation canals and irrigation water dams.	Algae, nutrients, suspended solids
Blocking, fouling or damage to irrigation equipment as a result of algae in the irrigation water.	Algae, nutrients, suspended solids
Agricultural water supply: Stock watering	
Eutrophication related water quality concerns associated with the production of livestock depends on a number of factors such as the type of livestock, the type of livestock products and type of production system in use. If water quality does not meet requirements, a wide range of problems can be encountered. These are generally categorized as: • Problems associated with the consumption of water by livestock, • Problems associated with the water distribution system to livestock, and • Problems associated with the quality of livestock products.	
Concerns	***Eutrophication related constituents***
Problems associated with the consumption of water by livestock. These include concerns about toxicological and/or palatability effects.	Toxic algae, algal scums, nitrate & nitrite
Eutrophication problems associated with the livestock watering systems include clogging or biofouling. Other more generic problems include corrosion, encrustation, scaling, and sediment.	Filamentous or free-floating algae, nutrients, biochemical oxygen demand
Eutrophication related problems associated with livestock product quality include concerns about consumer health hazards and/or product quality.	Toxic algae, blue-green algae, THMs

Agricultural water supply: Aquaculture

Aquaculture refers to aquatic agriculture and it can be divided into several sectors:

- breeding of fish in cages in dams and natural lakes (cage culture)
- extensive farming in small earthen farm dams
- extensive and semi-intensive fish farming in purpose designed fish ponds, and
- intensive farming in raceways and tanks.

Concern	***Eutrophication related constituents***
Concerns about low dissolved oxygen and eutrophication of the water	Algae, dissolved oxygen, carbon dioxide, nitrate and nitrite, ortho phosphate
Concerns about the presence of toxic compounds in the water	Toxic algae, ammonia (NH_4),
Discharge of nutrient rich water from intensive aquaculture units.	Nutrients

Aquatic environment

The Department of Water Affairs and Forestry considers aquatic ecosystems to be the base from which the water resource is derived. Man depends on many of the services provided by a healthy ecosystem. These include the ability to assimilate certain waste products, providing a pleasing environment for recreation, provide a livelihood for communities that depend on water bodies for food and maintaining biodiversity and habitats for the biota that depend on the ecosystem. Aquatic ecosystems must be protected to ensure the resource remains fit for all the other uses (domestic, agriculture, etc.) on a sustainable basis.

Concerns	***Eutrophication related constituents***
Toxic substances	Toxic algae, ammonia
Low dissolved oxygen	Algae, organic material
Nutrients	Inorganic nitrogen such as nitrate, nitrite and ammonium and inorganic phosphates such as ortho-phosphate

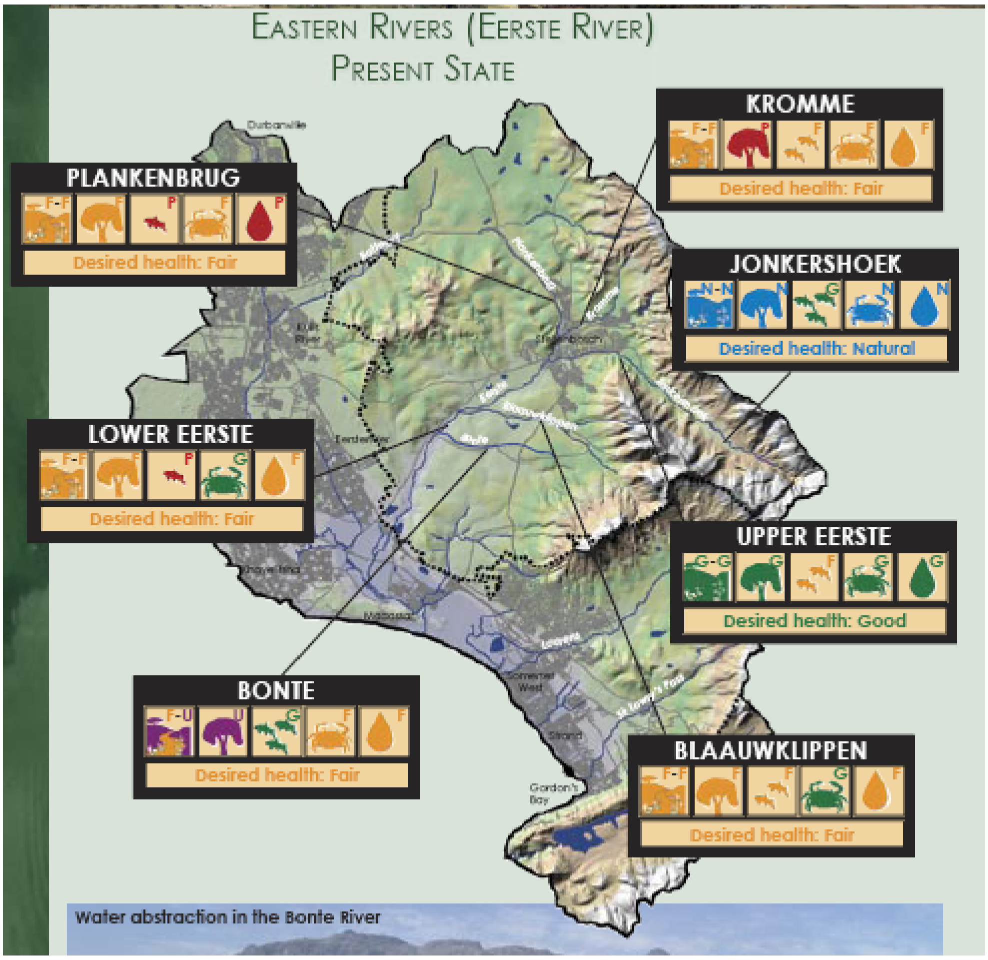
Recreational water use

Recreational water users experience a range of impacts as a result of changes in water quality and the type of recreation. Three types of recreation have been identified: Full-contact recreation such as swimming and diving, intermediate contact recreation such as water-skiing and angling, and Non-contact recreation such as picnicking and hiking next to a water body. Eutrophication related concerns include the following:

Concerns	***Eutrophication related constituents***
Human health impacts refer to concerns about waterborne diseases such as gastro-enteric diseases, skin and ear infections and carcinogenic risks.	Presence of toxic algae
Human safety impacts refer to concerns about poor visibility, profuse plant growth and benthic microbial and/or algal growth.	Filamentous or free-floating algae, nuisance plants
Aesthetic impacts refer to concerns about odour and/or colour of the water, discolouration and staining, objectionable floating matter and nuisance plants.	Filamentous or free-floating algae, nuisance plants, water clarity, odour
Economic impacts refer to concerns about damage to recreation equipment.	Algae, clarity, nuisance plants

DISPLAY AND PRESENTATION OPTIONS

An example of how water quality issues can be described:



REFERENCES

Gibson, G, Carlson, R, Simpson, L, Smeltzer, E, Gerritson, J, Chapra, S, Heiskary, S, Jones, J and Kennedy, R (2000). *Nutrient criteria technical guidance manual: Lakes and reservoirs*. USEPA report No. EPA-822-B00-001. United States Environmental Protection Agency.

COMPONENT 15

Catchment Management Implications of Eutrophication Related Water Quality Issues

PURPOSE

Generic catchment assessment context

The process of developing catchment management strategy is described in a document, *Guideline to the Water Quality Component of the Catchment Management Strategy* (DWAF, 2003). It describes procedures for:

- setting *medium-term resource objectives* and a long-term vision from the statement of variables of concern and user water requirements, via examination of water quality issues,
- setting of *source management objectives* for all management units and right-size water quality loads so that resource objectives can be met,
- developing *water quality management strategies* that prioritise sectors and sources so that source management objectives can be met, and
- the development of *water quality management plans* on a sector, source and management unit basis.

All the water quality issues, problems, concerns or opportunities (collectively called "issues") recorded in **Component 14** potentially requires attention in the catchment management strategy development process. This creates an issue-focused bridge between the catchment assessment study and the catchment management strategy.

Eutrophication assessment context

The eutrophication related issues, problems, concerns and opportunities recorded in **Component 14** need to be addressed in an eutrophication management strategy which should form part of a larger catchment management strategy. This component provides the framework for linking the issues to medium-term eutrophication management objectives, nutrient management objectives for different sources, nutrient or eutrophication management strategies or nutrient management plans for individual sources.

This component is not a primary component of an eutrophication assessment study but is included to bridge the gap between the assessment study and strategy development. It is the responsibility of the strategy development team to ensure that the strategy is 'issues driven'.

Output from **Component 0** (existing understanding) may already highlight eutrophication related issues that may need urgent *ad hoc* management intervention.

Purpose

The purpose of this component is to record how each eutrophication related issue, problem, concern, or opportunity should be linked to different phases of an eutrophication management strategy (as generically described in the *Guideline (DWAF, 2003)*) to ensure that it influences appropriate management decisions.

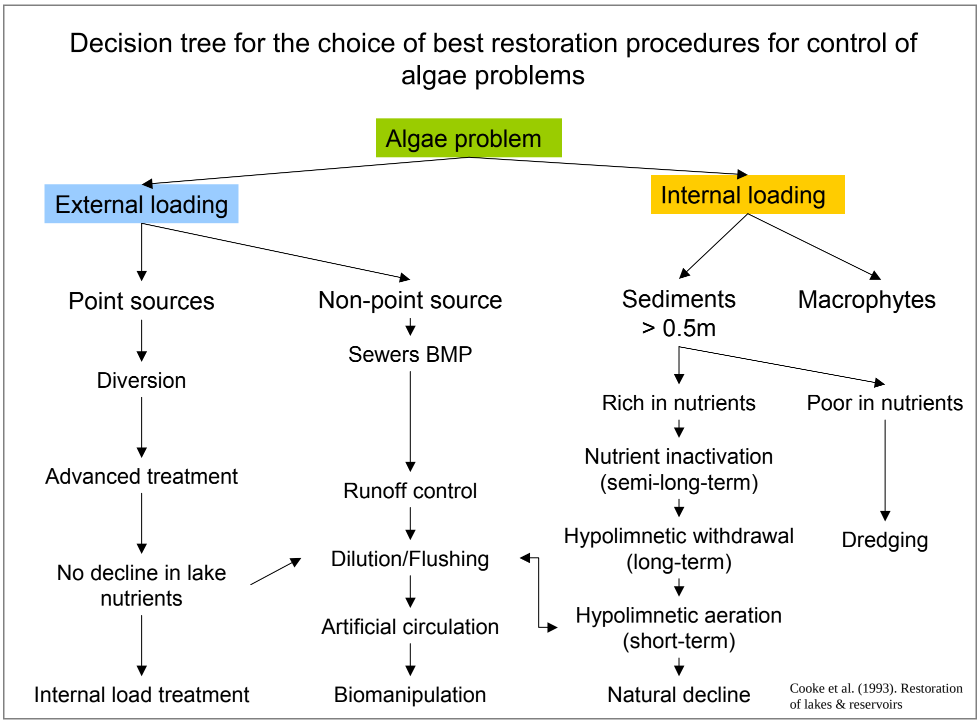
Prerequisite Components

Completion of Task 1 and **Components 14** and **18** are prerequisites.

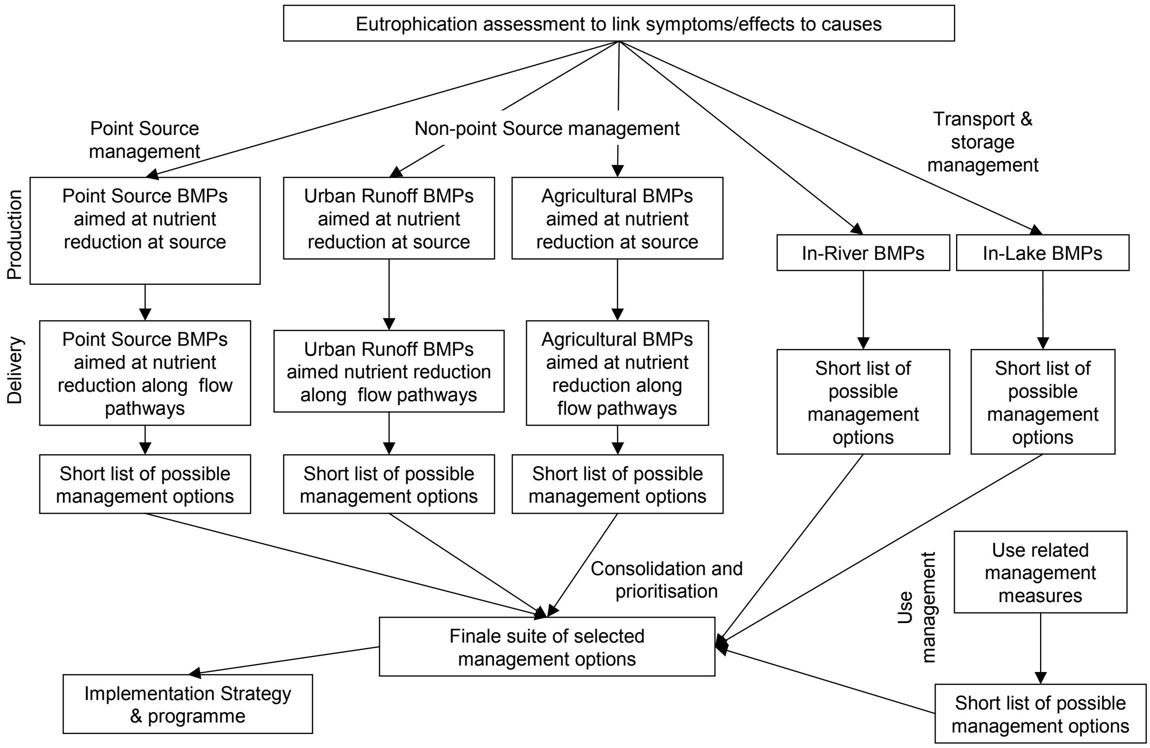
OUTPUTS	HOW TO ATTAIN OUTPUTS
Eutrophication assessment outputs	
Table and brief description that links eutrophication related issues with one or more of the phases of the eutrophication management strategy development process.	Interpret inputs and feedback from stakeholder participation processes, as well as from examining the findings of predictive studies.
Table that provides conceptual management options for each eutrophication related issue.	Obtain inputs during stakeholder participation processes and consult sectoral specialists.

METHODS AND TOOLS

Cooke *et al*. (1993) provided a decision tree than can guide water resource managers to select restoration options for the control of algae problems in lakes and reservoirs. This tree and others like it can be used to link eutrophication issues to management options and plans.



An example of a process for selecting a suite of eutrophication management options is illustrated below (DWAF, 2006):



The assessment of the eutrophication problems and linking them to their root causes determines where attention should be focused in the treatment train (sources and pathways/transport and storage/use). The next basic step is to develop a first-cut laundry list of management options that addresses all the components of the eutrophication management framework. The different laundry lists are then combined and prioritised and a shortened list of options is then organised, analysed and prioritised to become the strategy and programme of actions that will be implemented in the short to medium-term.

The DWAF hierarchy of water quality management decision-making encourages managers to start at pollution prevention (source management) and waste minimization (pathway management). This is done by identifying a short list of possible BMPs to manage point and/or non-point sources at source and/or along the flow pathways. The assessment will provide guidance on how much of the nutrient loads originated from point or non-point sources and how much of resources should be expended to control these sources and the pathways through which nutrient loads reach receiving water bodies. In general, it was found that sources and pathways are considered as a group, e.g. agricultural sources or urban sources.

The assessment also provides guidance on whether management in the receiving water body (transport and storage management) should be considered. These include in-river management options where the assimilative capacity of the river is used to reduce nutrient concentrations (transport management) or in-lake management options designed to reduce algal growth, suppress internal loading or reduce water retention time.

CHECKLISTS

Management options to address **point sources** of nutrients, include:

Municipal wastewater treatment

- Pond treatment systems
  - Facultative ponds
  - Anaerobic ponds
  - Aerobic ponds
  - Reed beds
  - Trickling filters
- Activated Sludge Process
  - Aerobic system
  - Anoxic-aerobic system
  - Anaerobic-anoxic-aerobic system
  - Chemical precipitation
- Post-treatment systems
  - Constructed wetlands

Small community treatment systems

Management options to address **agricultural non-point sources** of nutrients, include:

- Fertilizer application management
- Riparian buffer strips
- Vegetated filter strips
- Contour cultivation
- Stream and river bank protection
- Strip cropping
- Management of pastures
- Accurate fertiliser application
- Grassed waterways
- Management of livestock manure
- On-site management of waste from intensive animal feeding units
- Stormwater runoff management

Management options to address **urban non-point sources** of nutrients, include: • Grass buffer areas • Grass swales • Porous pavement and porous pavement detention • Porous landscape detention • Dry ponds and extended detention basins • Wet detention ponds • Sand filter extended detention basins • Natural or artificial wetlands • Interception trench • Maintenance and upgrading of sewer infrastructure • Litter and pet waste control ordinance • Street sweeping • Catch basin cleaning • Public education programmes • Refuse collection and disposal
Management options to address eutrophication in **receiving rivers and reservoirs**, include: **In-river or in-stream management options** • Diversion of wastewater • Pre-impoundments • Dilution and flushing **In-lake management options** • Biomanipulation: coarse fish eradication • Biomanipulation: floating wetlands • Biomanipulation: riparian wetlands • Shoreline management • Chemical water treatment • Partitioning (mesocosms, corrals) • Wake controls (powerboats) • Biological controls: habitat protection • Biological controls: natural predators • Bottom sealing (physical) • Sediment treatment using chemicals • Macrophyte harvesting • Aeration • Augmented circulation • Algaecides • Dilution/flushing • Dredging • Hypolimnetic withdrawal • Light inhibiting dyes • Nutrient supplementation • Water level controls (drawdowns)

SOURCES

Below are sources of information on best eutrophication management practices that can be useful in the compilation of detailed interventions. This list is by no means exhaustive and the reader is encouraged to visit the websites listed, consult some of the references listed in the books and reports referred to below, as well as those listed in the Reference list of this report.

South African Reports

City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments.* Catchment, Stormwater and River Management Branch, Transport, Roads and Stormwater Directorate, City of Cape Town.

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R (2004). *Hartbeespoort Dam Remediation Project (Phase 1). Volume 1: Action Plan*. Department of Agriculture, Conservation, Environment and Tourism. Northwest Province.

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R (2004). *Hartbeespoort Dam Remediation Project (Phase 1). Volume 2: Annexures: Specialist reports*. Department of Agriculture, Conservation, Environment and Tourism. Northwest Province.

Hart, R and Hart, R C (2006). *Reservoirs and their management: A review of the literature since 1990*. WRC Report No. KV 173/06. Water Research Commission, Pretoria.

Marais, M and Armitage, N (2003). *The measurement and reduction of urban litter entering stormwater drainage systems*. WRC Report No. TT 211/03. Water Research Commission, Pretoria.

International reports and books

Campbell, N, D'Arcy, B, Frost, A, Novotny, V and Sansom, A (2004). *Diffuse Pollution - An introduction to the problems and solutions*. IWA Publishing, London.

Cooke, G D, Welch, E B, Peterson, S A and Nichols, S A (2005). *Restoration and management of lakes and reservoirs.* 3rd Edition. CRC Press, Taylor & Francis Group, Boca Raton.

Debo, T N and Reese, A J. (2003). *Municipal Stormwater Management.* Lewis Publishers, Boca Raton.

Evans, B M and Corradini, K J (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: www.predict.psu.edu/downloads/BMPManual.pdf

Haestad Methods & Durrans, S R (2003). *Stormwater conveyance modeling and design*. First edition. Haestad Methods, Haestad Press, Waterbury.

Holdren, C, Jones, W and Taggert, J (2001). *Managing Lakes and Reservoirs*. North American Lake Management Society and Terrene Institute, in co-operation with the Office of Water Assessment, Watershed Protection Division, USEPA, Madison, WI.

Moss, B (1998). *Shallow lakes, Biomanipulation and Eutrophication*. *Scope Newsletter Number 29*. Available online: http://www.ceep-phosphates.org/

Mudgeway, L B, Duncan, H P, McMahon, T A and Chiew, F H S (1997). *Best practice environmental management guidelines for urban stormwater.* Background report to the Environmental Protection Authority, Victoria, Melbourne Water Corporation and the Department of Natural Resources and Environment, Victoria. Co-operative Research Centre for Catchment Hydrology. Available online: http://www.catchment.crc.org.au

Muthukrishnan, S, Madge, B, Selvakumar, A, Field, R and Sulivan, D. *The use of Best Management Practices (BMPs) in Urban Watersheds.* EPA/600/R-04/184. Online: http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf

Ryding, S-O and Rast, W (Eds.) (1989). *The control of Eutrophication of Lakes and Reservoirs*. Man and the Biosphere Series. UNESCO, Paris.

Von Sperling, M and Chernicharo, C A L (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

Internet resources

SCOPE Newsletter - Centre Europeen d'Etudes des Polyphosphates (promotes the sustainable use of phosphates through recovery and recycling).

Online: http://www.ceep-phosphates.org/

Land and Water Australia. National Eutrophication Management Program.

Online: http://www.rivers.gov.au/Our Research/National Eutrophication Management Program/index.aspx

Massachusetts Nonpoint Source Pollution Management Manual - BMP Selector tool.

Online: http://projects.geosyntec.com/megamanual/default.html

Natural Environment Research Council, Centre for Ecology and Hydrology - compendium of some diffuse pollution control websites.

Online: www.dorset.ceh.ac.uk/River_Ecology/River_Systems/Diffuse_Pollution.htm

The Ohio State University. College of Food, Agricultural, and Environmental Sciences. Ohioline Factsheets.

Online: http://ohioline.osu.edu/lines/facts.html

UN Environmental Programme, Division of Technology, Industry, and Economics. Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication. Available

Online: http://www.unep.or.jp/ietc/Publications/techpublications/TechPub-11/index.asp

[Other related articles in the UN IETC archive can be found at http://www.unep.or.jp/ietc/knowledge/index.asp#start]

US Department of Agriculture. Agricultural Research Service. Agricultural Phosphorus and Eutrophication.

Online: http://www.unep.or.jp/ietc/kms/data/604.pdf

US Department of Agriculture. Natural Resources Conservation Service. National Conservation Practice Standards.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

US Department of Agriculture. Natural Resources Conservation Service. Nutrient and Pest Management.

Online: http://www.nrcs.usda.gov/technical/nutrient.html

US Department of Agriculture. Natural Resources Conservation Service. Water Related Best Management Practices in the Landscape.

Online: http://www.wsi.nrcs.usda.gov/products/UrbanBMPs/

US Department of Agriculture. National Agricultural Library. Water Quality Information Centre.

Online: http://www.nal.usda.gov/wqic/

US Environmental Protection Agency - Nonpoint Source News-Notes.

Online: http://www.epa.gov/OWOW/info/NewsNotes/

World Overview of Conservation Approaches and Technologies.

Online: http://www.wocat.org/default.asp

Wyoming Department of Environmental Quality. Water Quality Division. Watershed Program. Online: http://deq.state.wy.us/wqd/watershed/

REFERENCES

Cooke, G D, Welsch, E B, Peterson, S A, and Newroth, P R (1993). *Restoration and management of lakes and reservoirs*. 2nd Edition. Lewis Publishers, Boca Raton.

Department of Water Affairs and Forestry (DWAF) (2003). A guideline to the water quality management component of a catchment management strategy. Edition 1. Water quality management series, Sub-series No. MS 8.2. DWAF, Pretoria.

Department of Water Affairs and Forestry (DWAF) (2006). Operational Guideline for Best Eutrophication Management Practices. Draft Version 0.4, Pretoria.

Moss, B (1998). Shallow lakes, biomanipulation and eutrophication. *Scope Newsletter*, No. 29.

COMPONENT 16

Vision (or Long-Term Resource Objectives) for Eutrophication Related Water Quality

PURPOSE

Generic catchment assessment context

The first step in the process of developing a catchment management strategy (CMS) is to set *medium-term* (5 years) resource water quality objectives for the different management units that make up the catchment (DWAF, 2003). These objectives reflect the stakeholders' needs with respect to water quality over and above those outlined in the NWRS and by RDM. It is useful if this development can take place against the background of an "ideal", or a "vision", of the *long-term* future water quality desired by stakeholders. Furthermore, the Water Resource Classification process recognises the need to declare, on a provisional basis, a "desired future state" for each catchment. This preliminary vision needs to be converted to a long-term vision through stakeholder engagement during the CMS development process.

Note The tasks of vision formulation and resource objective determination belong to the CMS development process and are not usually the direct responsibility of the water quality assessment team. However, these tasks are strongly linked and should be undertaken as a single process.

Eutrophication assessment context

The aim of this component within the context of an eutrophication assessment study is to ensure that stakeholders' needs with respect to eutrophication related water quality are adequately reflected in the vision and/or resource quality objectives being developed.

Purpose

The purpose of this Component is two-fold:

- To provide the initial stages of the CMS development process with a narrative description of and motivation for the long-term future water quality status as provisionally foreseen by the Resource Classification process
- To record, during all stages of the CMS development process, the desired long-term future water quality status, and the motivation for it, formulated by stakeholders.

Prerequisite Components

Components 0, 1, 5, 12, 13, 14 and **15** are prerequisites for preparation of this output.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic water quality assessment outputs	
The *Catchment Water Quality Assessment Guide* describes the outputs as a description of existing vision and water quality objectives, and descriptions of the future water quality status.	Refer to the *Catchment Water Quality Assessment Guide* on how to produce the outputs.
Eutrophication assessments outputs	
Use the *Catchment Water Quality Assessment Guide* outputs for this comment and ensure that the eutrophication related stakeholder needs are appropriately addressed in the description of existing vision and water quality objectives, and descriptions of the future water quality status.	Consult existing studies (**Component 0**) for existing vision and objectives relating to eutrophication. Determine if any classes or reserves have been set in the study area and refer to their descriptions for future eutrophication water quality status. Liaise with the CMS development team to record any outcomes relevant to eutrophication in the study area.

SOURCES
DWAF (2006) defines catchment visioning as the iterative process of evolving, over time, a more relevant and more detailed: • Collective statement from all stakeholders of future aspirations regarding the relationship between the stakeholders, in particular their quality of life in its broadest sense, and the water resources in a catchment, and • Strategy to move towards that vision, being either the catchment management strategy itself or one that directly supports it. The following quotes taken directly from DWAF (2006) on what catchment visioning entails: "The Department regards catchment visioning as an important planning instrument for integrated water quality management. It is also an essential participatory management process for ensuring that use of the country's water resources is "in the public interest" (a specific mandate of the NWA (36:1998)). The catchment vision should be progressively realised over time by applying adaptive management and prudent pragmatism within the catchment management strategy. The products of the catchment visioning exercise should inform, and be quantified by, classification of the resources and the setting of the associated resource quality objectives. In the interim transitional phase, and under special circumstances, the Department will permit catchment visioning at lower levels of confidence (referring to the level of confidence that can be placed in the appropriateness of the vision). The dangers of doing this will be explicitly acknowledged and carefully weighed against the advantages. For example, in catchments that are not water quality stressed (in respect of any variable of concern) the Department may permit catchment visioning with minimal levels of stakeholder engagement and less than ideal catchment assessment data in the interests of (a) cost-effectively initiating the longer-term progressive development and attainment of a vision, and (b) preparing for a process that is more inclusive. Furthermore, in the interim transitional phase, while recognising that water quality problems are more acute in some areas than in others, and that cost-effective use of human and financial resources is essential, the catchment management strategy will focus initial implementation on those management units in which the need is most urgent." DWAF (2006a) and DWAF (2006b) are recommended for guidance on the process of developing a catchment vision. The generic sources listed in **Component 20** are recommended for guidance on the format of vision formulations in specific catchments where water management plans have been developed. DWAF (2006c) provides guidance on setting Resource Water Quality Objectives that meets the needs of water users and ecosystem health.
CHECKLISTS
The *Catchment Water Quality Assessment Guide* lists the characteristics of a vision statement and its supporting documentation. Refer to the Guide document for the notes on the nature of the vision (idealistic, future target state, non-technical language, supporting technical information). Walmsley (2003) provides some guidance on a policy statement on eutrophication and the development of a strategy to control eutrophication in South Africa.

DISPLAY AND PRESENTATION OPTIONS

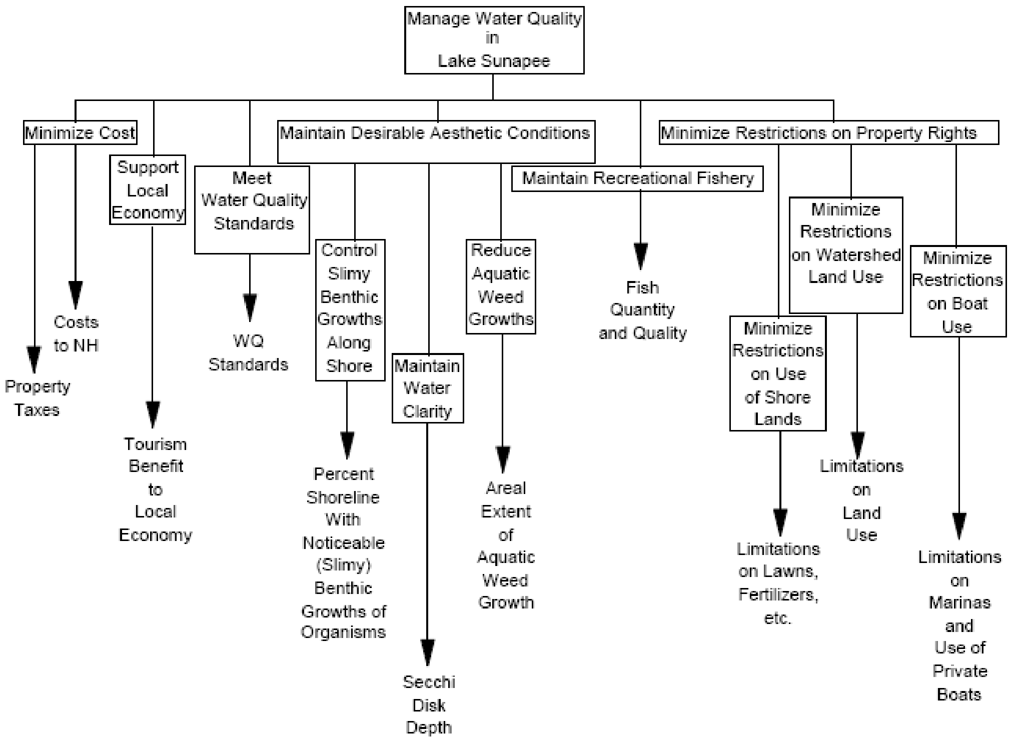
The following is an example of a vision and statement of objectives for eutrophication related water quality that was developed for Hartbeespoort Dam (Harding *et al*., 2004):

"The primary management objectives (= management goals) for Hartbeespoort Dam include:

1) providing water quality suitable for the maintenance of fish and other aquatic life;
2) reducing the severity of existing nuisance problems resulting from excessive algae growth which constrains or preclude intended water uses (raw potable and irrigation water supply and recreational/commercial uses), and;
3) improving opportunities for water based recreational activities while maintaining the availability of waters for irrigation and domestic consumptive uses."

Objectives hierarchy

Water quality objectives and their attributes can be displayed in an objectives hierarchy (Reckhow, 1999). The diagram below illustrates an example of such an objectives hierarchy. The hierarchy begins with an all-encompassing objective at the top. A comprehensive set of issue-specific objectives is then derived containing objectives that are consistent with the overall objective. Finally, attributes (identified by the arrowheads in the figure) that are meaningful, measurable, and can be predicted are selected for each specific objective.



REFERENCES

Department of Water Affairs and Forestry (DWAF) (2006a). *Resource Directed Management of Water Quality: Volume 1.2: Policy. Edition 1.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.4.2. ISBN No. 0-621-36788-5. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF) (2006b). *Resource Directed Management of Water Quality: Volume 4.1: Guideline for Catchment Visioning for the Resource Directed Management of Water Quality. Edition 2.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.1. ISBN No. 0-621-36792-3. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF) (2006c). *Resource Directed Management of Water Quality: Management Instruments. Volume 4.2: Guideline for Determining Resource Water Quality Objectives (RWQOs), Allocatable Water Quality and the Stress of the Water Resource.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.2, Edition 2. ISBN No. 0-621-36793-1. Department of Water Affairs and Forestry, Pretoria, South Africa.

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R (2004a). *Hartbeespoort Dam Remediation Project (Phase 1): Action Plan (Volume 1 and 2) Final Report.* Department of Agriculture, Conservation, Environment and Tourism, North West Province Government, Mmabatho.

Reckhow, K H (1999). Lessons from risk assessment. *Human and Ecological Risk Assessment*, Vol. 5:245-253 .

Walmsley, R D (2003). *Development of a Strategy to Control Eutrophication in South Africa: Phase 1. A review and discussion document.* Water Quality Management Series. Report No. U 2.1, Department of Water Affairs and Forestry, Pretoria.

Route Map of the Guide

Eutrophication Management question 1

What is the eutrophication status of the study area and how did it get to this point?

Eutrophication Management question 2

What are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?

Eutrophication Management question 3

What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?

You are here

Eutrophication Management question 4

Where might the eutrophication related water quality status of the study area be heading in the future?

Output 17: National and regional plans and projections of future water demands and catchment development

Output 18: Predicted future eutrophication related water quality at sites of management focus

Eutrophication Management question 5

What are the appropriate (priority) eutrophication management options?

Eutrophication Management question 6

Have the eutrophication management strategies achieved their objectives?

Eutrophication Management Question 4:

WHERE MIGHT THE EUTROPHICATION RELATED WATER QUALITY STATUS OF THE STUDY AREA BE HEADING IN THE FUTURE?

Eutrophication Assessment Task 4:
Projection of eutrophication related water quality impacts of future water-related development scenarios

COMPONENT 17
National, Regional and Local Plans and Projections of Future Water Demands and Catchment Development

PURPOSE

Generic catchment assessment context

Catchment management is part of a wider planning and development environment, which is often fragmented in nature. In **Component 13**, the institutional linkages that are required to counter this fragmentation are addressed. In this component, the focus is on the fragmented statutory arrangements for spatial, land-use and infrastructural development planning.

This Component ensures that the CMS is aligned with national, provincial, regional and local planning initiatives by institutions outside the water management sector. By being informed about such planning processes, the CMS may be oriented to influence them to the advantage of water quality management. The CMS needs to take account of demographic trends, which determine future water demand and waste discharge patterns, as well as spatial patterns of potential future water quality impacts.

Eutrophication assessment context

The challenge in an eutrophication assessment study is to identify those development plans and demographic projections that would either affect the nutrient status in the study area, or would be impacted upon negatively by eutrophication related water quality. Development aspects such as envisaged urban and industrial expansion nodes, new irrigation projects, new wastewater treatments works, upgrading of informal settlements, would all have an impact on the nutrient status of a catchment.

Purpose

The purpose of this component is to document those developments at national, provincial and local government level that may modify the current nutrient status of a catchment. The objective would be to identify at least the likely large-scale developments and their potential impacts on the nutrient status. This task needs to be undertaken at a scoping level or detail.

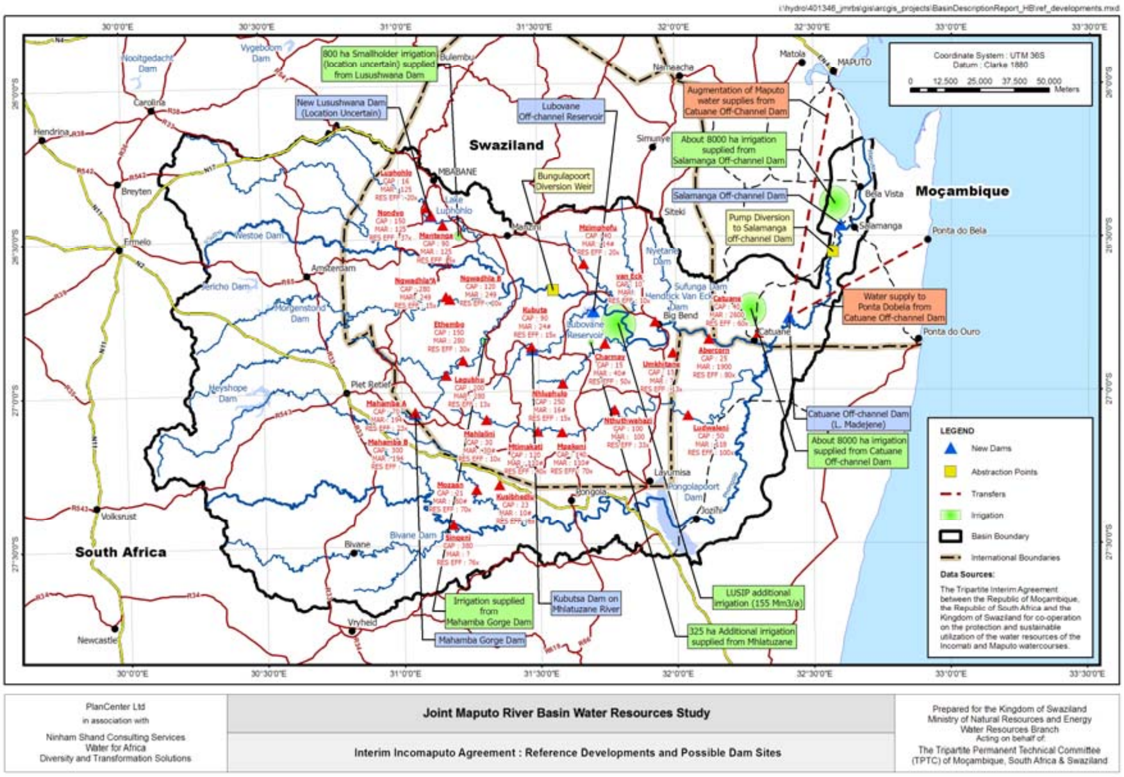
Prerequisite Components

The output from **Components 0, 1, 3, 12, 13**, and **15** would inform this Component in various ways.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Outline of available outputs from all national, provincial, regional and local planning processes. The **Checklist** section below provides examples of such outputs.	Obtain plans from all organs of state in all spheres of government that deal with: Natural resource use (agriculture, environment, mining, water services, forestry) Land-use and infrastructure development (local government, housing, transport, land affairs) Spatial planning (provincial planning, land affairs, economic affairs)
Outline of demographic projections that are differentiated for different parts of the catchment.	This should not normally be the task of the water quality assessment and should be derived by preceding or simultaneous water resource planning studies. Derived by combining census results with alternative economic, health and social development scenarios. Best performed by economics professionals or social scientists.
Detailed chapter on projections of future water demands due to population growth and potential physical developments in the catchment.	These should not normally be the task of the water quality assessment and should be derived by preceding or simultaneous water resources planning studies. However, projections of physical developments may require refinements under a water quality perspective.

SOURCES
Planning Information: Planning Divisions of organs of state in all spheres of government, particularly the National Departments dealing with: water affairs, forestry, environment, agriculture, minerals and energy, transport, land affairs, health, trade and industry, economic affairs, constitutional development, housing, defence, labour. Secretariat of Provincial Heads of Departments (HOD) Committee and of the Provincial Directorate-General's Office. Secretariat of the Provincial Water Liaison Committee (formal interface between provincial government and DWAF Regional Offices). Secretariat for the Committee for Environmental Coordination (CEC) (created under the National Environmental Act to oversee the EIP and EMP processes).
Projections: Water resource planning or design reports with the following themes: *Water Resources, Water Demands, Demand Management, Water Supply Augmentation Scheme Design, Economics of Augmentation Scheme Options (*Obtainable from DWAF addresses provided under **Component 4**). Scientific institutions that specialise in demographic analyses and population projections, such as the Institute for Futures Studies and the Bureau for Economic Studies (both University of Stellenbosch), or the Human Sciences Research Council, Pretoria.
CHECKLISTS
National Departments: • Water Services Development Plans (WSDP) – Department of Water Affairs and Forestry. • Integrated Development Plans (IDP) – Department of Constitutional Development. • Land Development Objectives (LDO) – Department of Land Affairs. • Hazardous Waste Management Plans (HWMP) – Department of Environmental Affairs and Tourism. • Spatial Development Initiatives (SDI) – Department of Trade and Industry. • Environmental Implementation Plans (EIP) – Departments of Environmental Affairs and Tourism, Land Affairs, Agriculture, Housing, Trade and Industry, Water Affairs and Forestry, Transport, Defence, Minerals and Energy, Health, Labour. • Environmental Management Plans (EMP) – Departments of Environmental Affairs and Tourism, Land Affairs, Water Affairs and Forestry, Minerals and Energy, Health, Labour.
Provincial Governments: • Environmental Implementation Plans (EIP) • Strategic Environmental Assessments (SEA) • Environmental Management Frameworks (EMF) • General Waste Management Plans (GWMP) • Spatial Development Initiatives (SDI) • Conservation of Agricultural Resources Plans (CARP)
Local Authorities: • Metropolitan Spatial Development Frameworks (MSDF) • Urban Structure Plans • Land Development Objectives (LDO) • Town Planning Schemes

DISPLAY AND PRESENTATION OPTIONS
An example of a catchment scale map showing potential water resource development options in the Maputo River basin and potential new dams sites as envisaged in the Interim IncoMaputo Agreement endorsed by the governments of South Africa, Swaziland and Mozambique. Some of these, such as the development of new irrigation projects and dams could have an impact on the nutrient status of the basin.



COMPONENT 18

Predicted Future Eutrophication Related Water Quality At Sites Of Management Focus

PURPOSE

Generic catchment assessment context

A water quality CMS is aimed not only at current water quality issues, but also at issues that would arise from planned future water-related developments in the catchment. The information on water quality issues (**Component 14**), catchment management implications of those issues (**Component 15**), long-term resource water quality objectives (**Component 16**), future development scenarios (**Component 17**), the spatial discretisation of management units (**Component 19**) and configured decision support tools (**Component 9**), provides the foundation for analysing future water quality trends in space and time. The aim of this Component is to ensure that the development of management options does not only focus on the current issues, but is also informed by an understanding of potential future water quality outcomes in the catchment.

Eutrophication assessment context

Eutrophication management strategies or the eutrophication component of a catchment management strategy also needs to take into account how the current eutrophication status is likely to change in the future.

Purpose

The aim of this task is to predict the future eutrophication status at sites of management focus and to ensure that the management strategies are mindful of these potential changes in the catchment. The management strategy can be oriented to influence planned development processes to the advantage of nutrient management.

Prerequisite Components

Most Components from Tasks 1 to 4, as well as **Component 19** would inform this Component in various ways. Cross-referencing of the predicted water quality issues with catchment management implications analysed under **Component 15** is also important.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Guide to Water Quality Catchment Assessment Studies* lists three outputs; predicted water quality, issues identified from the predictions, and feedback to **Component 15** (Water quality issues).	Use appropriate predictive tools (**Component 9**) and potential future developments to predict the future water quality, evaluate these predictions against water quality requirements to identify potential water quality issues, and include these issues in the strategy development process.
Eutrophication assessment outputs	
Predicted time series, or order statistics, of eutrophication related constituents, at management unit level or at sites of management focus.	Estimate the future eutrophication status using appropriate modelling tools (**Component 9**) and possible development scenarios (future loadings, etc.). Sensitivity analyses should be performed in terms of all primary development assumptions.
Record of potential eutrophication issues derived from the predicted eutrophication trends.	Compile a record of potential water quality issues by evaluating the predicted trends against the water quality requirements, constituents of concern (**Component 5**) and the vision or objectives for the catchment (**Component 16**). Update the outputs of **Components 14** and **15**.

CHECKLISTS
The assessment should include expansion in: • *Urbanisation (increases in urban runoff, increases in wastewater discharges, etc.)* • *Dense informal settlements (increases in polluted stormwater runoff, etc.)* • *Industrial clusters (increases in effluent discharges)* • *Irrigation areas (increases in irrigation return flows, etc)* • *Large water resource and wastewater infrastructure developments (water availability, effluent discharges, new dams etc.)*
DISPLAY AND PRESENTATION OPTIONS
The display and presentation options described in **Components 6, 7** and **8** are applicable here.

Route Map of the Guide

Eutrophication Management question 1

What is the eutrophication status of the study area and how did it get to this point?

Eutrophication Management question 2

What are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?

Eutrophication Management question 3

What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?

Eutrophication Management question 4

Where might the eutrophication related water quality status of the study area be heading in the future?

You are here

Eutrophication Management question 5

What are the appropriate (priority) eutrophication management options?

Output 19: Eutrophication related management units and assessment spatial and temporal resolution

Output 20: Prioritised eutrophication management options

Eutrophication Management question 6

Have the eutrophication management strategies achieved their objectives?

Eutrophication Management Question 5:

WHAT ARE THE APPROPRIATE (PRIORITY) EUTROPHICATION RELATED MANAGEMENT OPTIONS?

Eutrophication Assessment Task 5:
Formulate and prioritise eutrophication management options

COMPONENT 19

Eutrophication Related Management Units and Assessment of Spatial and Temporal Resolution

PURPOSE

Generic catchment assessment context

The NWA states that the CMS "...may be established in a phased and progressive manner and in separate components over time…" [*s8(3)(a)*]. This refers not only to variable timing of aspects of the CMS, but also to the spatial implementation. The CMS implementation can focus more intensely on some portions of a catchment and less so on others. This flexibilities are necessary to accommodate four realities about the catchment:

- *Urgency* - some issues and problems are more acute in some areas of the catchment and there is therefore a greater urgency to attend to these "stressed or threatened" areas.
- *Capacity* – the human and financial capacity to intervene is not limitless and a higher return on management intervention can be obtained by attending to the more urgent problems first.
- *Importance* – some river reaches are important water supply points and the sub-catchments upstream of these points warrant higher management investment.
- *Information availability* – in some catchments there may not be sufficient information to justify detailed interventions.

The outcome of a water quality catchment assessment study should be aligned to the management units that underlie the catchment management strategy development process.

In the document *Guideline for Determining Resource Water Quality Objectives (RWQOs), Allocatable Water Quality and the Stress of the Water Resource* (DWAF, 2006), guidance is given on how to delineate water resource management units. Due consideration should be given to ecoregion boundaries, the network of significant resources as specified in the National Water Resources Classification System, geohydrological response units, and the confidence required for setting resource water quality objectives.

Eutrophication assessment context

The process of identifying water quality management units is sufficiently generic that one would use the same considerations for identifying management units and spatial and temporal resolution for eutrophication assessment studies. The development of an eutrophication management strategy would probably be integrated with other water quality management strategies which provide impetus for having a single management unit.

Purpose

The purpose of this Component is to provide to the CMS process with a pragmatic but relevant spatial structure, and decisions on appropriate spatial and temporal resolutions for the WQ-CAS in each management unit which reflect the aforementioned four "reality checks".

Prerequisite Components

Component 0 and early versions of **Components 1, 3, 6, 7** and **8**.

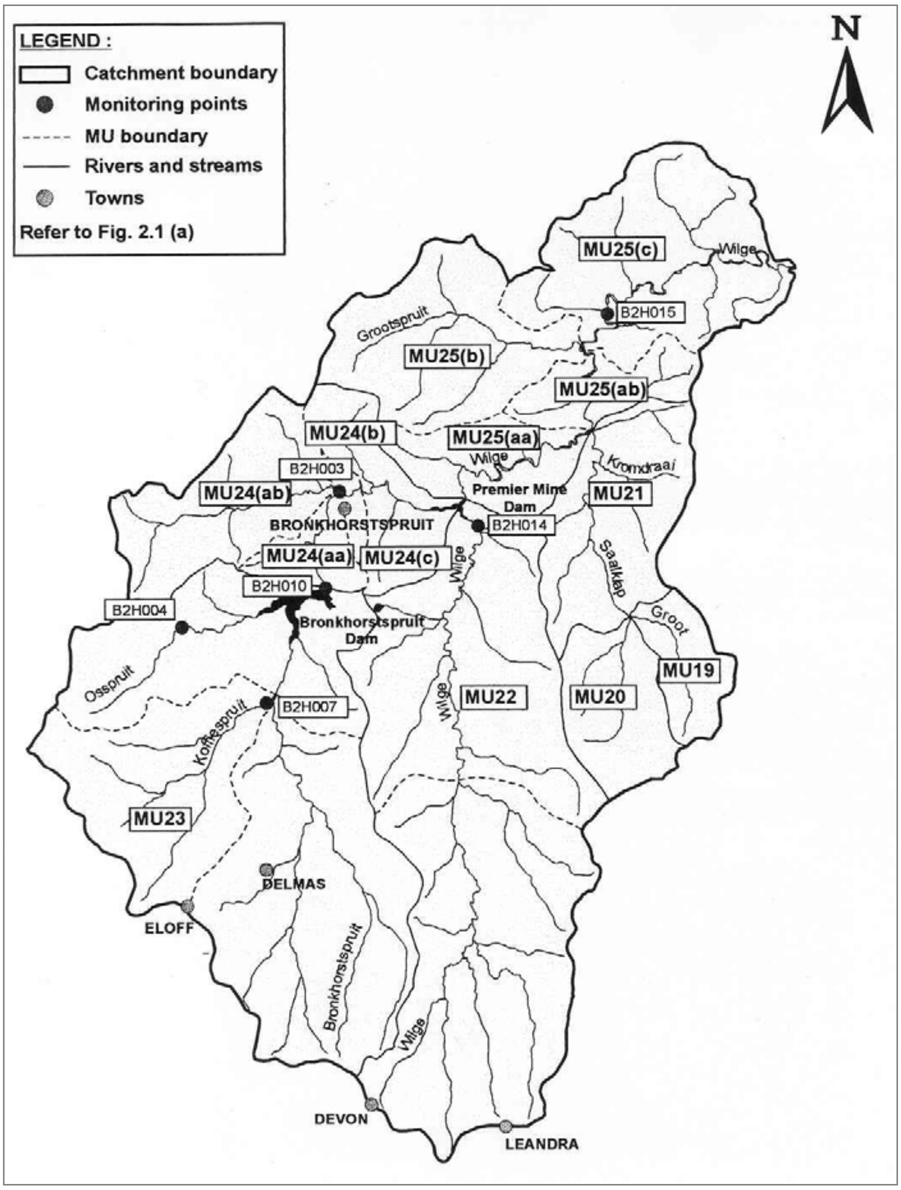
OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
GIS maps of the study area showing the proposed management units, supported with brief descriptions of proposed management units and motivations for the delineations.	Use the criteria listed in the checklist below to delineate the proposed management units. This task may require further iterations as the overall catchment assessment study yields additional information.

<table>
<tr><td>Descriptions of the levels of detail appropriate for each management unit and motivations for each case.</td><td>Two levels of detail of the WQ-CAS are suggested:

Scoping-level: Broad indications, at the quaternary scale or coarser, of water quality issues and the relative importance of non-point and point sources, and provisional identification of the most important sources of either variety. This is the preferred initial level for all sub-catchments.

Evaluation/prioritisation level: Detailed quantification on a sub-area basis of priority point and non-point source impacts, and the key source types and areas requiring management. This is the preferred level only for those sub-catchments which are important existing water supply sources, which are known to be “water-stressed or threatened”, or where a scoping-level assessment indicates acute problems.</td></tr>
<tr><td colspan="2">Eutrophication assessment outputs</td></tr>
<tr><td colspan="2">Same as the generic catchment assessment outputs.</td></tr>
<tr><td colspan="2">SOURCES</td></tr>
<tr><td colspan="2">The Catchment Water Quality Assessment Guide lists examples of: scoping-level and evaluation-level catchment water quality assessment studies (refer to NSI, 1996 a, b for examples) and an example of a water quality assessment framework (Pegram et al., 1997).

Also refer to DWAF (2006) for guidance on delineating water resource management units.</td></tr>
<tr><td colspan="2">CHECKLISTS</td></tr>
<tr><td colspan="2">Criteria that may be applied to identify particular management sub-catchments/ units:
• upstream of primary water supply points
• level of “water stress”
• upstream/downstream of critical water quality problem sites
• relatively low variability in bioclimatic and geophysical characteristics
• relatively pristine or relatively degraded (the particular water resource class)
• particular dominant user sectors or dominant land-uses.
• heterogeneity of the catchment, i.e. topography, land-use, geology, ecology, etc.
• spatial scale of available data and information</td></tr>
</table>

DISPLAY AND PRESENTATION OPTIONS
The following illustration shows the management units that were selected for the Wilge River Sub-catchment as part of the water quality situation assessment of the Loskop Dam catchment (DWAF, 2002). 

REFERENCES
Department of Water Affairs and Forestry (2002). *Water quality situation assessment of the Loskop Dam catchment*. Development of an Integrated Water Resources Model of the Upper Olifants River (Loskop Dam) Catchment. Report No. PB B100/00/0898
Department of Water Affairs and Forestry (2006c). *Resource Directed Management of Water Quality: Management Instruments. Volume 4.2: Guideline for Determining Resource Water Quality Objectives (RWQOs), Allocatable Water Quality and the Stress of the Water Resource.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.2, Edition 2. ISBN No. 0-621-36793-1. Department of Water Affairs and Forestry, Pretoria, South Africa.
NSI (1996a). *Preliminary Assessment*. Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0194. Pretoria.
NSI (1996b). *Pollution Sources*. Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0193. Pretoria.
Pegram, G C, Görgens, A H M and Ottermann, A (1997). *A framework for addressing the information needs of catchment water quality management.* Water SA, Vol 23, No 1.

COMPONENT 20
Prioritised Eutrophication Management Options

PURPOSE

Generic catchment assessment context

A Water Quality Management Strategy entails the allocation of loads to different source sectors in order to meet the specified resource water quality management objectives. In order to give effect to the load allocations, Water Quality Management Plans are assembled that specify the management actions, responsibilities, resources and timeframes required to mitigate or remediate the water quality impacts associated with priority sectors/sources.

In order to allocate the loads between sectors/sources, information or estimates are required about the relative load contribution from each source type (or each large source), both for present day conditions and expected future developments. Furthermore, the relative differences in water quality outcomes of different management options which will enable these allocations to be achieved, need to be estimated. The purpose of this Component is to provide quantitative "what if" support for the development of the Water Quality Management Strategy and the Water Quality Management Plans, using the decision support tools of **Component 9**, and to provide support to the evaluation of the non-technical aspects of water quality management options

At this stage, catchment water quality assessment is strongly integrated with the strategy development process. There is so much overlap and iteration that for all practical purposes the two processes can be viewed as one. It is important to note that this Component is usually driven by the strategy development team and is not the direct responsibility of the assessment team.

The design and detailed analysis of individual water quality management actions are operational tasks and they do not usually form part of the catchment water quality assessment study. These operational tasks are usually undertaken by the sectors/sources or their consultants. It was recommended that the designers consult with the assessment study knowledge base, including its predictive tools, to ensure appropriate knowledge dissemination.

Eutrophication assessment context

For an eutrophication assessment study, this component provides the eutrophication strategy development process with quantitative modelling support to allocation of nutrient loads between sectors/sources for a given array of eutrophication management options. It also provides support for the qualitative assessment of the potential impacts of the eutrophication management options.

Purpose

The purpose of this Component is to provide quantitative "what if" modelling support variety for the development of the eutrophication management strategies and plans, using the modelling tools of **Component 9**, and to provide qualitative support to assess the non-technical aspects of the eutrophication management options.

Prerequisite Components

All **Components** from **0** to **19** are prerequisites to this Component.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Catchment Water Quality Assessment Guide* describes the outputs as (1) the predicted water quality load and concentration scenarios for the proposed management options, (2) an assessment of the viability of the management options, and (3) an inventory of the priority sources and their proposed management options.	Refer to the *Catchment Water Quality Assessment Guide* for guidance on how to attain the three outputs.

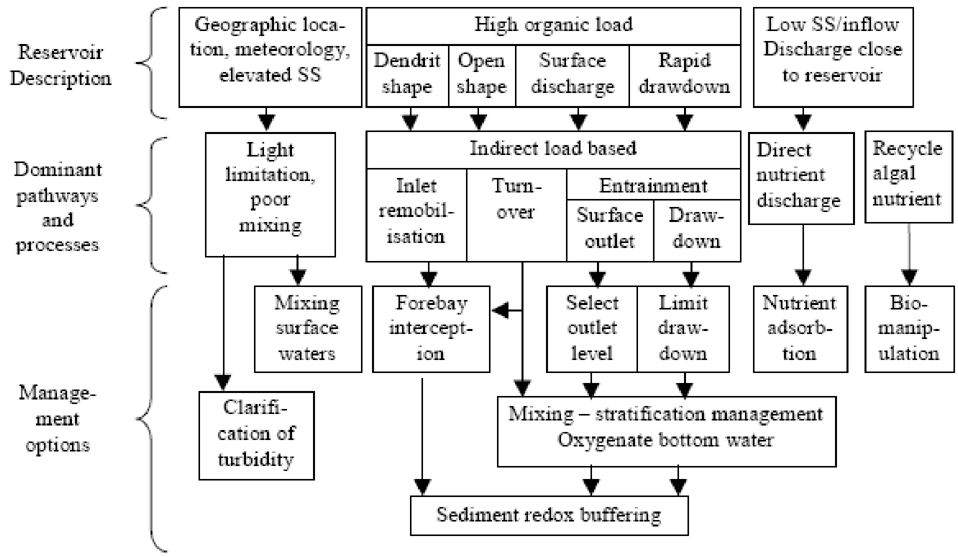
Eutrophication assessment outputs	
Predicted nutrient concentrations and loads resulting from the proposed eutrophication management options for particular sub-catchments or management units.	Apply the predictive eutrophication models and assessment tools produced in **Component 9**. Modelling can be undertaken at empirical or semi-empirical level, or at mechanistic level. Simpler empirical or semi-empirical predictions or qualitative assessments can be used in unstressed situations. A more mechanistic approach of accurate sector/source load estimates, based on detailed point and non-point source modelling (based on monitored data), would provide the best support for management decisions in stressed situations. The selection of assessment approach should be based on a trade-off between the resources required to use a particular technique and the increase in accuracy and reliability of the results. The process of identifying and evaluating eutrophication management options should also consider the effectiveness of an option to achieve the allocated load. This can be achieved by assessing the relative effectiveness of different eutrophication management options.
An assessment of the technical and operational viability of the proposed eutrophication management options.	The manageability must be estimated in terms of the: • background nutrient constituent concentrations, • the technical effectiveness of the management options, and • the social and economic impacts of those management options.
An inventory of priority nutrient sources and their proposed management options by management unit.	The prioritisation of largest sources or source areas of nutrients should receive priority for management intervention. However, those sources with the highest relative impact (e.g. per unit area or per capita loading) should also have a higher priority for management, because the interventions may be more effective in these areas. Similarly, the potential future impacts of these sources should be a major consideration, because these impacts may be more easily mitigated before they are fully realised.

SOURCES

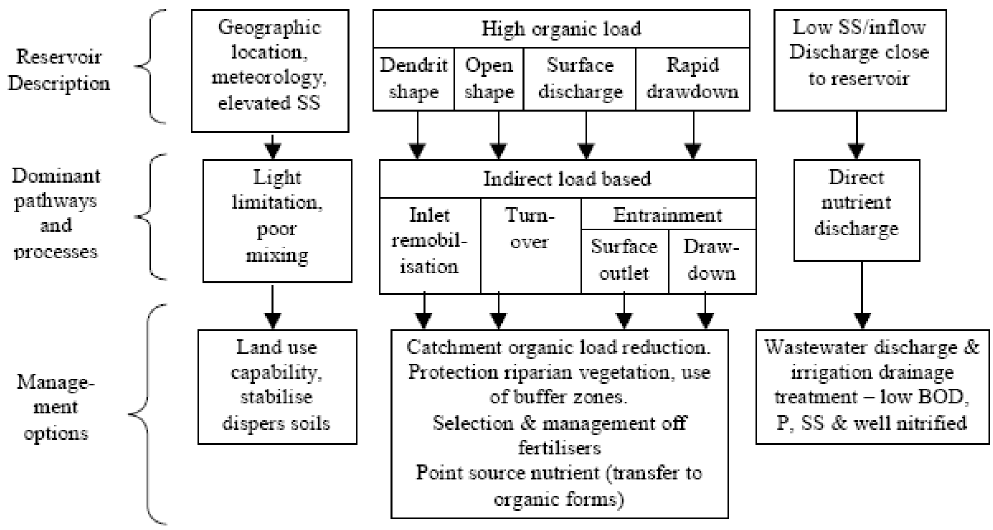
The following sources contain useful examples of management options that have eutrophication management components, formulated under particular management strategies:

- *Plettenberg Bay Water Resources Management* (DWAF, 1999a).
- *Catchment Management Strategy for the Modder and Riet Rivers - Situation Assessment and Draft Management Strategy*. (DWAF, 1999b)
- *Mgeni Catchment Management Plan*. (DWAF/Umgeni Water, 1997)
- *A Framework for Implementing Non-Point Source Management under the NWA*. (DWAF/WRC, 1999)

Lawrence *et al*. (2000) developed a guideline for selecting reservoir management options to address eutrophication concerns. This decision tree considers the reservoir, the dominant pathways and processes and reservoir management options.



Lawrence *et al*. (2000) also developed a guideline for selecting catchment management options to address eutrophication concerns. This decision tree considers the reservoir, the dominant pathways and processes and catchment management options.



CHECKLISTS

Management focus areas:

- *point source discharges*, such as municipal wastewater, mining, industrial, manufacturing;
- *non-point source discharges*, such as irrigated agriculture, dry-land agriculture, urban runoff, dense settlements;
- *in-stream management*, including rehabilitation, minimum streamflows or operating rules.

Management approaches to nutrient management (refer to DWAF 2003 for a description of the current functional strategies and approaches to source management in South Africa): • *Best practice* – these are established and effective processes and methodologies which are generally recognised as being the best available in the field of nutrient management and provides DWAF with a benchmark to test the performance of, for example, wastewater treatment plants. These are regarded as the minimum required from the regulated facilities. • *Authorisations* – Water use authorisations are regarded as the primary instruments for source management. Full compliance with the existing authorisation conditions, for which RQOs would have been recognised according to the resource class. • *Statutory controls* - Statutory controls on water use, including more stringent authorisation conditions (through area-specific general authorisation or licences), or compulsory licensing of relevant water quality based water users. • *Waste discharge charge system* - Waste discharge charges used as an economic incentive to reduce loads to the required levels, together with the funding of direct interventions to implement technologies and practices, to manage loads from particular sources. • *Co-operative incentives* - Non-statutory options, particularly co-operative governance and capacity building to improve the effectiveness of land-use and infrastructure management that has an impact on water quality and to change human behaviour to mitigate impacts. • *Resource management* - In-stream management, through remediation of the water resource, reservoir system operation and/or ensuring adequate water quantity allocation to streamflow for dilution and assimilation of loads (possibly above the Reserve and RQOs).
Sectors and Source Types: The DWAF source classification (DWAF, 2003) recognises five main sectors (mining, industry, agriculture, settlements and national infrastructure) and a threat level of high, medium and low. Sectors and sources that contribute to nutrient enrichment include: • *Agriculture*: irrigated crops; dry-land crops; irrigated pastures; confined animal facilities, feedlots, livestock grazing. • *Waste Disposal*: general solid waste; sludge disposal; effluent irrigation. • *Food Processing*: canning; dairy-related processing; breweries, abattoirs. • *Industry*: fertilizer related industries. • *Mining:* phosphate mining. • *Power generation*: coal fired power stations. • *Municipal*: urban stormwater; wastewater treatment plants; informal settlements. • *Transport*: highways and roads.

DISPLAY AND PRESENTATION OPTIONS

Table of Water Quality Management Options

Water quality management options can be summarized in a table. *The Plettenberg Bay Water Resources Management Study* (DWAF, 1999) provides a good example of how these may be summarized (see the extract below):

Keurbooms River Management Issues and Actions (Extracted from the original report)

Problem	Perceived problem	Concern	Technical data	Guidelines for applicable criteria	Possible solutions	Possible actions
Faecal contamination from cattle watering directly from the river	Y	Y	*E.coli* concentrations taken at Newlands between July 1996 and July 1998 50th percentile = 35 80th percentile 120 counts/100 ml	*E.coli*: TWQR for full and intermediate contact recreation: 0-130, and 0-1000 counts/100 ml respectively	Restrict cattle access	Fence grazing areas and restrict cattle from watering directly from the river
Impact of SAFCOL plantations on base flows	Y	Y	The % runoff reduction in the middle Keurbooms catchment as a result of plantations in approximately 2.5%	Reserve, still to be determined	Maintain natural riparian vegetation along streams and conservation programme	SAFCOL to improve their public image by educating the public regarding their efforts to minimize the impacts of plantations
Nutrient enrichment of river from fertilizer	Y	?	Avg PO_4 = 0.1 Avg NO_3 = 0.73 Avg NH_3 = 0.55	PO_4: Limit for eutrophication : 0.025 mg/l NO_3: Limit for eutrophication : 2.5 mg/l	Educate farmers Create incentives to reduce use of fertilizers Carry out mandatory independent soil evaluations at regular intervals	Undertake regular water quality monitoring Inform farmers through the forum regarding the impacts of nutrient rich irrigation return flows Investigate alternative irrigation practices

REFERENCES

Department of Water Affairs and Forestry (1999a). *Plettenberg Bay Water Resources Management. Part 1: Management Strategy.* Report by Sakaza and Ninham Shand to D: Water Quality Management, DWAF, Pretoria.

Department of Water Affairs and Forestry (1999b). *Catchment Management Strategy for the Modder and Riet Rivers. Phase 1: Situation Assessment and Draft Management Strategy.* Report by Ninham Shand to D: Water Quality Management, DWAF, Pretoria.

Department of Water Affairs and Forestry/Umgeni Water (1997). *Mgeni Catchment Management Plan.* Report WQM U200/00/0196 by Ninham Shand to DWAF, Pretoria and Umgeni Water, Pietermaritzburg.

Department of Water Affairs and Forestry/WRC (1999). *A Framework for Implementing Non-Point Source Management under the NWA*. WRC Report No TT 115/99 and DWAF Report No WQP 0.1, DWAF, Pretoria.

Department of Water Affairs and Forestry (2003). *Source management in South Africa* [online]. First Edition released for review and comment. Department of Water Affairs and Forestry, Pretoria. Available: http://www.dwaf.gov.za/dir_wqm/docsframe.htm

Lawrence, I, Bormans, M, Oliver, R, Ranson, G, Sherman, B, Ford, P and Schofield, N (2000). *Factors controlling algal growth and composition in reservoirs: Report of Reservoir Managers' Workshops January 2000*. National Eutrophication Management Program. Co-operative Research Centre for Freshwater Ecology.

Route Map of the Guide

Eutrophication Management question 1

What is the eutrophication status of the study area and how did it get to this point?

↓

Eutrophication Management question 2

What are the water-related stakeholders and institutions in the study area and what are their respective jurisdictions, relationships, linkages and roles?

↓

Eutrophication Management question 3

What are the study area's eutrophication related water quality issues, problems, concerns and opportunities?

↓

Eutrophication Management question 4

Where might the eutrophication related water quality status of the study area be heading in the future?

↓

Eutrophication Management question 5

What are the appropriate (priority) eutrophication management options?

↓

You are here →

Eutrophication Management question 6

Have the eutrophication management strategies achieved their objectives?

Output 21: Monitoring and auditing of eutrophication assessment strategies

Eutrophication Management Question 6:

HAVE EUTROPHICATION MANAGEMENT STRATEGIES ACHIEVED THEIR OBJECTIVES?

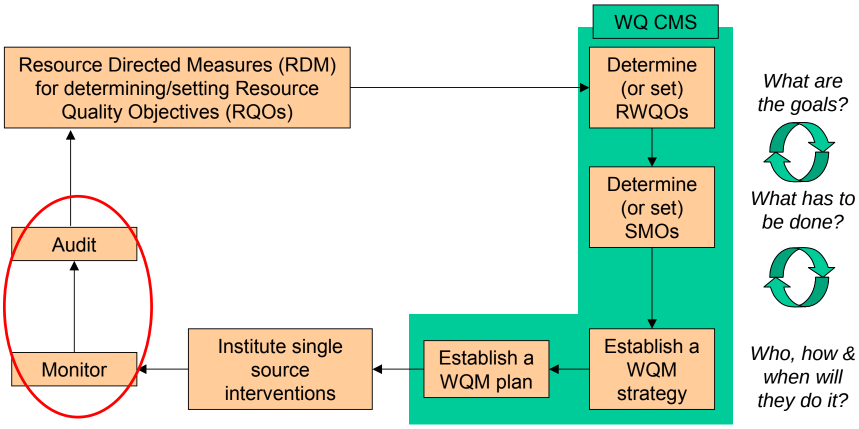
Eutrophication Assessment Task 6: Monitoring and auditing of implementation of eutrophication management options

COMPONENT 21
Monitoring and auditing the implementation of eutrophication management strategies

PURPOSE

Catchment water quality assessment context

Although monitoring and auditing is not strictly viewed as part of a catchment water quality assessment study, it closes the loop because it re-informs the catchment assessment study of how the water quality status has changed as a result of management interventions (as illustrated below).



Water quality monitoring is the planned, systematic collection of water quality data through a series of repetitive measurements. In this instance, a monitoring programme is specifically designed to collect data that can be used to review the effectiveness of water quality management strategies and plans.

Auditing water quality is a 'once-off' picture of the current water quality status. It involves the organisation and interpretation of water quality data to establish a record of change associated with the implementation of a water quality management option. It is a process to determine if the management strategy and plans are meeting the set performance limits (or resource water quality objectives).

Eutrophication assessment context

Monitoring and auditing the implementation of eutrophication management strategies is not a focus of an eutrophication assessment study. As with a generic water quality assessment, the objective is to determine if eutrophication management strategies and plans are having the desired effect. Monitoring refers to systematically collecting data on the causes (e.g. nutrient concentrations) and effects (e.g. *chlorophyll-a* concentrations, algal species composition) and using the data at regular intervals (e.g. yearly, 5 yearly) to assess if eutrophication management plans are having the desired effect of reducing nutrient concentrations or algal biomass.

Purpose

The purpose of this section is to describe an approach to monitoring progress with the implementation of eutrophication management options to rehabilitate eutrophied water resources and meet eutrophication goals or objectives.

Prerequisite Components

To undertake this Component, most of the preceding Components should be completed or implementation of strategies and plans should be well advanced.

<table>
<tr><th colspan="2">OUTPUTS</th><th>HOW TO ATTAIN OUTPUTS</th></tr>
<tr><td colspan="3">Water quality assessment outputs</td></tr>
<tr><td colspan="2">The Catchment Water Quality Assessment Guide describes two performance assessment outputs, one aimed at meeting operational objectives and one aimed at meeting strategic management goals.</td><td>Refer to the Catchment Water Quality Assessment Guide for a description of how to assess the present status and trends against operational and strategic goals.</td></tr>
<tr><td colspan="3">Eutrophication assessment outputs</td></tr>
<tr><td>Performance assessment - Meeting operational nutrient and algal management objectives.</td><td colspan="2">Assess compliance with short-term operational management goals using nutrient and algal monitoring data collected for that purpose.
Graphically and statistically compare the monitoring results of key eutrophication indicators with the management goals to assess whether management goals have been met during the review period.</td></tr>
<tr><td>Performance assessment - Meeting strategic management goals.</td><td colspan="2">Review the medium to long-term trends in key eutrophication indicator variables to assess how long-term water quality is changing in relation to long-term management goals.
Examples of statistical methods to assess water quality trends are described in Ward et al. (1990) and Harris et al. (1992).</td></tr>
<tr><th colspan="3">METHODS AND TOOLS</th></tr>
<tr><td colspan="2">Statistical analysis of the water quality data
Water quality data must be processed before statistical trends or comparisons over time can be made. Outlying values must be identified and dealt with, and data must be adjusted for missing values, non-detects, laboratory duplicates and field replicates.</td><td>Methods for pre-processing data can be found in Harris et al. (1992).</td></tr>
<tr><td colspan="2">Independence of observations
Statistical analysis should be done on independent observations.</td><td>Water quality taken at short intervals (daily or weekly) can be serially correlated, i.e. each observation repeating part of the information contained in the previous observation. Monthly observations should be used for analyses. Methods to derive independent samples are described in Harris et al. (1992).</td></tr>
<tr><td colspan="2">Trend analysis
It is difficult to detect a significant trend with less than 5 years of data if significant seasonality is present. Seasonality occurs when one part of the year tends to produce consistently higher or lower values that other parts of the year.</td><td>Significant seasonality should be removed from the data before trend analysis can be done. For more than 5 years of data, monthly box-and-whisker plots can be used to detect seasonality. For less than 5 years of data, quarterly box-and-whisker plots can be used. The Kruskal-Wallis test, at the 90% confidence level, can also be used to test for seasonality.
For data sets longer that 5 years, the seasonal Kendall test can be used to detect long-term trends (Harris et al., 1992). For data sets less that 5 years, the seasonality must first be removed and the Kendall Tau test can then be used to detect a trend.</td></tr>
</table>

Assessing changes after implementation of management options To determine whether there has been a change in water quality after a management option has been implemented; two statistical tests can be used.	For same size data sets, the Wilcoxon signed rank test (Harris *et al*., 1992) can be used to determine whether the medians over the two data sets are similar. For data sets of unequal size, the Mann-Whitney or the Wilcoxon Rank Sum test (Harris *et al*., 1992) can be used to assess whether the medians of the two data sets are different. The data needs to be deseasonalised before the comparison is made.
Software for statistical analysis of water quality data	*General statistical software packages* Statistica - http://www.statsoft.com/ SAS: http://www.sas.com/ Statgraphics - http://www.statgraphics.com/ *Custom designed water quality statistical software* WQStat Plus - http://idt.nicusa.com/wqstats/wqstats.html

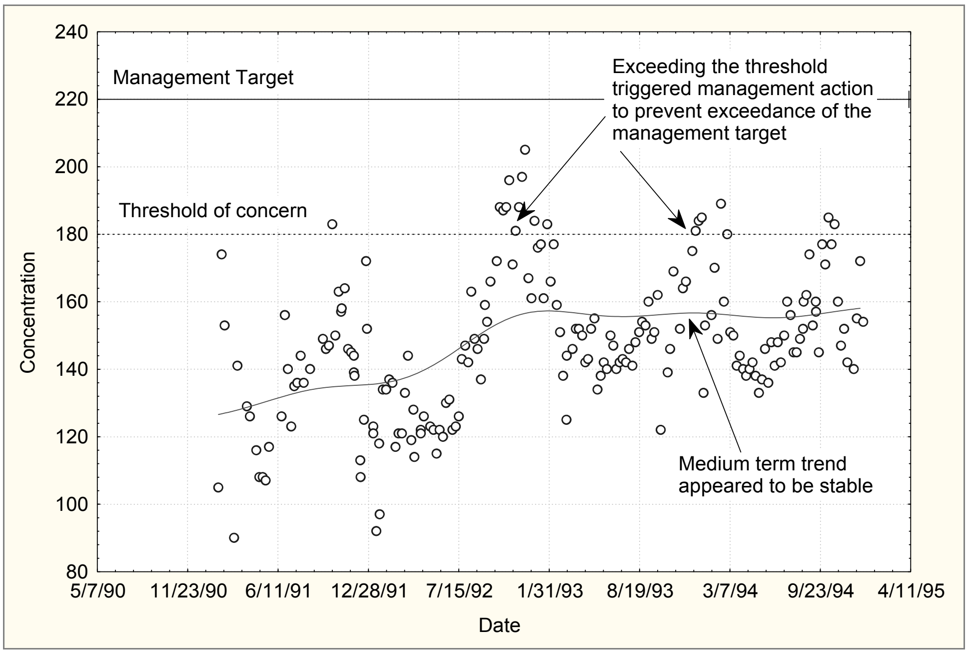
SOURCES	
Management information system	Water Resource Management Institution (Catchment Management Agency or the DWAF Regional Office)
National, provincial, local and other data sources	Potential data sources were identified in **Component 11**.

CHECKLISTS
Use the constituents of concern identified in **Component 5** and the variables used for setting resource water quality objectives.

DISPLAY AND PRESENTATION OPTIONS

Meeting operational management goals

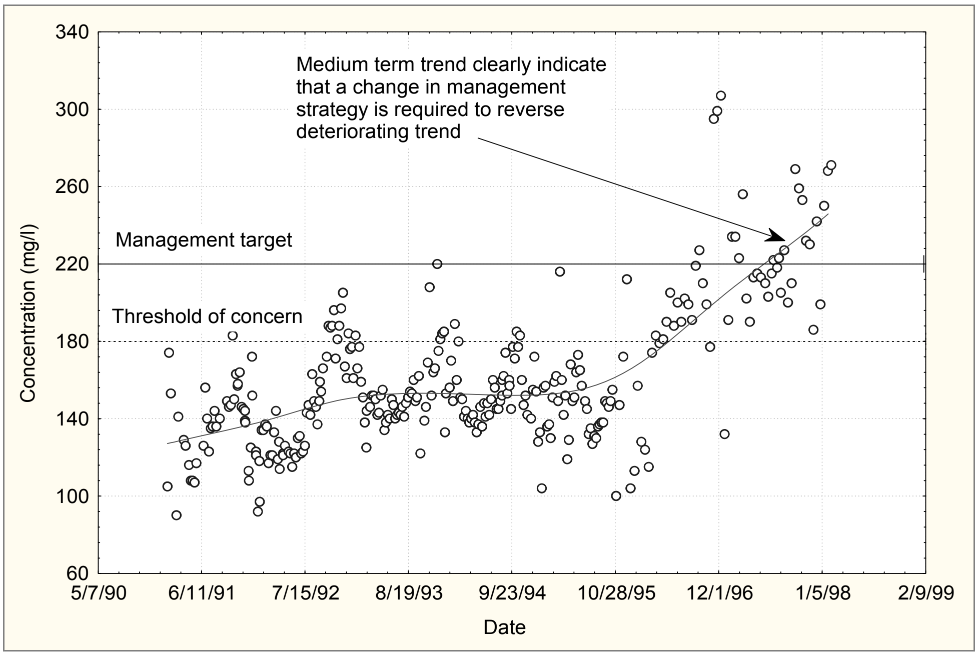
Monitoring the implementation of an eutrophication strategy involves setting a management target (which may be an interim resource water quality objective) to be maintained and setting a Threshold of Concern[5] value or early warning value. The Threshold value is a trigger for management intervention if water quality exceeds the threshold value and is a function of the response time of the catchment to management actions. The present water quality is compared to these two values on a continuous basis to determine whether corrective action is required. The medium term trend is evaluated when a water quality audit is undertaken. In the example below, no change in management strategy is required because the trend appears to have stabilised.



[5] This concept is similar to the water quality management model developed by Van Veelen (2002) who used the words "Target range", "Monitor range", "Action range" and "Intervention range" to describe a range of management situations that arise with deteriorating water quality.

Meeting strategic management goals

The medium term trend is tracked as part of the process to audit whether strategic eutrophication management goals are met. If the trend changes negatively and short-term eutrophication management actions do not reverse the trend, the overall eutrophication management strategy may need to be updated to reserve the situation (illustrated in the graph below).



REFERENCES

Harris, J M, van Veelen, M and Gilfillan, T C (1992). *Conceptual Design Report for a National River Water Quality Assessment Programme.* Water Research Commission. Report No. 204/1/92

Van Veelen, M (2002). The development of principles and procedures for the establishment of water quality objectives for aquatic systems and their application on the Jukskei River system, Gauteng. PhD Thesis. Rand Afrikaans University.

Ward, R C, Loftis, J C and McBride, G B (1990). *Design of Networks for Monitoring Water Quality.* Van Nostrand Reinhold, New York, NY, USA 231pp.

COMPONENT 0

Inception Summary of Existing Understanding, Knowledge and Past Studies with Regard to Eutrophication Related Water Quality in the Catchment

RATIONALE

Generic catchment assessment context

No catchment is a clean slate in terms of information or knowledge about it. Some experienced-based understanding of the functioning of at least some parts of a catchment is usually present among some of the long-standing inhabitants of a catchment, as well as among state officials or professionals active in water-related matters. Similarly, the existence of water-related issues and problems is often common knowledge. In many instances, particular water-related studies have historically been conducted in the catchment under consideration.

Eutrophication assessment context

Eutrophication knowledge and information about eutrophication related water quality problems are often available:

From catchment reports, basin studies, water quality assessment studies, effluent discharge investigations, waste load allocation studies, reports dealing with drinking water treatment, water use licence applications and research reports, or

Reside in long-standing inhabitants of an area, state officials such as water bailiffs or water/wastewater treatment plant operators or professionals active in water-related matters.

Similarly, the existence of eutrophication related issues and problems is often common knowledge and can be brought to the fore through an initial public participation process.

Purpose

The purpose of this component is to provide the eutrophication assessment study at an early stage with a provisional overview of readily available eutrophication related knowledge and information, and of existing issues, concerns, problems and opportunities related to eutrophication. Such an overview can be used as an inception report to bring all stakeholders and interested parties to a similar level of understanding of the overall problem, to identify key issues (symptoms and causes) and to provide an early focus on acute eutrophication problems that may require urgent attention.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Two outputs are produced in a generic catchment water quality assessment study; a summary document providing an overview of known water quality characteristics, and a summary report on existing water quality problems and issues.	The generic outputs are produced using information that is readily available at the start of a catchment assessment study.
Eutrophication assessment outputs	
A brief overview document giving a summary of eutrophication related characteristics of the study area.	Assemble readily available reports on relevant past technical and scientific studies and summarise the primary aspects mentioned under Checklists below. Identify persons with knowledge of eutrophication (causes or consequences) in the study area and capture their knowledge through interviews and/or correspondence.

<table>
<tr><td>An initial report on real or perceived eutrophication related problems and issues, and challenges and opportunities to mitigate its impacts. [Refer to Component 15 for a Checklist of typical eutrophication issues]</td><td>Summarise the eutrophication concerns, issues, challenges and opportunities that are contained in reports on past studies. Be specific about spatial and temporal extent of problems.
Obtain further inputs from knowledgeable persons through interviews (telephone or personal) and/or correspondence.</td></tr>
<tr><td colspan="2">METHODS AND TOOLS</td></tr>
<tr><td colspan="2">• Compile a bibliography of previous studies, investigations, papers and journal articles, etc.
• Use standard research protocols to synthesise the available information and to identify eutrophication concerns, issues, challenges and opportunities.
• Compile a contact database of persons with experience in eutrophication in the study area or being affected by eutrophication symptoms.
• Use standard referral techniques to identify persons with knowledge of eutrophication related water quality in the study area.</td></tr>
<tr><td colspan="2">SOURCES</td></tr>
<tr><td>Reports of the study area with the following themes:
Catchment Description; Hydrology; Land-use; Water Resources; Water Quality Situation Analysis; System Analysis; etc.</td><td>• DWAF: Directorates responsible for water resources management, water quality planning and management, setting resource water quality objectives, and resource protection
• Catchment Management Agencies
• Water Service Providers
• Local Authorities</td></tr>
<tr><td>Reports with the following themes:
Water Quality Situation Analysis/ Study; Waste Load Allocation; Water Quality Management Plan, etc.</td><td>• DWAF: Directorates responsible for water quality management, resource protection, and scientific support
• Catchment Management Agencies
• Water Service Providers
• Local Authorities</td></tr>
<tr><td>Reports with the following themes:
Catchment Management; Catchment Management Plans; etc.</td><td>• DWAF: Directorates responsible for Catchment Management
• Catchment Management Agencies
• Water Service Providers
• Local Authorities (district municipalities and local councils)</td></tr>
<tr><td colspan="2">CHECKLISTS</td></tr>
<tr><td colspan="2">The generic water quality overview reports should typically <u>summarise</u> the following, at coarse scales, with a focus on the following general water resource issues (if appropriate): climate, surface water and groundwater resources; demography; water use and demands; land-use; water quality; return flows; Environmental Reserve, water balance, water-related infrastructure; water management institutions; water-related issues, problems and opportunities.</td></tr>
</table>

The ***eutrophication assessment overview*** should typically summarise the following, *at coarse scale*, with a focus on eutrophication related water quality: *water quality (e.g. nutrient concentrations, chlorophyll-a concentrations, benthic algae, water clarity); water quantity (e.g. flow rates, residence times, flushing rates); physical characteristics (e.g. temperature regime, dissolved oxygen regime) reservoir morphology (e.g. mean depth, shape, thermal stratification) return flows (e.g. treated wastewater effluent, irrigation); agricultural runoff (e.g. fertilized lands, feedlots), Ecological Reserve, known eutrophication-related issues, problems and opportunities (e.g. what? where? when? how severe? who affected?)*.
DISPLAY AND PRESENTATION OPTIONS
The format of the output would typically be similar to that of a scoping report and the focus would be on factors that affect nutrient enrichment and eutrophication. Information should preferably be presented graphically or in map form (with GIS support), while text should be limited to significant observations or concerns only. Any changes required to the study brief as a result of the preliminary findings should be included in the initial overview report. The overview report should include a complete bibliography of previous studies and reports consulted, as well as relevant reports and journal articles that need to be consulted during further phases of the study. The contact details of persons consulted for this component should also be included.

COMPONENT 1

Details of Physical, Developmental and Administrative Attributes and Characteristics of the Catchment Relevant to the Assessment of the Eutrophication Status

RATIONALE

Generic catchment assessment context

Every human being lives in a catchment. Therefore, one of the challenges of integrated water resource management at the catchment scale is to be able to identify the natural characteristics of the water resource and the degree to which these have been modified by developments in the catchment. A description of these natural and human-related elements and their linkages is therefore a fundamental prerequisite of a catchment assessment study.

Eutrophication assessment context

Eutrophication is the enrichment of water bodies leading to excessive production of organic materials by algae and/or aquatic plants. The symptoms of eutrophication (e.g. high algal biomass, reduced water transparency, hypolimnetic oxygen depletion) are related to external nutrient loadings, hydrology and river and reservoir morphometric characteristics. External nutrient loads of nitrogen and phosphorus are mobilised by rain and transported to rivers and reservoirs through processes such as overland flow, groundwater seepage, drainage networks, and urban and industrial wastewater. Once in the rivers and reservoirs, the nutrients can be taken up by algae, macrophytes and micro-organisms, it can be adsorbed onto organic or inorganic particles in the water and sediments, it can be accumulated and recycled in the sediments, or transformed and released as a gas from the water body (denitrification).

In order to understand the process of eutrophication, it is important to understand where and how nutrients are produced in the catchment, how these are mobilised and transported to a water body, and their fate once in a river or reservoir. It is therefore important to identify those characteristics of the catchment that promote nutrient production, enrichment and contribution to nuisance algal growth. Some of the features identified in this component are investigated in greater detail in later components (e.g. point and non-point sources, etc).

Purpose

The purpose of this component is to identify and describe those features of the catchment that lead to elevated nutrient concentrations in rivers, reservoirs and wetlands, the water body characteristics that promote algal growth, and identification of the users that are negatively affected by nuisance algal growth. This component informs the eutrophication assessment study of the following generic aspects:

- Natural attributes of the catchment or study area (e.g. what would the nutrient status have been under natural conditions given the natural geomorphological template of the catchment?)
- Extent of human development and impacts (e.g. what were the modifications to the catchment that would effect changes to the nutrient status?)
- Socio-economic profile (e.g. what socio-economic developments have contributed to nutrient enrichment and which were negatively affected by eutrophication?)
- Water-related infrastructure and monitoring (e.g. has water-related infrastructure contributed to or mitigated eutrophication in the catchment, what monitoring is done?)
- Administrative arrangements (e.g. which organisations are responsible for managing water quality and eutrophication and what is their area of jurisdiction?)
- These catchment characteristics are relevant to water resources management in general but the descriptions should focus on those aspects that relate to eutrophication in the study area.

Prerequisite Components

The outputs from **Component 0** should guide the data and information collection for this component.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic Catchment Assessment Outputs	
For a generic catchment water quality assessment, georeferenced data and information are required on the following land-use aspects: • Natural attributes (e.g. geology or land cover) • River system details (e.g. river channels and tributaries) • Location of monitoring points • Infrastructure (e.g. dams, irrigation schemes, WWTWs, etc.) • Current and past land-use • Socio-economic profile • Areas of jurisdiction • Boundaries of water resource management units	Sources of this data are listed in the *Catchment Water Quality Assessment Guide*[2].
Eutrophication Assessment Outputs	
User-friendly GIS coverages and tables, as well as detailed database storage sets of the following information: • Natural attributes with special attention on geological formations, soil types, vegetation and sediment production potential.	Method of information assembly to attain the corresponding outputs in the left-hand column: • Use available GIS coverages or digitise from available maps or aerial photos.
• River system details such as main stem channels and tributaries, wetlands and reservoirs and catchment boundaries (primary, secondary, tertiary, and quaternary, as the need arises).	• Use available national coverage from DWAF, CMA, or local authority, or digitise from existing maps.
• Monitoring locations, type and responsible organisation; this would include stations for water quality sampling of rivers, reservoirs, and effluent discharges, and flow gauging points (also see **Component 11** for more information).	• Locate via latitudes and longitudes obtained from data custodians, or determine with the aid of maps, aerial photos or a GPS.
• Infrastructure locations and dimensions with specific attention to locating return flow points from wastewater treatment works, irrigation schemes, urban stormwater, etc.	• Locate via latitudes and longitudes, obtained from scheme or infrastructure owners, or their consultants, or digitise from maps or aerial photos.
• Land-use (current and past), with specific attention to human settlements with different degrees of sanitation services; commercial and industrial areas; dryland agriculture; mining areas and solid waste sites.	• Use existing GIS coverages available from custodians of remotely sensed data, based on interpretation of satellite imagery, aerial photographs and orthophotos; alternatively, perform land-use identifications from aerial photographs supported by ground-truthing in the field.

[2] Department of Water Affairs and Forestry (2003c). *A Guide to conduct Water Quality Assessment Studies: In support of the Water Quality Management component of a Catchment Management Strategy.* Water Quality Management Series, Sub-series No. MS 8.3. Pretoria.

• Boundaries and *areas of jurisdiction* of water management institutions and service providers.	• Use existing GIS coverages available from DWAF, CMAs and municipalities, or digitise from appropriate maps.
• Boundaries of water resource *management units* (see **Component 19**).	• This is one of the outputs from the consultative tasks in a catchment assessment (see **Component 14**) and would usually follow physiographic boundaries; digitised from maps.
METHODS AND TOOLS	
The information collated in this component serves as a baseline for both the technical assessment tasks as well as the consultative/public participation tasks. The information needs to be spatially organised, with three levels of output: • In map form for easy visualisation (for consultative tasks). • In numerical/ tabular form with explanatory text (for consultative and technical tasks). • In database storage form (for technical tasks).	
SOURCES	
Maps, aerial photographs and orthophotos	• Chief Directorate: Surveys and Mapping, Department of Land Affairs. • Map Office – all major cities.
GIS coverages	• Directorate: Geomatics, DWAF, Pretoria • CSIR, Pretoria • District municipalities and local authorities • Catchment Management Agencies • Large Water Service Providers • Water Users Associations
Institutional boundaries	• Directorate: Geomatics, DWAF, Pretoria
CHECKLISTS	
Refer to the *Catchment Water Quality Assessment Guide* for the checklists for human settlements, irrigation activities, afforestation and plantations, dryland agriculture, and institutional boundaries. In terms of eutrophication, the following catchment characteristics should be considered (location and aerial extent): • *Eco- and water quality regions* – Level 1 and Level 2 eco-regions that were derived from terrain and vegetation, with some consideration of altitude, rainfall, runoff variability, air temperature, geology and soil (Available online at www.dwaf.gov.za) and water quality regions (Day *et al*, 1998). • *Human settlements*: High, medium and low-density urban areas (stormwater runoff), high-density settlements (stormwater runoff), urban areas or settlements with poor sanitation services (stormwater runoff, surcharging sewers and dry weather flow in stormwater system), Smallholdings (stormwater and irrigation runoff). • *Irrigation activities*: Irrigation schemes, crop types, type of irrigation practices, location of return flows, fertilizer application practises (Non-point source nutrient loads).	

- *Dryland agriculture*: Summer crops; winter crops; perennial crops, subsistence crops and fertilizer application practises (non-point source nutrient loads, sediment loads, turbidity).
- *Infrastructure:* wastewater treatment plants (effluent volume & nutrient concentrations, location of discharge points), water treatment plants and abstraction points (abstraction volumes).
- *Institutional boundaries*: Water Management Areas, Magisterial districts, district councils, metropolitan councils, TLCs, TRCs, water boards, government water control areas, provincial and international boundaries (required to identify, for example, institutions responsibilities for the management of water quality in a region).

The following water body characteristics should be collected during the execution of this component for use in later components of the assessment:

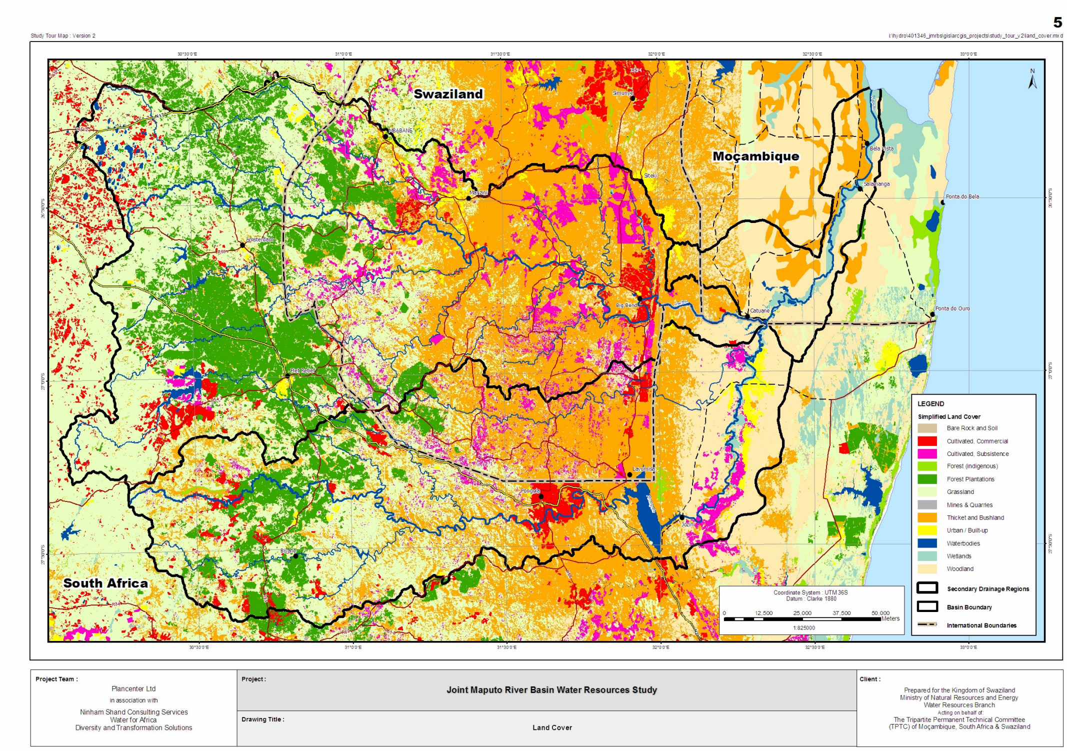
Reservoirs	Full supply volume* and area*, maximum depth and mean depth*, catchment area and mean annual runoff*, longitude and latitude coordinates, height above mean sea level, reservoir form and bathymetric information, precipitation and evaporation*, reservoir operating rules, abstraction/release depth at reservoir outlet. * = *inputs needed for the NEAP model*
Rivers	Stream order, mean flow.
Wetlands	Aerial extent, wetland type

The most common source of land-use information is the CSIR's South African Land Cover Database (www.csir.co.za) that was mapped from a series of 1:250 000 scale satellite images captured primarily during 1994 and 1995. Land cover was mapped using 31 land-cover classes. The land-cover generally of concern for eutrophication assessments includes Urban/Built-up land (urban runoff concerns), Bare Rock and Soil – erosion surfaces, and Degraded Lands (high suspended sediment load concerns), Cultivated lands – irrigated (high nutrient return flow concerns), and Cultivated lands – temporary crops – commercial – dryland (wash-off of fertiliser concerns).

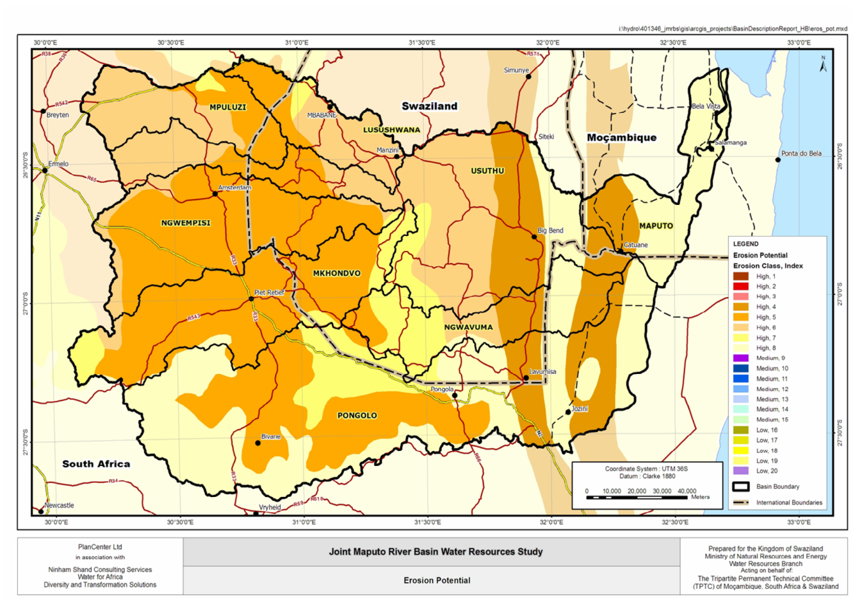
NEAP requires catchment areas matching the following land-use types for which TP export coefficients have been developed: High, medium and low density urban, smallholdings, horticulture, grasslands/pastures, row crops, and forestry. It is recommended that professional judgement and knowledge of the study area be used to match CSIR land-cover information to the land-use data required for NEAP.

DISPLAY AND PRESENTATION OPTIONS

An example of a catchment scale map[3] showing land-uses that could potentially affect eutrophication related water quality such as irrigation areas, degraded lands, urban areas, commercial forestry, etc.



An example of a catchment scale map showing erosion potential.



[3] Examples of maps are presented in this report to illustrate how information can be presented using maps. The above map is a generic example (for conceptual purposes only) illustrating how this information can be presented in a visual format. For the purposes of this guide document, the detail contained within the examples is not necessarily intended to be presented at a legible scale.

REFERENCES

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

COMPONENT 2

Requirements of the National Water Resource Strategy and Resource Directed Measures with regard to Nutrient Management

RATIONALE

Generic catchment assessment context

The National Water Resource Strategy (NWRS) and Resource Directed Measures (RDM) can place specific constraints on the development of catchment water quality management strategies and plans. The ***National Water Resource Strategy*** (NWRS) provides the framework for the implementation of the National Water Act, 1998 (No. 36 of 1998). The first edition was published for comment in August 2002 (DWAF, 2002a) and the revised NWRS is due for completion in 2004. The national strategy is being progressively developed to set out policies, strategies, objectives, plans, guidelines, procedures and institutional arrangements for the protection, use, development, conservation, management and control of the country's water resources. The NWRS identifies, *inter alia*, development opportunities and constraints with respect to water availability (quantity and quality). The NWRS was given further impetus through the development of ***Internal Strategic Perspective*** (ISP) documents for the 19 water management areas (for example DWAF, 2003). These documents present more detail on the Department's strategic perspective on how it wishes to protect, allocate usage, develop, conserve, manage and control water resource in the WMA's until the functions have been delegated to Catchment Management Agencies (CMAs). ***Resource-Directed Measures*** (RDM) focus on the quality and the overall health of water resources (DWAF, 1999, DWAF, 2002b, Kleynhans *et al*, 2005). Resource quality includes water quantity and water quality, the character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota. Resource-directed measures include a National Classification System; determination of the Management Class of specific water resources; and the establishment, for each significant water resource, of resource quality objectives and determination of the Reserve in accordance with the Management Class of the resource.

Eutrophication assessment context

Examination of the ***NWRS and ISPs*** within the context of an eutrophication assessment should focus on strategies and plans that would affect the nutrient status of the catchment. For example, in a specific catchment, effluent return flows may be viewed as an important water resource for downstream users or for transfer between river basins. The high nutrient concentrations in the return flows result in eutrophication related water quality problems in the receiving rivers and reservoirs. However, due to the strategic importance of the return flows, management options that would affect the return flow volume would be constrained (e.g. effluent diversion or irrigation options) and consideration be given to managing the causes (e.g. limiting the discharge nutrient concentrations) and the consequences in the receiving waters. In some international agreements such as the Incomaputo Agreement between South Africa, Swaziland and Mozambique, water quality targets are specified and eutrophication management strategies need to consider these targets.

The ***Reserve*** includes the water quantity and quality required to meet basic human needs, and to protect aquatic ecosystems. The Reserve specifies, amongst others, the nutrient concentrations required to maintain a resource in a specific Management Class. It should be noted that reservoirs were specifically excluded from ecological Reserve determinations due to their artificial nature.

Purpose

The purpose of this component is to identify and document the:

- Strategies and plans in the NWRS and ISP's that would affect the nutrient status in a catchment as well as the constraints imposed by these strategies on options to manage eutrophication.
- Management objectives and actions described in the ISP documents that address issues relating to nutrient enrichment and its impacts.
- Nutrient objectives contained in the Resource Directed Measures for a specific catchment or water resource unit.
- Nutrient objectives specified in international agreements with co-basin states.

Prerequisite Components

Geographical boundaries of the study area (**Component 1**).

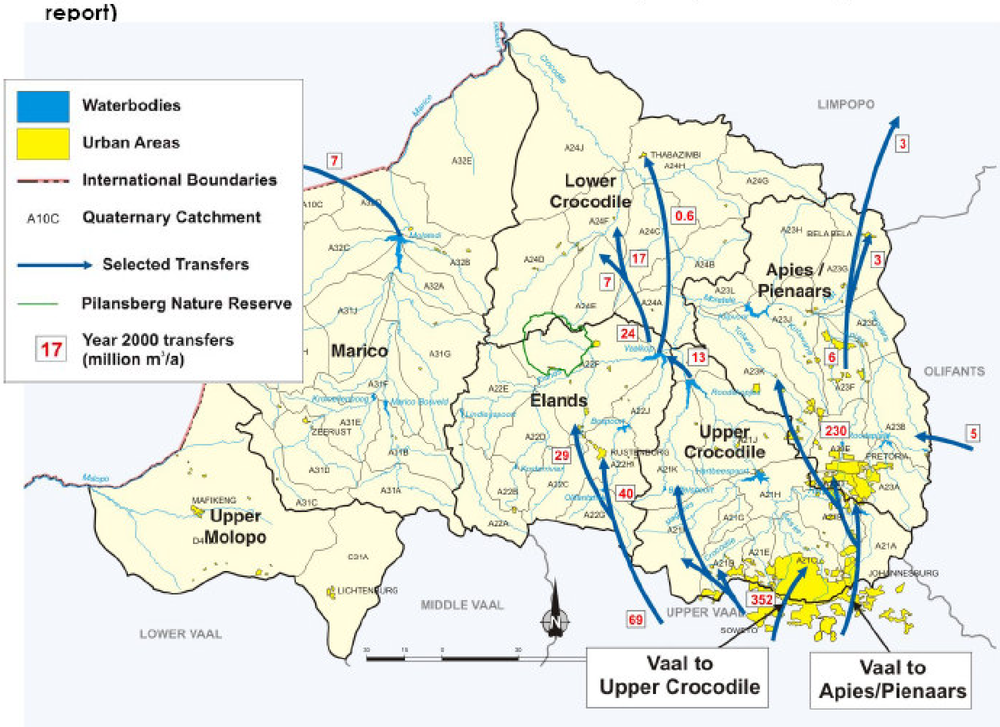
OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Description of the NWRS and ISP strategies, and resource directed measures (class, reserve and resource quality objectives) that would affect the development of a catchment water quality management strategy.	Examine the NWRS, ISP and Reserve documents and summarise the aspects relevant to a catchment water quality strategy.
Eutrophication assessment outputs	
Description of NWRS and ISP constraints that would affect the nutrient status or the selection of nutrient management options for the study area.	Use the checklist below as a guide to extract information relevant to the nutrient status and management strategies in the study area.
Description of the management class and nutrient objectives that has been set for water resources in the study area. GIS Map showing river reaches where Reserve determinations have been done, indicating nutrient objectives.	Use the **checklist** below as a guide to collate nutrient water quality Reserve information from Reserve study documents.
SOURCES	
Information on the National Water Resources Strategy can be obtained from the Directorate: Policy and Strategy Co-ordination.	Director: Policy and Strategy Coordination Website: www.dwaf.gov.za
Information on the ISPs for the study area can be obtained from the Directorate: National Water Resource Planning.	Director: National Water Resource Planning Website: www.dwaf.gov.za
Information on international agreements can be obtained from the Directorate: International Development Co-operation.	Director: International Development Co-operation Website: www.dwaf.gov.za
Information on Reserve determinations that have been undertaken in the study area can be obtained from the RDM Directorate.	Director: Resource Directed Measures Website: www.dwaf.gov.za

CHECKLISTS	
National Water Resource Strategy Information on usable return flows, balancing supply and demand, resource protection and water quality management can be found in the following sections of the NWRS.	Chapter 2: South Africa's water situation, and strategies to balance supply and demand 2.3 Water Resources 2.5 Strategies to balance supply and demand (Reconciliation) Chapter 3: Strategies for Water Resources Management Part 1 – Protection of Water Resources Part 3 – Water conservation and water demand management Part 6 – Monitoring and information systems
Internal Strategic Perspective Information on strategies, management objectives, strategic approaches and management actions relating to nutrient management can be found in the following sections if an ISP document.	Part 2 – Strategies Strategic area 1: Yield, water balance and reconciliation (requirements and availability) Strategic area 2: Water resource protection (Reserve and resource quality objectives, water quality) Strategic area 3: Water use management (pollution control) Strategic area 9: Monitoring and information
International agreements The Incomaputo agreement that was signed between South Africa, Swaziland and Mozambique has a resolution on the exchange of information and water quality. Similar agreements are being considered for other shared rivers like the Orange River.	Copies of international agreements are available on the DWAF website at www.dwaf.gov.za The Incomaputo agreement provides, for example, guidelines for nitrogen and phosphorus concentrations at borders between the basin countries as well as guidelines for sample analysis, monitoring and information exchange.
Reserve Information The Reserve describes the quality and quantity of water required to maintain a water resource in a specific ecological management class and is set for rivers, wetlands, groundwater and estuaries. Information on the water quality components of the Reserve can be obtained from Reserves signed off by the Director-General of DWAF and in the supporting documentation for a Reserve determination.	The water quality component of the Reserve for river ecosystems is set in terms of: • Inorganic salts • *Nutrients such as ortho-phosphate and total inorganic nitrogen* • Physical variables such as pH, temperature, dissolved oxygen and turbidity • Toxic substances, and • Response variables such as *algal abundance*, a biotic invertebrate index and toxicity *Note*: The revised documentation for the water quality component of the Reserve was due for release towards the end of 2003 (Jooste and Rossouw, 2002).

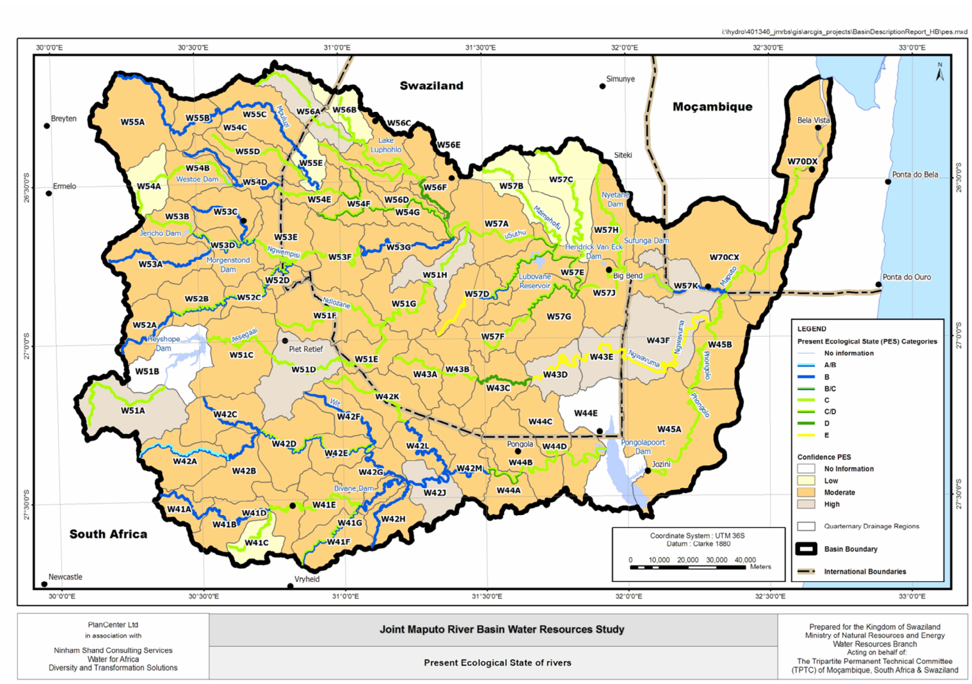
DISPLAY AND PRESENTATION OPTIONS

Maps can be used to illustrate existing and envisaged water resource development options (for example DWAF, 2004).

Figure 3.1: Transfers in and out of the Crocodile River (West) catchment (Source: WMA report)



Example of a map showing the Present Ecological Status of rivers.



Tables can be used to quantify available water resources such as urban return flows which can be high in nutrient content (for example DWAF, 2004).

Table 3c: Available Yield in the Year 2000 (million m³/annum)

Component / Sub-area	Natural Resource		Usable Return Flow			Total Local Yield
	Surface Water (1)	Groundwater	Irrigation	Urban	Mining & Bulk	
Upper Crocodile	111	31	21	158	15	336
Apies/Pienaars	38	36	4	106	2	186
Elands	30	29	3	10	14	86
Lower Crocodile	7	29	14	1	8	59
Total for Catchment	**186**	**125**	**42**	**275**	**39**	**667**

REFERENCES

Department of Water Affairs and Forestry (1999). *Resource Directed Measures (RDM) for protection of water resources*. Department of Water Affairs and Forestry, Pretoria (Various volumes for river, wetland, groundwater and estuarine ecosystems).

Department of Water Affairs and Forestry (2002a). *National Water Resource Strategy* (Proposed first edition). , Pretoria.

Department of Water Affairs and Forestry (2002b). *Manual for Assessing the Ecological Reserve for Rivers*. Report No. RDM 000-01-COM-Meth-0102. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry (2003). *Gouritz WMA: Internal Strategic Perspective*. Draft 1. Prepared by Ninham Shand (Pty) Ltd on behalf of the Directorate: Resource Planning (South). DWAF Report No. P WMA 16/HJK/0303.

Department of Water Affairs and Forestry (2004). *Crocodile River (West) and Marico Water Management Area: Internal Strategic Perspective of the Crocodile River (West) Catchment* : Prepared by Goba Moahloli Keeve Steyn (Pty) Ltd, Tlou & Matji (Pty) Ltd and Golder Associates (Pty) Ltd, on behalf of the Directorate: National Water Resource Planning. DWAF Report No. 03/000/00/0303.

Jooste, S and Rossouw, J N. (2002). *Hazard-based Water Quality EcoSpecs for the Ecological Reserve in Fresh Surface Water Resources*. Report No. N/0000/REQ0000. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kleynhans, C J, Louw, M D, Thirion, C, Rossouw, J N and Rowntree, K. (2005). *River Ecoclassification: Manual for Ecostatus Determination. Version 1*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

COMPONENT 3
Water Use and Conservation relating to Eutrophication Assessment

PURPOSE

Generic catchment assessment context

One of the reasons why water resource management has a high priority in South Africa is the rapid increase in water use which in turn results in effluents and return flows that reduces the assimilative capacity in streams, rivers and reservoirs. Section 21 of the National Water Act defines a wide range of activities as water use.

An inventory of water uses, both current and historical, provides one of the basic templates for structuring the water quality assessment of a catchment. Historical water use trends are important to help explain the current water quality status, and provides crucial input data to enable the calibration of water quality models. A description of water conservation measures and their outcomes helps explain historical water use trends and to assess the impacts on the water quality status.

Eutrophication assessment context

The focus in an eutrophication assessment study is to identify water use activities that affect the nutrient status of the catchment and receiving streams, rivers and reservoirs. The key activities that should be considered are all aspects of discharging wastes into water resources:

Section 21(f) discharging waste or water containing waste into a water resource – many waste streams are high in nutrients,

Section 21(g) disposing of waste in a manner which may detrimentally impact on a water resource – improper disposal of waste high in nutrients (e.g. manure, wastewater sludge, etc.) can result in high nutrient loadings to streams through leaching or direct wash-off,

Section 37.1(a) the disposal of wastewater by irrigation – improper disposal of wastewater high in nutrients can also result in high nutrient loadings through processes such as wash-off,

Section 21(a) and (b) abstracting water from a water resource (and storing it) affects capacity of the resource to assimilate waste,

Section 21(c) making changes to the physical structure of rivers and streams (impeding or diverting the flow of water in a watercourse – affects the assimilative capacity of the resource,

Section 21(j) altering the bed, banks, course or characteristics of a watercourse – these activities often affect water clarity during construction and can expose nutrient rich sediments thereby increasing nutrient loads.

Purpose

For eutrophication assessment, the objective is to identify and list those activities described in Section 21 of the NWA that affect the nutrient status of the catchment and receiving water bodies.

The output from this component should help focus the activities undertaken in **Component 4** – Overview of water availability, **Component 7** – Point source discharges, and **Component 8** – Non-point source loadings. The primary output is what activities are taking place where and who are the primary stakeholders involved in those activities. These are investigated in greater detail in **Components 4, 7** and **8**.

Prerequisite Components

Component 1 – Description of the study area.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The generic catchment water quality assessment study requires an inventory of all effluents and return flows, effluent irrigation activities, water abstractions, stream flow reduction or alteration activities, and water conservation measures.	These activities are assembled by examining records at DWAF, CMAs, WUAs, and local authorities.

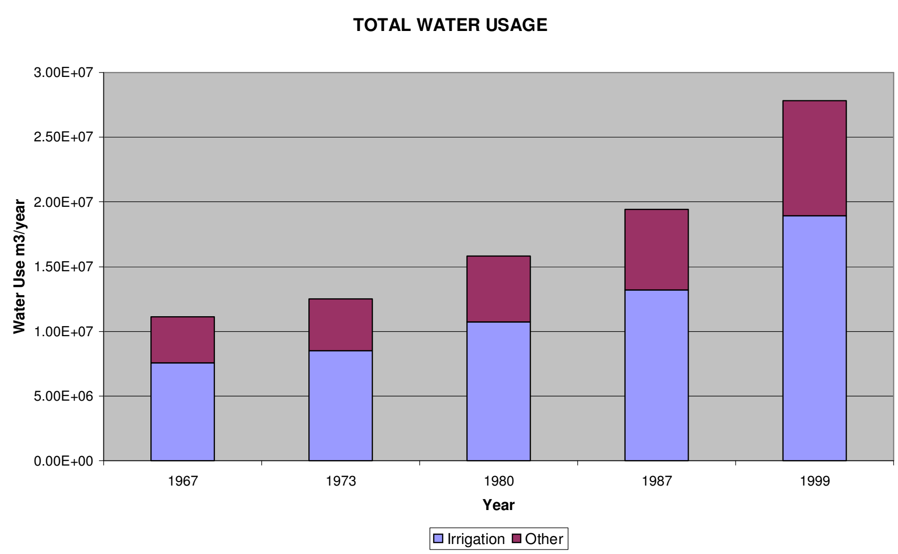
Eutrophication assessment activities	
Geo-referenced inventory of all effluent discharges and return flows, arranged by sub-catchment and by type.	Assemble water use licence information from DWAF or the licensees. Point source discharges are unpacked in **Component 7**.
Geo-referenced inventory of effluent irrigation activities arranged by sub-catchment.	Assemble licence information from DWAF or the licensee
Geo-referenced inventory of all water abstractions summarised by sub-catchment and by water use category (see **Checklist** below).	Assemble a list all water abstractions or bulk water suppliers and their locations from relevant sources (DWAF, CMAs, WSPs, WUAs).
Geo-referenced database of all streamflow reductions or alteration activities summarised by sub-catchment unit and by category.	Identify the type of streamflow reduction activities (see **Checklist** below) and their locations from maps and other relevant sources.
SOURCES	
Controlled activity licences WARMS database (Water use licensing, registration and revenue collection database).	Available from DWAF (Chief Directorate: Water Use and Conservation), Regional Office, or CMAs. Website: www.dwaf.gov.za.
Water abstraction or delivery records.	Available from DWAF (Directorates: Water Utilisation; Hydrology), WUAs, CMAs, Water Boards, mines and municipalities.
Database on SFRAs such as afforested, alien infested and sugarcane areas.	**Component 1**

CHECKLISTS

- *Water use categories*: domestic; irrigation; industrial; power generation; mining; livestock.
- *Streamflow reduction categories*: commercial timber plantations (pines, eucalypts, wattles); range of classes of alien vegetation; dryland agricultural crops (at least sugar cane).

DISPLAY AND PRESENTATION OPTIONS

The graph below shows an example of how the growth in water usage in a catchment can be displayed using a stacked bar graph.



COMPONENT 4
Overview of Adequacy of Water Availability

PURPOSE

Generic catchment water quality assessment context

A sound understanding of the adequacy of water quantity availability in a catchment is a prerequisite to the understanding of water quality issues and appropriate management responses to them. At the heart of certain water quality issues lie inadequate or unreliable supplies of fresh water, needed for dilution, flushing, assimilative capacity, river channel maintenance, or as alternative supplies to existing supplies that have problematic quality. This component provides an integrated picture of how much water is available *at particular assurances/reliabilities* at key locations in the catchment, and how this availability balances the demand for water. The water balance assessment should include not only the current water use situation, but also projected future water demands. Water quality issues that arise in areas of potential supply shortfall obviously need different management responses to those in areas of supply surplus.

Eutrophication assessment context

Eutrophication problems can be alleviated or exacerbated by dilution or over-exploitation of water resources in parts of the study area.

Purpose

This component provides the catchment management strategy development process with an integrated picture of how much surface water and groundwater is available at particular assurances/ reliabilities at key locations in the catchment, and how this availability balances the demand for water (Output **Component 3**). The assessment should include potential future impoundments or groundwater development schemes.

Prerequisite Components

Component 3 (Water use and Conservation) and the provisional version of **Component 20** (Management Options).

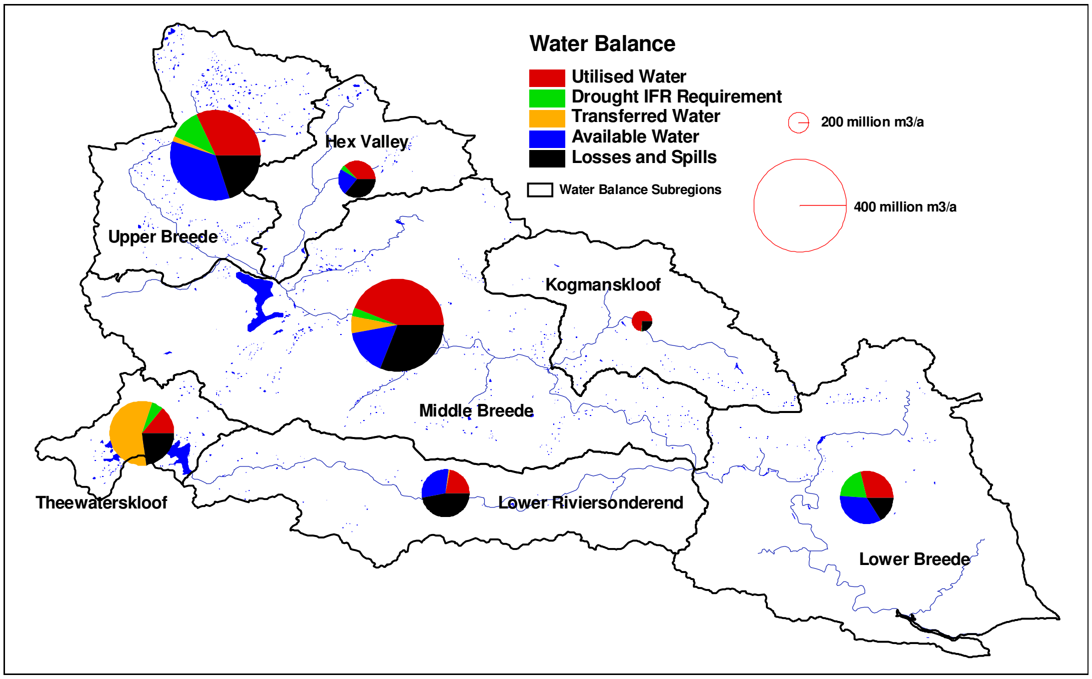
OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Overview chapters on surface and groundwater availability-reliability characteristics at key locations in catchment, and a description of the balance of available water supplies and demands.	A detailed water resources analyses does not usually form part of a water quality management assessment, and should precede or be conducted simultaneously to it. Refer to the *Catchment Water Quality Assessment Guide* for a description of how to produce this output.
Eutrophication assessment outputs	
This component would not be undertaken differently from that of a generic catchment assessment study. The outputs are therefore the same as the ones described in the *Catchment Water Quality Assessment Guide.*	Refer to the *Catchment Water Quality Assessment Guide* for a description of how to produce the outputs.

SOURCES

Planning or Design Reports with the following themes: *Hydrology; Water Resources; System Analysis; Water Demands; Water Supply Augmentation Scheme Design*; *Groundwater Studies; Geohydrology; Demand Management*; etc.	DWAF - Directorates of National Water Resources Planning or Geohydrology, or Relevant Metropolitan or Local Councils.
Reports with the following themes: *Catchment Management; Catchment Management Plans*; etc.	DWAF – Regional Offices Catchment Management Agencies.

CHECKLISTS
Apply checklists of **Components 3** and **20**.
DISPLAY AND PRESENTATION OPTIONS

Example of a map showing a water balance in different sub-catchments of the Breede River basin.



Example of a table listing a water balance for a water management area (DWAF, 2004).

Table 3d: Reconciliation of Water Requirements and Available Water for the Year 2000 (million m³/annum)

Component/Sub-area	Local Yield	Transfers In (2)	Local Requirements	Transfers Out (2)	Balance (1)
Upper Crocodile	336	279	556	17	42
Apies/Pienaars	186	182	280	87	1
Elands	86	71	113	24	20
Lower Crocodile	59	112	171	0	0
Total for Catchment	**667**	**519**	**1120**	**3**	**63**

COMPONENT 5

Water Quality Requirements, and Constituents of Concern relating to Eutrophication

PURPOSE

Generic catchment assessment context

Section 9(h) of the National Water Act specifies that the "Needs and expectations of existing and future water users" be taken into account when developing a catchment management strategy. Not all the users have the same water quality requirements, are not concerned about the same water quality constituents, and have different tolerances for changes in water quality. This component is aimed at identifying the water quality required by different user groups because it provides one of the measures against which the present water quality can be assessed.

Eutrophication assessment context

In the context of an eutrophication assessment, the objective is to identify the primary and secondary variables of concern. Primary variables of concern are often related to the symptoms of eutrophication (nuisance or toxic algae, unpleasant odours etc.) while secondary variables of concern are more related to the causes (elevated nutrient concentrations, improvement in water clarity, etc.). The implication in terms of eutrophication related water quality is that the constituents of concern regarding nutrient enrichment be identified and that the requirements for these constituents be documented.

Purpose

The purpose of this component is to describe the water quality requirements for each water user. The default water quality requirements should at least be the Target Water Quality Range for nutrients and eutrophication related variables as specified in the South African Water Quality Guidelines. However, where appropriate, the requirements should be made site specific to account for local conditions.

Prerequisite components

To undertake this component, the following information should be available: Initial scoping (**Component 0**), Reserve water quality requirements (**Component 2**), Water users in the study area (**Component 3**), draft Water quality issues (**Component 15**).

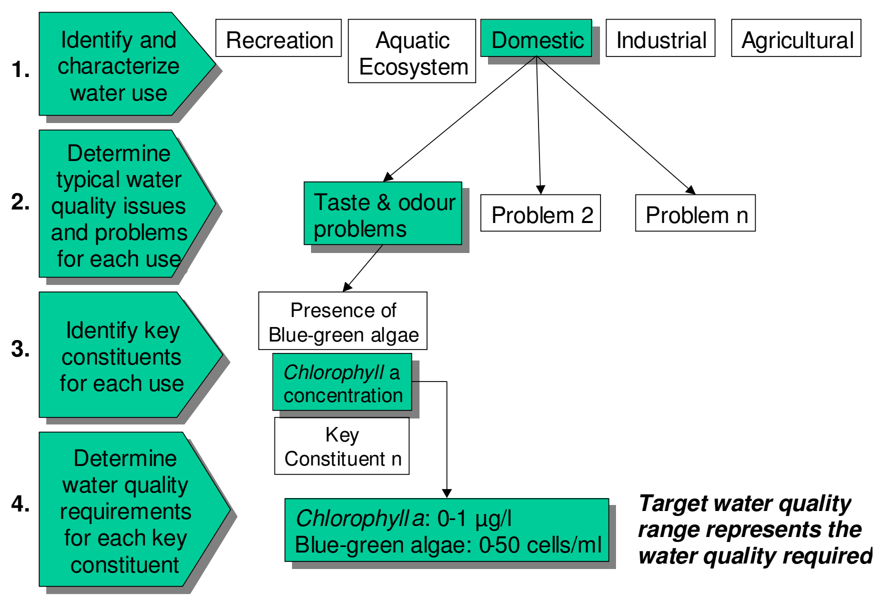
OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The Catchment Water Quality Assessment Guide describes two outputs, an inventory of water quality issues and an inventory of water quality constituents.	Refer to *Catchment Water Quality Assessment Guide* for a description of how to develop the two inventories.
Eutrophication assessment outputs	
Inventory of the eutrophication related water quality issues and problems that concern different water users in the study area.	Public participation process or specialist knowledge and insights of the study area. Use the checklist as a guide to identify the water quality variables of concern. Also refer to the checklist of **Component 14** for a list of typical eutrophication related water quality issues and concerns and the variables associated with it.
Inventory of eutrophication related water quality constituents and target water quality ranges for different water uses.	Summarize the target water quality guidelines for the eutrophication related water quality constituents for the different water uses using the South African Water Quality Guidelines. Develop site-specific guidelines where the SA Water Quality Guidelines are not appropriate for local conditions.

	Summarize the water quality reserve requirements for aquatic ecosystems. If a water quality reserve for aquatic ecosystems does not yet exist, use the default "natural" range values for nutrients and *chlorophyll-a* as an initial target for aquatic ecosystem requirements.
Inventory of resource water quality objectives for nutrients.	Document any resource water quality objectives that have been set for nutrients and other eutrophication related water quality variables.

DETAILED METHODS

The steps to identify site specific water quality requirements are (see example below):

- Identifying and characterising the main water uses for a specific water resource,
- Determining the water quality issues or problems experienced by the main water users,
- Identifying the water quality constituents associated with the each problem or issue, and
- Specifying a target water quality range for each of the key constituents.



SOURCES

The primary sources of information on user requirements for water uses in South Africa are the South African Water Quality Guidelines, the Assessment Guide for Domestic Water Supply, and the SABS specifications for drinking water.

South African Water Quality Guidelines, Vol 2 (1996): Volume 1: Domestic water use Volume 2: Recreational water use Volume 3: Industrial water use Volume 4: Agricultural water use: Irrigation Volume 5: Agricultural water use: Livestock watering	Can be obtained from the DWAF (hard copy or on CD): Director: Water Quality Management Web page: www.dwaf.gov.za

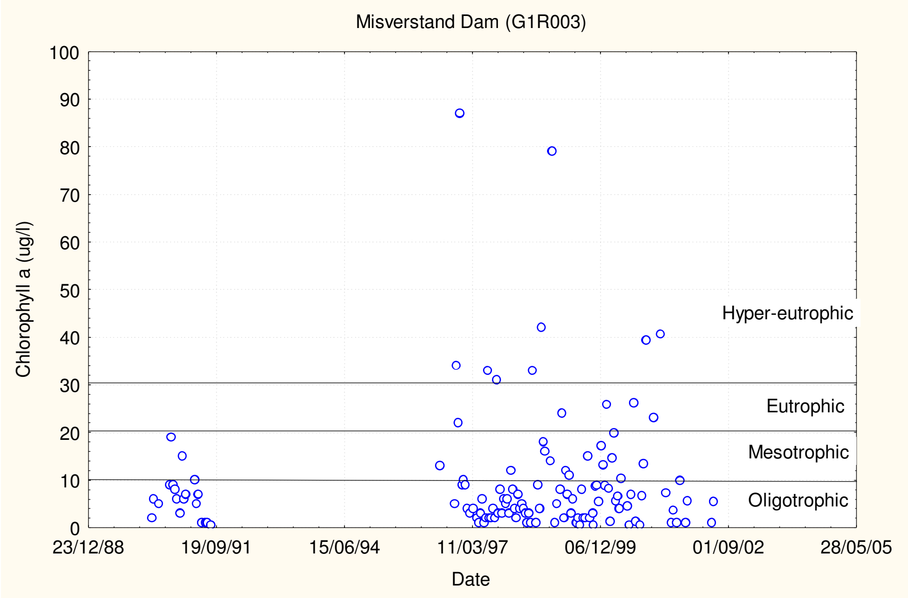
Volume 6: Agricultural water use: Aquaculture Volume 7: Aquatic ecosystems Volume 8: Field guide	
Quality of domestic water supplies. Volume 1: Assessment Guide. Second edition. Water Research Commission Report TT 101/98.	Can be obtained from: Water Research Commission Web page: www.wrc.org.za
South African Bureau of Standards 241-2001 *Specifications for drinking water.*	Can be obtained from: South African Bureau of Standards Web page: www.sabs.co.za
Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems.	Can be obtained from the DWAF: Director: Resource Directed Measures Web page: www.dwaf.gov.za
Manual for Ecostatus Determination (Version 1).	Kleynhans *et al.* (2005) Can be obtained from the Water Research Commission. Web page: www.wrc.org.za
Guideline for Determining Resource Water Quality Objectives (RWQOs), Water Quality Stress and Allocatable Water Quality.	DWAF (2006) Can be obtained from the DWAF. Web page: www.dwaf.gov.za
Local sources of information that can be used to supplement the Guidelines are:	
Site specific nutrient or chlorophyll management objectives for specific catchments or sub-catchments.	Contact the Regional Office of DWAF responsible for water quality management in the area under consideration. Contact the local authorities or Water Service Providers in the area under consideration.
Eutrophication related water quality guidelines and criteria that have been developed and applied in South Africa.	Consult the following publications: Walmsley and Butty (1980) Walmsley (1984) DWAF (2002) Van Ginkel *et al*., (2000)
International sources that can be used to supplement the South African Water Quality Guidelines include (only those which can be accessed via the Internet are listed here):	
Australian and New Zealand Guidelines for Fresh and Marine Water Quality (1999)	Australian and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand http://www.deh.gov.au/water/quality/nwqms/index.html#quality
USEPA Water Quality Criteria	USEPA Water Quality Standards Section http://epa.gov/waterscience/criteria/nutrient/index.htm
Canadian Water Quality Guidelines	Environment Canada http://www.ec.gc.ca/CEQG-RCQE/English/Ceqg/Water/
Guidelines for Drinking Water Quality	World Health Organisation http://www.who.int/water_sanitation_health/dwq/guidelines2/en/

<table>
<tr><th colspan="2">CHECKLISTS</th></tr>
<tr><td colspan="2">Key water uses that are affected by eutrophication related water quality problems</td></tr>
<tr><td>Water use</td><td>Typical variables of concern</td></tr>
<tr><td>Domestic water use
• Drinking water (health and aesthetic considerations)
• Food preparation
• Bathing</td><td>Algae (taste and odours)
Cyanobacteria (toxicity, taste and odours)
THMs</td></tr>
<tr><td>Agricultural water use
• Irrigation water supply
• Livestock watering
• Aquaculture</td><td>Cyanobacteria (toxicity, taste and odours)
Algae (phytoplankton, filamentous algae)
Low dissolved oxygen concentrations
Nutrients (excess fertilizer application)</td></tr>
<tr><td>Recreational use
• Full contact recreation
• Limited contact recreation
• Non-contact recreation</td><td>Algae (phytoplankton, filamentous algae)
Algal scums
Water clarity
Aesthetic appeal (visual impairment, odours)
Anoxic products (odours)</td></tr>
<tr><td>Aquatic ecosystem health
• Habitat impacts</td><td>Algae (periphyton, filamentous algae)
Low dissolved oxygen
Anoxic products (odours)</td></tr>
<tr><td>Industrial water use</td><td>Biofilms (biofouling)
Algae (toxicity, taste and odours)
Nutrients (biofouling)</td></tr>
<tr><td colspan="2">Water quality constituents of concern relating to eutrophication</td></tr>
<tr><td>Algae
• Phytoplankton, periphyton
Physical properties
• pH, temperature, suspended solids, turbidity, water clarity
Nutrients
• Total and dissolved phosphorus, total and dissolved nitrogen</td><td>Metals
• Copper (Cu)
Other inorganic constituents
• Silica (Si), total dissolved solids
Organic constituents and compounds</td></tr>
<tr><td colspan="2">Water quality problems or concerns and problems associated with eutrophication</td></tr>
<tr><td colspan="2">Refer to Component 14 (Record of water quality issues) for a discussion of water quality concerns, problems and variables of concern that are associated with eutrophication.</td></tr>
</table>

DISPLAY AND PRESENTATION OPTIONS

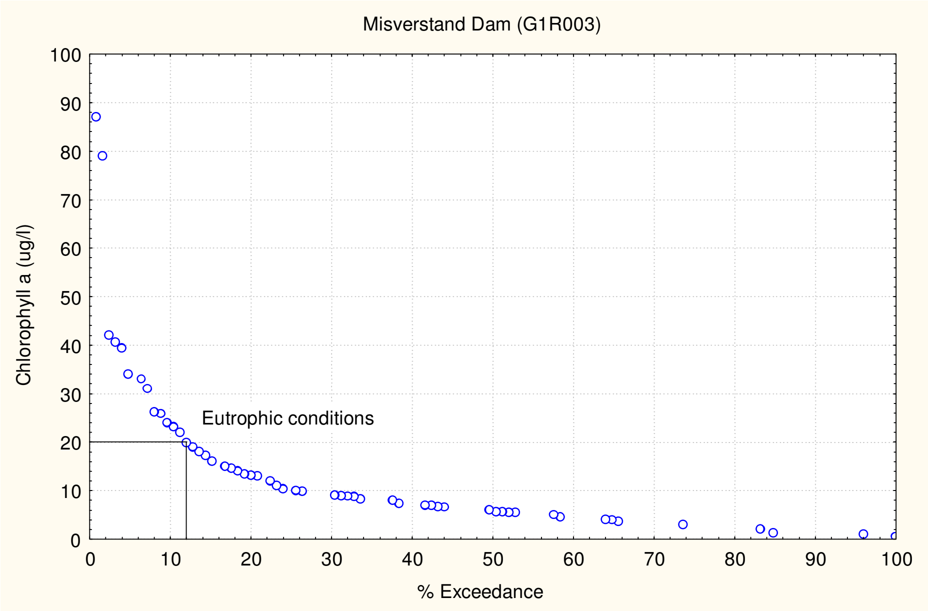
Time series plot

A time series plot like the example shown here can be used to indicate the eutrophication status at one location, over time. The example shows a time series of *chlorophyll-a* concentrations measured as Misverstand Dam on the Berg River as well as the DWAF boundary concentrations for oligotrophic, mesotrophic, eutrophic and hypertrophic conditions.



Exceedence diagram

An exceedence diagram can be used to illustrate the percentage of observations that exceeded a specific value. In the example below it can be seen that at Misverstand Dam, about 12% of the observations exceeded the 20 µg/l Chl, a eutrophic boundary value.



Summary Tables of water quality guidelines and objectives

The example below shows the water quality guidelines that were developed for the Modder/Riet Catchment Management Strategy (DWAF, 2006b).

Table 7.5: Proposed water quality guidelines

Variable	Unit	Upper Bound of Water Quality Guideline Boundary														
		Domestic			Agriculture			Recreation			Ecosystem			Combined		
		Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable	Ideal	Acceptable	Tolerable
Electrical Conductivity	mS/m	70	150	370	40	90	270	X	X	X	X	X	X	40	90	270
pH Upper	units	9.0	9.5	10.0	8.4	X	X	8.5	9.0	X	8.5	9.0	9.5	8.4	9.0	9.5
pH Lower	units	6.0	5.0	4.0	6.5	X	X	6.5	5.0	X	6.5	5.5	5.0	6.5	5.5	5.0
Nitrate	mg/l N	6	10	20	5.0	30.0	X	X	X	X	0.5	2.5	10.0	0.5	2.5	10
Fluoride	mg/l F	0.70	1.00	1.50	2.00	4.00	6.00	X	X	X	0.75	1.50	2.00	0.70	1.00	1.50
Sulphate	mg/l S	200	400	600	1000	1500	2000	X	X	X	52.0	100.0	200.0	52	100	200
Sodium	mg/l Na	100	200	400	70	115	230	X	X	X	31.0	60.0	120.0	31	60	120
Potassium	mg/l K	25	50	100	X	X	X	X	X	X	X	X	X	25	50	100
Magnesium	mg/l Mg	30	70	100	X	X	X	X	X	X	23.0	50.0	100.0	23	50	100
Calcium	mg/l Ca	32	80	150	X	X	X	X	X	X	348.0	700.0	1400.0	32	80	150
Chloride	mg/l Cl	100	200	600	100	175	350	X	X	X	537.0	1000.0	2000.0	100	175	350
Ammonia	mg/l N	X	X	X	5.0	30.0	X	X	X	X	0.057	0.121	0.650	0.057	0.121	0.65
Orthophosphate	mg/l P	X	X	X	X	X	X	X	X	X	0.005	0.025	0.050	0.005	0.025	0.050
Total Hardness	mg/l $CaCO_3$	100	200	300	X	X	X	X	X	X	X	X	X	100	200	300
Sodium Adsorption Ratio	units	X	X	X	2	8	15	X	X	X	X	X	X	2	8	15
Faecal Coliforms	CFU/100 ml	X	X	X	1.0	1000.0	X	130	600	2000	X	X	X	1	600	2000

The example below shows water quality objectives, including objectives for nutrients, that were developed for the Modder/Riet system (DWAF, 2006b).

Table 7.6: Water Quality Objectives (95TH percentile values) For the Modder and Riet River Catchment

Variable	Unit	Objective
Electrical Conductivity	mS/m	90
pH Upper	units	9
pH Lower	units	5
Nitrate	mg/l N	2.5
Fluoride	mg/l F	1
Sulphate	mg/l S	100
Sodium	mg/l Na	100
Potassium	mg/l K	50
Magnesium	mg/l Mg	50
Calcium	mg/l Ca	150
Chloride	mg/l Cl	150
Ammonia	mg/l N	0.3
Nitrite	mg/l N	0.25
Orthophosphate	mg/l P	0.025
Total Hardness	mg/l CaCO3	300
Sodium Adsorption Ratio	units	6
Faecal Coliforms	CFU/100ml	600

REFENCES

Department of Water Affairs and Forestry (2002). *National Eutrophication Monitoring Programme: Implementation Manual*. [Online]. South African National Water Quality Monitoring Programmes Series.

Available: http://www.dwaf.gov.za/IWQS/eutrophication/NEMP/NEMP_implementation.htm

Department of Water Affairs and Forestry (2006a). *Resource Directed Management of Water Quality Series: Management Instruments. Volume 4.2: Guideline for Determining Resource Water Quality Objectives (RWQOs), Water Quality Stress and Allocatable Water Quality.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.2, Edition 2. ISBN No. 0-621-36793-1. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (2006b). *Development of a Catchment Management Strategy for the Modder and Riet Rivers in the Upper Orange Catchment Management area: Catchment Management Strategy*. Report prepared by BKS for the DWAF Free State Regional Office.

Kleynhans, C J, Louw, M D, Thirion, C, Rossouw, J N and Rowntree, K. (2005). *River Ecoclassification: Manual for Ecostatus Determination. Version 1*. Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Van Ginkel, C E, Hohls, B C, Belcher, A, Vermaak, E and Gerber, A. (2000). *Assessment of the Trophic Status Project*. Internal Report No. N/0000/00/DEQ/1799. Institute for Water Quality Studies. Department of Water Affairs and Forestry. Pretoria.

Summary available online: http://www.dwaf.gov.za/IWQS/eutrophication/NEMP/default.htm

Walmsley, R D. (1984). *A chlorophyll-a trophic status classification system in South Africa*. Special report, Water Research Commission.

Walmsley, R D and Butty, M. (1980). *Guidelines for the Control of Eutrophication in South Africa*. Water Research Commission, National Institute for Water Research, CSIR.

COMPONENT 6
Eutrophication Related Water Quality for Streamflow, Reservoirs and Wetlands

PURPOSE

Generic catchment assessment context

The present water quality status needs to be described in order for the CMA and/or the Department and other stakeholders to make informed decisions on how to manage water quality in a specific catchment. An analysis of water quality data needs to provide information on the present water quality status, how the status may possibly change over time if current trends continue and, by comparing it to the user water quality requirements, determine whether user requirements are met or not.

Eutrophication assessment context

The present eutrophication status needs to be described to determine by how much water quality has deteriorated in a study area and to focus the development of management options on those variables and "hot spots" where the desirable uses of water are compromised. An analysis of water quality data needs to provide information on the present eutrophication status, how the status has changed over time and whether user water quality requirements are being met or not.

Purpose

The purpose of this component is to obtain eutrophication related water quality data and information for the study area from appropriate sources and to analyse the data to describe:

- Eutrophication related water quality in the catchment at an overview level
- Spatial trends for the water quality variables of concern
- Temporal trends for the water quality variables of concern
- The fitness of water resources for the key water uses in the study area

Prerequisite Components

To undertake this component, the following information should be available:

Component 1 – Details of physical, developmental and administrative attributes and characteristics of the catchment relevant to water resources management, **Component 3** – Water use and conservation and **Component 5** – User water requirements, constituents of concern and water quality management objectives.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
For a generic catchment assessment study, the outputs would include an inventory of water quality data sources and a description of the temporal and spatial trends in water quality, summarised in a water quality assessment report.	The methods for attaining the output are described in the Catchment Water Quality Assessment Guide document (DWAF, 2003) and are similar to the methods described for eutrophication below.
Eutrophication assessment outputs	
Inventory of eutrophication related water quality data sources for the study area. *Note: A detailed assessment of different monitoring programmes are undertaken in **Component 11**.*	Identify the key sources of data and information for the study area using the national, provincial and local authorities, water service providers, and other institutions listed in the checklist below. For each data source, list the name of the monitoring program, name of the institution responsible for the monitoring programme, and key objectives of their monitoring programme.
Inventory of key water quality reaches in the study area where eutrophication interferes with the desirable water uses.	• Define the geographical boundaries and describe the key water quality reaches. • Compile a GIS map showing the location of the water quality reaches. *Also refer to **Component 1**.*

Temporal trends in eutrophication related water quality variables	• Describe and illustrate the temporal trends, at specific points in the study area, for eutrophication related water quality constituents, using the presentation and display options listed below. Use statistical procedures to determine whether the trends are significant. • Use a statistical software package (such as WQStat or Statistica) and the Kruskal-Wallis test for seasonality, to determine whether there is seasonality in the data. Seasonality can be illustrated with monthly box-and-whisker plots (see display options below).
Spatial trends in key water quality variables	• Describe and illustrate spatial trends, in eutrophication related water quality, along the length of key water quality reaches. • Use statistical procedures to confirm the statistical significance of spatial trends.
Eutrophication assessment report	Compile an eutrophication assessment report which addresses the following aspects: • A summary of the affected water users in the study area (refer to detailed descriptions in **Component 12**). • A summary of the eutrophication problems experienced by users (refer to detailed descriptions in **Components 4** and **15**). • List of the eutrophication related water quality variables investigated (refer to detailed descriptions in **Components 4** and **15**). • A description of the temporal trends determined. • A description of the spatial trends determined.

METHODS AND TOOLS

Standard methods for the analysis of water quality data applies. Graphical and statistical procedures for analysing and reporting on water quality data are described in the document *Conceptual design report for a National River Water Quality Assessment Programme* (Harris *et al*., 1992). Other detailed descriptions of water quality data analysis can be found in Gilbert (1987) and Ward *et al*. (1990). See also the display options below.

SOURCES

Eutrophication related water quality data and information are generally collected as part of monitoring water quality in a catchment. The Department of Water Affairs and Forestry probably operates the most inclusive water quality monitoring programme in the country. Other potential sources include Water Service Authorities (local authorities, metropolitan councils, etc.), Water Service Providers such as water boards, as well as research institutions. The list of potential data sources is by no means complete and is presented here to serve as a guide to the types of organizations involved in collecting water quality data. It is up to the study team to identify the key sources of water quality data and information in the catchment under investigation.

National government department data sources	
Department of Water Affairs and Forestry • National Eutrophication Monitoring Programme • National chemical water quality monitoring programme • Groundwater quality	Director: Resource Quality Services Private Bag X313 Pretoria 0001 Website: www.dwaf.gov.za
DWAF Regional Offices Regionally, offices often monitor specific water quality variables as part of their water quality management activities.	Contact details of regional offices available on the DWAF website Website: www.dwaf.gov.za
Catchment Management Agencies	Catchment Management Agencies may in future be delegated the responsibility of monitoring in their Water Management Area. The DWAF Regional office is the de facto CMA until a CMA has been established.
Provincial government sources	
Provincial nature conservation departments mostly participate in the River Health Programme that collects information on the ecosystem health of rivers. Some observations might be available about excessive periphyton growth at survey sites.	Contact the relevant provincial nature conservation department about eutrophication related water quality data that may be available from them, or Visit the River Health Programme website Website: www.csir.co.za/rhp
Examples of Water Service Providers and Water User Associations involved in water quality monitoring	
Most Water Service Providers have extensive monitoring networks in their area of operation and often collect specialist eutrophication data such as algal species composition.	Rand Water Website: www.randwater.co.za Umgeni Water Website: www.umgeni.co.za
Water user associations (WUAs), such as former Irrigation Boards or Water Conservation Boards, may be a source of qualitative observations on eutrophication, such as excessive filamentous algae in canals or nuisance algal blooms in irrigation dams.	WUA's are too numerous to list in this document and it is recommended that WUA's in the study area be identified and contacted about the availability of water quality data. *Refer to **Component 12**.*
Examples of Water Service Authorities data sources	
City of Cape Town	City of Cape Town Scientific Services Website: www.capetown.gov.za
Durban Metropolitan Council	Durban Metro Water Services Laboratory Website: www.durban.gov.za

Examples of other organizations involved in eutrophication studies and monitoring	
Universities and Technikons sometimes collect project specific water quality data.	Contact the natural sciences departments at Universities and Technikons in the study area to find out whether they have undertaken any project-specific water quality data collection that would be relevant to an eutrophication assessment study.

DISPLAY AND PRESENTATION OPTIONS

Summary statistics

Summary statistics provide a good overview of the order of magnitude of concentrations recorded for different variables in the study area. Summary statistics can include the average, median, minimum, maximum, standard deviation and number of samples over a specified period of time. The example below shows the summary statistics output of statistical analysis of PO_4-P concentrations measures in the Pongola River catchment.

MONITORI	PO4_P Means	PO4_P N	PO4_P Std.Dev.	PO4_P Variance	PO4_P Minimum	PO4_P Maximum	PO4_P Q25	PO4_P Median	PO4_P Q75	PO4_P 10%tile	PO4_P 90%tile
W4H003Q0	0.021	261	0.024	0.001	0.003	0.329	0.011	0.017	0.026	0.003	0.038
W4H004Q0	0.022	326	0.039	0.001	0.003	0.458	0.008	0.014	0.025	0.003	0.043
W4H006Q0	0.026	604	0.077	0.006	0.003	1.770	0.010	0.018	0.027	0.003	0.042
W4H007Q0	0.018	41	0.022	0.000	0.003	0.148	0.009	0.013	0.019	0.007	0.027
W4H008Q0	0.067	113	0.065	0.004	0.003	0.456	0.025	0.049	0.097	0.011	0.140
W4H009Q0	0.027	262	0.037	0.001	0.003	0.438	0.011	0.019	0.029	0.003	0.047
W4H010Q0	0.013	39	0.008	0.000	0.003	0.049	0.007	0.013	0.015	0.005	0.020
W4H011Q0	0.028	56	0.048	0.002	0.003	0.285	0.003	0.012	0.033	0.003	0.070
W4H012Q0	0.014	3	0.007	0.000	0.009	0.022	0.009	0.010	0.022	0.009	0.022
W4H013Q0	0.016	280	0.013	0.000	0.003	0.117	0.009	0.013	0.020	0.006	0.027
W4H014Q0	0.020	251	0.034	0.001	0.003	0.434	0.009	0.013	0.020	0.006	0.032
W4R001Q0	0.020	244	0.047	0.002	0.003	0.671	0.008	0.012	0.018	0.003	0.033
W4R001Q1	0.024	4	0.004	0.000	0.021	0.030	0.021	0.023	0.028	0.021	0.030

The example below demonstrates how a colour coding system can be used to illustrate the fitness for use (from DWAF, 2006). For example, blue indicates ideal water quality, green is acceptable water quality, and orange is tolerable water quality.

Table 6.4: Water quality assessment results for Recreation, Ecology and Industry

(Values shown are 75th percentile values)

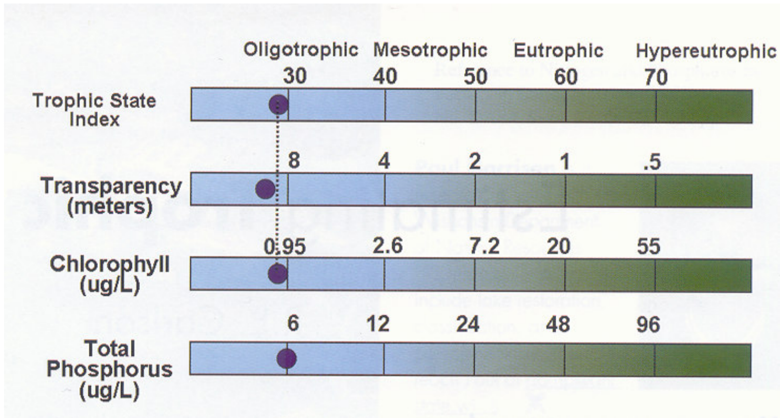
SUB-CATCHMENT	DESCRIPTION	STATION	RECREATION	ECOLOGY				INDUSTRY		
			pH	pH	Ammonia (mg/l N)	Flouride (mg/l)	Phosphorous (mg/l)	Silica	Sulphate (mg/l)	Chloride (mg/l)
1 Upper Modder	Rustfontein Dam	C5R003	8.37	8.37	0.06	0.30	0.04	2.59	13.7	7.10
2 Middle Modder	Krugersdrift Dam	C5R004	8.61	8.61	0.06	0.31	0.09	2.35	24.7	36.6
3 Lower Modder	Tweerivier	C5H018	8.35	8.35	0.05	0.27	0.02	8.16	113	158
4 Upper Riet	Tierpoort Dam	C5R001	8.36	8.36	0.07	0.40	0.21	6.32	23.3	12.7
5 Middle Riet	Kalkfontein Dam	C5R002	8.52	8.52	0.08	0.54	0.03	1.51	43.8	53.7
6 Lower Riet	Aucampshoop	C5H016	8.31	8.31	0.05	0.25	0.02	7.61	147	200

Trophic State Index

The trophic state index developed by Carlson can be used to assess the current (or historical) state of eutrophication (Carlson, 1977, 2007; Carlson and Havens, 2005). The index is based on water clarity (measured as the Secchi disk depth), the algal concentration (measured as the *chlorophyll-a* concentration) and the nutrient concentration (measured as the total phosphorus concentration). Below is an example of how the results can be displayed graphically (Carlson, 2007).

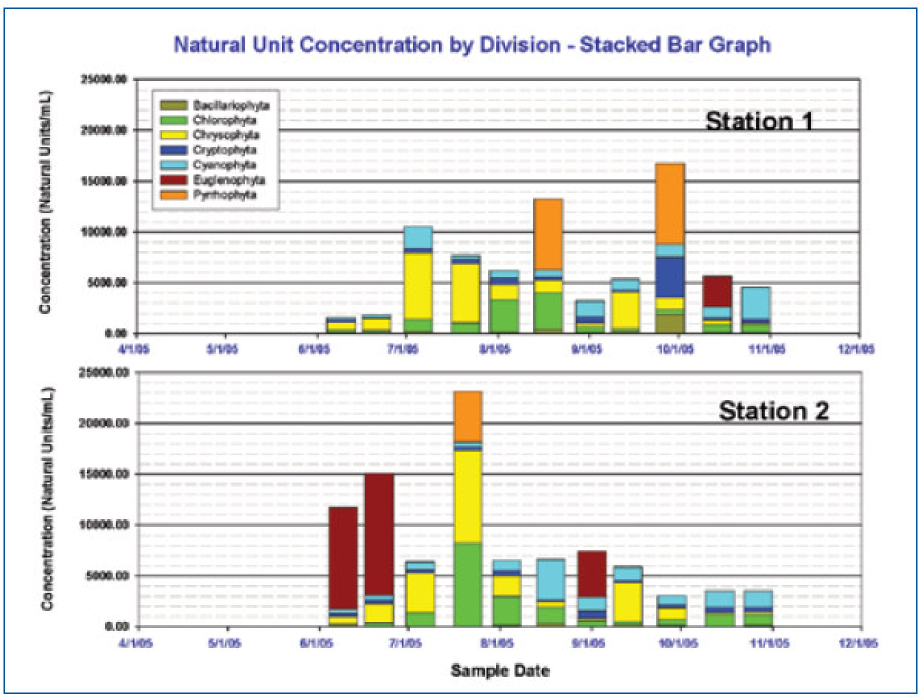
The following equations are used to calculate the three indices:

Transparency	TSI = 60 – 14.41 In (SD)	SD = Secchi disk depth (m)
Chlorophyll	TSI = 9.81 In(CHL) + 30.6	CHL = *Chlorophyll-a* (µg/l)
Total-P	TSI = 14.42 In(TP) + 4.15	TP = Total phosphorus (µg/l)



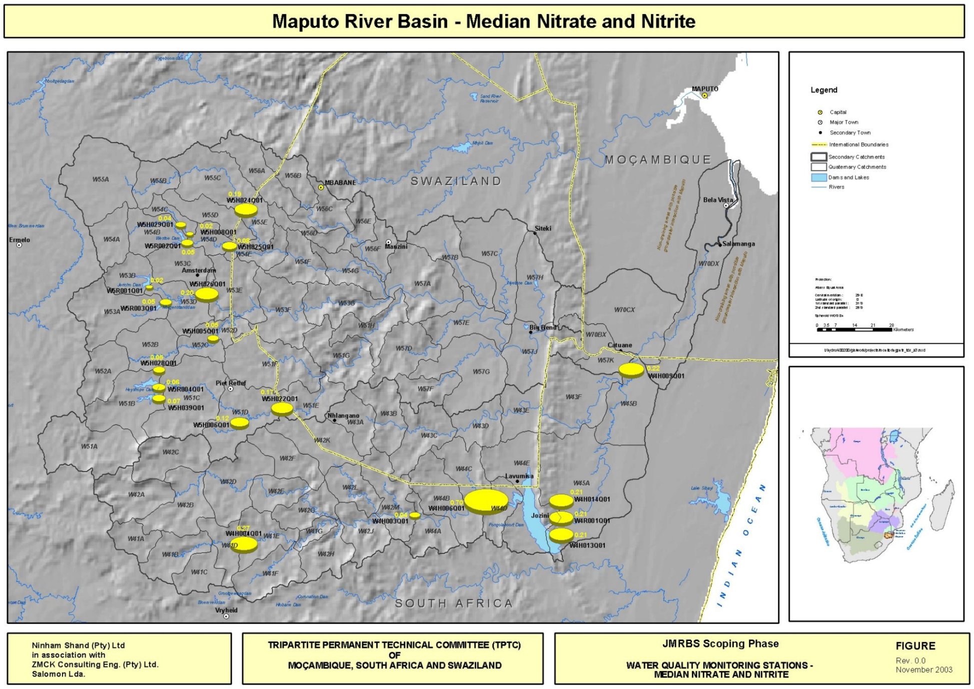
Displaying algal data

The figure below demonstrates how stacked box plots can be used to illustrate the algal species composition of different samples (St. Amand and Chapman, 2007).



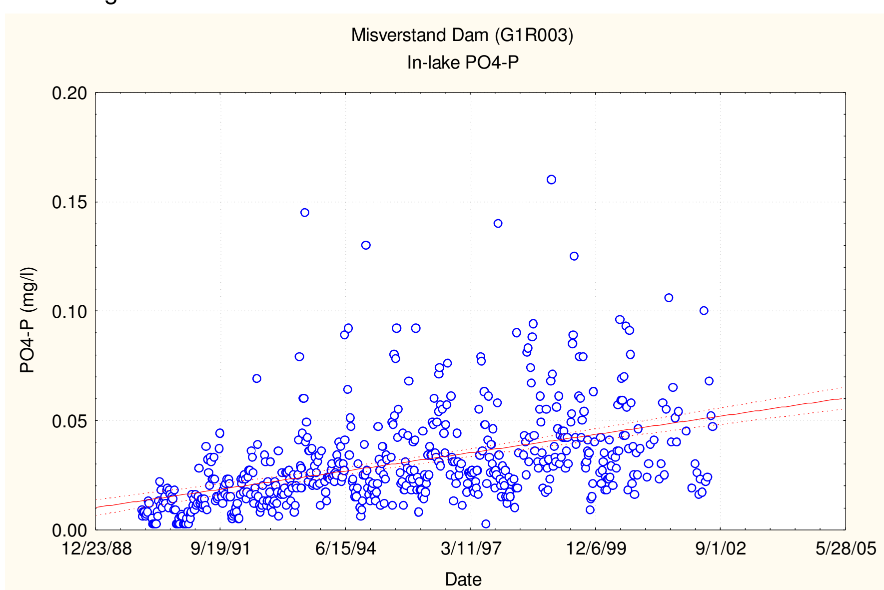
GIS maps for synoptic overviews

GIS maps of the study area can provide a good spatial overview of eutrophication related water quality in a catchment. The maps are used to illustrate spatial trends in water quality rather than actual values. In the example below the size of the circles are proportional to the median concentration.



Time series plot

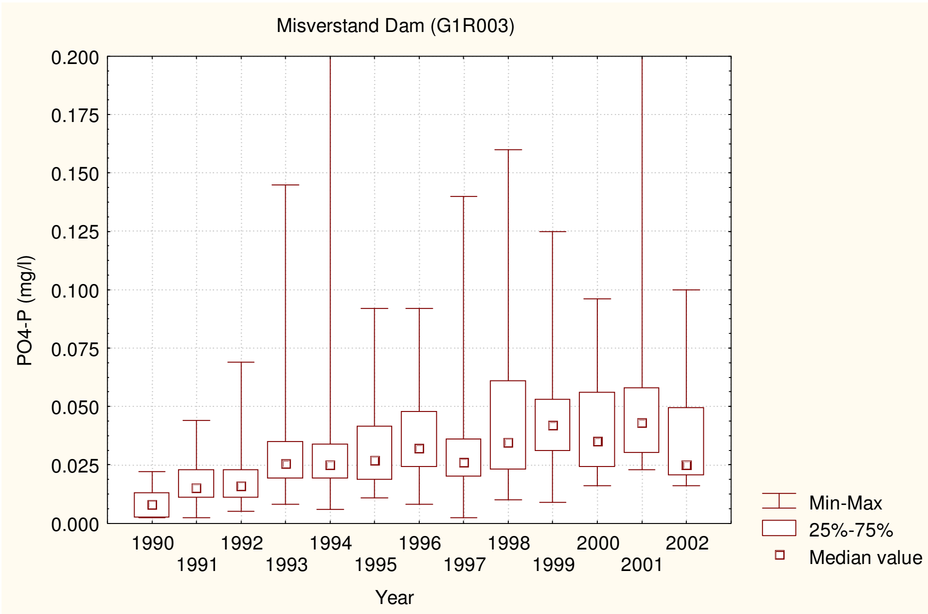
A plot of the water quality variable against time. A visual examination of the time series plot can show suspect outliers as well as some indication of seasonal or longer-term trends. In the example below there appears to be an increase in PO_4-P concentrations over time as well as some seasonal differences in quality. Fitting a linear line through the points provides some indication of a long-term trend.



Annual box-and-whisker plot

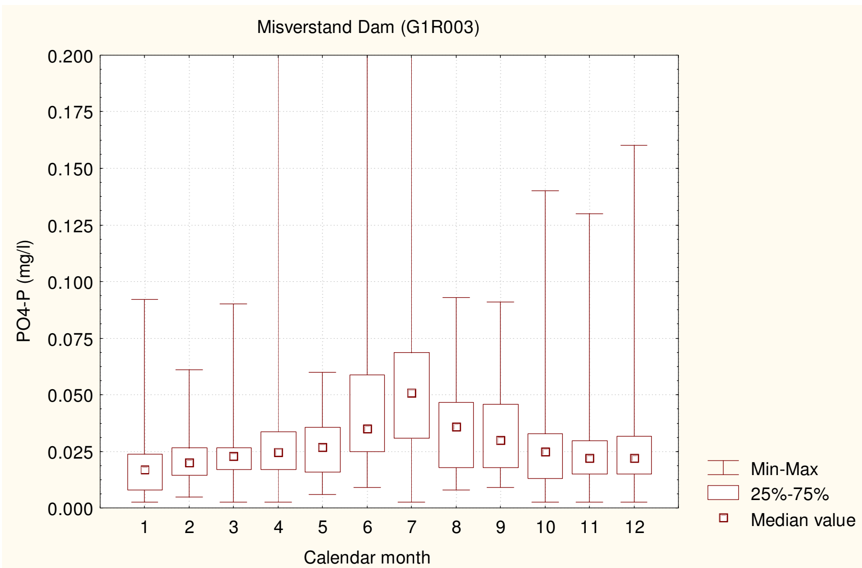
A box-and-whisker plot is based on a five number summary consisting of the 95th (or maximum), 75th, 50th, 25th and 5th (or minimum) percentiles. The box is enclosed by the 75th and 25th percentile and contains the 50th percentile (also called the median). The whiskers join the box to 95th and 5th percentiles or maximum or minimum depending on the software being used.

An annual box-and-whisker plot is obtained by plotting the data collected during a specific year as a box-and-whisker plot. An examination of the annual box-and-whisker plot of PO_4-P concentrations indicates that there has been an increase in concentrations since the early 1990's.



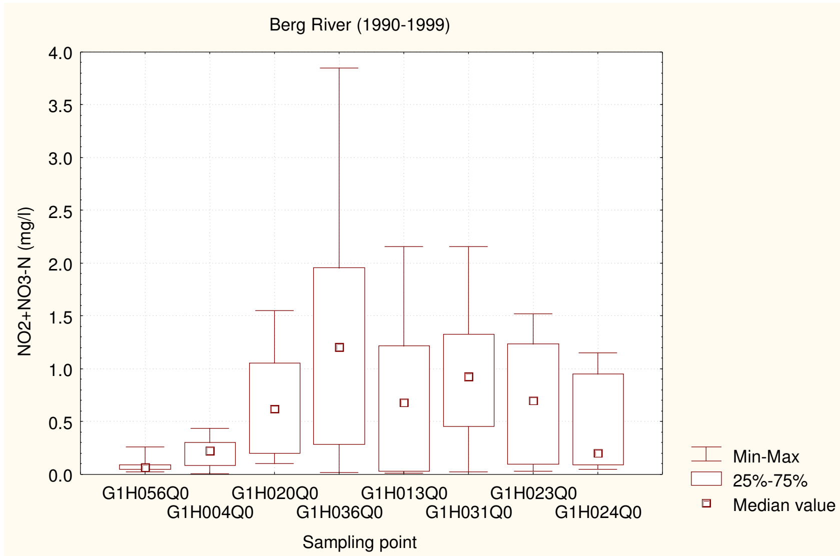
Seasonal box-and-whisker plot

A seasonal box-and-whisker plot is obtained by plotting all the data collected during a specific month as a box-and-whisker graph. An examination of a monthly box-and-whisker plot can give an indication of seasonal differences in the data. This can be confirmed with statistical tests for seasonality. For example, this box-and-whisker plot shows some seasonality with higher PO_4-P concentrations occurring during the early and mid-winter months in a winter rainfall region.



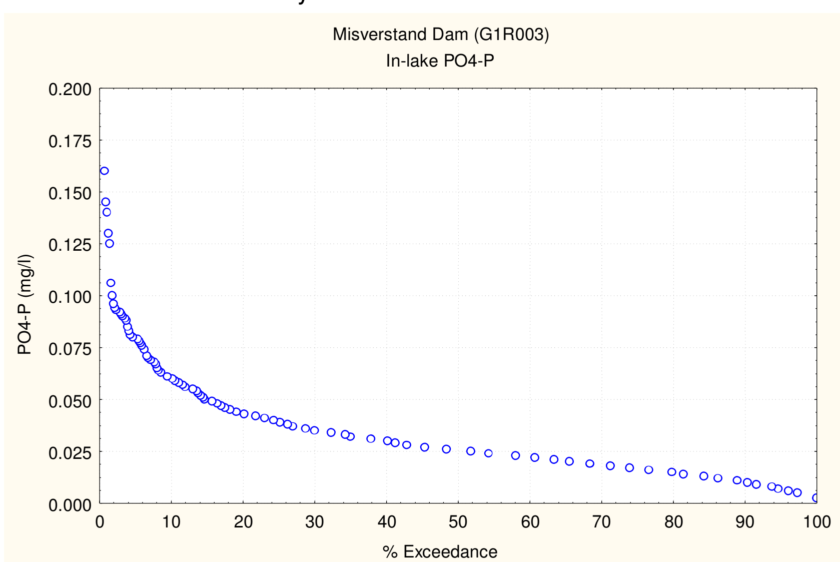
Spatial box-and-whisker plot

A spatial box-and-whisker plot is compiled by arranging the sampling stations according to their downstream position in the river. An examination of a spatial box-and-whisker plot can give an indication of the water quality changes along the length of a river. For example, this spatial box-and-whisker plot of NO_2+NO_3-N concentrations along the Berg River shows a sharp increase in the Paarl/Wellington area (G1H020 and G1H036) and a gradual decrease in a downstream direction even though the concentrations remain relatively high.



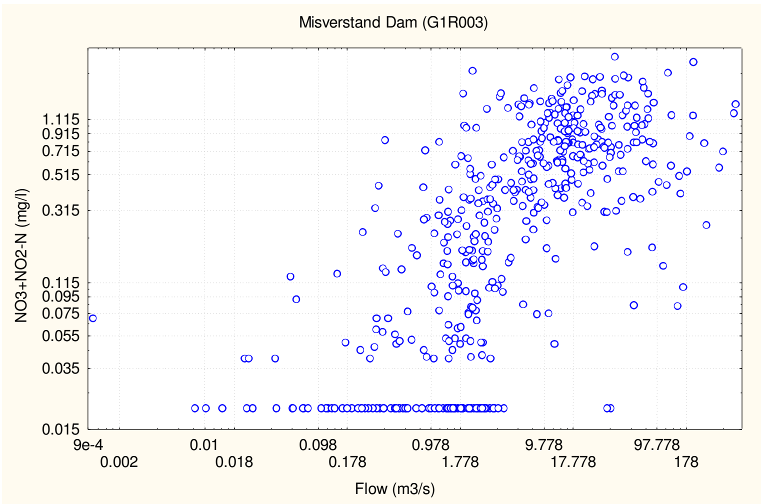
Exceedence diagram

An exceedence diagram shows the percentage of time a specific concentration was exceeded in the data recorded. This is obtained by ranking the data from large to small and calculating the plotting position as the rank divided by the total number of data+1.



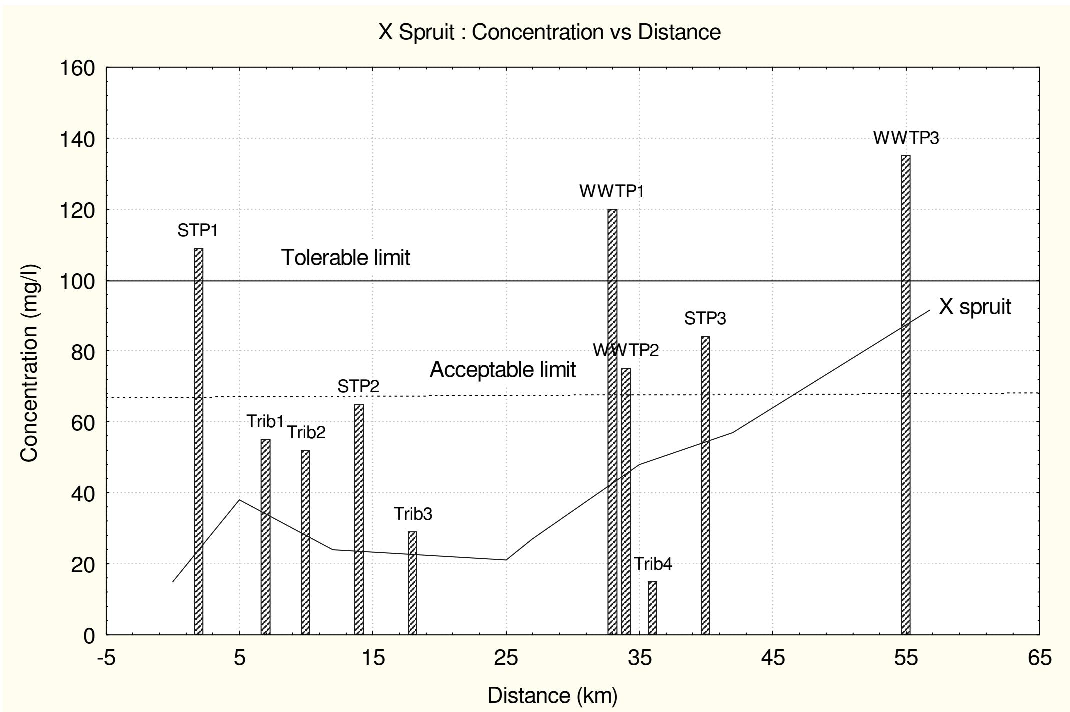
Concentration *vs* Flow plot

A plot of nutrient concentration against flow can be used to illustrate the relationship with flow. For example, it may illustrate that there are sufficient nutrients available on the catchment surface to be washed off during rainfall events, that is, the nutrient concentration increases as flow increases, as illustrated in the log-log plot below.



Concentration *vs* Distance Diagram

A concentration vs. river distance diagram can provide valuable information on spatial changes in water quality especially when reconciling source water quality data with in-river data. The example below illustrates the effect of sampling the river, tributaries and point sources on a specific day and then plotting the concentrations as a function of river distance. This type of graph can be used to assess whether the changes concentration can be explained with data from the known point sources in the catchment. A more accurate estimate can be obtained for catchment processes if concentrations are replaced with constituent loads.



REFERENCES

Carlson, R E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, 22:361-369.

Carlson, R E and Haven, K E. (2005). Graphical methods for the interpretation of relationships between trophic state variables. *Lake and Reservoir Management*, 21:107-118.

Carlson, R.E. (2007). Estimating Trophic State. *Lakeline*, 27(1): 25-28.

Department of Water Affairs and Forestry (2006). *Development of a Catchment Management Strategy for the Modder and Riet Rivers in the Upper Orange Catchment Management area: Catchment Management Strategy*. Report prepared by BKS for the DWAF Free State Regional Office

Gilbert, R O. (1987). Statistical *Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York, NY, USA

Harris, J, Van Veelen, M and Gilfillan, T C. (1992). *Conceptual design report for a National River Water Quality Assessment Programme*. Water Research Commission, Report No. 204/1/92, Pretoria, South Africa.

St. Amand, A and Chapman, A. (2007). Using plankton data. *Lakeline,* 27(1):34-40.

Ward, R C, Loftis, J C and McBride, G B. (1990). *Design of Water Quality Monitoring Systems*. Van Nostrand Reinhold, New York, NY, USA.

COMPONENT 7

Point Source Waste Discharges and Source Characteristics relating to Eutrophication

PURPOSE

Generic catchment assessment context

Wastewater treatment works or industrial plants usually discharge their effluents to stream channels or surface water bodies through conduits such as outfall pipes, ditches or canals. Such "end-of-pipe" sources of pollutant loading of surface water bodies are known as point sources. The quality of effluent discharges must conform to standards prescribed in licences or other forms of authorisations. Such effluent quality standards are intended to safeguard the fitness-for-use of the receiving waters. Point source assessment does not only comprise the processing of available effluent stream records, but may also include scrutiny of streamflow water quality records to identify unknown contaminant loadings, which may signify unauthorised discharges.

Eutrophication assessment context

In South Africa, many of the eutrophication related water quality problems are related to the cumulative effects of point source discharges of nutrient rich effluents that in turn contribute to deteriorating fitness-for-use in terms of the requirements of specific water users (e.g. Van Ginkel *et al*, 2000, Walmsley, 2003). Consequently, the assessment of point source nutrient contaminant loads to streams, rivers and reservoirs is a prerequisite for understanding the eutrophication patterns and problems in a catchment. Point source data are also essential inputs for the configuration and calibration of eutrophication simulation models for use in water quality assessments (see **Component 9**) and the investigation of eutrophication management options. It is not only the present day point source waste discharges, but also historical waste discharge records or trends that are required for proper calibration of the models.

Purpose

The purpose of this component assists in understanding the eutrophication characteristics and patterns in a catchment by examining both the detailed information of the location and magnitude of individual nutrient sources but also the cumulative nutrient loads and impacts. For instance, by subtracting known point source nutrient loadings from cascading incremental load balances at flow gauging/ water quality observation (or simulation) points in a river, non-point loadings, and unauthorised point sources, can be identified and quantified.

Prerequisite Components

Component 1- Description of the study area.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
An inventory of individual point sources in the study area listing the location, discharge volume, constituent loads, source type, primary activity involved, contact details, etc.	The inventory information can be compiled from the register of water use licences and compliance monitoring records.
Database of compliance monitoring data (sample analyses and flow rate data).	This raw data can be assembled from the records kept by DWAF (or a CMA) as responsible authority, or from the discharger's own monitoring data.
Monthly time series of historical waste discharge volumes and constituent loads.	These time series can be infilled or extrapolated from compliance monitoring data.

Eutrophication assessment outputs	
An inventory of point sources contributing high nutrient loads in the study area. The type of information to be captured includes the location and point of discharge, effluent volume, nutrient loads, type of source, and contact information of the accountable person.	Specific attention should be given to sources that are high in nutrients (see **checklist**). Current annual discharge volumes and loads are based on the monthly time series of historical discharges (the third output); and other information can be sourced from the register of water use licences.
Database of historical data of nutrient concentrations and flow rates for individual sources.	The historical data can be assembled from the records kept by DWAF as the licensing authority, or from the discharger's own monitoring data. Some additional monitoring may be required if a previously unknown point source is identified during the assessment.
Monthly time series of historical nutrient loads and effluent volumes.	These monthly nutrient time series can be developed by infilling or extrapolating the grab sample nutrient data (second output) using appropriate infilling methods (refer to **methods and tools**).

METHODS AND TOOLS

Load calculations

Generally, some effluent flow and nutrient concentration data are available for wastewater treatment discharges because monitoring requirements of the effluent discharge is specified in the water use licence issued by the DWAF.

Nutrient loads can be calculated by multiplying the concentration by the flow. The effluent discharge volume and nutrient concentrations are generally not as variable as those observed in rivers. Using discrete flow and concentration observations for estimating average loads is therefore adequate to estimate point source loads.

Two terms are generally encountered when calculating loads namely "Flux" and "Load". "Flux" is the rate at which a pollutant load passes a given point in a river or stream at a given moment. The integral of flux over time is the load. The flux is equal to the concentration multiplied by the flow at the time of the sample. "Load" is the mass of a chemical substance which passes a given point in a river or stream in a given period of time, a total quantity. The load for an entire period of interest, usually a month or a year is the sum of the daily loads in the period, or the product of the average daily load and the number of days.

SOURCES

Generic catchment assessment outputs	
DWAF pollution and other monitoring data on Water Management System (WMS).	Directorate: Resource Quality Services, DWAF Website: www.dwaf.gov.za
Water quality-focused reports or chapters in previous basin – or system analysis studies.	Director: Water Resources Planning, DWAF Website: www.dwaf.gov.za
Reports on assimilative capacity or waste load allocation studies for particular licence applications.	Director: Water Quality Management, DWAF Website: www.dwaf.gov.za
Reports on environmental management or impact assessment in urban rivers.	Metropolitan councils or local authorities

Eutrophication assessment outputs	
Nutrient data for point source stored on WMS. Old POLMON data that have not yet been imported. WMS can be obtained from the DWAF regional offices.	WMS: Director: Resource Quality Services. POLMON: Deputy-Director: Water Quality Management, any Regional Office of DWAF.
Nutrient and flow data for effluent discharges directly from the effluent producing facility.	An inventory of the licences can be obtained from the Deputy Director: Water Quality Management at the Regional Office of DWAF.
The nutrient components of water quality-focused reports or chapters in previous basin studies or system analysis studies.	Director: Water Resources Planning, DWAF Website: www.dwaf.gov.za
The nutrient components of reports on assimilative capacity or waste load allocation studies for particular licence applications.	Director: Water Quality Management, DWAF Website: www.dwaf.gov.za
CHECKLISTS	
• *Source Types with high nutrient concentrations*: Wastewater and wastewater treatment plants, animal feeding lots, canning and food-processing factories, wineries and breweries, and dairy-related factories. • *Other source types not known for high nutrient concentrations:* pulp and paper mills, textile factories, tanneries, petro-chemical plants, mine de-watering sites, ore processing plants, quarries, etc.	

DWAF uses a source classification system that classifies activities and processes on a first tier assessment of the level of threat to a water resource (DWAF, 2003). The classification system describes the sector, sub-sector and activities, a class, and a threat level. Using the classification system, the following point sources probably affect the nutrient status in the catchment (DWAF, 2003):

Sector	**Class**	**Threat level**	**Sub-sector**	**Activities**
Industry	A	High	Paper, pulp or pulp products industries	Industries that manufacture paper, paper pulp or pulp products
	B	Medium	Breweries or distilleries	Produce alcohol or alcoholic products
			Chemical industries	Agricultural fertilizers
				Explosive or pyrotechnics industries that manufacture explosives.
				Soap or detergent industries (including domestic, institutional or industrial soaps or detergent industries)
			Dredging works	Materials obtained from the bed, banks or foreshores of many waters.
Agriculture	A	High	Intensive livestock operations	Feedlots that are intended to accommodate in a confined area and rear or fatten (wholly or substantially) on prepared or manufactured feed (Piggeries, Poultry, Dairies, Saleyards)
			Livestock processing industries	Slaughter animals (including poultry), Manufacture products derived from the slaughter of animals including tanneries or fellmongeries or rendering or fat extraction plants, scour, top or carb onise greasy wool or fleeces with an intended production capacity.
	B	Medium	Agriculture	Industries that process agricultural produce including dairy, seeds, fruit, vegetables or other plant material.
			Aquaculture or mariculture	Commercial production (breeding, hatching, rearing or cultivation) of marine, estuarine or freshwater organisms, including aquatic plants or animals (such as fin fish, crustaceans, mollusks or other aquatic invertebrates) but not including oysters.
	C	Low	Other farming	All other farming and agricultural activities
Settlements urban	A	High	Wastewater treatment plants	Including the treatment works, pumping stations, wastewater overflow structures and the reticulation system (> 250 kiloliters/day)
	B	Medium	Wastewater treatment plants	Including the treatment works, pumping stations, wastewater overflow structures and the reticulation system (< 250 kiloliters/day)
			Composting	And related reprocessing or treatment facilities (including facilities that mulch or ferment organic waste, or that are involved in the preparation of mushroom growing substrate, or in a combination of any such activities).
Settlements, rural/dense	A	High	All	Wastewater, waste and water supply activities in areas outside designated urban settlements

DISPLAY AND PRESENTATION OPTIONS

Tables summarising point source information

Point source information can be summarised in table format as illustrated below (from DWAF, 1998).

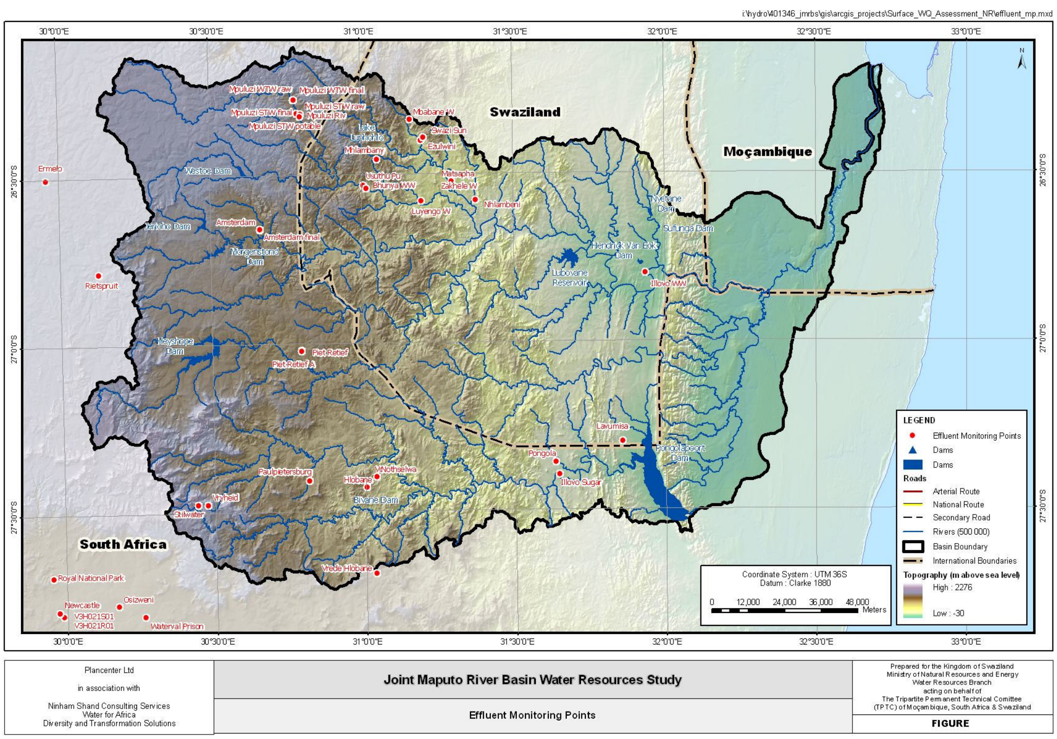
Table 5.8 Mean monthly loads from point sources in the Buffalo & Yellowwoods Catchments (for 1990 - 1996)

Point Source	TDS Load (ton/month)	PO_4 Load (ton/month)	SS Load (ton/month)
KWT STW	32.48	0.125	**0.842**
Zwelitsha STW	85	**0.345**	1.935
King Tanning	21	0.008	0.130
Da Gama Textiles	**104**	0.042	1.073
Bisho STW	22.43	0.124	1.0
Breidbach STW	6.53	0.037	0.448
Ilitha STW	8.25	0.058	0.411

Note: the highest loads are shown as bold values

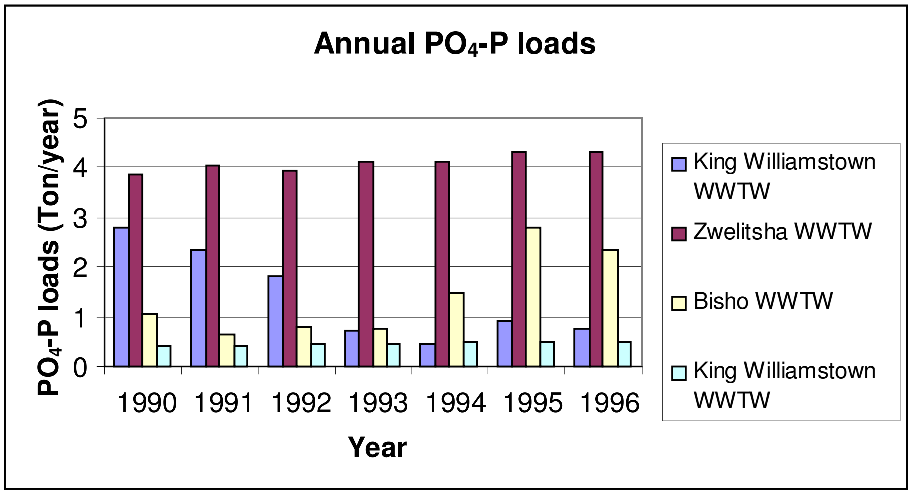
Catchment scale maps showing the location of point sources

Example of a catchment scale map showing the location of wastewater discharges and effluent monitoring points.



Graphs showing point source loads

The bar graph below illustrates the change in annual phosphate loads from four wastewater treatment works in the Buffalo River system (data from DWAF, 1998).



REFERENCES

Department of Water Affairs and Forestry (DWAF) (1998). Amatole Water Resource System Analysis Phase II. Volume 3: *Water quality Modelling. Part 1: Monthly model configuration*. DWAF Report No. PR 000/00/1798.

Department of Water Affairs and Forestry (DWAF) (2003). *Source management in South Africa* [online]. First edition for comment. Department of Water Affairs and Forestry, Pretoria.

Available: http://www.dwaf.gov.za/dir_wqm/docsframe.htm

COMPONENT 8
Non-Point Source Water Quality Loadings and Impacts relating to Eutrophication

PURPOSE

Generic catchment assessment context

Non-point sources (or diffuse sources) represent *land-use types, areas and activities* that result in the mobilisation and discharge of contaminants in any manner other than through a well defined point such as discharge pipe or group of pipes. In South Africa, non-point source pollution of surface waters is largely caused by rainfall and the associated surface runoff or groundwater discharge. Non-point sources are generally diffuse and intermittent, contributing to contamination of water resources over a widespread area, such as storm washoff and drainage from urban or agricultural areas. Alternatively, they may be concentrated, associated with localized high activity areas, such as mines, feedlots, landfills and industrial sites.

Non-point source contributions are generally not monitored directly but are inferred using techniques such as experience-based interpretation, mass balances against measured point source loadings, or simulation modelling. The nature of impacts determines spatial and temporal scale at which non-point sources need to be assessed which in turn determines the range of techniques that can be used for the analysis. Short-term, event-driven problems occurring at a local scale requires analysis at finer spatial and temporal resolutions than what is required for longer term or relatively constant problems with regional scale impacts.

Understanding point and non-point sources helps with the interpretation of water quality characteristics and patterns in a catchment because it yields both detailed and cumulative information on the location and magnitude of primary impactors on ambient water quality. Non-point source assessments can be very complex because they relates to the whole hydrological cycle. This Component can be undertaken at different levels of interest, each with a different suite of assessment tools. At a *scoping* level, it may simply determine whether, in a particular sub-catchment, non-point sources contribute more to water quality concerns than point sources, or which sub-catchment in a basin has the highest non-point loadings. At an *evaluation* level individual non-point source impacts are distinguished at the catchment level. At a *prioritisation* level the key source types, areas and activities are identified which require management attention.

Eutrophication assessment context

Non-point sources of nutrients are generally associated with surface runoff and sediment washoff from fertilised agricultural fields, atmospheric deposition of nitrogen compounds, and washoff from urban residential, commercial and industrial areas. Leaking sewers in poorly serviced dense settlements and poor or non-existent sanitation in informal settlements also represent important sources of diffuse nutrient loadings. Poor runoff control from concentrated sources such as feedlots and waste disposal sites can also contribute significantly to diffuse source nutrient loads.

Purpose

The purpose of this Component, together with the point source information from **Component 7** provides an overall understanding and interpretation of the nutrient dynamics in a catchment or study area by identifying and estimating the magnitude of the primary nutrient sources. The document, *A Guide to Non-point Source Assessment* (Pegram and Görgens, 2001) describes a protocol (scoping, evaluation and prioritisation levels) and a suite of predictive tools that can be applied to assess non-point source loadings and impacts. The configuration and calibration of these water quality predictive tools (see **Component 9**) require land-use and water use information as essential inputs. Not only the current day information, but also historical land-use and water use trends are required for proper calibration of the models over a representatively long time period.

*NB: **Component 9** and **Component 8** should be considered and developed simultaneously, as there is a strong overlap between them and their underlying processes.*

Prerequisite Components

Components 1, 3, 4, 5, 6, 7, and **9** need to be substantially completed and **14**, **15** and **16** reasonably progressed before this Component can be finalised.

<table>
<tr><th>OUTPUTS</th><th>HOW TO ATTAIN OUTPUTS</th></tr>
<tr><td colspan="2">Generic catchment assessment outputs</td></tr>
<tr><td colspan="2">The Catchment Water Quality Assessment Guide describes methods to assess non-point source (NPS) impacts at a coarse scoping level, more detailed evaluation level, and detailed prioritisation level. This approach has also been adopted for eutrophication assessment studies.</td></tr>
<tr><td colspan="2">Eutrophication assessment outputs</td></tr>
<tr><td>Scoping level: Aggregated (e.g. mean annual) nutrient loadings at a relatively coarse scale, such as quaternary catchments, or coarser.

Note: the assessment tools referred to in this section are outlined in Component 9 (Predictive tools)</td><td>Refer to Pegram and Görgens (2001) (Part 3c) for guidelines on assessing the relative contribution from NPS and the importance of NPS in a study area. Assessment tools include:
• knowledge based approaches
• data analysis techniques
• potential and hazard maps
• unit area loading/export coefficients</td></tr>
<tr><td>Evaluation level (depending on the resolution required): Either time series or aggregated nutrient loadings for individual land and water use categories at the scale of quaternary catchments.</td><td>Refer to Pegram and Görgens (2001) (Part 3d) for guidelines on assessing the contributions from NPS, the impacts and important processes. Assessment tools include
• unit area loading/export coefficients
• loading functions and potency factors
• simple process models
• detailed process models</td></tr>
<tr><td>Prioritisation level: Identification of those non-point nutrient sources that have the greatest existing or potential future impacts, the main processes causing the impacts from these priority nutrient sources, and how manageable the priority nutrient sources are.</td><td>Refer to Pegram and Görgens (2001) (Part 3e) for guidelines on how to determine priority nutrient sources and key sources requiring control. The Evaluation task will indicate what resolution is required and which of the following techniques are needed.
• data analysis techniques
• unit area loading/export coefficients
• loading functions and potency factors
• simple process models
• detailed process models</td></tr>
<tr><th colspan="2">METHODS AND TOOLS</th></tr>
<tr><td colspan="2">Calculating nutrient export from non-point sources
Accurate estimates of nutrient loads on receiving water bodies are essential to understand the functioning of the receiving water body and to predict the response of the water body to changes in the nutrient loads. There are two methods for estimating nutrient loads (Grobler, 1985):
• If simultaneous flow and concentrations data are available, direct methods can be used to estimate nutrient loads.
• In the absence of observed flow and concentrations records, indirect methods can be used to estimate loads.
In practice, both direct and indirect methods are employed to assess the impacts of alternative nutrient control strategies.</td></tr>
<tr><td colspan="2">Direct load calculation methods
Direct methods are subdivided into averaging, flow-interval and regression methods.
• Averaging methods refer to those in which loads are calculated as the sum of the products of the total flow and the average nutrient concentration that was obtained from fixed time interval sampling. Grobler et al. (1982) evaluated six different averaging methods for</td></tr>
</table>

calculating chemical loads in South Africa and found large uncertainties were associated with estimating phosphate loads by all the methods tested. They concluded that averaging methods should not be used to calculate phosphate loads in event-response rivers.

- Flow-interval and regression methods make use of concentration: flow or load:flow relationships to calculate nutrient loads. These methods do not require as intensive monitoring as do averaging methods. Grobler (1985) evaluated flow-interval and regression methods in South Africa and found log load:log flow regression models were best for calculating phosphate loads and for estimating annual P loads. Once the regression models was calibrated for a particular river, it could be used to estimate loads for periods when no sampling occurred. The FLUX program developed by Walker (1996) provides a convenient toolbox for determining the relationship between nutrient loads and flow and for estimating time series of nutrient loads (Grobler and Rossouw, 1988).
- Herold and Görgens (1991) also developed a good algorithm for infilling DWAF grab sample data and this method is often used in estimating TDS and nutrient time series in water resource assessment studies.

Indirect load calculation methods

Indirect methods can be used to calculate nutrient loads from catchments where no or very limited observed data are available. Loads are usually estimated as a function of catchment properties such as land-use, land form and runoff and nutrient export coefficients or loading functions for different types of land-use. The general procedure is to divide a catchment up into point and non-point sources. The non-point source contribution is then estimated by dividing the catchment up into different source areas and to estimate the load from each source area using a nutrient export coefficient characteristic of that source area. This is the approach followed in the NEAP model described in **Part 1** of this report.

More complex rainfall:runoff that simulates catchment processes can also be used to estimate nutrient loads. These include models such as SWAT (Neitsch *et al*., 2005) and ACRU-NP (Campbell *et al*., 2001). It is usually not practical to use complex models to predict nutrient loads due to the difficulty of applying them and their intensive data requirements.

SOURCES	
The FLUX program is available from the US Army Corps of Engineers.	Available online: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual
Current and historical land-use and water use information.	**Components 1**, **3, 5, 6** and **7**.
Water quality and flow data.	Refer to **Component 4**.
A description of non-point source assessment methodologies.	Refer to Pegram and Görgens (2001).
A synthesis of non-point source assessment case studies in South Africa.	Refer to Quibell *et al.* (2003).

CHECKLISTS

The non-point *source areas* can be determined by separating a catchment or sub-catchment into areas with relatively homogeneous non-point source characteristics, based on:

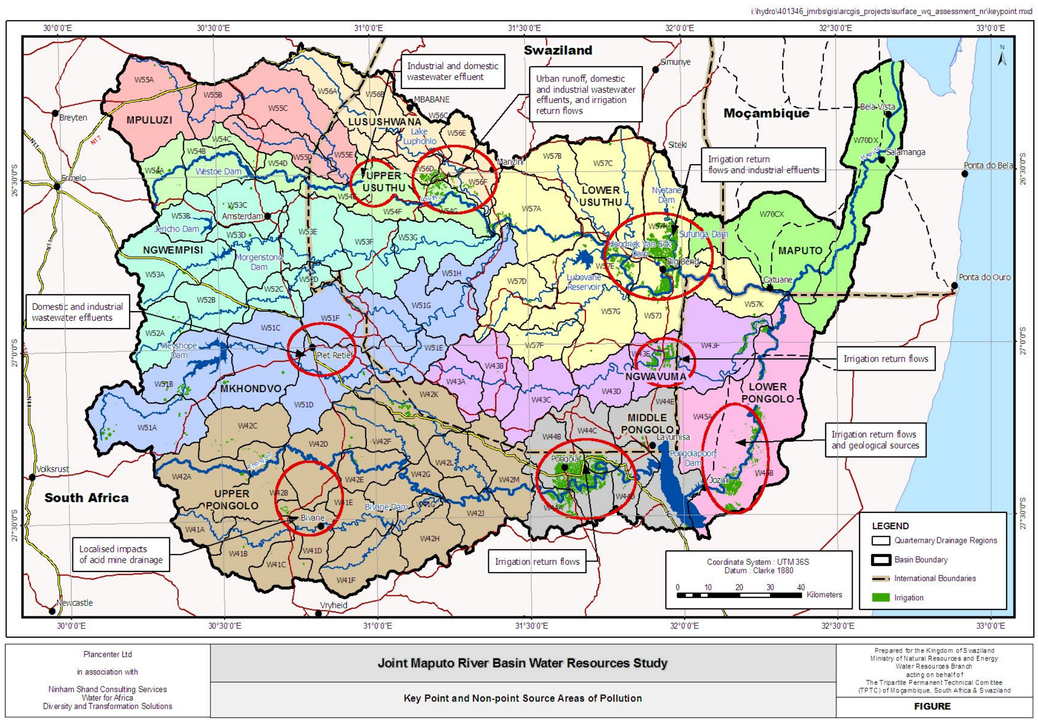
- *Land-use*: natural, different types of agricultural, different types of human settlement, CBD, different types of industrial, etc;
- *Natural features*: soils, topography, geology, natural vegetation, etc; and
- *Climate*: rainfall, temperature, evaporation, seasonality, etc.

Use **checklists** under **Component 1** as a guide.

DISPLAY AND PRESENTATION OPTIONS

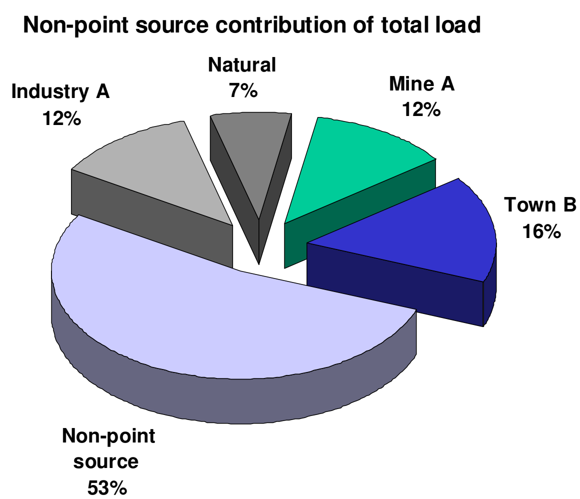
Catchment map showing location of known point and non-point sources

A catchment scale map of the study area can be used to indicate locations of known point and non-point sources. The example below illustrates areas of concern and whether these are related to point sources, non-point sources or a combination of the two.



Non-point source contribution to observed nutrient loads

Nutrient loads can be calculated at a known location in the study area (e.g. water quality monitoring point). If the known point source loads and natural background loads can be accounted for, the remainder can be assumed to originate from non-point sources. This information can then be displayed in a pie diagram as displayed in the example below or on a map of the study area.



REFERENCES

Campbell, K L, Kiker, G A and Clark, D L. (2001). *Development and testing of a nitrogen and phosphorus process model for Southern African water quality issues*. ASAE Annual International Meeting, Sacramento, CA, July 30-August 1, 2001. Available online:

http://www.beeh.unp.ac.za/acru/

Grobler, D C. (1985). *Management-oriented eutrophication models for South Afrcan Reservoirs*. PhD Thesis, University of the Orange Free State, Bloemfontein.

Grobler, D C, Bruwer, C A, Kemp, P J. (1982). *A comparison of chemical load estimation algorithms using data obtained by sampling four South African rivers at varying frequencies*. Water SA, 8(2): 121-129.

Grobler, D C and Rossouw, J N. (1988). *Non-point source derived phosphorus export from sensitive catchments in South Africa*. Confidential Report to the Department of Water Affairs, Pretoria.

Herold, C E and Görgens, A. (1991). *Vaal Dam salinity assessment with particular reference to atmospheric deposition*. Stewart Sviridov & Oliver in co-operation with Ninham Shand Inc. Report No. NC120/13/DEQ0391, Hydrological Research Institute, Department of Water Affairs and Forestry.

Neitsch, S L, Arnold, J G, Kiniry, J R, and Williams, J R. (2005). *Soil and Water Assessment Tool (SWAT): Theoretical documentation (Version 2005).* Grassland, soil and water research laboratory, Agricultural Research Service, Temple, Texas.

Pegram, G and Görgens, A. (2001). *A Guide to Non-point Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa.* WRC Report No. TT 142/01, Water Research Commission, Pretoria.

Quibble, G Pegram, G C, Moolman, J, Matji, M P, Hohls, B and Görgens, A H M. (2003). *Development of a guide to assess non-point source pollution of surface water resources in South Africa.* WRC Report No. 696/2/03. Water Research Commission, Pretoria.

Walker, W W. (1996). *Simplified procedures for eutrophication assessment and prediction: User manual,* Instruction Report W-96-2, U S Army Engineer Waterways Experiment Station, Vicksburg, MS.

COMPONENT 9

Configured and Calibrated Water Quality Predictive Tools/ Models with regard to Eutrophication Related Water Quality

PURPOSE

Generic catchment assessment context

The key to the water quality component of a catchment management strategy is the water quality use allocation strategy. That is the allocation of the available constituent load, defined by management objectives, to different water user groups, sectors and sources in order to meet the management objectives. Management plans relate to point source discharges, non-point source discharges and in-stream management, and include appropriate reservoir release operations, in-stream rehabilitation and environmental needs. A toolbox of predictive models is a key technology for the development of a water quality use allocation strategy and the applications of predictive models can serve to:

- Indicate which of point or non-point source pollution is dominant, or which sub-catchments in a basin are dominant water quality load contributors, etc; in turn, this would help to prioritise certain types of management actions
- Estimate water quality constituent loadings from a range of land-uses and water uses that result in non-point source pollution, and indicate which non-point sources are dominant
- Indicate the likely effects of pollution load increases or decreases on downstream water quality, or receiving waters
- Simulate water quality constituents at key points in river-reservoir systems in response to particular system operating rules
- Simulate water quality variables at points of concern for different future scenarios of land-use and water use
- Support prioritisation and appropriate selection of competing management options
- Extend, infill or simulate time series of water quality variables at points of concern.

Eutrophication assessment context

Eutrophication models relate the consequences of nutrient enrichment (excessive algal growth) to it's causes (elevated nutrient concentrations, improved underwater light climate) and the models range from very simple, empirical models to very complex catchment and water body process models. The NEAP model described in this document is an example of a simple empirical eutrophication model.

In the context of an eutrophication assessment, eutrophication models support the following components:

- The development of catchment nutrient management objectives, i.e. nutrient and algal targets that balance the national needs outlined in the NWRS and in RDM with the needs of stakeholders for disposing of wastewater with elevated nutrient concentrations.
- Development of nutrient management objectives, i.e. nutrient load reductions in stressed catchments, maintenance of nutrient loads in threatened catchments, or increases in nutrient loads in unstressed catchments.
- Development of the water quality use allocation strategy, i.e. allocating nutrient loads to different sectors or groups.
- Development of the individual sectoral or source-based nutrient management plans that form the heart of the allocation strategy.
- Development of suitable interventions where a single nutrient source (rather than a whole catchment) has been identified as the cause of eutrophication problems.

Application of some of the predictive tools listed in this Component requires a reasonable degree of technical and scientific understanding of the models, application procedures, dependence on other supporting tools or software, limitations and data preparation requirements. This Guide is not designed to educate users in modelling protocols and users are encouraged to consult the original source material listed in the "**Sources**" section below.

Purpose

The outputs that are specified in this section are predictive methods or tools, which have been applied to the particular catchment and constituents of concern.

*NB: It is recommended that **Component 9** and **Component 8** be considered and developed simultaneously because there is a strong overlap between them and their underlying processes.*

Prerequisite Components

Components 1, **2**, **3**, **5**, **6** and **7** should be completed, or at least, well advanced, before substantial progress becomes possible with this Component.

<table>
<tr><th>OUTPUTS</th><th>HOW TO ATTAIN OUTPUTS</th></tr>
<tr><td colspan="2">Generic catchment water quality assessment outputs</td></tr>
<tr><td colspan="2">The Catchment Water Quality Assessment Guide lists models or predictive tools for non-point sources, simple water quality process models, detailed process models, systems analysis models, and hydrodynamic models for rivers and reservoirs. Only models or methods that have been applied operationally in South Africa have been listed. Systems analysis models, commonly used to generate flow and demand sequences, often provide these flow sequences to water quality models as inputs. These are hydrological tools and are not discussed in this document.</td></tr>
<tr><td colspan="2">Eutrophication assessment outputs</td></tr>
<tr><td colspan="2">Not all the outputs listed here are applicable to a specific catchment or study area. The user needs to select the appropriate model or suite of models for the assessment based on the level of stress of the catchment (unstressed, threatened, or stressed) in terms of eutrophication problems and the availability of data to calibrate the model(s).</td></tr>
<tr><td colspan="2">Export coefficients and loading functions</td></tr>
<tr><td colspan="2">Export coefficients (also referred to as unit area loads), are empirical estimates of the mass of pollutant exported (usually annually) per unit area per unit time for a particular land-use. Export coefficients are reported as mass of pollutant per unit area per year (annum), with units of kg/ha/yr or kg/ha/a. Loading functions on the other hand, calculate constituent loads by multiplying the estimated runoff by their empirically determined parameters that describe the relationship between the constituent (e.g. nutrient concentration) and flow.</td></tr>
<tr><td>Parameterised non-point source Scoping tools:
• knowledge based approaches
• data analysis techniques
• potential and hazard maps
• unit area loading/export coefficients</td><td>Follow the Non-Point Source Assessment Guide (Pegram and Görgens, 2000) (see “Sources” section below).</td></tr>
<tr><td>Calibrated and verified non-point source Evaluation and Prioritisation tools that produce aggregate loads (e.g. mean annual):
• unit area loading/export coefficients
• loading functions and potency factors</td><td>Follow the Non-Point Source Assessment Guide (Pegram and Görgens, 2000) (see “Sources” section below).</td></tr>
<tr><td colspan="2">Simple empirical and semi-empirical reservoir models</td></tr>
<tr><td>Simple, empirical nutrient budget models relate the in-reservoir nutrient concentrations to nutrient loads. These models are based on the principle of conservation of mass and are used to simulate the change in nutrient concentraton stored in a water body at any time.</td><td>Identify an appropriate nutrient budget model and calibrate it against observed in-reservoir nutrient concentrations.</td></tr>
</table>

<table>
<tr><td>Empirical and semi-empirical models are simple equations that generally relate algal concentrations to in-lake nutrient concentrations. These are based on theoretical considerations and observed/ experimental data.</td><td>Identify an appropriate Chlorophyll-a – Nutrient model and calibrate/verify it against observed in-reservoir chlorophyll and nutrient data.</td></tr>
<tr><td colspan="2">Simple catchment process models</td></tr>
<tr><td>Simple, mass balance catchment models link different empirical models that simulate different catchment processes. These include (1) the washoff of nutrients from different catchment sources using export coefficients and/or loading functions, (2) routing the loads through the river network and estimating in-river losses, (3) estimating the in-reservoir nutrient concentrations using nutrient mass balance models, and (4) relating the in-reservoir nutrient concentrations to chlorophyll-a concentrations. These models run at different time scales.</td><td>Calibrate and verify the appropriate catchment water quality simulation tools so that load and concentration time series can be produced at all points of management interest.</td></tr>
<tr><td colspan="2">Monthly: IMPAQ. This is a medium-to-fine-scaled model for salinity, sediment and phosphate production and transport in large multi-use catchments, specially designed to be driven by the same natural flows that drive the water resources yield model (WRYM) and the water resources planning model (WRPM) system analysis models. It has a washoff routine that uses SCS Curve Numbers to allow any mix of land-uses to affect sediment and phosphate production, which are derived from a combination of loading functions, potency factors and the USLE approach. Non-conservative processes are allowed to play a role in a channel transport module and a simple mixed reactor reservoir module. IMPAQ is used in conjunction with WRYM to generate very long sequences of monthly loads/concentrations of selected constituents in large river systems.</td></tr>
<tr><td colspan="2">Daily: ACRU-NP. This is a fine-scaled model for sediment and phosphate production from individual small catchments with a limited range of agricultural land-uses. It is driven by daily rainfall and uses soil-moisture budgeting according to a discretisation based on soil texture classes and agricultural practices. It is recommended to investigate localised impacts of land-use and their related management options.

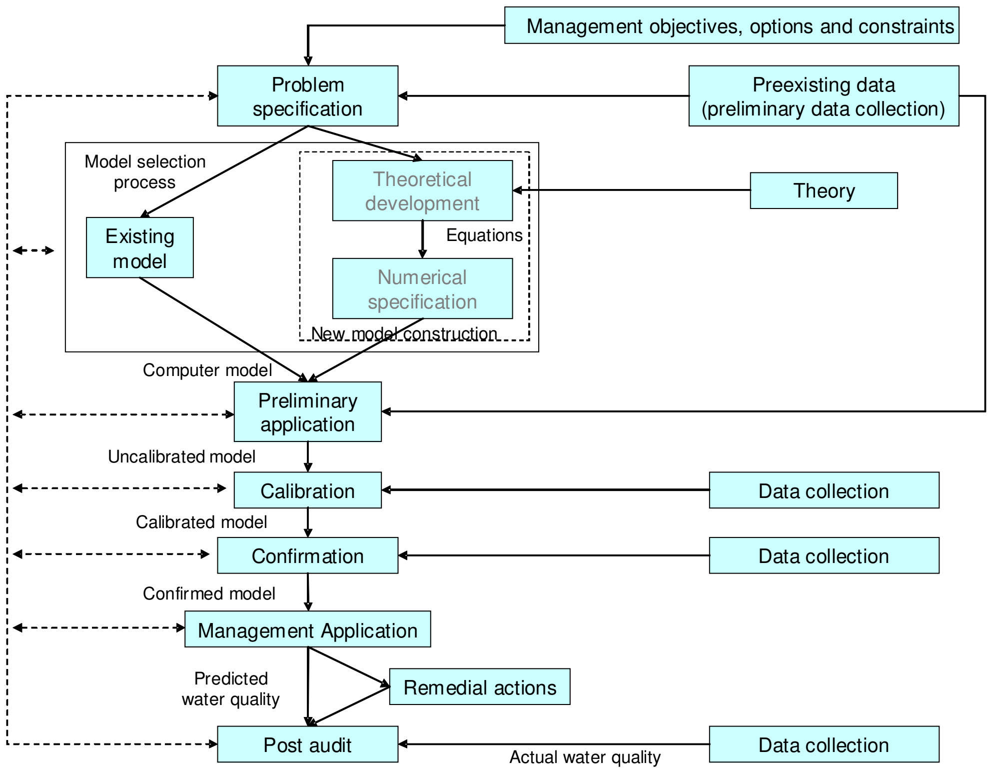
Sub-hourly to daily: HSPF. This is a medium-to-coarse-scaled model for production and transport of salinity, temperature, sediment and a range of non-conservative constituents in medium-to-large multi-use catchments. Its water quality chemical simulation components are comprehensive and it uses relatively black-box rainfall-runoff functions, different forms of hydrological channel routing and treats reservoirs as simple mixed reactors. It may be used to assess water quality outcomes of management and operational options in medium-to-large catchments.</td></tr>
<tr><td colspan="2">Detailed Process Models</td></tr>
<tr><td>Detailed process models incorporate sophisticated processes, such as adsorption-desorption, decay and plant uptake, into the simulation of contaminant movement and transformation in soil and water. These contaminant processes are integrated with relatively complex hydrological and sediment models.

NB: These models require specialised support and are not recommended for general use in catchment assessments. Their main function would be to optimise management options for site-specific water quality issues.</td><td>These models tend to be very data intensive and limited to areas where there has been intensive data collection. The uncertainty of a-priori parameter estimates can lead to highly inaccurate output estimates in unmonitored catchments where calibration and verification are not possible. However, the model parameters often have physical interpretations and can be linked to observed catchment characteristics. The requirements of these models are not usually warranted in urban situations, so detailed process models are generally oriented towards rural, waste-related and agricultural land-uses.</td></tr>
</table>

Daily Reservoir Hydrodynamics and Water Quality Models	
The following daily reservoir hydrodynamic and water quality models have seen operational use in South Africa: **CE-QUAL-W2** – a 2-D finite difference model that incorporates all primary hydrodynamic processes as well as a range of conservative and non-conservative water quality processes. **DYRESM** – a 1-D finite difference model using LaGrangian principles to simulate all energy and kinetic exchanges as well as salinity processes.	The models are configured according to the reservoir's specific depth-area-volume, spillway, and off-take characteristics. Daily inflow and relevant water quality values need to be provided, as well as a range of meteorological variables. The hydrodynamics of these models require no calibration and are completely deterministic. The water quality process parameters of CE-QUAL do require calibration. If the primary interest of the simulation is stratification, then DYRESM is the more complete model in an energy balance sense. It should be noted that CE-QUAL does not perform its own mass balance, and needs outflows and spills as input.
Sub-daily River Hydrodynamics Models	
Three 1-D river hydrodynamics models have seen operational use in South Africa: MIKE11, ISIS and DUFLOW. All three models are based on a finite difference application of the full St Venant's flow equations to a series of cross-sections of the river channel and flood-plain. A range of conservative and non-conservative water quality routines are incorporated into all three models.	The basic requirements for applying these models are regular cross-sections of the river channel and its flood-plains, boundary conditions in the form of upstream and tributary inflow series (including water quality), and certain meteorological time series. Friction loss factors and water quality parameters are derived by calibration. This means that reasonable flow and water quality records of in-channel conditions are required. These models are useful to assess short-term downstream water quality impacts of upstream operations, or to examine management options relating to localised water quality issues.

METHODS AND TOOLS

The water quality modelling process is illustrated below (from Chapra, 1997) showing the modelling process along with the necessary information that is required for its effective implementation.



Good modelling practices should be followed to identify suitable models, configuring and applying them, calibrating the models, confirming the models, and then applying the confirmed models to predict the potential outcome of different eutrophication management interventions. Good modelling practices are described in Chapra (1997, 2003) and Pascual *et al*. (2003).

SOURCES	
Non-point Source Scoping and Evaluation Tools	*A Guide to Non-point Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa*. WRC Report by G Pegram and A Görgens, 2000. Water Research Commission, Pretoria.
Empirical models (examples)	
REMDSS	Rossouw, J N. (1990). *The development of management orientated models for eutrophication control*. WRC Report No. 174/1/90. Water Research Commission, Pretoria.
NEAP	• **Part 1** of this document. • Harding, W R. (2007). *The determination of annual phosphorus loading limits and land-use-based phosphorus loads for 30 key South African dams in relation to their present and likely future trophic status*. WRC Report. Water Research Commission.

Empirical equations	A large number of empirical equations exist in the literature that relate nutrient loadings to algal concentrations. Examples include: • Walmsley, R D and Butty, M. (1980). *Guidelines for the control of eutrophication in South Africa.* Collaborative report by Water Research Commission and National Institute of Water Research, CSIR, Pretoria. • Walker, W W. (1996). *Simplified procedures for eutrophication assessment and prediction: User manual,* Instruction Report W-96-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS. • Cooke, G D, Welch, E B, Peterson, S A and Nichols, S A. (2005). *Restoration and management of lakes and reservoirs*. Third edition. Taylor & Francis, Boca Raton.
Simple Catchment Process Models (examples)	
IMPAQ	Bath A, Reid C and Görgens A (1997). Amatola Water Resource System Analysis: *Water Quality Modelling*. DWAF Report No. PR 000/00/1798
ACRU-NP (Water Quality)	ACRU - Schulze, R E (1995). Hydrology and Agrohydrology: A text to accompany ACRU 3.00 agrohydrological modelling system, WRC Report No. TT69/95 ACRU2000 – Kiker, G A and Clark, D J. (2001). *The development of a Java-based, Object-oriented Modelling System for Simulation of Southern African Hydrology*. ASAE Paper No. 012030, St. Joseph, MI.
Reservoir Hydrodynamics Models (examples)	
DYRESM and CE-QUAL-W2	Görgens A, Bath, A. Venter, A, De Smidt, K and Marais, G. (1994). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa.* WRC Report No. 304/1/93. Bath A, De Smidt, K, Görgens, A and Larsen, E J. (1997). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa: Application of DYRESM and CE-QUAL-W2* . WRC Report No. 304/2/97.
River Models (examples)	
QUAL2K	Chapra, S, Pelletier. G and Tao, H. (2006). *QUAL2K: A modelling framework for simulating river and stream water quality (Version 2.04). Documentation and Users Manual.* Civil and Environmental Engineering Department, Tufts University, Medford, MA.
MIKE11	DHI (1992) *Mike11 Version 3.01. A micro-computer based modelling system for rivers and channels, Reference Manual*, Danish Hydraulic Institute Software.
ISIS	HR (1997) *ISIS Flow, User Manual.* Halcrow/HR Wallingford, UK.
DUFLOW	STOWA/EDS (1998). *DUFLOW for Windows, Version 3.0.* EDS, Leidschendam, The Netherlands.

REFERENCES

Bath, A, De Smidt, K, Görgens, A and Larsen, E J (1997). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa*: *Application of DYRESM and CE-QUAL-W2* . WRC Report No. 304/2/97.

Bath A, Reid, C and Görgens, A (1997). *Amatola Water Resource System Analysis: Water Quality Modelling.* DWAF Report No. PR 000/00/1798.

Bricknell, B R, Imhoff, J C, Kittle, J L, Donigan, A S and Johanson, R C (1993). *Hydrological Simulation Program-Fortran: Users Manual, Release 10*, EPA Report 600/R-93/174, Athens.

Chapra, S C (1997). *Surface water-quality modelling*. McGraw-Hill Companies, Inc., New York.

Chapra, S C (2003). *Engineering water quality models and TMDLs*. Journal of Water Resources Planning and Management, 129(4): 247-256.

DHI (1992) Mike11 Version 3.01. A micro-computer based modelling system for rivers and channels, Reference Manual, Danish Hydraulic Institute Software.

DWAF (1994). Vaal River System Analysis: Analysis procedures manual Addendum A. DWAF Report No PC000/00/6986 by BKS Inc, Pretoria.

Görgens, A, Bath, A, Venter, A, De Smidt, K and Marais, G (1994). *The applicability of hydrodynamic reservoir models for water quality management in stratified water bodies in South Africa*. WRC Report No. 304/1/93.

HR (1997) ISIS Flow, User Manual. Halcrow/HR Wallingford, UK.

Kiker, G A and Clark, D J (2001). *The development of a Java-based, Object-oriented Modelling System for Simulation of Southern African Hydrology*. ASAE Paper No. 012030, St. Joseph, MI.

Pegram, G and Görgens, A (2001). *A Guide to Non-point Source Assessment to Support Water Quality Management of Surface Water Resources in South Africa*. WRC Report No. TT 142/01, Water Research Commission, Pretoria.

Pascaul, P, Stiber, N and Sunderland, E (2003). *Draft guidance on the development, evaluation, and application of regulatory environmental models*. Prepared by The Council for Regulatory Environmental Modeling.

Rossouw, J N (1990). *The development of management orientated models for eutrophication control*. WRC Report No. 174/1/90. Water Research Commission, Pretoria.

Schulze, R E (1995). Hydrology and Agrohydrology: A text to accompany ACRU 3.00 agrohydrological modelling system, WRC Report No. TT69/95.

STOWA/EDS (1998). DUFLOW for Windows, Version 3.0. EDS, Leidschendam, The Netherlands.

Walker, W W (1996). *Simplified procedures for eutrophication assessment and prediction: User manual,* Instruction Report W-96-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

COMPONENT 10
Reconciliation: Catchment Sources and Eutrophication Related Water Quality Patterns

PURPOSE

Generic catchment assessment context

The patterns of water quality changes through space (say, along a river) are related to (a) the spatial variability of the natural background soil and geological materials and rainfall, and (b) the spatial location of point and non-point anthropogenic sources. Similarly, sustained temporal trends in water quality, over and above the usual "noise" caused by hydrometeorological variability, indicate that such anthropogenic sources have "kicked in" and/or are growing in impact. **Component 6** (water quality data review) provides the basic information on patterns and trends.

Eutrophication assessment context

Spatial and temporal patterns in nutrients are complicated due to the non-conservative behaviour of nutrients in rivers, reservoirs and wetlands. Nutrients exhibit losses due to uptake by plants in these water bodies and/or adsorption onto suspended sediment particles and co-settling with these particles. They can also exhibit gains due to resuspension of bottom sediment or disassociation from sediments due to anaerobic conditions. Many of these processes are light and temperature dependent and the rate of change therefore exhibits seasonal differences.

Purpose

The purpose of this Output is diagnostic: it provides a knowledge-based interpretation and reconciliation of all spheres of information - land-use, water samples, model findings - relating to known sources or sinks that contribute to our understanding of nutrient loads. This interpretation represents a final "sweep" through the catchment to spot hitherto unsuspected sources or sinks of nutrients. An easy example is as follows: if **Component 6** shows that phosphorus concentrations at low flows jumps between Point X and Point Y (10 km apart) along a river, and no major tributary enters that reach, then a clandestine effluent discharge or previously unsuspected irrigation return flow might need to be investigated, which would require management attention. A more complex example is: checking the presence of observed nutrients against expected background nutrient concentrations, or the expected impacts of known land-uses, and finding them discrepant.

Prerequisite Components

This Component can only be substantially completed if **Components 1** and **6** have already been completed and **Components 7** and **8** are quite advanced.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Catchment Water Quality Assessment Guide* describes three outputs that document discrepancies in spatial water quality patterns and in temporal water quality patterns, and unexpectedly high concentrations.	Refer to the *Catchment Water Quality Assessment Guide* for a description of how to examine the data and information for spatial and temporal discrepancies, and unexpectedly high concentrations.

Eutrophication assessment outputs	
Diagnostic table of discrepancies in spatial patterns in terms of nutrient concentrations.	Discrepant *point* discharges can be detected from (a) same-day sampling of low flows at sequential locations, (b) consistent differences between low flow concentrations at sequential locations from routine grab sampling over longer periods, (c) extraordinary model parameter values/settings required in order to achieve reasonable simulations, (d) systematic deviations of calibrated model outputs from observed values. Discrepant *non-point* contributions are more difficult to ascertain, as they are driven by rainfall-runoff events, which are highly variable and seasonal by nature. A powerful clue can be found in consistent under-estimation of spatially sequential concentrations or loads during simulation modelling of rainfall-runoff events in that catchment.
Diagnostic table of discrepancies in temporal trends in terms of particular constituent concentrations.	Abrupt steps or sustained trends in observed constituent values not explained by known trends in land- or water uses, provide a first clue. Trends in *moving averages* over a number of months or years smooth out the variability caused by climate and seasonality and buoy the underlying tendency. A powerful clue is offered when simulation modelling reveals a *systematically changing deviation* between observed and simulated concentrations or loads on a moving average basis. Trends in the *lowest few concentrations* per *wet* season would indicate non-point source change trends, while trends in the *highest few concentrations* per *dry* season would indicate point source change trends.
Diagnostic table of water quality constituents with unexpectedly high concentrations.	Interpret, on the basis of experience, values in grab-sample records in terms of the effluent constituents that might usually be associated with the known land- or water uses.

METHODS AND TOOLS

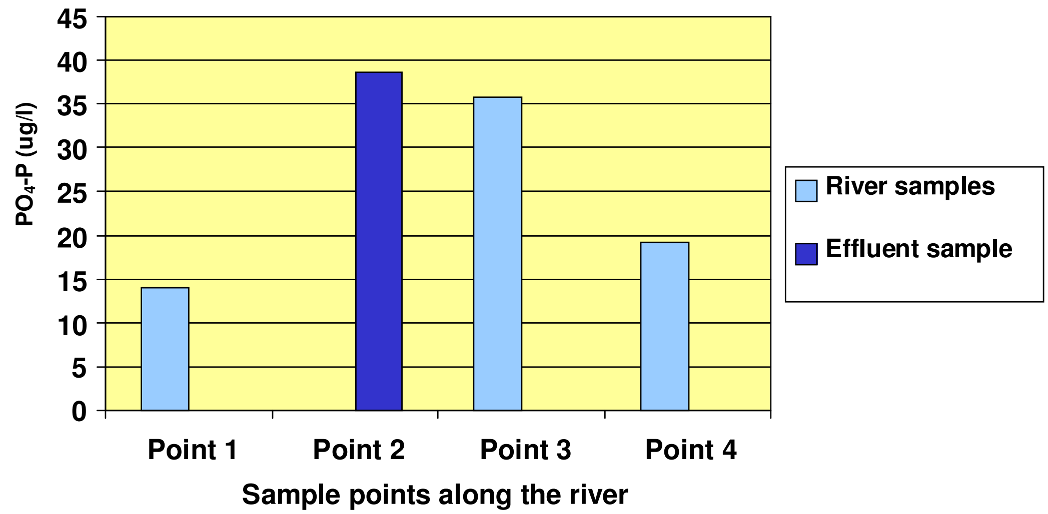
Diagnose against temporal trends or steps in nutrient concentrations (sometimes, loads) as follows:

- Dry season flow – flow-weighted mean per season, as well as moving average
- Monthly flow-weighted means and their moving averages
- Trends in lowest few wet-season values/season
- Trends in highest few dry-season values/season
- Trends against modelled values.

Diagnose against spatial steps or spatial trends in nutrient concentrations (sometimes, loads) as follows:

- Same-day nutrient concentrations at different locations along the river
- Consistent deviations between sequential spatial values over time with simulated values
- Spatial trends in lowest few wet-season values/season
- Spatial trends in highest few dry-season values/season
- Spatial trends against modelled values.

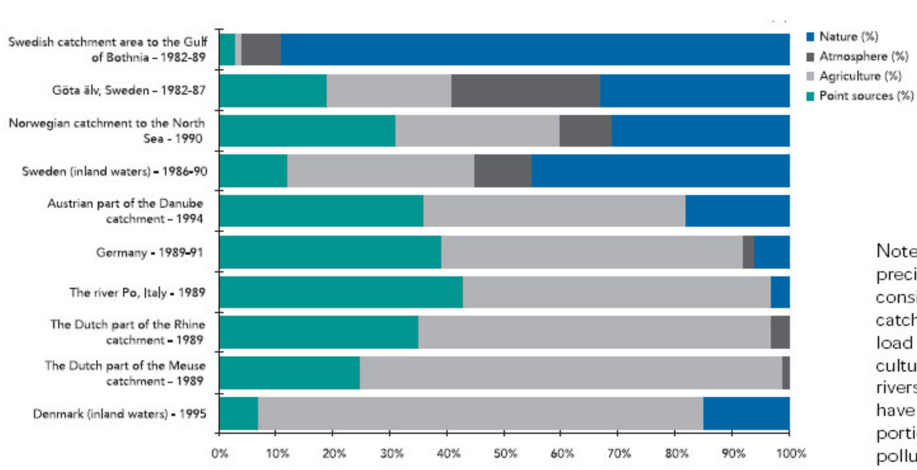
SOURCES
Information for these outputs is sourced from the prerequisite Components mentioned in the "**Purpose**" section above.
CHECKLISTS
None
DISPLAY AND PRESENTATION OPTIONS
An example of how same day monitoring of a point source and river samples can explain temporal trends.



The example below shows the apportionment of nitrogen loads to different sources. These can be compared to know data from those sources to determine if the know loads match apportionment.

Source apportionment of nitrogen load. Source: compiled by ETC/IW from state of the environment reports: Windolf, 1996; Swedish EPA, 1994; Umweltbundesamt, 1994; BMLF, 1996; Ibrekk *et al.*, 1991; Italian Ministry of the Environment, 1992; RIVM, 1992; Löfgren and Olsson, 1990

Figure 3.14



Notes: Atmospheric precipitation only considered for some catchments. Natural load included in agriculture for the Dutch rivers. The lower bars have the highest proportion of agricultural pollution

COMPONENT 11
Status Report on Eutrophication Monitoring, Physical Data and Characterization Information

PURPOSE

Generic catchment assessment context

A Catchment Management Agency may have to rely on a number of water quality data sources to assess the water quality status in the study area. The purpose of this component is to provide guidance on methods to assess the suitability of the data for a catchment water quality assessment.

Eutrophication assessment context

In an eutrophication assessment study, data may be sourced from a number of sources. The assessment team needs to assess whether:

- The spatial and temporal distribution of nutrient and other data is adequate to describe the eutrophication dynamics of the study area,
- The appropriate nutrients fractions have been measured using appropriate detection limits, and
- Data from different sources are compatible.

Purpose

The purpose of assessing the status of monitoring systems in the study area is to address the problems associated with the location of sampling points, sampling frequency, variables monitored, detection limits, and data compatibility. This component includes a checklist that alerts the user to some of the common problems and shortcomings of water quality monitoring programmes.

Prerequisite Components

To undertake this component, information from the following Components are required:

Component 6 (Water quality of streamflow, reservoirs, estuaries, wetlands and groundwater), **Component 7** (Point source waste discharges), and **Component 9** (Non-point source water quality contributions and impacts).

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
GIS map showing the location of monitoring points in the study area	Compile a GIS map of the study area and plot the location of all the water quality monitoring points.
Monitoring system evaluation report for each of the key data sources used in the assessment.	Use the checklist and evaluation information described below to compile the monitoring system evaluation reports.
Monitoring data assessment report	Summarise the key findings of this component into a short data assessment report.
Eutrophication assessment outputs	
GIS map showing monitoring points	Use different symbols or colours to differentiate between different monitoring programmes (or organisations). Indicate which sampling points were used in the study to characterise the present eutrophication status.
Monitoring system assessment report for each of the data sources used in the assessment.	Use the checklist and evaluation guidelines described below to compile the monitoring programme assessment report. Give specific attention to the laboratory detection limits for nutrient concentrations used by different

	programmes as well as the way in which the concentrations are reported (for example reporting nitrate concentrations (NO_3) (uncommon) or as nitrate-nitrogen (NO_3-N) (common).
Monitoring assessment report	Conclude this component with an overall evaluation of the suitability of the monitoring programmes and motivate why some monitoring points or data sets were not used in the assessment. Identify any additional short-term monitoring that might be required to fill data gaps for the eutrophication assessment.

METHODS AND TOOLS

Examples of techniques to evaluate the suitability of monitoring data for a water quality assessment, are described in the following publications:

- Ward, R C, Loftis, J C and McBride, G B (1990). *Design of Networks for Monitoring Water Quality.* Van Nostrand Reinhold, New York, NY, USA 231pp.
- Harris, J M, Van Veelen, M and Gilfillan, T C (1992). *Conceptual Design Report for a National River Water Quality Assessment Programme*. Water Research Commission. Report No. 204/1/92. Available from the Water Research Commission. Website: www.wrc.org.za

SOURCES

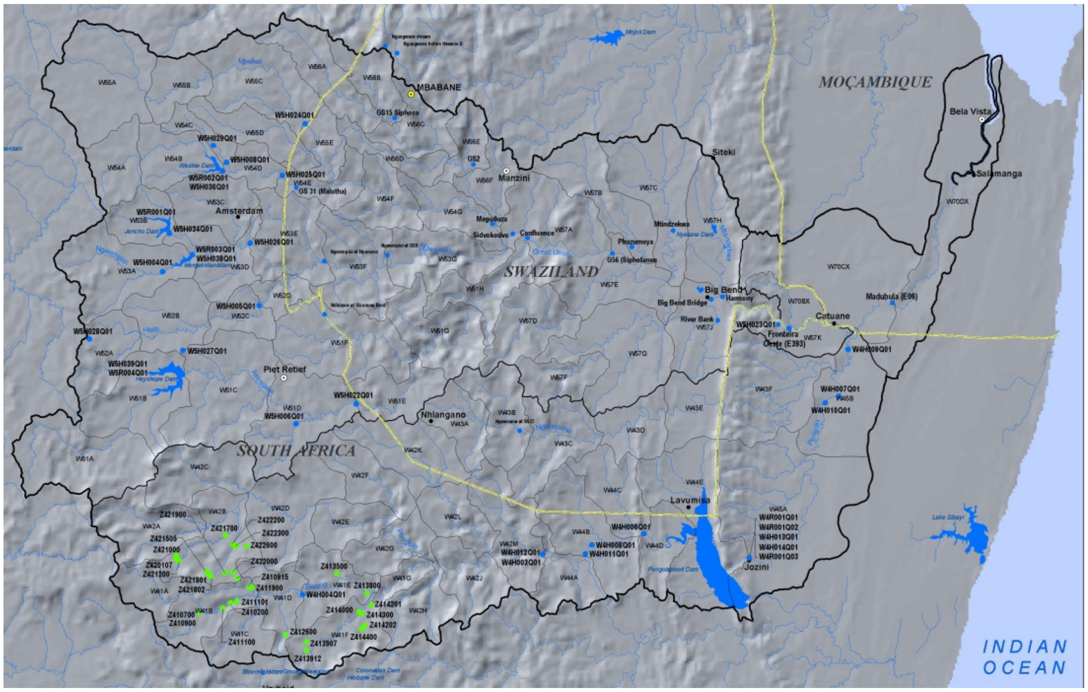
Contact the organisations responsible for operating the monitoring programmes for information on the design and operation of the monitoring programme.	Typical monitoring design and operation information includes : • Georeferenced location of monitoring points (e.g. name, description, geographic coordinates, etc) • Sampling frequency (daily, weekly, monthly, ad hoc) • Sampling procedures (e.g. grab or integrated samples, sample preservation, transport procedures, sampling bottle preparation) • Quality control/quality assurance procedures in the field and analysing laboratory • Nutrient analysis detection limits • Data storage and manipulation procedures

CHECKLISTS	
Limitations to monitoring data can generally be divided into two groups, namely limitations to the design of the monitoring system, and limitations to the data records. *The Catchment Water Quality Assessment Guide* (DWAF, 2003b) describes the limitations in the design of monitoring systems under the following headings: • Monitoring system design documentation, • Spatial distribution of sampling points, • Sampling frequency, • Sampling depth, • Sample preservation, • Quality assurance/quality control, • Analysing laboratory, • Data storage, • Data conversions, • Data availability and security, and • Flow measurements. Some of the limitations associated with monitoring eutrophication related water quality are discussed below.	
Limitations in the design of the monitoring system	
Spatial distribution of sampling points Ideally, monitoring points should be distributed over the catchment to provide a balanced view of water quality changes. However, nutrients are non-conservative substances and the location of a monitoring point in relation to a point or non-point source can be quite important. If the monitoring point is located close to a source in can potentially lead to an over-estimation of the impacts, or alternatively, an under-estimation if located far downstream from a point source.	Plot the monitoring points on a GIS map and examine the distribution of monitoring points in relation to major features which impact on the nutrient concentration such as major point and non-point sources.
Sampling depth The depth of sample collection in stratified reservoirs is important because vertical differences in nutrient concentrations occur. Water samples are generally collected as grab samples from just below the water surface. However, in deep water bodies samples can be collected at specific depths or a depth-integrated sample can be collected using a hosepipe.	Examine the data record for an indication of sampling depth, or contact the data supplier for information on the sampling depth.
Sample preservation Water quality samples for nutrient analysis should be preserved with a preservative like mercury chloride (HgCl) to prevent biological growth in the sampling bottle from modifying the nutrient fractions in the samples.	Examine the data records for an indication whether individual samples were preserved or not, or contact the data suppliers for information on sample preservation.
Analysing laboratory Nutrient concentrations, especially phosphorus, often occur in ppb (µg/l) concentrations in natural waters. Some laboratories, for example municipal laboratories, use nutrient analysis methods that detect in the ppt (mg/l) range of concentrations because they mostly analyse samples from wastewater treatment works.	Contact the analysing laboratory to find out what the detection limits are for their nutrient analysis methods.

They then report phosphorus concentrations in rivers in streams as less than 1 mg/l or less than 0.25 mg/l, depending on their detection limit.	
Limitations to data records	
The Catchment Water Quality Assessment Guide (DWAF, 2003b) describes the limitations to data records under the following headings: • Outliers • Non-detects • Laboratory duplicates, and • Missing data. Some of the limitations associated with eutrophication related water quality data records are discussed below.	
Outliers Nutrient data records often have a few very high observations. Outlying values can occur due to analysis errors or when conditions in the water body changes in a dramatic way.	Outlying values should be removed from the data set. Diagnosing a value as an outlying value can be complex. The publication of Harris *et al* (1992) provides a comprehensive method for identifying outlying values.
Non-detects Non-detects refers to cases where values are less than (or exceed) the detection limit of the analytical technique used in the laboratory. These are then recorded as less than the detection limit.	For data analysis, it is standard convention to change values reported as less than the detection limit, to half the detection limit. However, this practice can pose a problem in cases where the detection limit is high, say 1 mg/l for PO_4-P. Replacing the observation with 0.5 mg/l may lead to the wrong conclusion of the trophic status of a water body.
Derived data Some data is derived from other observations. For example, particulate P is sometimes calculated by subtracting the PO_4-P from the TP concentrations. In the water quality database, derived data should be clearly distinguished from the raw data.	Contact the data supplier to determine whether there are nutrient fraction data that are calculated from other observations and how these are calculated.

DISPLAY AND PRESENTATION OPTIONS

Example of mapping the location of sampling points



Monitoring Programme Evaluation

A monitoring evaluation sheet should have the following information on each monitoring programme in the study area:

- The name of the monitoring programme
- Contact details of the owner of the monitoring programme
- Contact details of the analysing laboratory
- Information about the purpose of the programme and quality assurance procedures
- Location of sampling points and length of data records at each sampling point
- A qualitative assessment of the suitability of the data for assessing the water quality status

Example of a monitoring programme evaluation sheet.

Monitoring Programme Evaluation Sheet (Example)

Name of monitoring programme								
	Data source				Analyzing laboratory			Date
Organization				Organization				
Contact person				Contact person				
Postal address				Postal address				
Tel #				Tel #				
Fax #				Fax#				
Email				Email				
Web site				Web site				
Brief description of the objectives of the monitoring programme								
Documentation for the monitoring system			Yes/No/Unknown		Comments			
Quality assurance / Quality control procedures			Yes/No/Unknown		Comments			
Data security			Public domain / Restricted / No access / Unknown		Comments			
For each sampling point in the study area, list the following								
Station number	Description		Longitude	Latitude	Total number of samples	Date of first sample	Date of latest sample	Sampling frequency
For each sampling point used in the analysis, list the following								
Station number	Assessment Good/Moderate/Poor		Comments					

COMPONENT 12
Stakeholder Details and Participation Processes

PURPOSE

Generic catchment assessment context

The National Water Act requires that a CMS must "…enable the public to participate in managing the water resources within its water management area" [*s9(g)*] and "…take into account the needs and expectations of existing and potential water users" [*s9(h)*]. In a generic catchment water quality assessment, the purpose of this component is to identify the "water quality stakeholders" and to engage them in the catchment management strategy process. These are *any people* or institutions interested in water quality, or affected by water quality and the way it might be managed. One of the best ways of understanding water quality issues in catchments is by engaging the people and the institutions who perceive them, or who are affected by them.

Eutrophication assessment context

In the context of an eutrophication assessment it is important to engage with stakeholders that are involved in the sources of nutrient enrichment (e.g. an effluent discharger) or those affected by the negative effects of eutrophication (e.g. domestic or recreational water users).

Purpose

This component will ensure that the primary groupings of people and institutions that have an interest in eutrophication in the study area are recognised and given the opportunity to make inputs into the assessment. The output from this Component is not only *stakeholder information*, but should also be viewed as a *process*; i.e. the first stage of a stakeholder engagement and participation process.

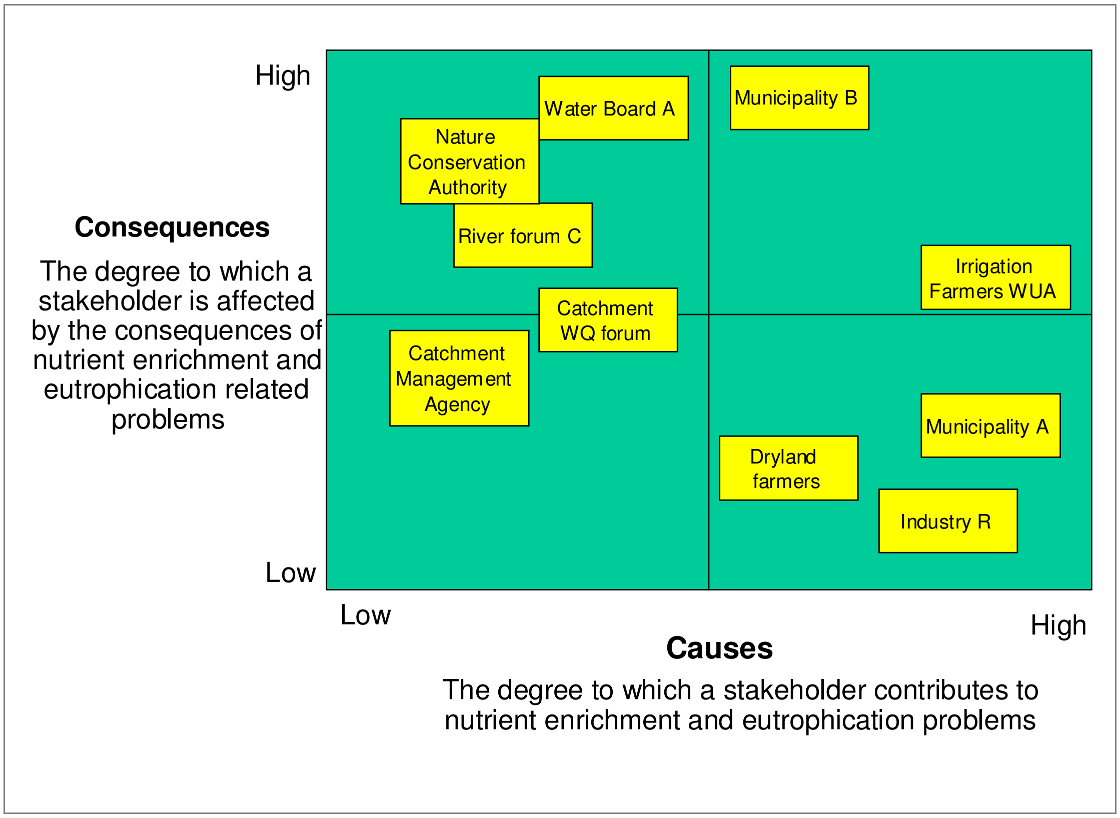
Prerequisite Components

This component starts simultaneously with **Component 0** (inherent knowledge), as well as **Component 5**, but requires crucial information from **Components 1, 5, 6** and **7** before it can be regarded as reasonably advanced.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
Stakeholder database, organised by sector and/or sub-catchment and cross-referenced for individuals' technical or scientific specialities.	Compile a stakeholder database using the stakeholder groupings listed in the checklist. This is generally an iterative process.
First stage of catchment management–related stakeholder participation processes.	For the catchment description phase, the minimum required output from the process is the identification of water quality issues and concerns. The formulation of a vision and management objectives for the catchment belongs to the management support phase of the catchment assessment study.
Eutrophication assessment outputs	
Same as the generic catchment assessment outputs.	Compile a stakeholder database using the checklist below to identify those stakeholders associated with the causes of eutrophication or affected by the symptoms of eutrophication.

SOURCES	
In many catchments, the process of establishing a Catchment Management Agency is well advanced and the regional DWAF office would have a good stakeholder database.	Regional CMA manager DWAF Regional offices Website: www.dwaf.gov.za

Technical Guide for public participation to support Integrated Water Resources Management.	Greyling, T and Manyaka, S (1999). *Appropriate Public Participation for Catchment Management Agencies and Water User Associations: Towards Co-operative Governance.* Technical Report to Directorate: Catchment Management, DWAF, Pretoria.
CHECKLISTS	
Water Management and Water Services Institutions	CMAs, catchment management committees, WUAs, and Water Boards are often affected by the symptoms of eutrophication and would therefore have knowledge of eutrophication problems in the study area.
Existing Forums and Steering Committees	Forums or Forum Committees, involved in aspects such as Water Quality, Irrigation, Environment, Catchment Management, Conservancies, Land Care, Green Belts, Wetlands, Wildlife, Coastline and Bays, Estuaries, can have specific knowledge of nutrient sources or eutrophication effects.
Civil Society	Community-based organisations (CBOs), residential organisations, traditional leaders, scientific organisations, professional organisations may have knowledge of specific eutrophication problems in the study area.
Agriculture	Sector organisations and *relevant* individual professionals, researchers and academics in this sectors often have knowledge of, for example, fertilizer use and possible load estimates from agricultural sources, eutrophication symptoms such as excessive nuisance algal growth in canals or algal blooms in irrigation dams.
Conservation, Environment and Health	Sector organisations and *relevant* individual professionals, researchers and academics in these sectors often have specialist knowledge of nuisance algal blooms in rivers (River Health Programme) or taste and odour problems in treated drinking water.
Government: Central, Provincial and Local	Government officials with responsibilities for water quality management often have specialist knowledge of eutrophication causes and symptoms in their area of jurisdiction.
Researchers and technical specialists	Relevant individuals who have local scientific and technical experience with eutrophication problems and who may have gathered local eutrophication related data and information.
DISPLAY AND PRESENTATION OPTIONS	
Stakeholder table See the example in the *Catchment Water Quality Assessment Guide* (DWAF, 2003b).	
Stakeholder Analysis Matrix The stakeholder profile of a study area can be analysed in different ways. For example, one way may be to assess the stakeholders on a two by two matrix where one axis could be the degree to which a stakeholder contributes to the causes of eutrophication, and the second axis could be the degree which a stakeholder is affected by the consequences of eutrophication. The study team can then develop different strategies for interacting with clusters of similar stakeholders. This example is illustrated below. Another possible two by two matrix would be to examine stakeholders and how they would be affected by proposed management strategies, against the power they have to influence strategy development process.	


High
Consequences
The degree to which a stakeholder is affected by the consequences of nutrient enrichment and eutrophication related problems
Low
Water Board A
Municipality B
Nature Conservation Authority
River forum C
Irrigation Farmers WUA
Catchment WQ forum
Catchment Management Agency
Municipality A
Dryland farmers
Industry R
Low
High
Causes
The degree to which a stakeholder contributes to nutrient enrichment and eutrophication problems

COMPONENT 13
Water-Interested Institutional Arrangements and Linkages

PURPOSE

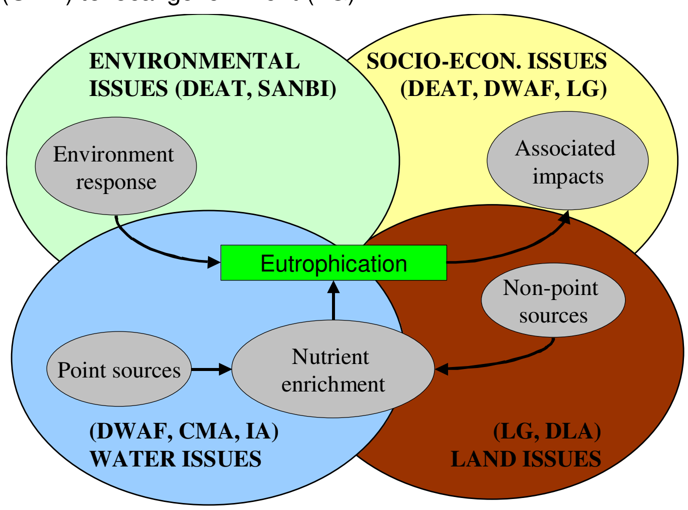
Generic catchment assessment context

Water quality in a catchment is an expression of the degree to which land-use and other physical developments have modified the terrestrial phase of the hydrological cycle. However, control over many land-uses and other physical developments lies outside the statutory domain of the National Water Act. Other laws and government institutions control many of the activities that affect catchment water quality. Against this fragmented background, the development and implementation of a catchment management strategy will be highly dependent on a process of co-operative governance. It is therefore important that a catchment water quality assessment study identifies and describes the water-interest institutions in a catchment and clarifies the linkages between them.

Eutrophication assessment context

The focus in an eutrophication assessment is to identify and describe the institutions that would have control over nutrient loads generated in the catchment and its fate in different components of the hydrological cycle.

Eutrophication has distinct water, land, environmental and socio-economic elements (as illustrated below) and institutional role players range from central government (DWAF, DEAT, DLA) to regional (CMA) to local government (LG)[4].



Water issues - Eutrophication is commonly perceived as a water quality problem because the environmental response to eutrophication occurs within water bodies and follows from the enrichment with nutrients. However, eutrophication is not only a water quality problem. In terms of nutrient enrichment, the point-source discharge of nutrient-rich effluent from, importantly, wastewater works but also from bulk industry (pulp and paper, textiles, agro-industry) and from intensive animal husbandry, is defined as a water use under the National Water Act (Section 21). Such enrichment therefore falls within the institutional realm of the Department of Water Affairs and Forestry (DWAF), the Catchment Management Agency (CMA) and the Infrastructure Agency (IA), where it influences the ability of the IA to recover costs.

Land issues - Nutrient enrichment also occurs from a number of non-point sources (NPS). Under some circumstances, these NPS are the dominant contributors to the eutrophication problem (see **Component 8**). These sources of nutrient enrichment are associated with issues of land-use and the management of these sources are based on the management of land and land-based activities.

[4] Extracted from documents prepared by C. von der Heyden of Pegasus Strategic Management for Operational Guideline for Best Eutrophication Management Practices.

The NPS fall within the institutional remit of either Local Government (LG) as the service provider and as the local development planner, or of the Department of Land Affairs and Agriculture (DLA). Relevant legislation in terms of the agricultural NPS includes the Conservation of Agricultural Resources Act (CARA) which describes the measures required to prevent the wash-off of soil and sediment, and to limit the return-flow of irrigation water.

Environmental issues - Eutrophication has a very clear environmental element, namely the environmental response to the increased availability of nutrient. The Environmental Conservation Act (ECA) and the National Environmental Management Act (NEMA) are key pieces of legislation that describe how, *inter alia*, eutrophication is governed. For example, Section 20 of the ECA provides for the licensing of waste disposal sites and affords protection to underground water resources from polluted seepage. The purpose of NEMA is to give effect to the Constitutional rights to an environment that is not harmful to health or well-being, and that is protected. The National Environmental Management: Biodiversity Act operates within the framework provided by NEMA. The Act is significant to eutrophication governance as Section 52 creates a mechanism for protecting ecosystems that are threatened or in need of protection. Chapter 5 deals with, *inter alia*, alien species that threaten water resources, such as the macrophytes associated with eutrophication. These issues fall within the mandate of the Department of Environmental Affairs and Tourism (DEAT). However, other statutory institutions, such as the South African National Botanical Institute (SANBI) and South African National Parks (SANParks), and the civil society conservation organisations, such as the Wildlife and Environment Society of South Africa (WESSA) and the conservancies, are intricately associated with the governance of the environment and with the ecological change inherent in eutrophication.

Socio-economic issues - The socio-economic issues of eutrophication are cross-cutting, in that eutrophication has some significant socio-economic impacts, while some of the causes of eutrophication (particularly nutrient enrichment) are related to socio-economic factors. Eutrophication results in increased costs to society and changes in social behaviour, both as a result of the enrichment of water bodies with nutrients and through the ecological response to such enrichment. As the socio-economic issues relating to eutrophication are diverse, so the institutional responsibilities for such issues are similarly diverse. Water quality for use is the responsibility of the DWAF, of Water Boards and of the service providers (LG). Changes in non-consumptive use of a resource and associated change in recreational and tourism revenue are the concern of DEAT, while the health effects and the poverty effects discussed are the mandate of LG. Clearly, civil society is involved in the governance frameworks at various points, for example community based organisation (CBO), community health organisation and recreational user associations.

Purpose

The purpose of this component is to compile an information base on water-related statutory institutions, their jurisdictions, functions, administrative structures and inter-institutional relationships, that have control over the production and delivery of nutrients in a study area as well as the impacts on water users.

Prerequisite Components

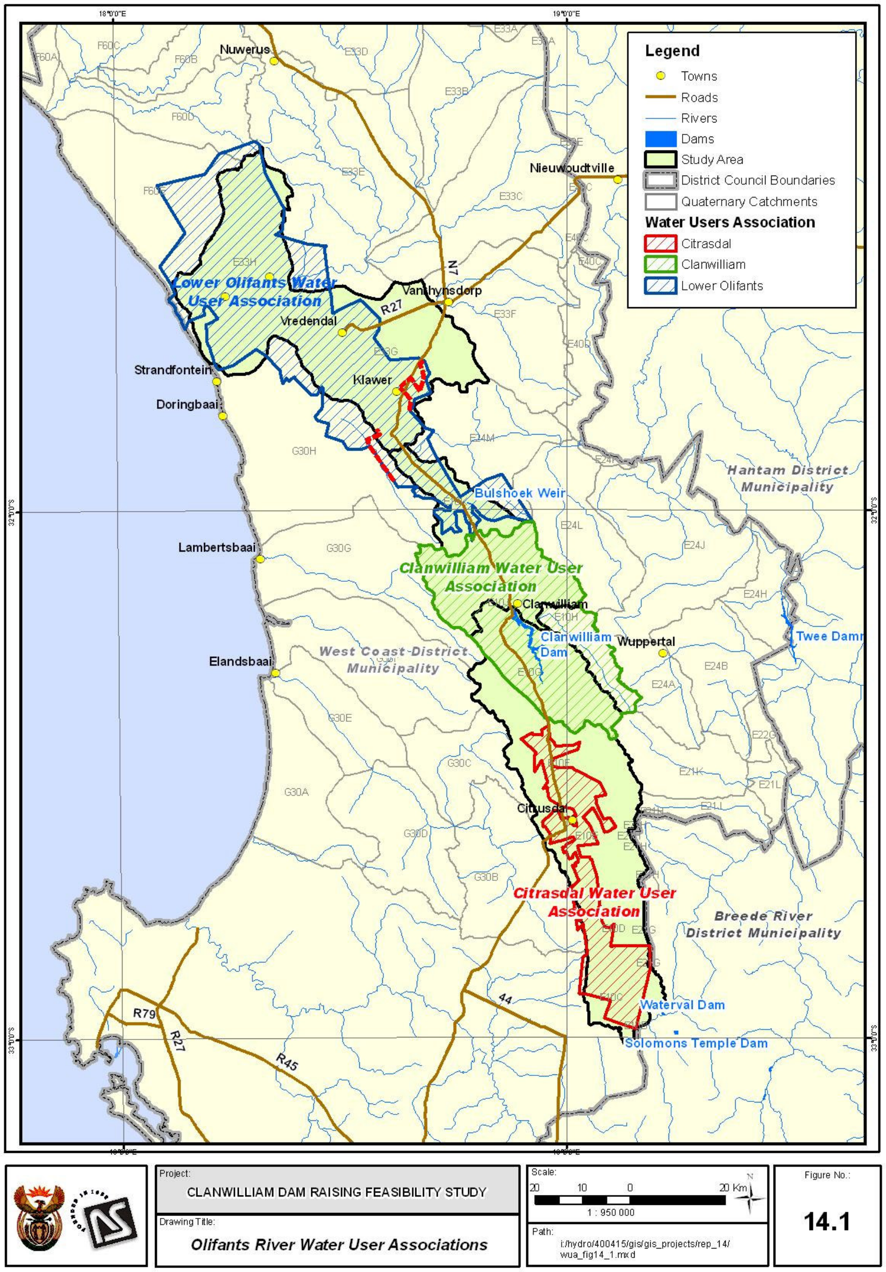
Components 0, 1 and **12** are prerequisites for this Component.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The catchment water quality assessment guide (DWAF, 2003b) lists three outputs: • An outline of all statutory water management and water services institutions in the catchment, • A description of *internal and external* institutional relationships, and • A schematic description of *internal* and *external* "voluntary" relationships with stakeholders and other interested parties.	Refer to the *Catchment Water Quality Assessment Guide* (DWAF, 2003b).

Eutrophication assessment output	
The outputs for an eutrophication assessment are similar to outputs required for a generic catchment assessment study.	Identify and describe the institutions that have control over the production and delivery of nutrients in the study area using the guidelines provided in the *Catchment Water Quality Assessment Guide* (DWAF, 2003b).
SOURCES	
Pegram, G C (1999). The Catchment Management Agency Establishment Process, Report to Directorate: Catchment Management, DWAF, Pretoria. Görgens, A H M (1999). Catchment Management Agency Functions and Organizational Considerations, Report to Directorate: Catchment Management, DWAF, Pretoria. Peart, R and Masia, M (1999). Relationship between Catchment Management Agencies and Other Institutions. Report to Directorate: Catchment Management, DWAF, Pretoria. Pegram, G C and Palmer Development Group (2000). Guidelines for Financing Catchment Management. Report to the Water Research Commission, Pretoria. Pegram, G and Mazibuko, G. (2003). Evaluation of the role of Water User Associations in water management in South Africa. Report to the Water Research Commission, Report No. TT 204/03. Pegram, G, Mazibuko, G, Hollingworth, B and Anderson, E (2006). Strategic review of current and emerging governance systems related to water in the environment in South Africa. WRC Report No. 1514/1/06, Water Research Commission.	
CHECKLISTS	
Refer to checklists for **Components 12** and **17**. ***Relationships between institutions*** The nature of the relationships between institutions can be described as: • Statutory (powers and duties assigned or delegated under an Act) • Regulatory (one monitors and audits the other) • Co-operative governance based (collaboration amongst various organs of state with differing competencies and jurisdictions) • Contractual (performing catchment management functions (not statutory) on behalf of each other in return for a management or service fee) • Representative (between stakeholders - particularly water user sectors – and their representative water management structures, as well as politically accountable spheres of government.	

DISPLAY AND PRESENTATION OPTIONS

Example of a map showing the geographic boundaries of different water user associations and district councils.



COMPONENT 14
Record of Eutrophication Related Water Quality Issues and their Origins

PURPOSE

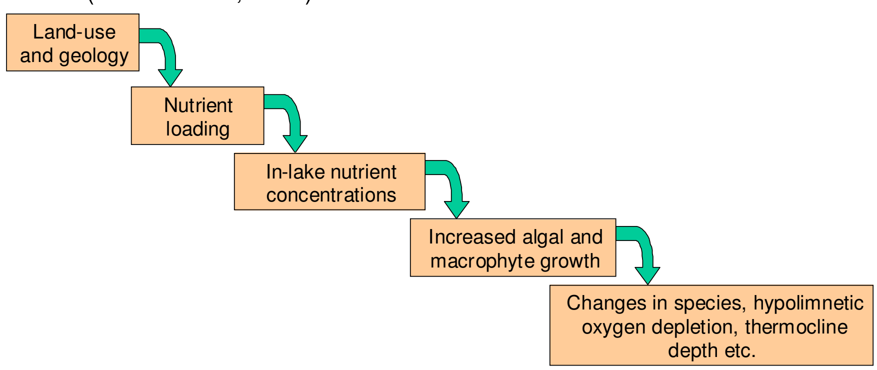
Generic catchment assessment context

Water quality issues are water quality related problems that users experience. These problems are based on perceptions of water users and may therefore be real problems or perceived problems. Real water quality issues and problems can be identified by determining if the observed water quality is poorer than the user water quality requirements, and by how much. The link between causes and consequences or symptoms can then be investigated in more detail.

Eutrophication assessment context

The cause-effect chain in eutrophication can be quite complex and in an eutrophication assessment study, the problems experienced by users are often far removed from its causes. It is therefore important to identify those water quality issues, concerns and problems that can be traced back to nutrient enrichment.

The components of reservoirs, rivers and lakes are interconnected. Increased nutrient loadings generally affect plants (algae etc.) directly but other components of the system are affected indirectly through various pathways. This is referred to as the trophic causal chain and is illustrated below (Gibson *et al.*, 2000).



Stakeholders often raise the symptoms of eutrophication as a water quality concern and one needs to step back through the trophic causal chain to identify the origins of the concern.

Purpose

The first objective of this component is to identify the water quality concerns relating to eutrophication (e.g. taste and odour problems in drinking water) and then to identify and understand the processes that contribute to the causes of the problem (e.g. presence of nuisance blue-green algae in the raw water as a result of high nutrient concentrations). The last step is to identify all the relevant water quality constituents that should be managed to alleviate the symptoms of the problem. This approach will also ensure an integrated approach to managing the physical, chemical and biological factors contributing to eutrophication problems.

Prerequisite Component

To undertake this Component, Task 1: Characterization of the current situation and historical trends must be completed.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Inventory of eutrophication related water quality problems, issues and the factors contributing to the problems.	Integration of eutrophication related water quality problems raised by stakeholders, water user requirements, and observed water quality status and trends.

SOURCES

The primary sources of generic information on water quality problems in South Africa and the water quality constituents associated with them, are the *South African Water Quality Guidelines* and the *Assessment Guide for Domestic Water Supply*.

South African Water Quality Guidelines (1996) Volume 1: Domestic water use Volume 2: Recreational water use Volume 3: Industrial water use Volume 4: Agricultural water use: Irrigation Volume 5: Agricultural water use: Livestock watering Volume 6: Agricultural water use: Aquaculture Volume 7: Aquatic ecosystems Volume 8: Field guide	*The South African Water Quality Guidelines* can be obtained from the Directorate of Water Quality Management, DWAF. Website: www.dwaf.gov.za
Quality of domestic water supplies. Volume 1: *Assessment Guide*. Second edition. Water Research Commission Report TT 101/98	*The Assessment Guide* can be obtained from Water Research Commission, Pretoria. Website: www.wrc.org.za

CHECKLISTS

The following is a range of common eutrophication related water quality issues that have been grouped per water use sector. The list can be used as a checklist to guide the identification of water quality issues in a catchment assessment study.

***Note: only the problems and constituents relating to eutrophication have been identified below. Other constituents associated with the problem are listed in the* Catchment Water Quality Assessment Guide.**

Domestic water supply

Water used for domestic purposes includes water for drinking, food & beverage preparation, hot water systems, bathing and personal hygiene, washing, laundry and gardening. Domestic water users can experience a wide range of water quality problems. These can be categorized as impacts on the health of consumers, aesthetic impacts and economic impacts.

Concerns	***Eutrophication related constituents***
Health impacts that includes short and long-term effects on the health of consumers. This includes the effect of toxic substances that can be harmful even at low concentrations.	Toxic algae, ammonia, trihalomethanes
Aesthetic impacts that include changes in water taste, odour or colour or staining of laundry or household fittings and fixtures.	Algae, dissolved organic carbon, nitrate, odour, suspended solids, turbidity
Economic impacts that include increased treatment costs.	Algae, taste and odours.

Industrial water supply

The eutrophication related water quality problems experienced in industries can be categorized in the following groupings:

- Potential damage to equipment, for example biofouling.
- Potential problems in the manufacturing process, for example precipitates and colour changes, and
- Impairment of product quality, for example taste or discolouration.

The eutrophication related water quality constituents generally associated with these industrial water quality problems are listed below.

Concern	***Eutrophication related constituents***
Biofouling	Nutrients, chemical oxygen demand, biochemical oxygen demand
Blockages	Algae (filamentous or free floating), chemical oxygen demand, biochemical oxygen demand
Discolouration	Algae, chemical oxygen demand
Foaming	Algae, chemical oxygen demand
Sediment	pH, total hardness, Iron, Manganese, Sulphate, suspended sediment
Gas production	Chemical oxygen demand
Taste and/or odours	Algae
Turbidity	Algae, Chemical oxygen demand
Colour	Algae, Chemical oxygen demand
Biological growth or biofouling	Algae, nutrients, suspended sediment, chemical oxygen demand

Agricultural water supply: Irrigation

Irrigation water users experience a range of impacts as a result of changes in water quality. These include:	The key water quality constituents which can be linked to these water quality problems include:
Concern	***Eutrophication related constituents***
Nuisance filamentous algae or blue-green algal scums in irrigation canals and irrigation water dams.	Algae, nutrients, suspended solids
Blocking, fouling or damage to irrigation equipment as a result of algae in the irrigation water.	Algae, nutrients, suspended solids

Agricultural water supply: Stock watering

Eutrophication related water quality concerns associated with the production of livestock depends on a number of factors such as the type of livestock, the type of livestock products and type of production system in use. If water quality does not meet requirements, a wide range of problems can be encountered. These are generally categorized as:

- Problems associated with the consumption of water by livestock,
- Problems associated with the water distribution system to livestock, and
- Problems associated with the quality of livestock products.

Concerns	***Eutrophication related constituents***
Problems associated with the consumption of water by livestock. These include concerns about toxicological and/or palatability effects.	Toxic algae, algal scums, nitrate & nitrite
Eutrophication problems associated with the livestock watering systems include clogging or biofouling. Other more generic problems include corrosion, encrustation, scaling, and sediment.	Filamentous or free-floating algae, nutrients, biochemical oxygen demand
Eutrophication related problems associated with livestock product quality include concerns about consumer health hazards and/or product quality.	Toxic algae, blue-green algae, THMs

Agricultural water supply: Aquaculture

Aquaculture refers to aquatic agriculture and it can be divided into several sectors:

- breeding of fish in cages in dams and natural lakes (cage culture)
- extensive farming in small earthen farm dams
- extensive and semi-intensive fish farming in purpose designed fish ponds, and
- intensive farming in raceways and tanks.

Concern	***Eutrophication related constituents***
Concerns about low dissolved oxygen and eutrophication of the water	Algae, dissolved oxygen, carbon dioxide, nitrate and nitrite, ortho phosphate
Concerns about the presence of toxic compounds in the water	Toxic algae, ammonia (NH_4),
Discharge of nutrient rich water from intensive aquaculture units.	Nutrients

Aquatic environment

The Department of Water Affairs and Forestry considers aquatic ecosystems to be the base from which the water resource is derived. Man depends on many of the services provided by a healthy ecosystem. These include the ability to assimilate certain waste products, providing a pleasing environment for recreation, provide a livelihood for communities that depend on water bodies for food and maintaining biodiversity and habitats for the biota that depend on the ecosystem. Aquatic ecosystems must be protected to ensure the resource remains fit for all the other uses (domestic, agriculture, etc.) on a sustainable basis.

Concerns	***Eutrophication related constituents***
Toxic substances	Toxic algae, ammonia
Low dissolved oxygen	Algae, organic material
Nutrients	Inorganic nitrogen such as nitrate, nitrite and ammonium and inorganic phosphates such as ortho-phosphate

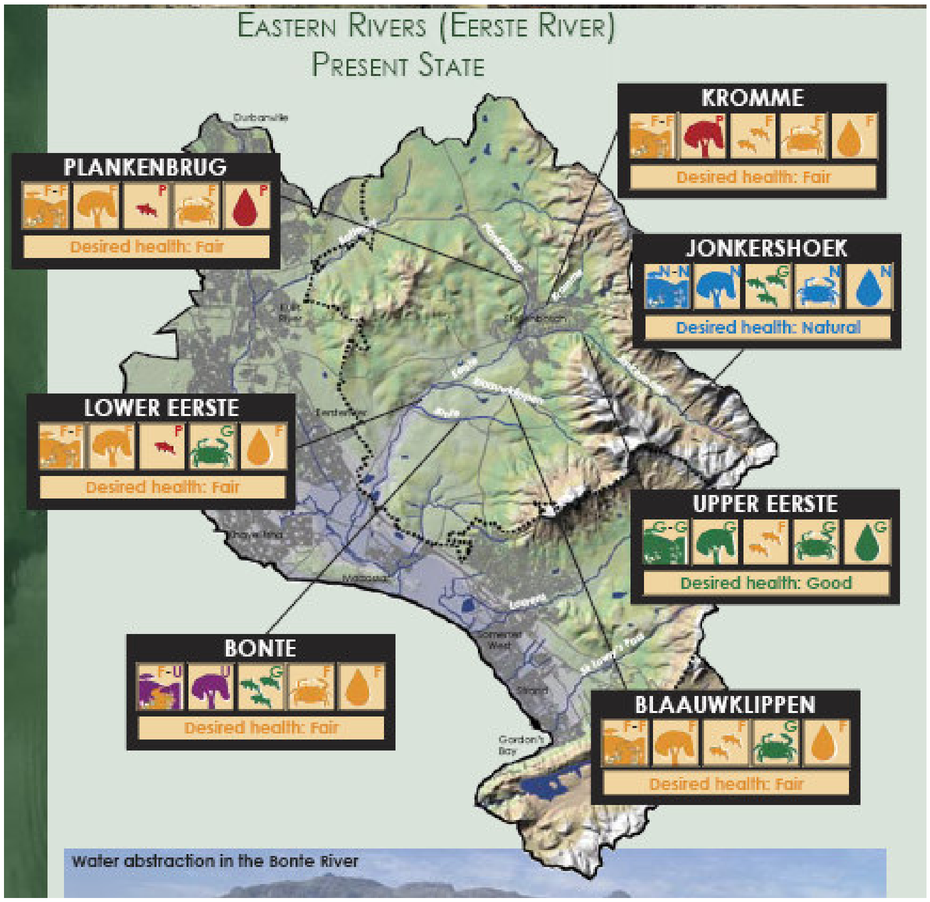
Recreational water use

Recreational water users experience a range of impacts as a result of changes in water quality and the type of recreation. Three types of recreation have been identified: Full-contact recreation such as swimming and diving, intermediate contact recreation such as water-skiing and angling, and Non-contact recreation such as picnicking and hiking next to a water body. Eutrophication related concerns include the following:

Concerns	***Eutrophication related constituents***
Human health impacts refer to concerns about waterborne diseases such as gastro-enteric diseases, skin and ear infections and carcinogenic risks.	Presence of toxic algae
Human safety impacts refer to concerns about poor visibility, profuse plant growth and benthic microbial and/or algal growth.	Filamentous or free-floating algae, nuisance plants
Aesthetic impacts refer to concerns about odour and/or colour of the water, discolouration and staining, objectionable floating matter and nuisance plants.	Filamentous or free-floating algae, nuisance plants, water clarity, odour
Economic impacts refer to concerns about damage to recreation equipment.	Algae, clarity, nuisance plants

DISPLAY AND PRESENTATION OPTIONS

An example of how water quality issues can be described:



REFERENCES

Gibson, G, Carlson, R, Simpson, L, Smeltzer, E, Gerritson, J, Chapra, S, Heiskary, S, Jones, J and Kennedy, R (2000). *Nutrient criteria technical guidance manual: Lakes and reservoirs*. USEPA report No. EPA-822-B00-001. United States Environmental Protection Agency.

COMPONENT 15

Catchment Management Implications of Eutrophication Related Water Quality Issues

PURPOSE

Generic catchment assessment context

The process of developing catchment management strategy is described in a document, *Guideline to the Water Quality Component of the Catchment Management Strategy* (DWAF, 2003). It describes procedures for:

- setting *medium-term resource objectives* and a long-term vision from the statement of variables of concern and user water requirements, via examination of water quality issues,
- setting of *source management objectives* for all management units and right-size water quality loads so that resource objectives can be met,
- developing *water quality management strategies* that prioritise sectors and sources so that source management objectives can be met, and
- the development of *water quality management plans* on a sector, source and management unit basis.

All the water quality issues, problems, concerns or opportunities (collectively called "issues") recorded in **Component 14** potentially requires attention in the catchment management strategy development process. This creates an issue-focused bridge between the catchment assessment study and the catchment management strategy.

Eutrophication assessment context

The eutrophication related issues, problems, concerns and opportunities recorded in **Component 14** need to be addressed in an eutrophication management strategy which should form part of a larger catchment management strategy. This component provides the framework for linking the issues to medium-term eutrophication management objectives, nutrient management objectives for different sources, nutrient or eutrophication management strategies or nutrient management plans for individual sources.

This component is not a primary component of an eutrophication assessment study but is included to bridge the gap between the assessment study and strategy development. It is the responsibility of the strategy development team to ensure that the strategy is 'issues driven'.

Output from **Component 0** (existing understanding) may already highlight eutrophication related issues that may need urgent *ad hoc* management intervention.

Purpose

The purpose of this component is to record how each eutrophication related issue, problem, concern, or opportunity should be linked to different phases of an eutrophication management strategy (as generically described in the *Guideline (DWAF, 2003)*) to ensure that it influences appropriate management decisions.

Prerequisite Components

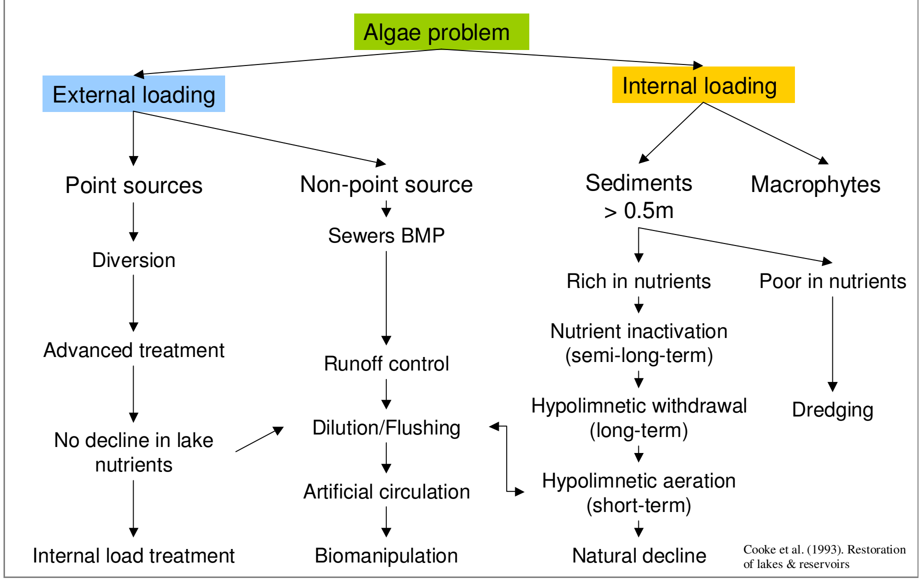
Completion of Task 1 and **Components 14** and **18** are prerequisites.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Eutrophication assessment outputs	
Table and brief description that links eutrophication related issues with one or more of the phases of the eutrophication management strategy development process.	Interpret inputs and feedback from stakeholder participation processes, as well as from examining the findings of predictive studies.
Table that provides conceptual management options for each eutrophication related issue.	Obtain inputs during stakeholder participation processes and consult sectoral specialists.

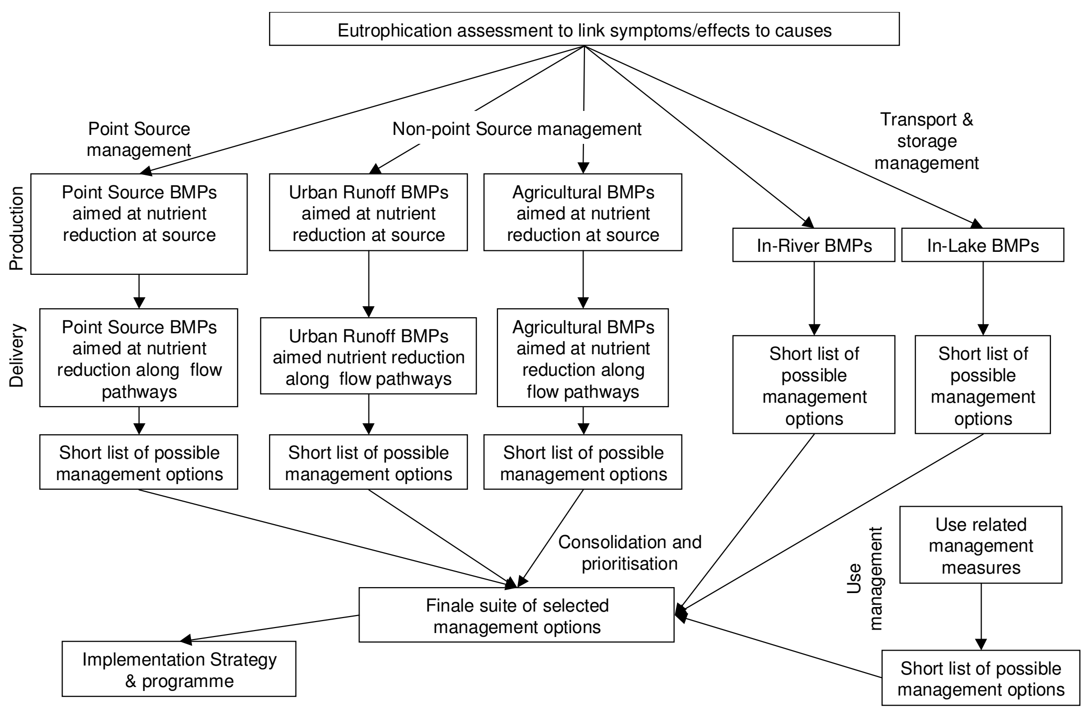
METHODS AND TOOLS

Cooke *et al*. (1993) provided a decision tree than can guide water resource managers to select restoration options for the control of algae problems in lakes and reservoirs. This tree and others like it can be used to link eutrophication issues to management options and plans.

Decision tree for the choice of best restoration procedures for control of algae problems



An example of a process for selecting a suite of eutrophication management options is illustrated below (DWAF, 2006):



The assessment of the eutrophication problems and linking them to their root causes determines where attention should be focused in the treatment train (sources and pathways/transport and storage/use). The next basic step is to develop a first-cut laundry list of management options that addresses all the components of the eutrophication management framework. The different laundry lists are then combined and prioritised and a shortened list of options is then organised, analysed and prioritised to become the strategy and programme of actions that will be implemented in the short to medium-term.

The DWAF hierarchy of water quality management decision-making encourages managers to start at pollution prevention (source management) and waste minimization (pathway management). This is done by identifying a short list of possible BMPs to manage point and/or non-point sources at source and/or along the flow pathways. The assessment will provide guidance on how much of the nutrient loads originated from point or non-point sources and how much of resources should be expended to control these sources and the pathways through which nutrient loads reach receiving water bodies. In general, it was found that sources and pathways are considered as a group, e.g. agricultural sources or urban sources.

The assessment also provides guidance on whether management in the receiving water body (transport and storage management) should be considered. These include in-river management options where the assimilative capacity of the river is used to reduce nutrient concentrations (transport management) or in-lake management options designed to reduce algal growth, suppress internal loading or reduce water retention time.

CHECKLISTS

Management options to address **point sources** of nutrients, include:

Municipal wastewater treatment

- Pond treatment systems
    - Facultative ponds
    - Anaerobic ponds
    - Aerobic ponds
    - Reed beds
    - Trickling filters
- Activated Sludge Process
    - Aerobic system
    - Anoxic-aerobic system
    - Anaerobic-anoxic-aerobic system
    - Chemical precipitation
- Post-treatment systems
    - Constructed wetlands

Small community treatment systems

Management options to address **agricultural non-point sources** of nutrients, include:

- Fertilizer application management
- Riparian buffer strips
- Vegetated filter strips
- Contour cultivation
- Stream and river bank protection
- Strip cropping
- Management of pastures
- Accurate fertiliser application
- Grassed waterways
- Management of livestock manure
- On-site management of waste from intensive animal feeding units
- Stormwater runoff management

Management options to address **urban non-point sources** of nutrients, include:

- Grass buffer areas
- Grass swales
- Porous pavement and porous pavement detention
- Porous landscape detention
- Dry ponds and extended detention basins
- Wet detention ponds
- Sand filter extended detention basins
- Natural or artificial wetlands
- Interception trench
- Maintenance and upgrading of sewer infrastructure
- Litter and pet waste control ordinance
- Street sweeping
- Catch basin cleaning
- Public education programmes
- Refuse collection and disposal

Management options to address eutrophication in **receiving rivers and reservoirs**, include:

In-river or in-stream management options

- Diversion of wastewater
- Pre-impoundments
- Dilution and flushing

In-lake management options

- Biomanipulation: coarse fish eradication
- Biomanipulation: floating wetlands
- Biomanipulation: riparian wetlands
- Shoreline management
- Chemical water treatment
- Partitioning (mesocosms, corrals)
- Wake controls (powerboats)
- Biological controls: habitat protection
- Biological controls: natural predators
- Bottom sealing (physical)
- Sediment treatment using chemicals
- Macrophyte harvesting
- Aeration
- Augmented circulation
- Algaecides
- Dilution/flushing
- Dredging
- Hypolimnetic withdrawal
- Light inhibiting dyes
- Nutrient supplementation
- Water level controls (drawdowns)

SOURCES

Below are sources of information on best eutrophication management practices that can be useful in the compilation of detailed interventions. This list is by no means exhaustive and the reader is encouraged to visit the websites listed, consult some of the references listed in the books and reports referred to below, as well as those listed in the Reference list of this report.

South African Reports

City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments.* Catchment, Stormwater and River Management Branch, Transport, Roads and Stormwater Directorate, City of Cape Town.

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R (2004). *Hartbeespoort Dam Remediation Project (Phase 1). Volume 1: Action Plan*. Department of Agriculture, Conservation, Environment and Tourism. Northwest Province.

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R (2004). *Hartbeespoort Dam Remediation Project (Phase 1). Volume 2: Annexures: Specialist reports*. Department of Agriculture, Conservation, Environment and Tourism. Northwest Province.

Hart, R and Hart, R C (2006). *Reservoirs and their management: A review of the literature since 1990*. WRC Report No. KV173/06. Water Research Commission, Pretoria.

Marais, M and Armitage, N (2003). *The measurement and reduction of urban litter entering stormwater drainage systems*. WRC Report No. TT 211/03. Water Research Commission, Pretoria.

International reports and books

Campbell, N, D'Arcy, B, Frost, A, Novotny, V and Sansom, A (2004). *Diffuse Pollution - An introduction to the problems and solutions*. IWA Publishing, London.

Cooke, G D, Welch, E B, Peterson, S A and Nichols, S A (2005). *Restoration and management of lakes and reservoirs.* 3rd Edition. CRC Press, Taylor & Francis Group, Boca Raton.

Debo, T N and Reese, A J. (2003). *Municipal Stormwater Management.* Lewis Publishers, Boca Raton.

Evans, B M and Corradini, K J (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: www.predict.psu.edu/downloads/BMPManual.pdf

Haestad Methods & Durrans, S R (2003). *Stormwater conveyance modeling and design*. First edition. Haestad Methods, Haestad Press, Waterbury.

Holdren, C, Jones, W and Taggert, J (2001). *Managing Lakes and Reservoirs*. North American Lake Management Society and Terrene Institute, in co-operation with the Office of Water Assessment, Watershed Protection Division, USEPA, Madison, WI.

Moss, B (1998). *Shallow lakes, Biomanipulation and Eutrophication*. *Scope Newsletter Number 29*. Available online: http://www.ceep-phosphates.org/

Mudgeway, L B, Duncan, H P, McMahon, T A and Chiew, F H S (1997). *Best practice environmental management guidelines for urban stormwater.* Background report to the Environmental Protection Authority, Victoria, Melbourne Water Corporation and the Department of Natural Resources and Environment, Victoria. Co-operative Research Centre for Catchment Hydrology. Available online: http://www.catchment.crc.org.au

Muthukrishnan, S, Madge, B, Selvakumar, A, Field, R and Sulivan, D. *The use of Best Management Practices (BMPs) in Urban Watersheds.* EPA/600/R-04/184. Online: http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf

Ryding, S-O and Rast, W (Eds.) (1989). *The control of Eutrophication of Lakes and Reservoirs*. Man and the Biosphere Series. UNESCO, Paris.

Von Sperling, M and Chernicharo, C A L (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

Internet resources

SCOPE Newsletter - Centre Europeen d'Etudes des Polyphosphates (promotes the sustainable use of phosphates through recovery and recycling).

Online: http://www.ceep-phosphates.org/

Land and Water Australia. National Eutrophication Management Program.

Online: http://www.rivers.gov.au/Our_Research/National_Eutrophication_Management_Program/index.aspx

Massachusetts Nonpoint Source Pollution Management Manual - BMP Selector tool.

Online: http://projects.geosyntec.com/megamanual/default.html

Natural Environment Research Council, Centre for Ecology and Hydrology - compendium of some diffuse pollution control websites.

Online: www.dorset.ceh.ac.uk/River_Ecology/River_Systems/Diffuse_Pollution.htm

The Ohio State University. College of Food, Agricultural, and Environmental Sciences. Ohioline Factsheets.

Online: http://ohioline.osu.edu/lines/facts.html

UN Environmental Programme, Division of Technology, Industry, and Economics. Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication. Available

Online: http://www.unep.or.jp/ietc/Publications/techpublications/TechPub-11/index.asp

[Other related articles in the UN IETC archive can be found at http://www.unep.or.jp/ietc/knowledge/index.asp#start]

US Department of Agriculture. Agricultural Research Service. Agricultural Phosphorus and Eutrophication.

Online: http://www.unep.or.jp/ietc/kms/data/604.pdf

US Department of Agriculture. Natural Resources Conservation Service. National Conservation Practice Standards.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

US Department of Agriculture. Natural Resources Conservation Service. Nutrient and Pest Management.

Online: http://www.nrcs.usda.gov/technical/nutrient.html

US Department of Agriculture. Natural Resources Conservation Service. Water Related Best Management Practices in the Landscape.

Online: http://www.wsi.nrcs.usda.gov/products/UrbanBMPs/

US Department of Agriculture. National Agricultural Library. Water Quality Information Centre.

Online: http://www.nal.usda.gov/wqic/

US Environmental Protection Agency - Nonpoint Source News-Notes.

Online: http://www.epa.gov/OWOW/info/NewsNotes/

World Overview of Conservation Approaches and Technologies.

Online: http://www.wocat.org/default.asp

Wyoming Department of Environmental Quality. Water Quality Division. Watershed Program. Online: http://deq.state.wy.us/wqd/watershed/

REFERENCES

Cooke, G D, Welsch, E B, Peterson, S A, and Newroth, P R (1993). *Restoration and management of lakes and reservoirs*. 2nd Edition. Lewis Publishers, Boca Raton.

Department of Water Affairs and Forestry (DWAF) (2003). A guideline to the water quality management component of a catchment management strategy. Edition 1. Water quality management series, Sub-series No. MS 8.2. DWAF, Pretoria.

Department of Water Affairs and Forestry (DWAF) (2006). Operational Guideline for Best Eutrophication Management Practices. Draft Version 0.4, Pretoria.

Moss, B (1998). Shallow lakes, biomanipulation and eutrophication. *Scope Newsletter*, No. 29.

COMPONENT 16

Vision (or Long-Term Resource Objectives) for Eutrophication Related Water Quality

PURPOSE

Generic catchment assessment context

The first step in the process of developing a catchment management strategy (CMS) is to set *medium-term* (5 years) resource water quality objectives for the different management units that make up the catchment (DWAF, 2003). These objectives reflect the stakeholders' needs with respect to water quality over and above those outlined in the NWRS and by RDM. It is useful if this development can take place against the background of an "ideal", or a "vision", of the *long-term* future water quality desired by stakeholders. Furthermore, the Water Resource Classification process recognises the need to declare, on a provisional basis, a "desired future state" for each catchment. This preliminary vision needs to be converted to a long-term vision through stakeholder engagement during the CMS development process.

Note The tasks of vision formulation and resource objective determination belong to the CMS development process and are not usually the direct responsibility of the water quality assessment team. However, these tasks are strongly linked and should be undertaken as a single process.

Eutrophication assessment context

The aim of this component within the context of an eutrophication assessment study is to ensure that stakeholders' needs with respect to eutrophication related water quality are adequately reflected in the vision and/or resource quality objectives being developed.

Purpose

The purpose of this Component is two-fold:

- To provide the initial stages of the CMS development process with a narrative description of and motivation for the long-term future water quality status as provisionally foreseen by the Resource Classification process
- To record, during all stages of the CMS development process, the desired long-term future water quality status, and the motivation for it, formulated by stakeholders.

Prerequisite Components

Components 0, 1, 5, 12, 13, 14 and **15** are prerequisites for preparation of this output.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic water quality assessment outputs	
The *Catchment Water Quality Assessment Guide* describes the outputs as a description of existing vision and water quality objectives, and descriptions of the future water quality status.	Refer to the *Catchment Water Quality Assessment Guide* on how to produce the outputs.
Eutrophication assessments outputs	
Use the *Catchment Water Quality Assessment Guide* outputs for this comment and ensure that the eutrophication related stakeholder needs are appropriately addressed in the description of existing vision and water quality objectives, and descriptions of the future water quality status.	Consult existing studies (**Component 0**) for existing vision and objectives relating to eutrophication. Determine if any classes or reserves have been set in the study area and refer to their descriptions for future eutrophication water quality status. Liaise with the CMS development team to record any outcomes relevant to eutrophication in the study area.

SOURCES
DWAF (2006) defines catchment visioning as the iterative process of evolving, over time, a more relevant and more detailed: • Collective statement from all stakeholders of future aspirations regarding the relationship between the stakeholders, in particular their quality of life in its broadest sense, and the water resources in a catchment, and • Strategy to move towards that vision, being either the catchment management strategy itself or one that directly supports it. The following quotes taken directly from DWAF (2006) on what catchment visioning entails: "The Department regards catchment visioning as an important planning instrument for integrated water quality management. It is also an essential participatory management process for ensuring that use of the country's water resources is "in the public interest" (a specific mandate of the NWA (36:1998)). The catchment vision should be progressively realised over time by applying adaptive management and prudent pragmatism within the catchment management strategy. The products of the catchment visioning exercise should inform, and be quantified by, classification of the resources and the setting of the associated resource quality objectives. In the interim transitional phase, and under special circumstances, the Department will permit catchment visioning at lower levels of confidence (referring to the level of confidence that can be placed in the appropriateness of the vision). The dangers of doing this will be explicitly acknowledged and carefully weighed against the advantages. For example, in catchments that are not water quality stressed (in respect of any variable of concern) the Department may permit catchment visioning with minimal levels of stakeholder engagement and less than ideal catchment assessment data in the interests of (a) cost-effectively initiating the longer-term progressive development and attainment of a vision, and (b) preparing for a process that is more inclusive. Furthermore, in the interim transitional phase, while recognising that water quality problems are more acute in some areas than in others, and that cost-effective use of human and financial resources is essential, the catchment management strategy will focus initial implementation on those management units in which the need is most urgent." DWAF (2006a) and DWAF(2006b) are recommended for guidance on the process of developing a catchment vision. The generic sources listed in **Component 20** are recommended for guidance on the format of vision formulations in specific catchments where water management plans have been developed. DWAF (2006c) provides guidance on setting Resource Water Quality Objectives that meets the needs of water users and ecosystem health.
CHECKLISTS
The *Catchment Water Quality Assessment Guide* lists the characteristics of a vision statement and its supporting documentation. Refer to the Guide document for the notes on the nature of the vision (idealistic, future target state, non-technical language, supporting technical information). Walmsley (2003) provides some guidance on a policy statement on eutrophication and the development of a strategy to control eutrophication in South Africa.

DISPLAY AND PRESENTATION OPTIONS

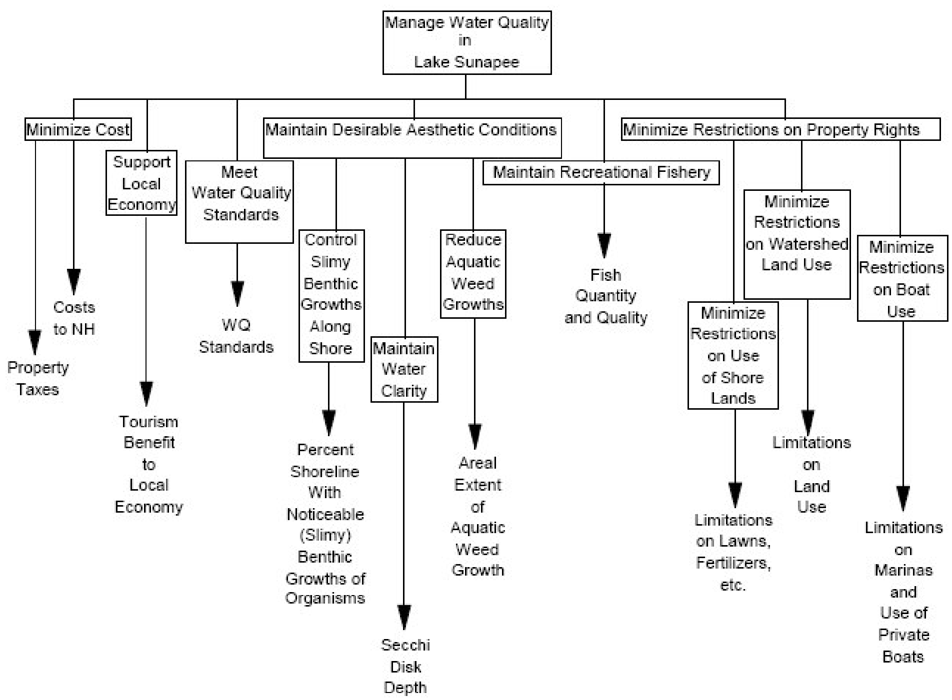
The following is an example of a vision and statement of objectives for eutrophication related water quality that was developed for Hartbeespoort Dam (Harding *et al*., 2004):

"The primary management objectives (= management goals) for Hartbeespoort Dam include:

1) providing water quality suitable for the maintenance of fish and other aquatic life;
2) reducing the severity of existing nuisance problems resulting from excessive algae growth which constrains or preclude intended water uses (raw potable and irrigation water supply and recreational/commercial uses), and;
3) improving opportunities for water based recreational activities while maintaining the availability of waters for irrigation and domestic consumptive uses."

Objectives hierarchy

Water quality objectives and their attributes can be displayed in an objectives hierarchy (Reckhow, 1999). The diagram below illustrates an example of such an objectives hierarchy. The hierarchy begins with an all-encompassing objective at the top. A comprehensive set of issue-specific objectives is then derived containing objectives that are consistent with the overall objective. Finally, attributes (identified by the arrowheads in the figure) that are meaningful, measurable, and can be predicted are selected for each specific objective.



REFERENCES

Department of Water Affairs and Forestry (DWAF) (2006a). *Resource Directed Management of Water Quality: Volume 1.2: Policy. Edition 1.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.4.2. ISBN No. 0-621-36788-5. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF) (2006b). *Resource Directed Management of Water Quality: Volume 4.1: Guideline for Catchment Visioning for the Resource Directed Management of Water Quality. Edition 2.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.1. ISBN No. 0-621-36792-3. Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF) (2006c). *Resource Directed Management of Water Quality: Management Instruments. Volume 4.2: Guideline for Determining Resource Water Quality Objectives (RWQOs), Allocatable Water Quality and the Stress of the Water Resource.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.2, Edition 2. ISBN No. 0-621-36793-1. Department of Water Affairs and Forestry, Pretoria, South Africa.

Harding, W R, Thornton, J A, Steyn, G, Panuska, J and Morrison, I R (2004a). *Hartbeespoort Dam Remediation Project (Phase 1): Action Plan (Volume 1 and 2) Final Report.* Department of Agriculture, Conservation, Environment and Tourism, North West Province Government, Mmabatho.

Reckhow, K H (1999). Lessons from risk assessment. *Human and Ecological Risk Assessment*, Vol. 5:245-253 .

Walmsley, R D (2003). *Development of a Strategy to Control Eutrophication in South Africa: Phase 1. A review and discussion document.* Water Quality Management Series. Report No. U 2.1, Department of Water Affairs and Forestry, Pretoria.

COMPONENT 17

National, Regional and Local Plans and Projections of Future Water Demands and Catchment Development

PURPOSE

Generic catchment assessment context

Catchment management is part of a wider planning and development environment, which is often fragmented in nature. In **Component 13**, the institutional linkages that are required to counter this fragmentation are addressed. In this component, the focus is on the fragmented statutory arrangements for spatial, land-use and infrastructural development planning.

This Component ensures that the CMS is aligned with national, provincial, regional and local planning initiatives by institutions outside the water management sector. By being informed about such planning processes, the CMS may be oriented to influence them to the advantage of water quality management. The CMS needs to take account of demographic trends, which determine future water demand and waste discharge patterns, as well as spatial patterns of potential future water quality impacts.

Eutrophication assessment context

The challenge in an eutrophication assessment study is to identify those development plans and demographic projections that would either affect the nutrient status in the study area, or would be impacted upon negatively by eutrophication related water quality. Development aspects such as envisaged urban and industrial expansion nodes, new irrigation projects, new wastewater treatments works, upgrading of informal settlements, would all have an impact on the nutrient status of a catchment.

Purpose

The purpose of this component is to document those developments at national, provincial and local government level that may modify the current nutrient status of a catchment. The objective would be to identify at least the likely large-scale developments and their potential impacts on the nutrient status. This task needs to be undertaken at a scoping level or detail.

Prerequisite Components

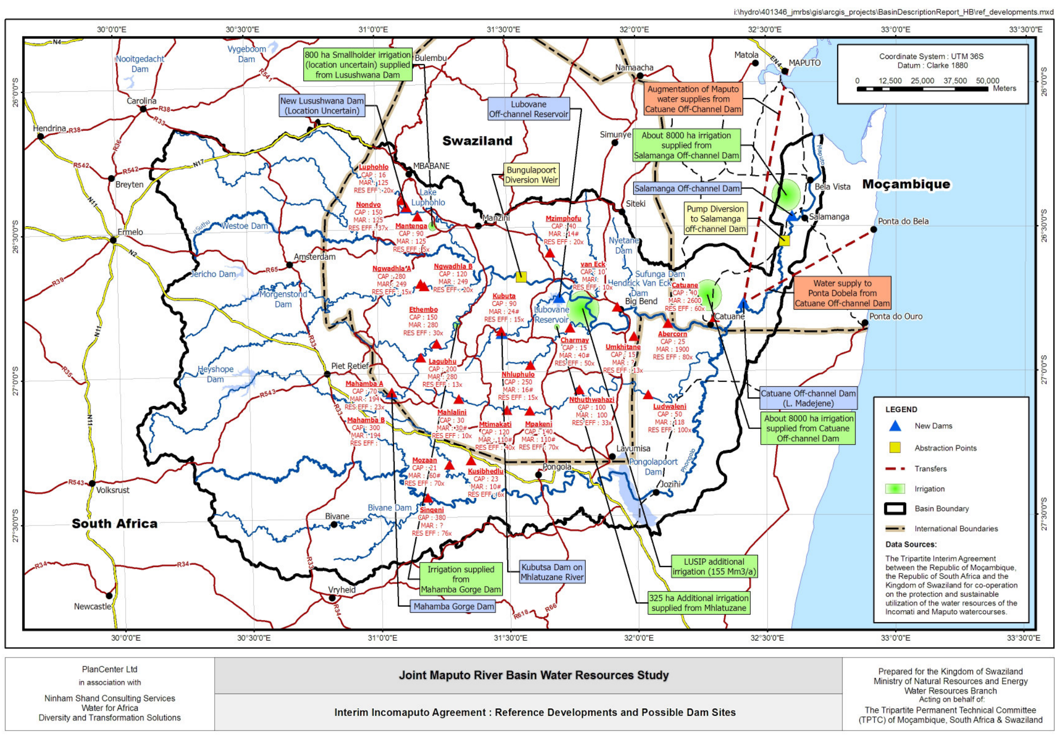
The output from **Components 0, 1, 3, 12, 13**, and **15** would inform this Component in various ways.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Outline of available outputs from all national, provincial, regional and local planning processes. The **Checklist** section below provides examples of such outputs.	Obtain plans from all organs of state in all spheres of government that deal with: Natural resource use (agriculture, environment, mining, water services, forestry) Land-use and infrastructure development (local government, housing, transport, land affairs) Spatial planning (provincial planning, land affairs, economic affairs)
Outline of demographic projections that are differentiated for different parts of the catchment.	This should not normally be the task of the water quality assessment and should be derived by preceding or simultaneous water resource planning studies. Derived by combining census results with alternative economic, health and social development scenarios. Best performed by economics professionals or social scientists.
Detailed chapter on projections of future water demands due to population growth and potential physical developments in the catchment.	These should not normally be the task of the water quality assessment and should be derived by preceding or simultaneous water resources planning studies. However, projections of physical developments may require refinements under a water quality perspective.

SOURCES
Planning Information: Planning Divisions of organs of state in all spheres of government, particularly the National Departments dealing with: water affairs, forestry, environment, agriculture, minerals and energy, transport, land affairs, health, trade and industry, economic affairs, constitutional development, housing, defence, labour. Secretariat of Provincial Heads of Departments (HOD) Committee and of the Provincial Directorate-General's Office. Secretariat of the Provincial Water Liaison Committee (formal interface between provincial government and DWAF Regional Offices). Secretariat for the Committee for Environmental Coordination (CEC) (created under the National Environmental Act to oversee the EIP and EMP processes).
Projections: Water resource planning or design reports with the following themes: *Water Resources, Water Demands, Demand Management, Water Supply Augmentation Scheme Design, Economics of Augmentation Scheme Options (*Obtainable from DWAF addresses provided under **Component 4**). Scientific institutions that specialise in demographic analyses and population projections, such as the Institute for Futures Studies and the Bureau for Economic Studies (both University of Stellenbosch), or the Human Sciences Research Council, Pretoria.
CHECKLISTS
National Departments: • Water Services Development Plans (WSDP) – Department of Water Affairs and Forestry. • Integrated Development Plans (IDP) – Department of Constitutional Development. • Land Development Objectives (LDO) – Department of Land Affairs. • Hazardous Waste Management Plans (HWMP) – Department of Environmental Affairs and Tourism. • Spatial Development Initiatives (SDI) – Department of Trade and Industry. • Environmental Implementation Plans (EIP) – Departments of Environmental Affairs and Tourism, Land Affairs, Agriculture, Housing, Trade and Industry, Water Affairs and Forestry, Transport, Defence, Minerals and Energy, Health, Labour. • Environmental Management Plans (EMP) – Departments of Environmental Affairs and Tourism, Land Affairs, Water Affairs and Forestry, Minerals and Energy, Health, Labour.
Provincial Governments: • Environmental Implementation Plans (EIP) • Strategic Environmental Assessments (SEA) • Environmental Management Frameworks (EMF) • General Waste Management Plans (GWMP) • Spatial Development Initiatives (SDI) • Conservation of Agricultural Resources Plans (CARP)
Local Authorities: • Metropolitan Spatial Development Frameworks (MSDF) • Urban Structure Plans • Land Development Objectives (LDO) • Town Planning Schemes

DISPLAY AND PRESENTATION OPTIONS

An example of a catchment scale map showing potential water resource development options in the Maputo River basin and potential new dams sites as envisaged in the Interim IncoMaputo Agreement endorsed by the governments of South Africa, Swaziland and Mozambique. Some of these, such as the development of new irrigation projects and dams could have an impact on the nutrient status of the basin.



COMPONENT 18

Predicted Future Eutrophication Related Water Quality At Sites Of Management Focus

PURPOSE

Generic catchment assessment context

A water quality CMS is aimed not only at current water quality issues, but also at issues that would arise from planned future water-related developments in the catchment. The information on water quality issues (**Component 14**), catchment management implications of those issues (**Component 15**), long-term resource water quality objectives (**Component 16**), future development scenarios (**Component 17**), the spatial discretisation of management units (**Component 19**) and configured decision support tools (**Component 9**), provides the foundation for analysing future water quality trends in space and time. The aim of this Component is to ensure that the development of management options does not only focus on the current issues, but is also informed by an understanding of potential future water quality outcomes in the catchment.

Eutrophication assessment context

Eutrophication management strategies or the eutrophication component of a catchment management strategy also needs to take into account how the current eutrophication status is likely to change in the future.

Purpose

The aim of this task is to predict the future eutrophication status at sites of management focus and to ensure that the management strategies are mindful of these potential changes in the catchment. The management strategy can be oriented to influence planned development processes to the advantage of nutrient management.

Prerequisite Components

Most Components from Tasks 1 to 4, as well as **Component 19** would inform this Component in various ways. Cross-referencing of the predicted water quality issues with catchment management implications analysed under **Component 15** is also important.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Guide to Water Quality Catchment Assessment Studies* lists three outputs; predicted water quality, issues identified from the predictions, and feedback to **Component 15** (Water quality issues).	Use appropriate predictive tools (**Component 9**) and potential future developments to predict the future water quality, evaluate these predictions against water quality requirements to identify potential water quality issues, and include these issues in the strategy development process.
Eutrophication assessment outputs	
Predicted time series, or order statistics, of eutrophication related constituents, at management unit level or at sites of management focus.	Estimate the future eutrophication status using appropriate modelling tools (**Component 9**) and possible development scenarios (future loadings, etc.). Sensitivity analyses should be performed in terms of all primary development assumptions.
Record of potential eutrophication issues derived from the predicted eutrophication trends.	Compile a record of potential water quality issues by evaluating the predicted trends against the water quality requirements, constituents of concern (**Component 5**) and the vision or objectives for the catchment (**Component 16**). Update the outputs of **Components 14** and**15**.

CHECKLISTS
The assessment should include expansion in: • *Urbanisation (increases in urban runoff, increases in wastewater discharges, etc.)* • *Dense informal settlements (increases in polluted stormwater runoff, etc.)* • *Industrial clusters (increases in effluent discharges)* • *Irrigation areas (increases in irrigation return flows, etc)* • *Large water resource and wastewater infrastructure developments (water availability, effluent discharges, new dams etc.)*
DISPLAY AND PRESENTATION OPTIONS
The display and presentation options described in **Components 6, 7** and **8** are applicable here.

COMPONENT 19
Eutrophication Related Management Units and Assessment of Spatial and Temporal Resolution

PURPOSE

Generic catchment assessment context

The NWA states that the CMS "...may be established in a phased and progressive manner and in separate components over time…" [*s8(3)(a)*]. This refers not only to variable timing of aspects of the CMS, but also to the spatial implementation. The CMS implementation can focus more intensely on some portions of a catchment and less so on others. This flexibilities are necessary to accommodate four realities about the catchment:

- *Urgency* - some issues and problems are more acute in some areas of the catchment and there is therefore a greater urgency to attend to these "stressed or threatened" areas.
- *Capacity* – the human and financial capacity to intervene is not limitless and a higher return on management intervention can be obtained by attending to the more urgent problems first.
- *Importance* – some river reaches are important water supply points and the sub-catchments upstream of these points warrant higher management investment.
- *Information availability* – in some catchments there may not be sufficient information to justify detailed interventions.

The outcome of a water quality catchment assessment study should be aligned to the management units that underlie the catchment management strategy development process.

In the document *Guideline for Determining Resource Water Quality Objectives (RWQOs), Allocatable Water Quality and the Stress of the Water Resource* (DWAF, 2006), guidance is given on how to delineate water resource management units. Due consideration should be given to ecoregion boundaries, the network of significant resources as specified in the National Water Resources Classification System, geohydrological response units, and the confidence required for setting resource water quality objectives.

Eutrophication assessment context

The process of identifying water quality management units is sufficiently generic that one would use the same considerations for identifying management units and spatial and temporal resolution for eutrophication assessment studies. The development of an eutrophication management strategy would probably be integrated with other water quality management strategies which provides impetus for having a single management unit.

Purpose

The purpose of this Component is to provide to the CMS process with a pragmatic but relevant spatial structure, and decisions on appropriate spatial and temporal resolutions for the WQ-CAS in each management unit which reflect the aforementioned four "reality checks".

Prerequisite Components

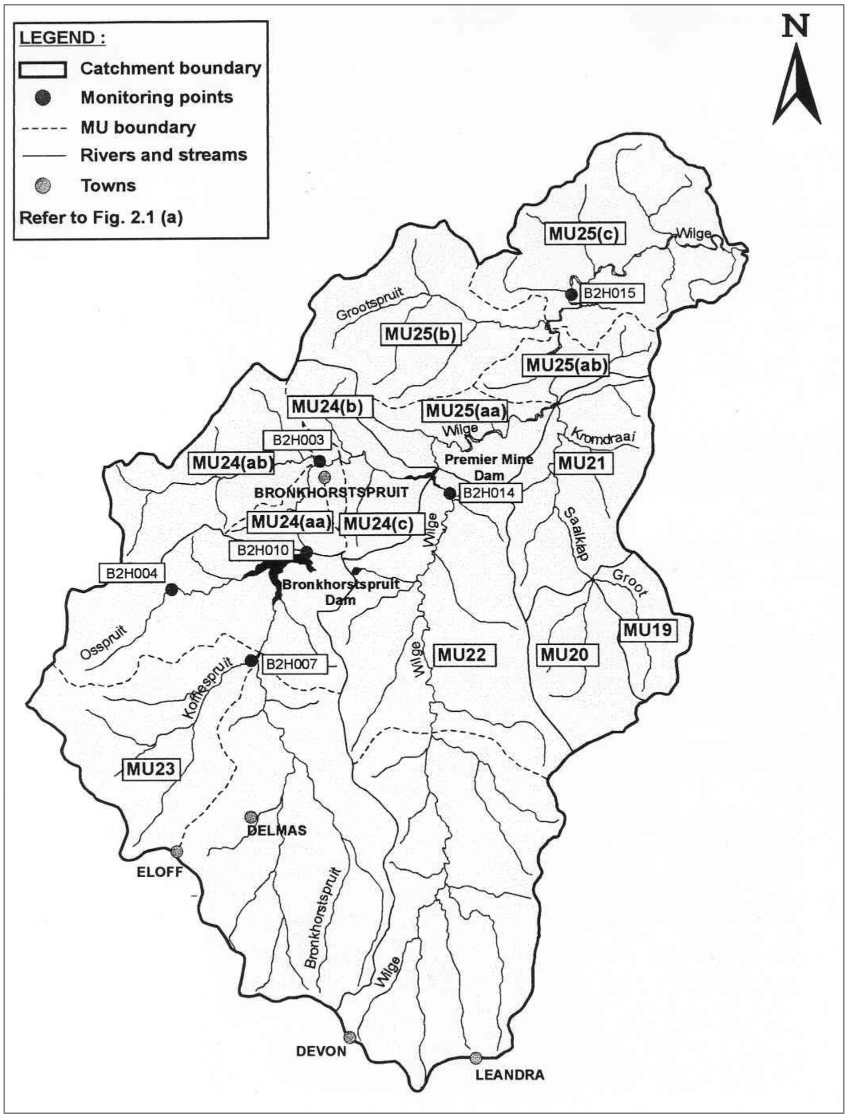
Component 0 and early versions of **Components 1, 3, 6, 7** and **8**.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
GIS maps of the study area showing the proposed management units, supported with brief descriptions of proposed management units and motivations for the delineations.	Use the criteria listed in the checklist below to delineate the proposed management units. This task may require further iterations as the overall catchment assessment study yields additional information.

<table>
<tr><td>Descriptions of the levels of detail appropriate for each management unit and motivations for each case.</td><td>Two levels of detail of the WQ-CAS are suggested:

Scoping-level: Broad indications, at the quaternary scale or coarser, of water quality issues and the relative importance of non-point and point sources, and provisional identification of the most important sources of either variety. This is the preferred initial level for all sub-catchments.

Evaluation/prioritisation level: Detailed quantification on a sub-area basis of priority point and non-point source impacts, and the key source types and areas requiring management. This is the preferred level only for those sub-catchments which are important existing water supply sources, which are known to be “water-stressed or threatened”, or where a scoping-level assessment indicates acute problems.</td></tr>
<tr><td colspan="2">Eutrophication assessment outputs</td></tr>
<tr><td colspan="2">Same as the generic catchment assessment outputs.</td></tr>
<tr><th colspan="2">SOURCES</th></tr>
<tr><td colspan="2">The Catchment Water Quality Assessment Guide lists examples of: scoping-level and evaluation-level catchment water quality assessment studies (refer to NSI, 1996a,b for examples) and an example of a water quality assessment framework (Pegram et al., 1997).
Also refer to DWAF (2006) for guidance on delineating water resource management units.</td></tr>
<tr><th colspan="2">CHECKLISTS</th></tr>
<tr><td colspan="2">Criteria that may be applied to identify particular management sub-catchments/ units:
• upstream of primary water supply points
• level of “water stress”
• upstream/downstream of critical water quality problem sites
• relatively low variability in bioclimatic and geophysical characteristics
• relatively pristine or relatively degraded (the particular water resource class)
• particular dominant user sectors or dominant land-uses.
• heterogeneity of the catchment, i.e. topography, land-use, geology, ecology, etc.
• spatial scale of available data and information</td></tr>
</table>

DISPLAY AND PRESENTATION OPTIONS
The following illustration shows the management units that were selected for the Wilge River Sub-catchment as part of the water quality situation assessment of the Loskop Dam catchment (DWAF, 2002). 

REFERENCES

Department of Water Affairs and Forestry (2002). *Water quality situation assessment of the Lopkop Dam catchment*. Development of an Integrated Water Resources Model of the Upper Olifants River (Loskop Dam) Catchment. Report No. PB B100/00/0898

Department of Water Affairs and Forestry (2006c). *Resource Directed Management of Water Quality: Management Instruments. Volume 4.2: Guideline for Determining Resource Water Quality Objectives (RWQOs), Allocatable Water Quality and the Stress of the Water Resource.* Water Resource Planning Systems Series, Sub-Series No. WQP 1.7.2, Edition 2. ISBN No. 0-621-36793-1. Department of Water Affairs and Forestry, Pretoria, South Africa.

NSI (1996a). *Preliminary Assessment*. Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0194. Pretoria.

NSI (1996b). *Pollution Sources*. Mgeni Catchment Management Plan. DWAF Report WQ U200/00/0193. Pretoria.

Pegram, G C, Görgens, A H M and Ottermann, A (1997). *A framework for addressing the information needs of catchment water quality management.* Water SA, Vol 23, No 1.

COMPONENT 20
Prioritised Eutrophication Management Options

PURPOSE

Generic catchment assessment context

A Water Quality Management Strategy entails the allocation of loads to different source sectors in order to meet the specified resource water quality management objectives. In order to give effect to the load allocations, Water Quality Management Plans are assembled that specify the management actions, responsibilities, resources and timeframes required to mitigate or remediate the water quality impacts associated with priority sectors/sources.

In order to allocate the loads between sectors/sources, information or estimates are required about the relative load contribution from each source type (or each large source), both for present day conditions and expected future developments. Furthermore, the relative differences in water quality outcomes of different management options which will enable these allocations to be achieved, need to be estimated. The purpose of this Component is to provide quantitative “what if” support for the development of the Water Quality Management Strategy and the Water Quality Management Plans, using the decision support tools of **Component 9**, and to provide support to the evaluation of the non-technical aspects of water quality management options

At this stage, catchment water quality assessment is strongly integrated with the strategy development process. There is so much overlap and iteration that for all practical purposes the two processes can be viewed as one. It is important to note that this Component is usually driven by the strategy development team and is not the direct responsibility of the assessment team.

The design and detailed analysis of individual water quality management actions are operational tasks and they do not usually form part of the catchment water quality assessment study. These operational tasks are usually undertaken by the sectors/sources or their consultants. It was recommended that the designers consult with the assessment study knowledge base, including its predictive tools, to ensure appropriate knowledge dissemination.

Eutrophication assessment context

For an eutrophication assessment study, this component provides the eutrophication strategy development process with quantitative modelling support to allocation of nutrient loads between sectors/sources for a given array of eutrophication management options. It also provides support for the qualitative assessment of the potential impacts of the eutrophication management options.

Purpose

The purpose of this Component is to provide quantitative “what if” modelling support variety for the development of the eutrophication management strategies and plans, using the modelling tools of **Component 9**, and to provide qualitative support to assess the non-technical aspects of the eutrophication management options.

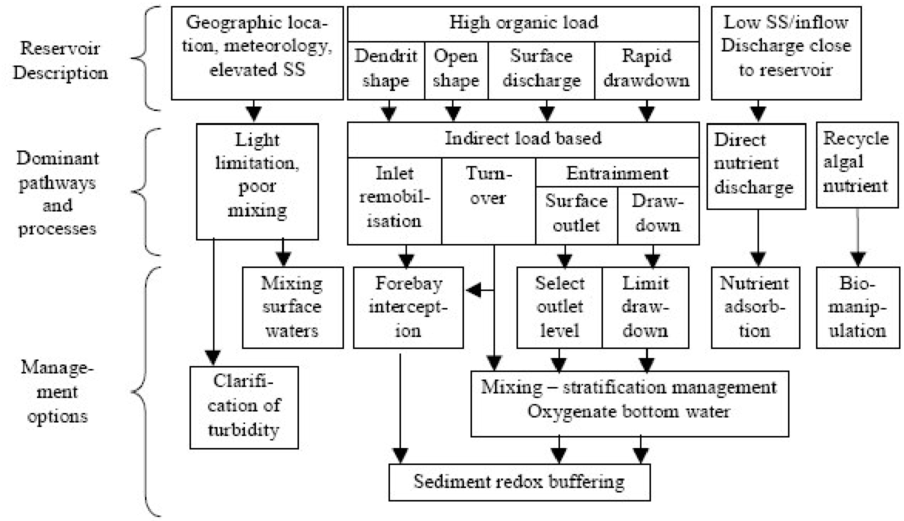
Prerequisite Components

All **Components** from **0** to **19** are prerequisites to this Component.

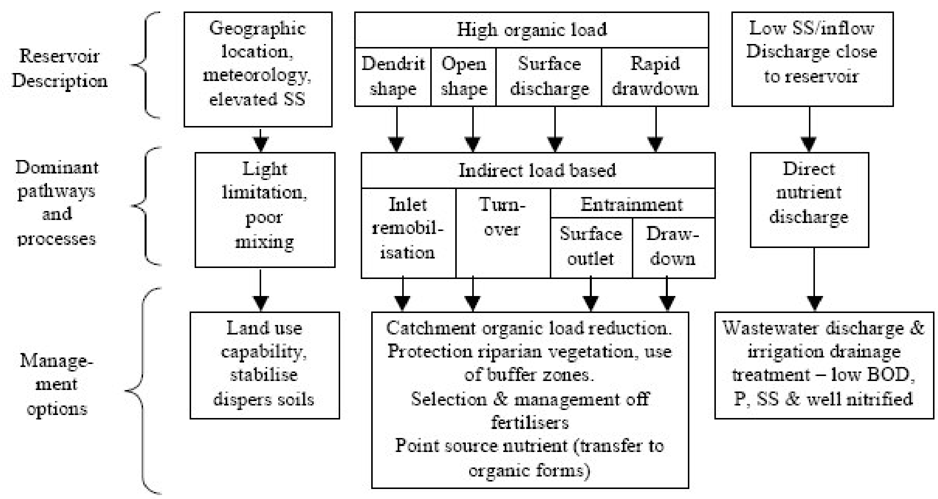
OUTPUTS	HOW TO ATTAIN OUTPUTS
Generic catchment assessment outputs	
The *Catchment Water Quality Assessment Guide* describes the outputs as (1) the predicted water quality load and concentration scenarios for the proposed management options, (2) an assessment of the viability of the management options, and (3) an inventory of the priority sources and their proposed management options.	Refer to the *Catchment Water Quality Assessment Guide* for guidance on how to attain the three outputs.

Eutrophication assessment outputs	
Predicted nutrient concentrations and loads resulting from the proposed eutrophication management options for particular sub-catchments or management units.	Apply the predictive eutrophication models and assessment tools produced in **Component 9**. Modelling can be undertaken at empirical or semi-empirical level, or at mechanistic level. Simpler empirical or semi-empirical predictions or qualitative assessments can be used in unstressed situations. A more mechanistic approach of accurate sector/source load estimates, based on detailed point and non-point source modelling (based on monitored data), would provide the best support for management decisions in stressed situations. The selection of assessment approach should be based on a trade-off between the resources required to use a particular technique and the increase in accuracy and reliability of the results. The process of identifying and evaluating eutrophication management options should also consider the effectiveness of an option to achieve the allocated load. This can be achieved by assessing the relative effectiveness of different eutrophication management options.
An assessment of the technical and operational viability of the proposed eutrophication management options.	The manageability must be estimated in terms of the: • background nutrient constituent concentrations, • the technical effectiveness of the management options, and • the social and economic impacts of those management options.
An inventory of priority nutrient sources and their proposed management options by management unit.	The prioritisation of largest sources or source areas of nutrients should receive priority for management intervention. However, those sources with the highest relative impact (e.g. per unit area or per capita loading) should also have a higher priority for management, because the interventions may be more effective in these areas. Similarly, the potential future impacts of these sources should be a major consideration, because these impacts may be more easily mitigated before they are fully realised.
SOURCES	
The following sources contain useful examples of management options that have eutrophication management components, formulated under particular management strategies: • *Plettenberg Bay Water Resources Management* (DWAF, 1999a). • *Catchment Management Strategy for the Modder and Riet Rivers - Situation Assessment and Draft Management Strategy*. (DWAF, 1999b) • *Mgeni Catchment Management Plan*. (DWAF/Umgeni Water, 1997) • *A Framework for Implementing Non-Point Source Management under the NWA*. (DWAF/WRC, 1999)	

Lawrence *et al*. (2000) developed a guideline for selecting reservoir management options to address eutrophication concerns. This decision tree considers the reservoir, the dominant pathways and processes and reservoir management options.



Lawrence *et al*. (2000) also developed a guideline for selecting catchment management options to address eutrophication concerns. This decision tree considers the reservoir, the dominant pathways and processes and catchment management options.



CHECKLISTS

Management focus areas:

- *point source discharges*, such as municipal wastewater, mining, industrial, manufacturing;
- *non-point source discharges*, such as irrigated agriculture, dry-land agriculture, urban runoff, dense settlements;
- *in-stream management*, including rehabilitation, minimum streamflows or operating rules.

Management approaches to nutrient management (refer to DWAF 2003 for a description of the current functional strategies and approaches to source management in South Africa):

- *Best practice* – these are established and effective processes and methodologies which are generally recognised as being the best available in the field of nutrient management and provides DWAF with a benchmark to test the performance of, for example, wastewater treatment plants. These are regarded as the minimum required from the regulated facilities.
- *Authorisations* – Water use authorisations are regarded as the primary instruments for source management. Full compliance with the existing authorisation conditions, for which RQOs would have been recognised according to the resource class.
- *Statutory controls* - Statutory controls on water use, including more stringent authorisation conditions (through area-specific general authorisation or licences), or compulsory licensing of relevant water quality based water users.
- *Waste discharge charge system* - Waste discharge charges used as an economic incentive to reduce loads to the required levels, together with the funding of direct interventions to implement technologies and practices, to manage loads from particular sources.
- *Co-operative incentives* - Non-statutory options, particularly co-operative governance and capacity building to improve the effectiveness of land-use and infrastructure management that has an impact on water quality and to change human behaviour to mitigate impacts.
- *Resource management* - In-stream management, through remediation of the water resource, reservoir system operation and/or ensuring adequate water quantity allocation to streamflow for dilution and assimilation of loads (possibly above the Reserve and RQOs).

Sectors and Source Types:

The DWAF source classification (DWAF, 2003) recognises five main sectors (mining, industry, agriculture, settlements and national infrastructure) and a threat level of high, medium and low. Sectors and sources that contribute to nutrient enrichment include:

- *Agriculture*: irrigated crops; dry-land crops; irrigated pastures; confined animal facilities, feedlots, livestock grazing.
- *Waste Disposal*: general solid waste; sludge disposal; effluent irrigation.
- *Food Processing*: canning; dairy-related processing; breweries, abattoirs.
- *Industry*: fertilizer related industries.
- *Mining:* phosphate mining.
- *Power generation*: coal fired power stations.
- *Municipal*: urban stormwater; wastewater treatment plants; informal settlements.
- *Transport*: highways and roads.

DISPLAY AND PRESENTATION OPTIONS

Table of Water Quality Management Options

Water quality management options can be summarized in a table. *The Plettenberg Bay Water Resources Management Study* (DWAF, 1999) provides a good example of how these may be summarized (see the extract below):

Keurbooms River Management Issues and Actions (Extracted from the original report)

Problem	Perceived problem	Concern	Technical data	Guidelines for applicable criteria	Possible solutions	Possible actions
Faecal contamination from cattle watering directly from the river	Y	Y	*E.coli* concentrations taken at Newlands between July 1996 and July 1998 50^{th} percentile = 35 80^{th} percentile 120 counts/100ml	*E.coli*: TWQR for full and intermediate contact recreation: 0-130, and 0-1000 counts/100ml respectively	Restrict cattle access	Fence grazing areas and restrict cattle from watering directly from the river
Impact of SAFCOL plantations on base flows	Y	Y	The % runoff reduction in the middle Keurbooms catchment as a result of plantations in approximately 2.5%	Reserve, still to be determined	Maintain natural riparian vegetation along streams and conservation programme	SAFCOL to improve their public image by educating the public regarding their efforts to minimize the impacts of plantations
Nutrient enrichment of river from fertilizer	Y	?	Avg PO_4 = 0.1 Avg NO_3 = 0.73 Avg NH_3 = 0.55	PO_4: Limit for eutrophication : 0.025 mg/l NO_3: Limit for eutrophication : 2.5 mg/l	Educate farmers Create incentives to reduce use of fertilizers Carry out mandatory independent soil evaluations at regular intervals	Undertake regular water quality monitoring Inform farmers through the forum regarding the impacts of nutrient rich irrigation return flows Investigate alternative irrigation practices

REFERENCES

Department of Water Affairs and Forestry (1999a). *Plettenberg Bay Water Resources Management. Part 1: Management Strategy.* Report by Sakaza and Ninham Shand to D: Water Quality Management, DWAF, Pretoria.

Department of Water Affairs and Forestry (1999b). *Catchment Management Strategy for the Modder and Riet Rivers. Phase 1: Situation Assessment and Draft Management Strategy.* Report by Ninham Shand to D: Water Quality Management, DWAF, Pretoria.

Department of Water Affairs and Forestry/Umgeni Water (1997). *Mgeni Catchment Management Plan.* Report WQM U200/00/0196 by Ninham Shand to DWAF, Pretoria and Umgeni Water, Pietermaritzburg.

Department of Water Affairs and Forestry/WRC (1999). *A Framework for Implementing Non-Point Source Management under the NWA*. WRC Report No TT 115/99 and DWAF Report No WQP 0.1, DWAF, Pretoria.

Department of Water Affairs and Forestry (2003). *Source management in South Africa* [online]. First Edition released for review and comment. Department of Water Affairs and Forestry, Pretoria. Available: http://www.dwaf.gov.za/dir_wqm/docsframe.htm

Lawrence, I, Bormans, M, Oliver, R, Ranson, G, Sherman, B, Ford, P and Schofield, N (2000). *Factors controlling algal growth and composition in reservoirs: Report of Reservoir Managers' Workshops January 2000*. National Eutrophication Management Program. Co-operative Research Centre for Freshwater Ecology.

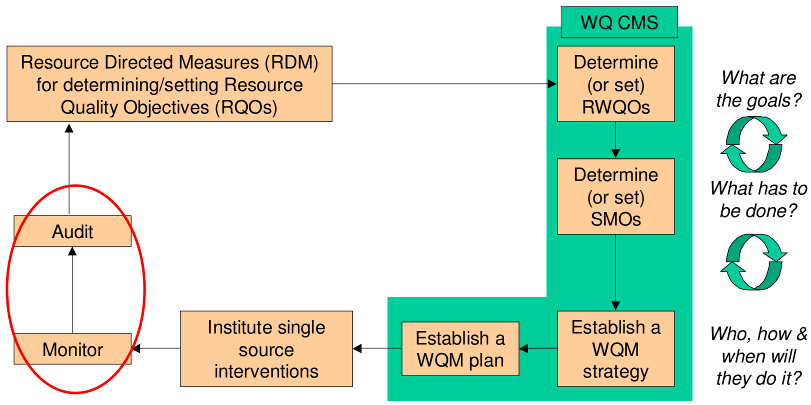
COMPONENT 21

Monitoring and auditing the implementation of eutrophication management strategies

PURPOSE

Catchment water quality assessment context

Although monitoring and auditing is not strictly viewed as part of a catchment water quality assessment study, it closes the loop because it re-informs the catchment assessment study of how the water quality status has changed as a result of management interventions (as illustrated below).



RWQO = Resource Water Quality Objective
SMO = Source Management Objective
WQ CMS = Water Quality Ctachment Management Strategy
WQM = Water Quality Management

Water quality monitoring is the planned, systematic collection of water quality data through a series of repetitive measurements. In this instance, a monitoring programme is specifically designed to collect data that can be used to review the effectiveness of water quality management strategies and plans.

Auditing water quality is a 'once-off' picture of the current water quality status. It involves the organisation and interpretation of water quality data to establish a record of change associated with the implementation of a water quality management option. It is a process to determine if the management strategy and plans are meeting the set performance limits (or resource water quality objectives).

Eutrophication assessment context

Monitoring and auditing the implementation of eutrophication management strategies is not a focus of an eutrophication assessment study. As with a generic water quality assessment, the objective is to determine if eutrophication management strategies and plans are having the desired effect. Monitoring refers to systematically collecting data on the causes (e.g. nutrient concentrations) and effects (e.g. *chlorophyll-a* concentrations, algal species composition) and using the data at regular intervals (e.g. yearly, 5 yearly) to assess if eutrophication management plans are having the desired effect of reducing nutrient concentrations or algal biomass.

Purpose

The purpose of this section is to describe an approach to monitoring progress with the implementation of eutrophication management options to rehabilitate eutrophied water resources and meet eutrophication goals or objectives.

Prerequisite Components

To undertake this Component, most of the preceding Components should be completed or implementation of strategies and plans should be well advanced.

OUTPUTS	HOW TO ATTAIN OUTPUTS
Water quality assessment outputs	
The *Catchment Water Quality Assessment Guide* describes two performance assessment outputs, one aimed at meeting operational objectives and one aimed at meeting strategic management goals.	Refer to the *Catchment Water Quality Assessment Guide* for a description of how to assess the present status and trends against operational and strategic goals.
Eutrophication assessment outputs	
Performance assessment - Meeting operational nutrient and algal management objectives.	Assess compliance with short-term operational management goals using nutrient and algal monitoring data collected for that purpose. Graphically and statistically compare the monitoring results of key eutrophication indicators with the management goals to assess whether management goals have been met during the review period.
Performance assessment - Meeting strategic management goals.	Review the medium to long-term trends in key eutrophication indicator variables to assess how long-term water quality is changing in relation to long-term management goals. Examples of statistical methods to assess water quality trends are described in Ward *et al*. (1990) and Harris *et al*. (1992).
METHODS AND TOOLS	
Statistical analysis of the water quality data Water quality data must be processed before statistical trends or comparisons over time can be made. Outlying values must be identified and dealt with, and data must be adjusted for missing values, non-detects, laboratory duplicates and field replicates.	Methods for pre-processing data can be found in Harris *et al*. (1992).
Independence of observations Statistical analysis should be done on independent observations.	Water quality taken at short intervals (daily or weekly) can be serially correlated, i.e. each observation repeating part of the information contained in the previous observation. Monthly observations should be used for analyses. Methods to derive independent samples are described in Harris *et al*. (1992).
Trend analysis It is difficult to detect a significant trend with less than 5 years of data if significant seasonality is present. Seasonality occurs when one part of the year tends to produce consistently higher or lower values that other parts of the year.	Significant seasonality should be removed from the data before trend analysis can be done. For more than 5 years of data, monthly box-and-whisker plots can be used to detect seasonality. For less than 5 years of data, quarterly box-and-whisker plots can be used. The Kruskal-Wallis test, at the 90% confidence level, can also be used to test for seasonality. For data sets longer that 5 years, the seasonal Kendall test can be used to detect long-term trends (Harris *et al*., 1992). For data sets less that 5 years, the seasonality must first be removed and the Kendall Tau test can then be used to detect a trend.

Assessing changes after implementation of management options To determine whether there has been a change in water quality after a management option has been implemented; two statistical tests can be used.	For same size data sets, the Wilcoxon signed rank test (Harris *et al*., 1992) can be used to determine whether the medians over the two data sets are similar. For data sets of unequal size, the Mann-Whitney or the Wilcoxon Rank Sum test (Harris *et al*., 1992) can be used to assess whether the medians of the two data sets are different. The data needs to be deseasonalised before the comparison is made.
Software for statistical analysis of water quality data	*General statistical software packages* Statistica - http://www.statsoft.com/ SAS: http://www.sas.com/ Statgraphics - http://www.statgraphics.com/ *Custom designed water quality statistical software* WQStat Plus - http://idt.nicusa.com/wqstats/wqstats.html

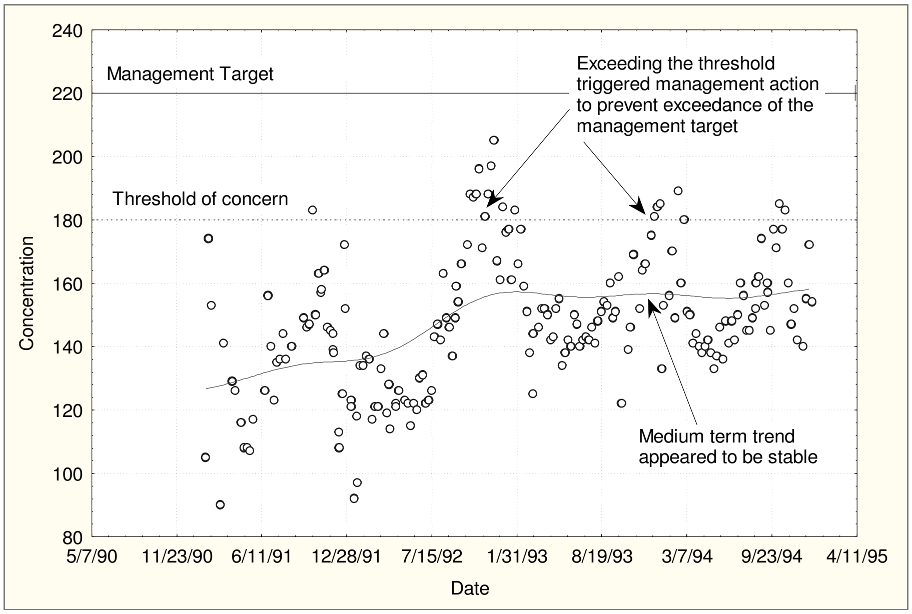
SOURCES	
Management information system	Water Resource Management Institution (Catchment Management Agency or the DWAF Regional Office)
National, provincial, local and other data sources	Potential data sources were identified in **Component 11**.

CHECKLISTS
Use the constituents of concern identified in **Component 5** and the variables used for setting resource water quality objectives.

DISPLAY AND PRESENTATION OPTIONS

Meeting operational management goals

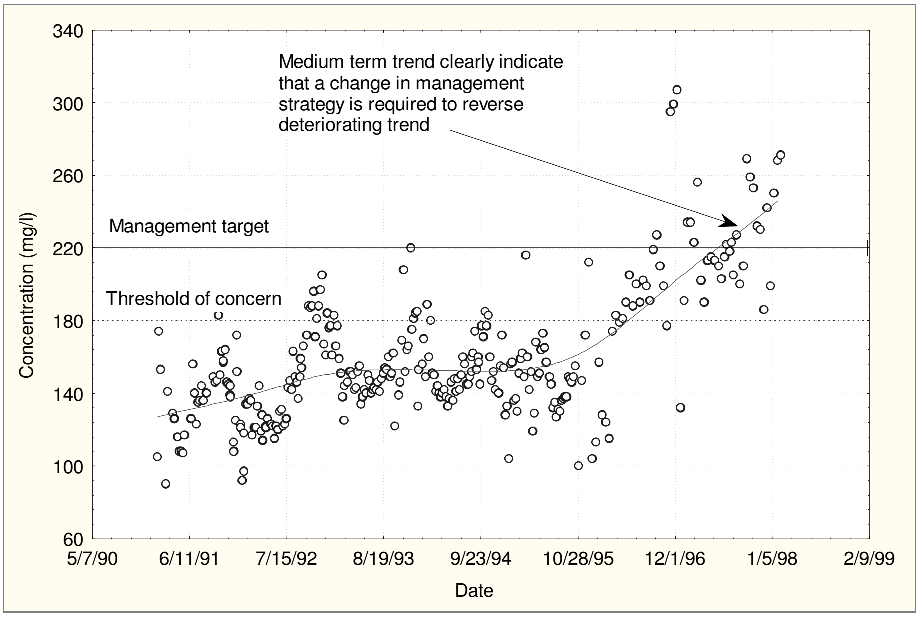
Monitoring the implementation of an eutrophication strategy involves setting a management target (which may be an interim resource water quality objective) to be maintained and setting a Threshold of Concern[5] value or early warning value. The Threshold value is a trigger for management intervention if water quality exceeds the threshold value and is a function of the response time of the catchment to management actions. The present water quality is compared to these two values on a continuous basis to determine whether corrective action is required. The medium term trend is evaluated when a water quality audit is undertaken. In the example below, no change in management strategy is required because the trend appears to have stabilised.



[5] This concept is similar to the water quality management model developed by Van Veelen (2002) who used the words "Target range", "Monitor range", "Action range" and "Intervention range" to describe a range of management situations that arise with deteriorating water quality.

Meeting strategic management goals

The medium term trend is tracked as part of the process to audit whether strategic eutrophication management goals are met. If the trend changes negatively and short-term eutrophication management actions do not reverse the trend, the overall eutrophication management strategy may need to be updated to reserve the situation (illustrated in the graph below).



REFERENCES

Harris, J M, van Veelen, M and Gilfillan, T C (1992). *Conceptual Design Report for a National River Water Quality Assessment Programme.* Water Research Commission. Report No. 204/1/92

Van Veelen, M (2002). The development of principles and procedures for the establishment of water quality objectives for aquatic systems and their application on the Jukskei River system, Gauteng. PhD Thesis. Rand Afrikaans University.

Ward, R C, Loftis, J C and McBride, G B (1990). *Design of Networks for Monitoring Water Quality.* Van Nostrand Reinhold, New York, NY, USA 231pp.