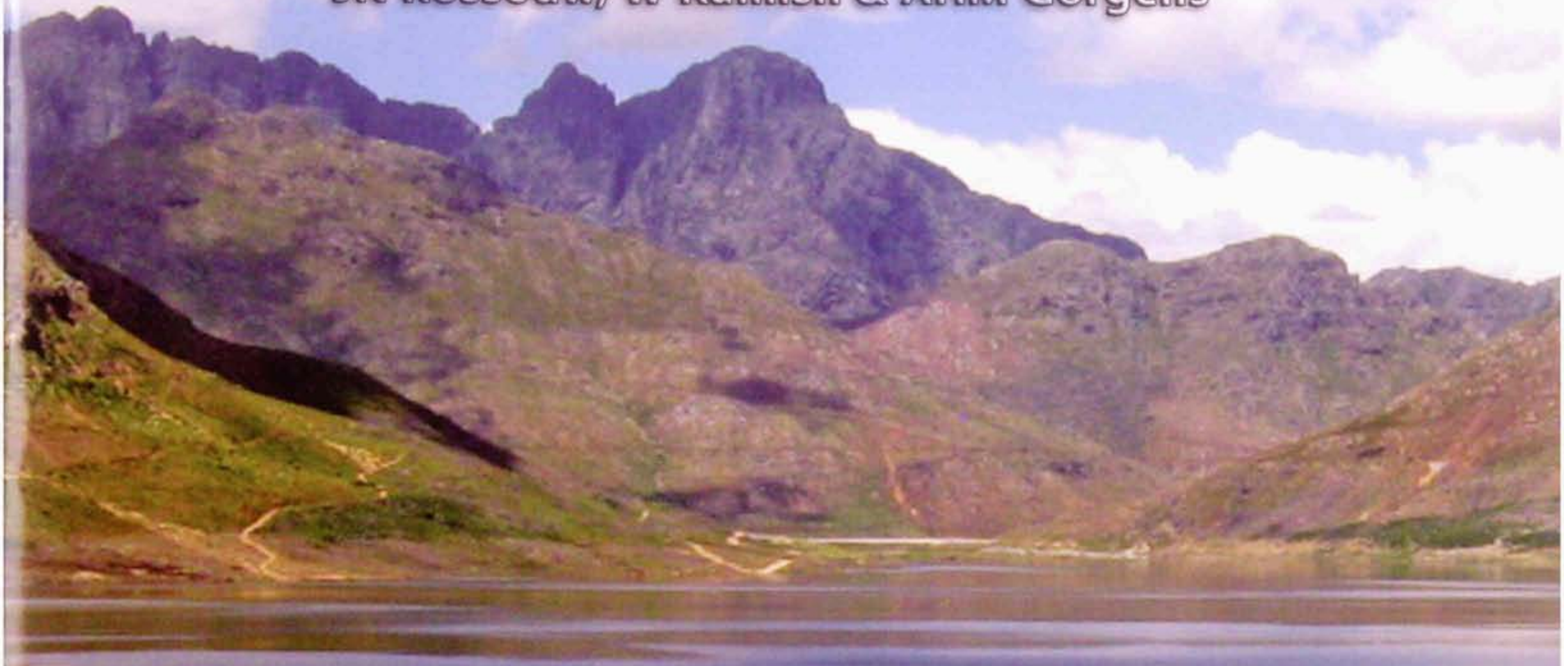
Technical Instruments to Support WATER QUALITY USE ALLOCATION

JN Rossouw, W Kamish & AHM Görgens



TT 363/08

Water Research Commission

TECHNICAL INSTRUMENTS TO SUPPORT WATER QUALITY USE ALLOCATION

JN Rossouw, W Kamish, & AHM Görgens

Report to the
Water Research Commission

by

Ninham Shand Consulting Services

WRC Report No. TT 363/08

October 2008

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031
Republic of South Africa

The publication of this report emanates from a project entitled: *"Development of Technical Guidelines under the NWA through Application of the Berg River Water Quality Information System"* (WRC Project No K5/1310).

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ISBN 978-1-77005-653-4
Set No. 978-1-77005-651-0

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

INTRODUCTION

Background to the study

The National Water Act (NWA) prescribes the minimum components of a catchment management strategy and prime amongst these are the formulation of water allocation principles and a Water Allocation Plan for each Water Management Area. This Project was proposed to focus on a very particular part of the allocation challenge, namely the allocation of "Water Quality Use". Intuitively, allocation may be associated with water quantity, but a significant innovation of the NWA is that it defines "water use" very broadly - amongst others to include the use of the resource to dispose of waste. The complexity of point and non-point delivery and transport processes that determine the water quality constituent loads in a catchment, the relatively poor water quality databases and the role that statutory Resource Quality Objectives are required to play in water resource management (WRM) (Section 13 of the NWA) all indicated that a focused research effort was required to unpack the conceptual and technical components of the water quality part of the allocation challenge.

An objective of the project was to effect a process of "learning-by-doing" by applying the framework in a stressed catchment with water quality concerns. For this purpose, the ACRU*salinity* model was applied to the Berg River catchment because it also offered a ready-made water quality information system (WQIS) previously developed under a Water Research Commission (WRC) Project. However, resolving technical problems during the ACRU modelling phase expended most of the project resources and the team had to forgo the critical testing of the water quality use allocation framework.

Aims of the project

The project objectives as formulated in the Agreement with the Water Research Commission, were:

- Develop a conceptual framework for water quality use allocation procedures, and
- Develop and disseminate Technical Guidelines for water quality use allocation procedures.

Research outputs

The research outputs from this project were two reports:

- Rossouw, J.N., Kamish, W. and Görgens, A.H.M. (2007). *Technical Instruments to Support Water Quality Use Allocation.* WRC Report No. K5/1301/1/07, Water Research Commission, Pretoria. **(This report)**
- Kamish, W., Rossouw, J.N., Görgens, A.H.M. and Clark, F. (2007). *Improvements to the ACRUsalinity model and upgrading of the Berg River Water Quality Information System.* WRC Report No. K5/1301/2/07, Water Research Commission, Pretoria.

REVIEW OF INTERNATIONAL BEST PRACTICE IN WATER QUALITY USE ALLOCATION

Objective

The conceptual review of international best practice in water quality use allocation procedures focused on reviewing the approaches and technical support required to implement these in the USA, European Union, and in Australia.

Australia

Australia is a commonwealth of states; the Commonwealth sets strategies and policies at a national level, and the state and territory governments develop implementation strategies and policies at state level to meet national goals and objectives.

A number of initiatives were reviewed:

- The National Water Quality Management Strategy that consisted of three key elements, namely policies, processes, and guidelines for water quality management,
- The National Action Plan for Salinity and Water Quality that was specifically developed to address severe salinity problems. Implementation of this strategy in the Murray-Darling Basin was specifically reviewed, and
- Use of market-based instruments in water quality management - the Hunter River Salinity Trading Scheme that was an example of trading salinity discharge allocations.

United States of America

Water quality management in the USA is rooted in the Clean Water Act. One of the provisions of the Act required all states to identify their impaired streams and to develop and implement Total Maximum Daily Loads (TMDLs) for those streams to halt and restore it to an unimpaired state. The TMDL process was reviewed to understand the key elements of the programme.

It was recognised that the core of a TMDL is usually a model that estimates the relationships between the water body, the pollutant sources, and/or the alternatives for loading reduction. Better water quality modelling was identified as among the most significant of all the TMDL-related scientific needs and five aspects were identified that needed urgent attention:

- Applied modelling technical support
- Development of models of appropriate complexity
- Filling gaps in model application
- Public domain model acceptance
- Training in modelling

A further recommendation was that better guidance should be given to the development of allocations and methods to translate allocations into implementable control actions.

It was concluded that the TMDL approach appeared to have a lot in common with the Resource Quality Objectives approach described in the South African National Water Act.

European Union

Water legislation aimed at ensuring water of an acceptable quality in the European Union (EU) is accomplished through the issuing of directives which member states have to comply with. Examples of directives dealing with water quality issues include (European Commission, 2003):

- Water Framework Directive (2000/60/EC)
- Urban Waste Water Treatment Directive (91/271/EEC)
- Discharges of Dangerous Substances Directive (76/464/EEC)
- Nitrates Directive (91/676/EEC)
- Drinking Water Directive (98/83/EC)

The Water Framework Directive was reviewed. The directive requires the setting of water quality objectives to meet, as a minimum, a good environmental status for EU Rivers. The directive required the signatories to comply by December 2003 and not much information could be obtained about how the total load on a system would be allocated to individual contributors. The administrative procedures to implement river basin management were largely left to the discretion of Member States.

In Denmark, for example, models are used to support integrated river basin management. Models are widely used by water authorities and these vary from very simple empirical models, up to fully dynamic models of lakes, rivers, groundwater and estuaries). For example, *empirical models* are used to make high-level decisions about the potential benefits of restoration projects. *Dynamic water quality models* are widely used in Danish water administration, in particular for water level or flood prediction applications that also require water quality assessments. Dynamic models are generally used to investigate specific water quality issues such measures to mitigate diffuse pollution and in-river nutrient retention. Empirical models are used as a first order estimate to short-list viable management options at coarser spatial scale and dynamic models are then used to assess specific management interventions, often at a finer spatial scale.

Common elements in international best practice of water quality use allocation

There were a number of common elements in the international approaches that were reviewed:

- Water quality standards or management objectives – water quality standards or water quality management objectives served as the departure point for allocating constituent loads that would not infringe on those targets.
- Identification of impaired water bodies – in many approaches the identification of impaired rivers or river reaches acted as the catalyst for specific actions. The level of impairment often dictated the level of effort expended or resources allocated to restore the impaired water body.
- Load allocations estimated at large scale to meet standards or targets – water quality targets were often set as end of catchment targets and total load allocations were then determined to meet those targets without necessarily apportioning the loads to specific contributors.
- Upstream/downstream dependencies taken into account – in

setting end of catchment, upstream/downstream dependencies were often taken into account because the targets may restrict certain upstream activities in order to protect the water quality of certain downstream users.

- Procedures supported by models with appropriate levels of complexity – models of differing complexity support the process. It appears that coarse scale models support the process of setting end of catchment while more complex models are used when considering management actions at a smaller geographic scale.

SOUTH AFRICAN WATER RESOURCE POLICIES THAT HAVE A BEARING ON WATER QUALITY USE ALLOCATION

The process of water resources management

The process of water resources management described in the National Water Act was reviewed. The class and resource quality objectives for a water resource provides the foundation for making decisions about the allocation of water and the allocation of allocatable water quality for the discharge of water containing waste.

Water quality component of a catchment management strategy

The Department developed a set of guidelines for the development of the water quality component of a catchment management strategy. A Water Quality Use Allocation Plan will be developed as part of a catchment water quality management strategy. This strategy sets the goals for water quality management in a catchment. The National Water Resource Classification System provides the *resource quality objectives* (RQOs) for a water resource. *Resource water quality objectives* (RWQOs) are derived from these, taking into account the requirements of users and use of the resource to dispose of water containing waste. This forms the foundation for determining the *source management objectives* (SMOs). The next step is to decide how SMOs will be managed across a water management area by formulating a *water quality management framework-plan.* A Water Quality Allocation Plan is one of the components of such a framework-plan.

Water allocation planning

The framework for water allocation planning was designed to address three broad scenarios:

- Catchments where water is freely available for the foreseeable future
- Catchments which are exhibiting some signs of stress and where licence applications may exceed the remaining available resources
- The compulsory licensing situation, i.e. closed or soon to be closed catchments

The complexity of the allocation process, and supporting technical tools, increased as the level of stress increased. The processes clearly point towards a two-tiered approach to water allocation in those cases where compulsory licences are required; the first tier being undertaken at a strategic level and focusing on water use sectors, and the second tier focusing on individual users and local impacts.

Source management

The document, *Source Management in South Africa* provides a detailed description of the development of a Source Management Plan (SMP) at a regional/Catchment Management Agency (CMA) level. It describes the steps that should be followed to develop a SMP and provides a guide for selecting the most appropriate source management instrument for different sectors.

Resource directed management of water quality

The document, *Resource Directed Management of Water Quality*, provided a guideline which describes a practical, consistent approach to the determination of RWQOs, by integrating the results of Catchment Vision, Resource Classification and Reserve, and water user requirements to develop RWQOs. It also provides definitions and practical tools for deriving RWQOs for different levels of water quality stress in a catchment.

National Water Resource Classification System

A National Water Resource Classification System (NWRCS) was still under development at the time of preparing this report. However, some of the concepts that were emerging from the development were used to inform the development of a water quality allocation framework. It transpired that the need to take upstream/downstream dependence into account and the need to evaluate alternative scenarios could only be addressed if simple, strategic level analytical tools or models were available to support decision making in the classification process.

CONCEPTUAL FRAMEWORK FOR WATER QUALITY USE ALLOCATION PROCEDURES

Guiding principles

The *technical components* of a Water Quality Use Allocation plan should be guided by the following principles:

- Precautionary principle approach
- Integrated and holistic approach
- Due consideration given to alternative options
- Carrying capacity
- Equity and fairness
- Simplicity

Principles that have more to do with the *process* being followed were briefly described in the main report.

Regulatory environment

The sections of the National Water Act that have a bearing on water quality use allocation planning were reviewed to determine the statutory requirements of the Act.

Technical support for water quality use allocation

The degree of technical support for Water Quality Use Allocation was dependent on the degree of water quality stress in the catchment. Three scenarios are envisaged:

- a water quality unstressed situation (i.e. water quality is still ideal to acceptable)
- a potentially water quality stressed situation (i.e. water

quality is tolerable but approaching a poor, status)
- A water quality stressed situation (i.e. water quality is poor)

In a **water quality unstressed** situation, simple tools can be used to support the water quality use allocation process. These tools could entail an inventory of the sources and their loads, per water resource management area, combined with simple mass balance models with conservative assumptions that could be used to allocate loads to individual sources, and to verify if source management objectives and resource water quality objectives were not exceeded.

In a **potentially water quality stressed** situation, the technical support required would be more complex. Allocation scenarios need to be considered at a coarse catchment scale in order to consider upstream/downstream dependencies and impacts. This would entail a simple coarse scale catchment model (no smaller than quaternary catchment scale) and a temporal scale that is equivalent to the water resource planning models commonly used in South Africa. The model needs to accommodate loads from point as well as non-point sources and the models should be calibrated against observed water quality data.

In a **water quality stressed situation**, two tiers of support are required:
- *First tier support* - a simple coarse scale catchment water quality model as described above. The coarse scale catchment model should be set up for the whole catchment.
- *Second tier support* - a finer scale model, set up for complex and problematic sub-catchments or river reaches. The fine scale model would only be set up for specific areas (quaternaries or river reaches) where disaggregation of loads to individual users, or site specific estimates of the water quality impacts, are required. The model would be more deterministic and typically focus on non-conservative substances. The temporal scale would be daily or sub-daily.

Technical Guidelines for water quality use allocation

The following guidelines were proposed to support water quality use allocation:

- **Focus on water quality variables of concern** - water quality use allocation and the tools designed to support the process should focus on the water quality variables of concern.
- **Two tiers of modelling support** - in order to promote efficiency, two tiers of decision support should be applied to water quality load allocations. The decision whether only the first tier or both tiers are appropriate should be based on the level of water quality stress in the catchment or in specific water resource management units. In an unstressed and potentially water quality stressed situation, coarse scale tools would be appropriate to allocate loads to sectors. In a water quality stressed situation, coarse scale tools should be used for allocating loads to sectors within sub-catchments, and finer scale models should be used in

complex sub-catchments to disaggregate the sector allocations to individual users.

- **Link to water resource planning tools** - the coarse scale models should be compatible with water resource planning models, in terms of its spatial and temporal scale.
- **Application of good modelling practices** - modelling and data preparation procedures should be consistent with good modelling practices.
- **Rapid scenario development and evaluation** - the water quality allocation support tools should facilitate the rapid development and evaluation of waste load allocation scenarios.
- **User-friendly model outputs and stakeholder communication** - the tools to support water quality use allocation are technically quite complex and the tools being used should be selected not only according to their ability to produce user-friendly output which the water quality modeller can interpret but also according to their ability to produce output that can be used in interactions with institutional stakeholders.

CONCLUSIONS AND RECOMMENDATIONS

Water quality use allocation framework

The degree of technical support for water quality use allocation is dependent on the degree of water quality stress in a catchment and sub-catchment. The need for higher confidence decision-making increases as the degree of water quality stress increases and the complexity of technical support tools need to mirror this. In a water quality unstressed catchment, simple management oriented tools would be sufficient. However, in a potentially water quality stressed catchment; a coarse catchment scale water quality model would be required. In a water quality stressed catchment, a coarse catchment scale water quality model is required for sector level allocations, and a fine scale river reach or reservoir model is required to support individual allocation decisions at a fine spatial scale.

This approach is aligned with policies that seek to find pragmatic solutions to water quality management and only increases the complexity of the decision-making process and support tools when the situation in the catchment justifies it.

Recommendations

The following research needs have been identified to support water quality use allocation:

Modelling research needs – there is a need for a simple, catchment scale model that can be used for the first tier of water quality use allocations. Such public-domain models should interface with water resource planning models so that the water quality modelling can use the flow simulations that would form the basis of the Water Use Allocation Planning process. There is specifically a need for credible catchment scale models that can simulate nutrients and microbial water quality (non-conservative constituents).

Allocation of loads to individual sources – there is a wide range of methods for allocating constituent loads to individual dischargers. There is a need to investigate which of the methods is appropriate to South Africa given the primary objectives of equity and sustainability embedded in the National Water Act.

Appropriate export coefficients – there is a need to develop export coefficients and/or loading functions for different South African land-uses in order to estimate coarse scale non-point source pollution loads at a quaternary catchment scale. Despite the advances in research on complex physically based models for nutrient transport, the export coefficients approach still plays an important role in regional and catchment scale management.

Uncertainty analysis – there is a need to incorporate uncertainty analysis into the water use allocation process. Decisions would often be taken in a data sparse environment. There is a need to build uncertainty analysis into the modelling processes that would account for the uncertainty or inherent errors in the data and model calculations.

ACKNOWLEDGEMENTS

The research in this report emanated from a project that was undertaken by the Water Research Commission, entitled:

Development of Technical Guidelines under the NWA through Application of the Berg River Water Quality Information System

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 A H M Görgens	Ninham Shand Consulting Services
Mr A S Roux	Department of Agriculture
Dr D van Driel	Scientific Services, Cape Town City Council
Prof A Rooseboom	Sigma Beta
Mr P Viljoen	Department of Water Affairs and Forestry
Mr J van Wyk	Department of Water Affairs and Forestry
Mr P van Niekerk	Department of Water Affairs and Forestry
Mr F Stoffberg	Department of Water Affairs and Forestry
Ms M Kunneke	Department of Water Affairs and Forestry (Western Cape)
Dr G R Cooper	Department of Agriculture

The following persons who have contributed their knowledge and insights to the project also attended Steering Committee meetings on an *ad hoc* basis.

Dr W P de Clercq	University of Stellenbosch
Dr S Lorentz	University of KwaZulu-Natal
Prof MV Fey	University of Stellenbosch
Mr G McConkey	Department of Water Affairs and Forestry (Western Cape)

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ACRU	Agricultural Catchment Research Unit
BPEO	Best Practical Environmental Option
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CRC	Cooperative Research Centre (Australia)
CSIRO	Council for Scientific and Industrial Research Organisation (Australia)
CWA	Clean Water Act (USA)
DHI	Danish Hydraulics Institute
DLWC	Department of Land and Water Conservation (Australia)
DWAF	Department of Water Affairs and Forestry
EMSS	Environmental Management Support System (Australia)
EU	European Union
IWRM	Integrated Water Resource Management
LA	Load Allocation (USA)
MC	Management Class
MOS	Margin of Safety (USA)
NWA	National Water Act
NWQMS	National Water Quality Management Strategy (Australia)
NWRCS	National Water Resource Classification System
NWRS	National Water Resource Strategy
RDM	Resource Directed Measures
RQO	Resource Quality Objectives
RWQO	Resource Water Quality Objectives
SDC	Source Directed Controls
SMO	Source Management Objectives
SMP	Source Management Plan
TMDL	Total Maximum Daily Load (USA)
USA	United States of America
USEPA	United States Environmental Protection Agency
WFD	Water Framework Directive (EU)
WLA	Waste Load Allocation (USA)
WMA	Water Management Area
WQIS	Water Quality Information System
WRC	Water Research Commission
WRM	Water Resource Management

1 INTRODUCTION

1.1 Background to the study

The implementation of the National Water Act (NWA) (Act No. 36 of 1998) is gradually unfolding at both the national scale and at the catchment scale across South Africa. The NWA provides a statutory framework for integrated water resource management (IWRM) at the catchment scale through two tiers of interlinked water resource management (WRM) strategies:

- A National Water Resource Strategy (NWRS), which provides a large-scale planning framework, procedures and guidelines to ensure that water deficits or poor water quality do not arise on a regional basis at the scale of declared Water Management Areas (WMAs) and that international water sharing obligations are met, and
- Catchment Management Strategies (CMSs) inside Water Management Areas (WMAs), which ensure sustainable, equitable and optimal water resource utilisation at the catchment scale with due ecological protection of the resource and with full participation by stakeholders and affected communities.

The NWA prescribes the minimum components of the CMS and prime amongst these are the formulation of water allocation principles and a Water Allocation Plan for each WMA (Section 9). However, for individual catchments in which water "stress" (water supply deficits or unacceptable water quality) exists or is threatened, or where redress of past discrimination in terms of water use is urgently needed, the NWA requires the compulsory re-allocation of water, followed by compulsory licensing on the basis of elicited licence applications (Sections 43-47).

No compulsory re-allocations have hitherto been undertaken, even though the initial screening of catchments has indicated a number of catchments which fall in that category. At the time the project was proposed, no deep understanding existed of what would constitute best practice procedures in the water allocation process. From the Department of Water Affairs and Forestry (DWAF) Strategic Plan for the period 2001-2005, it was envisaged that the earliest compulsory licensing that was foreseen would be during 2004. Therefore, in the project proposal, a case was made that time was available to engage in a learning process to develop adequate understanding of what the compulsory re-allocation and licensing procedures would entail both in a technical IWRM context and in a participatory WRM context.

This Project was proposed as such a learning process, but focused on a very particular part of the allocation challenge, namely the allocation of "Water Quality Use". Intuitively, allocation may be associated with water quantity, but a significant innovation of the NWA is that it defines "water use" very broadly - amongst others to include the use of the resource to dispose of waste (Section 21). At the time this project was initiated, allocation procedures based on "water quantity use" of the resource was under development by the DWAF, but the same could not be said for allocation procedures of the "water quality use" of the resource. The complexity of point and non-point delivery and transport processes that determine the water quality constituent loads in a catchment, the relatively poor water quality databases and the role that statutory Resource Quality Objectives are required to play in WRM (Section 13 of the NWA) all indicated that a focused research effort was required to unpack the conceptual and technical components of the water quality part of the allocation challenge.

To ensure that this learning process was rooted in reality, it was the intention of the project to effect a process of "learning-by-doing" in a stressed catchment with water quality concerns. For this purpose the Berg River catchment in the Western Cape offered an opportunity because it was stressed, had serious water quality problems, and it offered a ready-made water quality information system (WQIS) developed at the University of Stellenbosch under WRC Project No 951.

The WQIS comprised all the components, bar one, needed to support the quantification of specific water quality constituent loads needed for a Water Quality Use Allocation exercise at the catchment scale. The lacking component was a daily catchment simulation model with which the impacts of human land-use and system operation could be linked to hydrodynamic river flow simulations.

The daily agro-hydrological model, ACRU, is such a daily catchment simulation model and it was configured and calibrated for the Berg River basin (Kamish, 2006). The latest version of the ACRU model was incorporated in this Project and interfaced with the existing WQIS. However, configuration and calibration of the model proved to be very resource intensive because several errors were discovered during the application that had to be resolved by the developers of ACRU. As a result, there were insufficient resources to apply the model and WQIS system to the Berg River system to realise the goal of "learning-by-doing". That component of the project was therefore terminated.

1.2 The overall objectives of the project

The project objectives, as formulated in the Agreement with the Water Research Commission, were:

- to develop a conceptual framework for water quality use allocation procedures, and
- to develop and disseminate Technical Guidelines for water quality use allocation procedures

The first objective of the project was met and is described in this document. The second objective was partly met. Technical Guidelines for water quality use allocation procedures were proposed in this document but due to problems encountered during the application of the ACRU model (Kamish and Clarke, 2006) – the guidelines could not be applied and evaluated in the Berg River catchment as originally envisaged.

1.3 Description of the research products

In the original proposal two research products were envisaged for this Project:

- Technical Guidelines for Water Quality Use Allocations under the NWA

- Extended version of the Water Quality Information System for the Berg River

The project yielded two deliverables in the form of reports:

- Rossouw, J.N., Kamish, W. and Görgens, A.H.M. (2007). *Technical Instruments to Support Water Quality Use Allocation.* WRC Report No. K5/1301/1/07, Water Research Commission, Pretoria **(this report)**
- Kamish, W., Rossouw, J.N., Görgens, A.H.M. and Clark, F. (2007). *Improvements to the ACRUsalinity model and upgrading of the Berg River Water Quality Information System.* WRC Report No. K5/1301/2/07, Water Research Commission, Pretoria.

The approach to water quality use allocation and Technical Guidelines for its implementation are described in this report. The target group for the guidelines is officials at the DWAF and at CMAs involved in integrated water resource management, as well as professional practitioners that provide technical support services in the field of water resources management.

The application of the ACRU model to the Berg River and the development of an updated version of the Water Quality Information System for the Berg River is described in Kamish and Clarke (2006). The updated WQIS for the Berg River system can provide support to officials of the Western Cape Regional Office of the DWAF and the future catchment management agency of the Berg Water Management Area as well as professional practitioners that supply support services in the field of water resources management.

1.4 Methodology

The objectives of this project required a multi-disciplinary research effort, combining intensive conceptual development work, discussions with WRM stakeholders, development of databases and the implementation of related visualisation software, Geographic Information Systems (GIS) applications, simulation modelling and development of Technical Guidelines. The Project comprised three primary components in the form of overlapping phases: the first relating to the conceptual development of the Water Quality Use Allocation Framework; the second relating to the quantification tools and information for support to, and testing of, the Conceptual Framework; and the third relating to the recording and dissemination of the learning acquired in this project. It should be noted that the project was of a purely technical nature and did not embrace the public participation processes and stakeholder prioritisation procedures that should accompany a full-blown allocation exercise under the NWA.

The three overlapping project phases were:

- Phase 1: Conceptual Framework for Water Quality Use Allocation Procedures
- Phase 2: Quantification of all Water Quality Use Allocation Components for the Berg River Catchment through implementation of the existing Berg River Water Quality Information System
- Phase 3: Preparation and dissemination of the Guidelines for Water Quality Use Allocation Procedures

The activities that were envisaged and subsequently undertaken during each phase are described below.

Phase 1: Conceptual Framework for Water Quality Use Allocation Procedures:
The following Phase 1 activities were anticipated at the onset of the project. An opinion is also expressed on what was accomplished by the project team:

- Review of conceptual development work and applications undertaken in other studies related to the implementation of the NWA and, specifically, the Allocation and Compulsory Licensing processes provided for in the Act, as well as international best practices in this context (*fully completed*)
- Formulation of a draft Conceptual Framework, including provisional principles for Water Quality Use Allocation, and review of the draft Framework (*fully completed*), and
- Refinement of the draft Conceptual Framework after the Quantification Processes of Phase 2 has reached an advanced stage and endorsement of the refined Conceptual Framework through a suitable Workshop environment (*partly accomplished, updated after presentation of the Conceptual Framework to a stakeholder workshop*)

This report is the deliverable on this component of the project.

Phase 2: Quantification of all Water Quality Use Allocation Components for the Berg River Catchment through implementation of the existing Berg River Water Quality Information System:
The following Phase 2 activities were anticipated for this component of the project:

- Updating the existing Water Quality Information System (WQIS) developed for the Riviersonderend-Berg River system to encompass about 10 years of recent time series data, with a particular focus on daily streamflows and salinity and phosphates as key water quality variables (t*his activity was abandoned to focus resources on ACRU modelling*).
- Collaboration with the Department of Soil and Agricultural Water Science at the University of Stellenbosch to ensure development of suitable salinity algorithms for the daily ACRU catchment model and appropriate configuration of the modified ACRU model for the Berg River catchment, which that Department undertook as part of a WRC project on dryland salinisation (WRC Project No 1342). (*ACRU modelling task reformulated with permission from the Reference Group, refer to Kamish et al. (2007)*).
- Creation of an interface between the output of the modified ACRU model and the WQIS so that the WQIS could be used as the primary visualisation tool for the outcome of ACRU operations (c*ompleted*).
- Using the extended and updated WQIS to quantify water quality loads for salinity and phosphates at suitable locations in the Berg River system for a range of catchment development scenarios, and testing the application of the Conceptual Framework for Water Quality Use Allocation across the range of scenarios (*cancelled due to budget constraints*).

- Refining the Framework using water quality loads for salinity and phosphates (*cancelled due to budget constraints*).

The report, *Improvements to the ACRUsalinity model and upgrading of the Berg River Water Quality Information System* (Kamish *et al.*, 2007) is the deliverable for this component of the project.

Phase 3: Preparation and dissemination of the Guidelines for Water Quality Use Allocation Procedures.
The following activities were envisaged for the third phase of the project:

- Recording all learning acquired during the previous two Phases and formulating a set of draft Technical Guidelines for Water Quality Use Allocation Procedures under the NWA, within the context of the Conceptual Framework developed in Phase 1 *(partly accomplished, approach and guidelines were refined based on feedback from stakeholders*)
- Reviewing the draft Guidelines by a suitable Reference Group (*partly accomplished, guidelines reviewed by members of the project reference group*), and
- Disseminating the final Technical Guidelines to the professional WRM operational and support community and organised water user sectors (*partly accomplished, dissemination through distribution of this WRC report to reference group members and interested parties*)

The outcome of these activities was integrated into this report.

1.5 Layout of the report

The remainder of the report consists of the following chapters:

Chapter 2 describes the review of international practices in approaches to waste load allocation and key lessons that could be incorporated into a framework for water quality use allocation. The practices in Australia, the USA and the European Union were reviewed to identify the common elements in their approaches and to identify the similarities with policies and approaches to water quality use allocation being developed in South Africa.

Chapter 3 describes the review of policies and approaches developed or still under development in South Africa that have a bearing on water quality use allocation. Policies and guidelines that were reviewed included guidance for developing the water quality component of a catchment management strategy, the proposed approach to water use allocation, policy statements on source management in South Africa, resource directed water quality management, and early indicators of the key elements of the National Water Resource Classification System.

In **Chapter 4** a conceptual framework for water quality use allocation procedures are developed and Technical Guidelines are presented for water quality use allocation.

The report concludes with **Chapter 5** which provides a brief discussion of the key findings of the study, draws some conclusions from those and makes recommendations on future research needs in the field of water quality use allocation.

2 REVIEW OF INTERNATIONAL PRACTICE IN WATER QUALITY USE ALLOCATION PROCEDURES

2.1 Introduction

In order to develop technical guidelines for water quality use allocation procedures, a number of tasks were undertaken:

- A review was done of conceptual development work and applications undertaken in other studies relating to the implementation of the NWA and, specifically, the Allocation and Compulsory Licensing processes provided for in the Act, as well as international best practices in this context,
- A draft Conceptual Framework was formulated, including provisional principles for Water Quality Use Allocation, and reviewed, and
- The draft Conceptual Framework was presented, workshopped and refined with key stakeholders on the 6th of October 2005.

The results of these reviews, and framework and guideline formulations are presented in the following sections.

The focus of this component was specifically on the development of a *technical* framework and guidelines rather than on a procedural framework. In the study, note was taken of procedures developed or being developed at the DWAF in order to understand the *context* within which technical assessments and support would be required. The project therefore focused on the technical support required to allocate water quality use.

The conceptual review of international best practice in water quality use allocation procedures focused on reviewing the approaches and technical support required to implement these approaches in the United States of America (USA), European Union (EU) and Australia. A review was also undertaken of the current views in the DWAF, of policies and protocols being developed with regard to Water Allocation Plans, the Compulsory Licensing processes, and other relevant developments to support implementation of the National Water Act.

2.2 Australia

Australia is a commonwealth of states and as such has two top levels of governments; the Commonwealth that sets strategies and policies at a national level, and the state and territory governments who develop implementation strategies and policies at state level to meet national objectives. The same is true for water quality management.

2.2.1 National Water Quality Management Strategy (NWQMS)

The Australian National Water Quality Management Strategy was introduced in 1992 as a response to concerns about the country's water bodies and the need to manage these in an environmentally sustainable way (ANZECC, 1994, Environment Australia, 2003). The strategy has three main elements:

- Policies – the policy objective is to "achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development".
- Process – the process involves communities working with the government to set (and achieve) local environmental and water quality objectives for water bodies and to develop management plans for catchments, aquifers, etc. State and Territory governments are responsible for implementing the NWQMS and developing policies that reflect the preferences of its communities.
- Guidelines – guidelines developed under the NWQMS cover issues over the whole water cycle and include guidelines for ambient and drinking water quality, monitoring, groundwater, stormwater, sewerage and effluent management for specific industries. Nineteen guidelines documents have been developed when this review was done and two are under development.

Implementation of the NWQMS takes place at state, regional and local levels and states have developed State Water Quality Management Strategies (Western Australia, 2001).

The approach to setting local environmental and water quality objectives appears to have a lot in common with South Africa's Resource Quality Objectives approach.

2.2.2 National Action Plan for Salinity and Water Quality

Salinity is a particularly severe and urgent problem in Australia and a National Action Plan for Salinity and Water Quality was developed and endorsed in 2000 at the Council of Australian Governments (Commonwealth of Australia, 2002). The purpose of the Action Plan is to identify “high priority, immediate actions to address salinity, particularly dryland salinity, and deteriorating water quality in key catchments and regions across Australia”.

The plans call for, amongst others, states and territories to set targets and standards for salinity, water quality and associated flows, and stream and terrestrial biodiversity. Integrated catchment management plans must then be developed where immediate action will result in substantial progress towards meeting the state/territory targets to reverse the spread of dryland salinity. Twenty catchments have been identified as high priorities for implementation of the National Action Plan for salinity and water quality.

An example of the implementation of the National Action Plan at a catchment level is the Basin Salinity Management Strategy 2001-2015 that was developed by the Murray-Darling Basin Commission (Murray-Darling Basin Commission, 2001). The strategy refers specifically to salinity credits and debits and setting end-of-basin and end-of-valley salinity targets. The Murray-Darling Basin Ministerial Council is responsible for whole-of-basin outcomes and states are responsible for within-valley outcomes. A key feature of the strategy is the adoption of salinity targets for each tributary and for the whole basin. The whole basin target is to maintain salinity at less than 800 µS/cm for 95% of the time at a reporting site near the downstream boundary of the basin. Interim targets have also been developed for the different tributaries. These targets were based on statistical analysis of historical concentrations and salt loads and the period 1975 – 2000 was used as the climatic benchmark for the analysis of historical data. The tributary targets were then expressed as a percentage of the median, the 95th percentile (or 80th percentile for tributaries) and the average salt load.

The plan describes four levels: assigning salinity credits or debits to all major actions; annual reporting of progress of works and measures; five-yearly audits of impacts on river salinities; and a review of the strategy itself. The plan also refers to the use of models to assess the effect of actions using an agreed climatic/hydrologic sequence or benchmark period. Specific models are not mentioned in the plan although a CSIRO publication refers to a joint project with the Co-operative Research Centre (CRC) (Australia) for Catchment Hydrology to develop a tool for catchment scale prediction of water quality and salt loads (CSIRO, 2002) called EMSS – Environmental Management Support System Tool.

The EMSS predicts daily runoff, and daily loads of total suspended sediment, total nitrogen and total phosphorous from different sub-catchments, and routes these through a river and reservoir network. The model predictions are sensitive to changes in climate, land-use and land management practices, including point and diffuse-source loadings and treatments. The EMSS is deployed in a GIS-like environment on a personal computer (PC) and has been designed for use by a range of stakeholders with varying levels of computer and technical proficiency. Three separate component models underpin the EMSS, including (i) a lumped-conceptual rainfall-runoff and pollutant export model, (ii) a flow and pollutant routing model, and (iii) a model of reservoir storage dynamics (Vertessy, 2002). The model has been used to model the South-East Queensland Region.

2.2.3 Hunter River Salinity Trading Scheme

An example of trading salinity discharge allocations is the Hunter River Salinity Trading Scheme in New South Wales. The objective of the scheme is to manage saline water discharges from mines and power stations in the catchment in order to minimise the impacts on irrigation and domestic users as well as the aquatic ecosystem (NSWEPA, 2002).

Flows in the river are divided into blocks. A block is a body of water that is predicted to pass a specific gauging station in a 24-hour period. The block is classified as Low (no discharge allowed), high (discharges allowed using tradable credits) or Flood (no volume discharge unless limited by licence conditions).

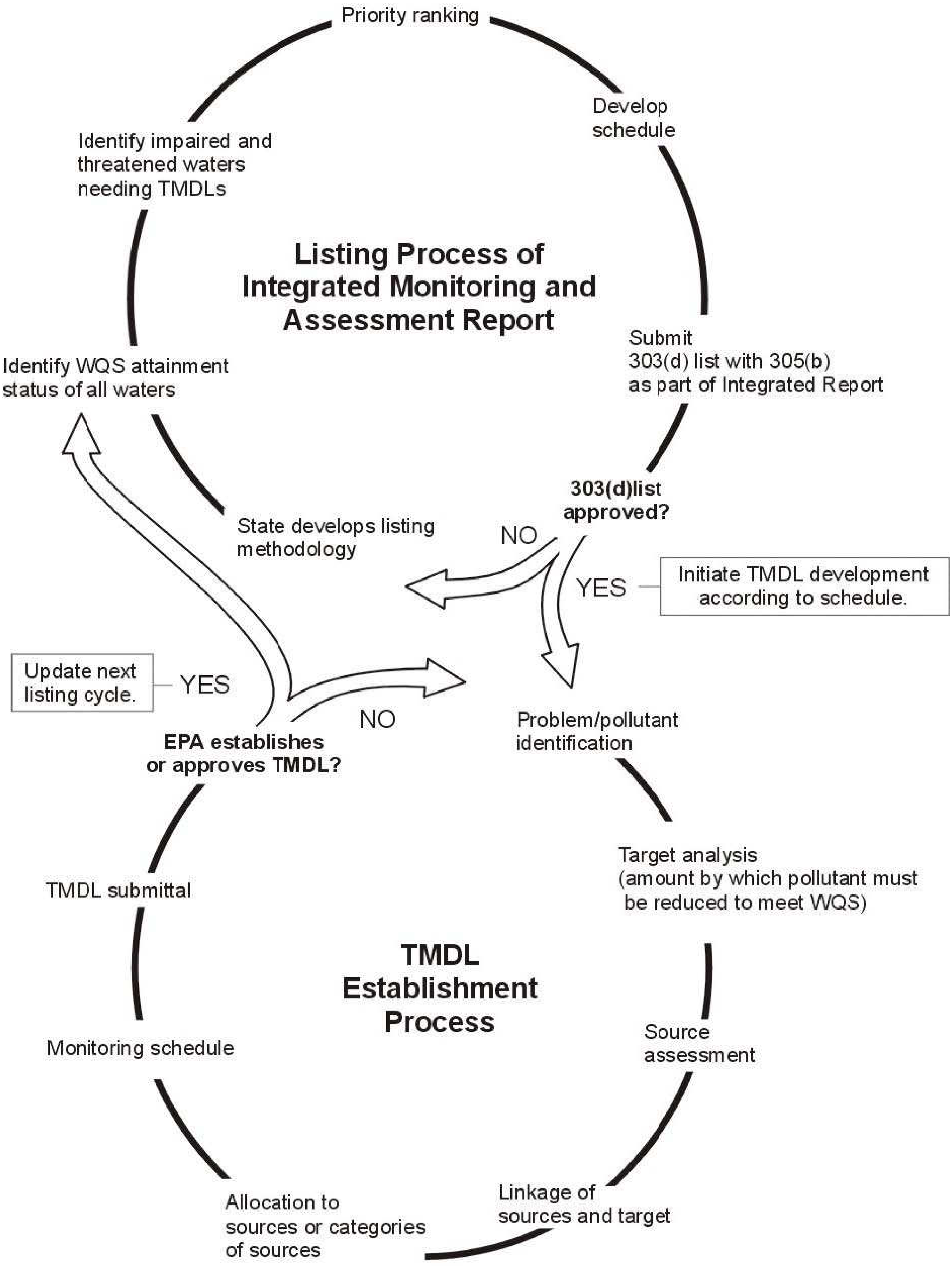
During high flow, participants can discharge a share of the total allowable discharge on each block according to the number of shares that they hold. There are only 1000 credits and one credit gives a holder the ability to discharge 0.1% of the daily total allowable discharge of salt to a block of water. Credits can be traded between participants using an online facility so that holders that do not need to discharge can sell their entitlements to others with a greater need. During high flow, the Department of Land and Water Conservation (DLWC) calculates the total allowable discharge of salt that will keep the river below the objective of 900 µS/cm. Each participant is then entitled to discharge a share of the total salt mass according to the number of salt credits that they hold. The credit holder can then choose to use their credits to authorise their own discharge or they can trade them with others who want to use them. Trades can be permanent or temporary.

2.3 United States of America

Water quality management in the USA has its roots in the Clean Water Act (CWA). In 1972, the Federal Water Pollution Control Act Amendments were enacted in response to growing concerns about the control of water pollution. After amendments in 1977, the law became known as the Clean Water Act which has undergone a number of revisions since the seventies (USEPA, 2003).

One of the provisions of the Act required all states to identify their impaired (or about to become impaired) streams and to develop and implement Total Maximum Daily Loads (TMDLs) for these streams to halt and restore it to a specified state. This requirement was not enforced, largely because it was difficult to enforce. However, in recent times a large number of lawsuits compelled the United States Environmental Protection Agency (USEPA) to again focus on the TMDL requirements of the Clean Water Act (Martin and Kennedy, 2000). The steps to identify and list impaired waters and to develop TMDLs for the impaired ones are illustrated in **Figure 1:** Diagram showing the process of identifying impaired waters (top loop) and developing TMDLs for the impaired ones (bottom loop). TMDL = Total Maximum Daily Load, WQS = water quality standards (on next page) .

Impaired Waters Listing and TMDL Establishment Processes



A TMDL is an estimate of the maximum amount of a given pollutant that a water body can assimilate without violating water quality standards. It is expressed as

$$TMDL = \sum WLA + \sum LA + MOS$$

where WLA is the waste load allocation, the portion of the load allocated to existing or future points sources, LA is the portion of the load allocated to existing and future non-point sources and the natural background, and MOS is a margin of safety (**Figure 1**).

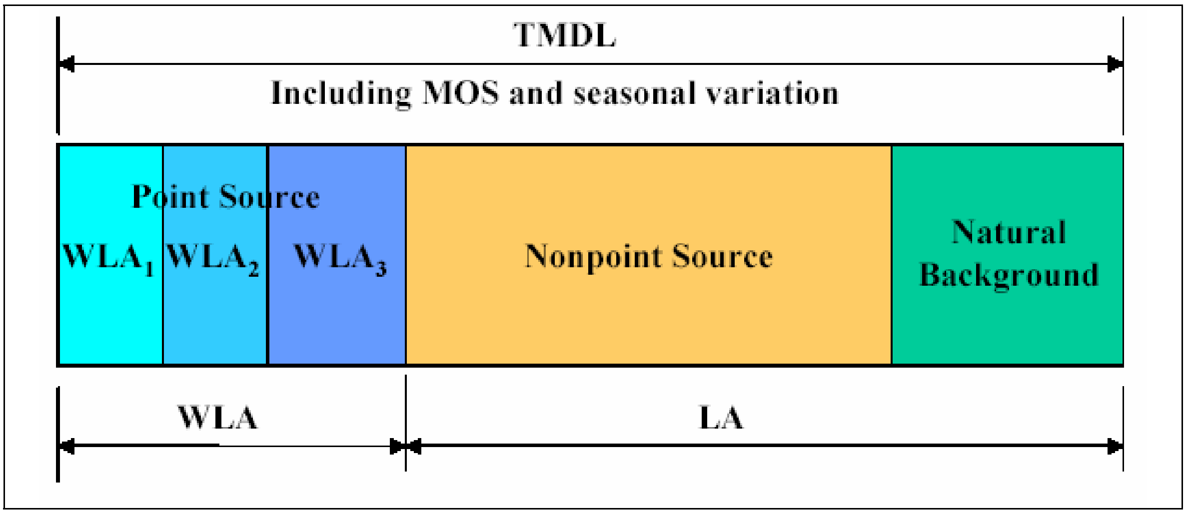


Figure 1 Diagram showing the components of a TMDL

One additional component for determining the allowable load is temporal changes, i.e. when the loading can occur without violating the water quality criteria. This is done by identifying the critical condition or "reasonable worst case scenario". For dissolved oxygen, the critical condition is taken as low flow summertime condition (typically the 7Q10 flow which is the 7-day mean flow with a 10 year recurrence interval).

Once a TMDL has been determined for a worst case condition (e.g. low flow conditions for salinity or high flow conditions for sediments), the loads can then be allocated between point, non-point and natural background loadings. There are no guidelines for allocating the load between contributing sources although the USEPA recommends a fair distribution of control costs to allocate loads to individual sources (USEPA, 2002a). Other examples of allocating loads between sources include equal percentage overall removal, equal percentage incremental removal, equal cost per mass of pollutant removal, and minimum total compliance cost (Chadderton *et al*., 1981).

It was recognised that the core of a TMDL is usually a model that estimates the relationships between the water body, the pollutant sources, and/or the alternatives for loading reduction (NRC, 2001, USEPA, 2002b). Better water quality modelling was identified as among the most significant of all the TMDL-related scientific needs identified in a review of the TMDL approach to water quality management (NRC, 2001). In order to meet this need, five aspects were identified that needed urgent attention:

- Applied modelling technical support – the report makes a case for establishing a technical support centre, such as the Centre for Exposure Assessment Modelling that used to be housed in Athens, GA, to provide technical support to model users, to maintain modelling tools and if necessary, provide modelling services.
- Development of models of appropriate complexity – the report argued that models of low to moderate complexity should be developed and that this would meet the needs of states better, especially for routine applications.
- Filling gaps in model application – existing models do not make provision for all the pollutants of concern. It was also felt that there was a special need for models that link stressors to biological responses.
- Public domain model acceptance – the report argued that public domain models should be maintained, especially those frequently used by states.
- Training in modelling – all the reviewers recommended more widespread modelling training for state and regional staff of the USEPA.

A further recommendation of the report was that better guidance should be given to the development of allocations and methods to translate allocations into implementable control actions. The reason is that the allocation process considers different combinations of allocations to meet the TMDL. Socio-economic considerations add a new dimension to deciding on the best allocation.

In summary, the TMDL approach appears to have a lot in common with the Resource Quality Objectives approach of the National Water Act. South Africa can learn a lot from the problems experienced in implementing TMDLs in the USA and can leapfrog some of the obstacles by taking note of recommendations that have been made to improve the implementation of the TMDL program.

2.4 European Community

Water legislation aimed at ensuring water of an acceptable quality in the EU is accomplished through the issuing of directives which member states have to comply with. Examples of directives dealing with water quality issues include (European Commission, 2003):

- Water Framework Directive (2000/60/EC)
- Urban Waste Water Treatment Directive (91/271/EEC)
- Discharges of Dangerous Substances Directive (76/464/EEC)
- Nitrates Directive (91/676/EEC)
- Drinking Water Directive (98/83/EC)

2.4.1 EU Water Framework Directive

The directive that appears to provide the best indication of how the EU may deal with water quality allocations is the EU Water Framework Directive (WFD) (2000/60/EC) (European Union, 2003). Member states were required to comply with the directive by December 2003. The framework aims to achieve four objectives of a sustainable water policy:

- Sufficient provision of drinking water

- Sufficient provision of water for other economic requirements
- Protection of the aquatic environment, and
- Alleviation of the adverse impacts of floods and droughts

The following are key features of the framework:

- Co-ordination of administrative arrangements within river basin districts – Article 3 of the directive requires member states to manage rivers on the basis of river basins rather than administrative or political boundaries. It requires that a river basin management plan be established and updated every six years.
- Environmental objectives – Article 4 of the directive requires that protection of the aquatic environment should apply to all waters. Requirements for ecological protection and minimum chemical standards were introduced for all surface waters. "Good ecological status" was defined in terms of the quality of biological communities, hydrological and chemical characteristics. "Good chemical status" was defined in terms of compliance with standards for chemical substances.
- Other uses – objectives for other uses such as bathing waters and drinking water sources are set on a site-specific basis.
- Combined approach for point and diffuse sources – the approach to managing point and non-point sources are combined. The first step is to establish objectives for a river basin. The next step is to examine the human impacts (identify all the sources of contamination) and determine if the objectives are met. If existing legislation can solve violations then the objectives of the directive are met. If not, additional measures must be designed and implemented to ensure compliance with objectives.
- Strategies against pollution of water - Co-ordination of pollution control measures – historically a number of approaches to pollution management have been implemented in member countries, some dealt with best available technology for source control, others with receiving water quality objectives. The directive now requires a combined approach and as a first measure, all source based controls to be implemented. The next step is to set new overall objectives of a good status for the water bodies and ensure that these are met even if it requires additional source control measures.

In summary, the directive requires the setting of water quality objectives to meet, as a minimum, a good environmental status for EU Rivers. The directive requires the signatories to comply by December 2003 and not much information could be obtained about how the total load on a system would be allocated to individual contributors. The administrative procedures to implement river basin management are left to the discretion of Member States.

2.4.2 Modelling decision support

Organisations in the EU have always been at the cutting edge of developing good models for water resources decision-making. Organisations like Delft Hydraulics, HR Wallingford and Danish Hydraulics Institute (DHI) have developed excellent models that are used to simulate complex river systems. The only constraint to using these models has been the fact they are propriety models and the cost of obtaining them is often very high. However, these models generally have very good user interfaces and tools to support the preparation of input data and for the examination of the model output.

The EU framework directive does not provide any guidance on the tools to be used in setting objectives and managing towards these objectives.

Dørge and Windolf (2003) describe the use of models to support integrated river basin management in Denmark. Models are widely used by water authorities and these vary from very simple empirical models, up to fully dynamic models of lakes, rivers, groundwater and estuaries. For example, *empirical models* for nutrient runoff and retention in freshwater systems have been developed using data collected from all over Denmark. Water authorities, for example, use these models to make high-level decisions about the potential benefits of restoration projects. *Dynamic water quality models* such as the MIKE systems (e.g. MIKE 11, MIKE SHE, MIKE RESERVOIR) developed by the DHI are also widely used in Danish water administration, in particular for water level or flood prediction applications that also require water quality assessments. These models require data on the natural characteristics of the basin (e.g. topography and land cover, rainfall and evaporation, etc.) and basin characteristics that are subject to human intervention (e.g. land-use changes, point sources, agricultural practices, etc.). Dynamic models are generally used to investigate specific water quality issues such measures to mitigate diffuse pollution and in-river nutrient retention. It appears that empirical models are used as a first order estimate to short-list viable management options at a higher scale and dynamic models are then used to assess specific management interventions, often at a finer spatial scale.

2.5 Summary of common elements in the international practices

There appears to be a number of common elements in the approaches that were reviewed:

- Water quality standards or management objectives – water quality standards or water quality management objectives that were set for a specific river reach or geographic area served as the departure point for allocating constituent loads that would not infringe on targets.
- Identification of impaired water bodies – in many approaches the identification of impaired rivers or river reaches acted as the catalyst for specific actions. The level of impairment often dictated the level of effort expended or resources allocated to restore the impaired water body.
- Load allocations estimated at large scale to meet standards or targets – water quality targets or standards were often set as end of catchment or end of sub-catchment targets. Total load allocations were then determined to meet those targets without necessarily breaking the apportioning of the loads to specific contributors. That was often viewed as part of the management action required to meet the targets as was the setting of interim management targets within catchment to aid the management of individual point and non-point sources.
- Upstream/downstream dependencies taken into account – in setting end of catchment or end of sub-catchment targets, upstream/downstream dependencies were often taken into account because the targets might have restricted certain

upstream activities in order to protect the water quality of certain downstream users. It was also recognised that upstream of a point where a water quality target had been set, there had to be a balanced mix of protected sub-catchments and these sub-catchments where developments were allowed which might use up some of the total allowable load,

- Procedures supported by models with appropriate levels of complexity – models of differing complexity supported the process. It appears that coarse scale models supported the process of setting end of catchment or end of sub-catchment targets while more complex models were used when considering management actions at a smaller geographic scale.

3 SOUTH AFRICAN WATER RESOURCE POLICIES THAT HAVE A BEARING ON WATER QUALITY USE ALLOCATION

3.1 The Process of Water Resources Management

The process of water resources management described in the National Water Act (Act 36 of 1998) is illustrated in its simplest form in **Figure 2**.

In principle, **Figure 4** illustrates that the class and resource quality objectives of a water resource provides the foundation for making decisions about the allocation of water and the allocation of assimilative capacity for the discharge of water containing waste. The spirit of the National Water Act is encapsulated in the National Water Resource Strategy (NWRS), published in September 2004 (DWAF, 2004).

The process that is illustrated in **Figure 2** is clearly not that simple. Provision is also made in the NWRS for compulsory licensing in those catchments experiencing water stress. Compulsory licensing is not a simple act of issuing licences but a complex process of closely related and interdependent activities (**Figure 3**) (DWAF, 2003b). The compulsory licensing process is probably where water quality allocations would first be developed in parallel with water allocation plans.

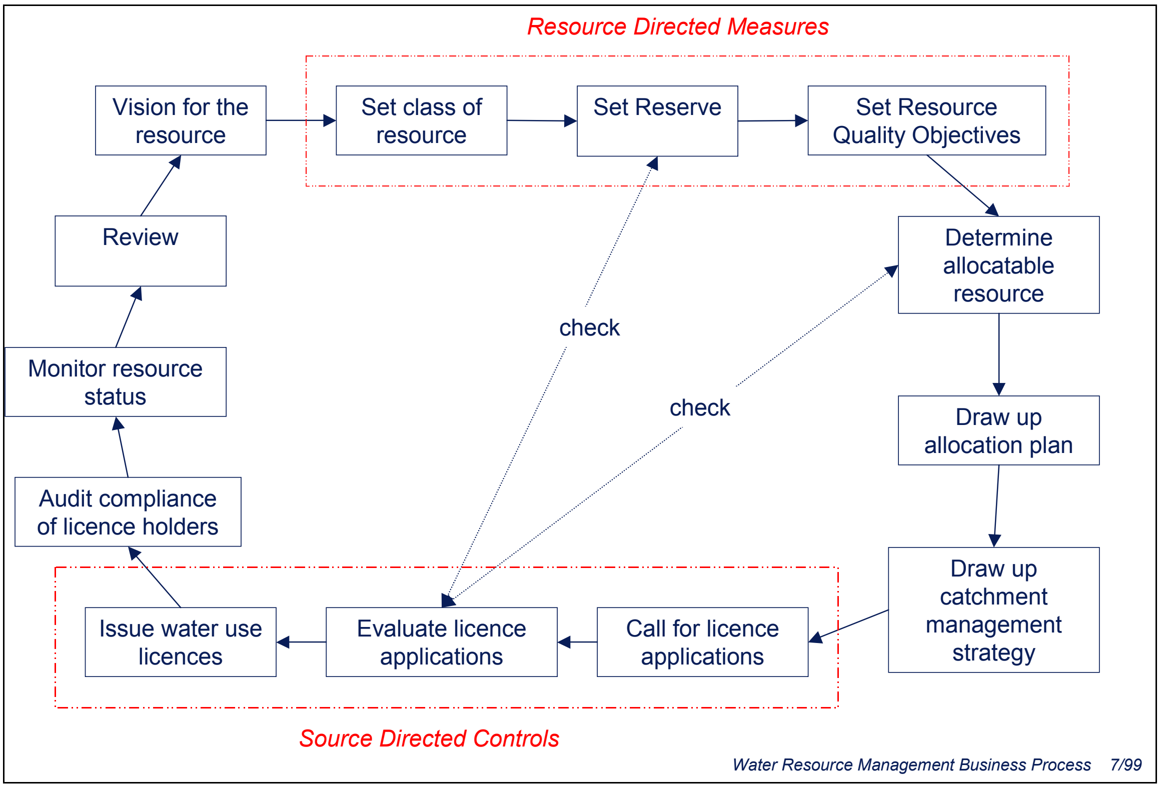


Figure 2 Simplified diagram of the water resources management process in South Africa

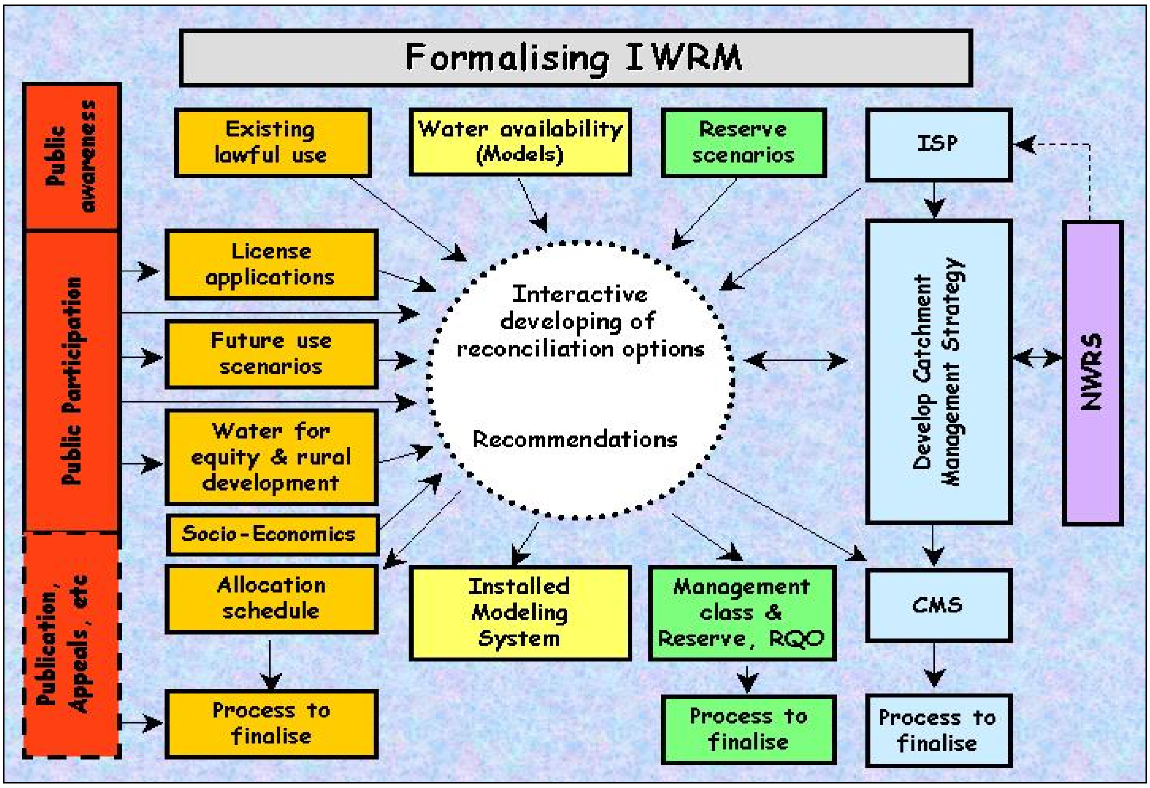


Figure 3 **Diagram showing the DWAF integrated water resources management approach**

The policy framework for water quality management was published as part of the National Water Resource Strategy (DWAF, 2004) and in the framework, compulsory licensing is envisaged as an operational strategy for those water resources that have been identified as water quality stressed. A national water quality improvement schedule will provide guidance on those water resources identified for compulsory licensing. This implies that compulsory licensing for water quantity and quality may not necessarily coincide.

One of the best examples of water quality allocation in South Africa is the controlled release of excess saline water from mining and power generation industries that has been implemented in the Witbank Dam and Middleburg Dam catchments (Coleman *et al.*, 2003). According to the DWAF hierarchy of water quality management, the release of contaminated water in a river when assimilative capacity is available can only be considered after waste minimisation and recycling have been implemented. Modelling plays a central role in the implementation of the controlled release scheme.

3.2 The Water Quality Component of a Catchment Management Strategy

A Water Quality Use Allocation Plan will be developed as part of a catchment water quality management strategy (DWAF, 2003a) (**Figure 4**). The point of departure for the catchment water quality management strategy is the goals for water quality management. These are normally described as *resource quality objectives* (RQOs) that are set for different management units. The next step is to derive the *resource water quality objectives* (RWQOs) for each management unit that takes into account the requirements of users and use of the resource to dispose of water containing waste, based on the needs expressed by stakeholders. The next step is to decide by how much water quality loads must change to achieve the resource water quality objectives by determining the *source management objectives* (SMOs). The next step is to decide how this will be managed across a water management area by formulating a *water quality management framework-plan* that indicates the WMA-wide management priorities, requirements, sectoral responsibilities and programme to achieve these objectives. The Water Quality Allocation Plan is one of the components of the framework-plan. The last step is the development of an individual water quality implementation plan that may be source, issue or sector specific.

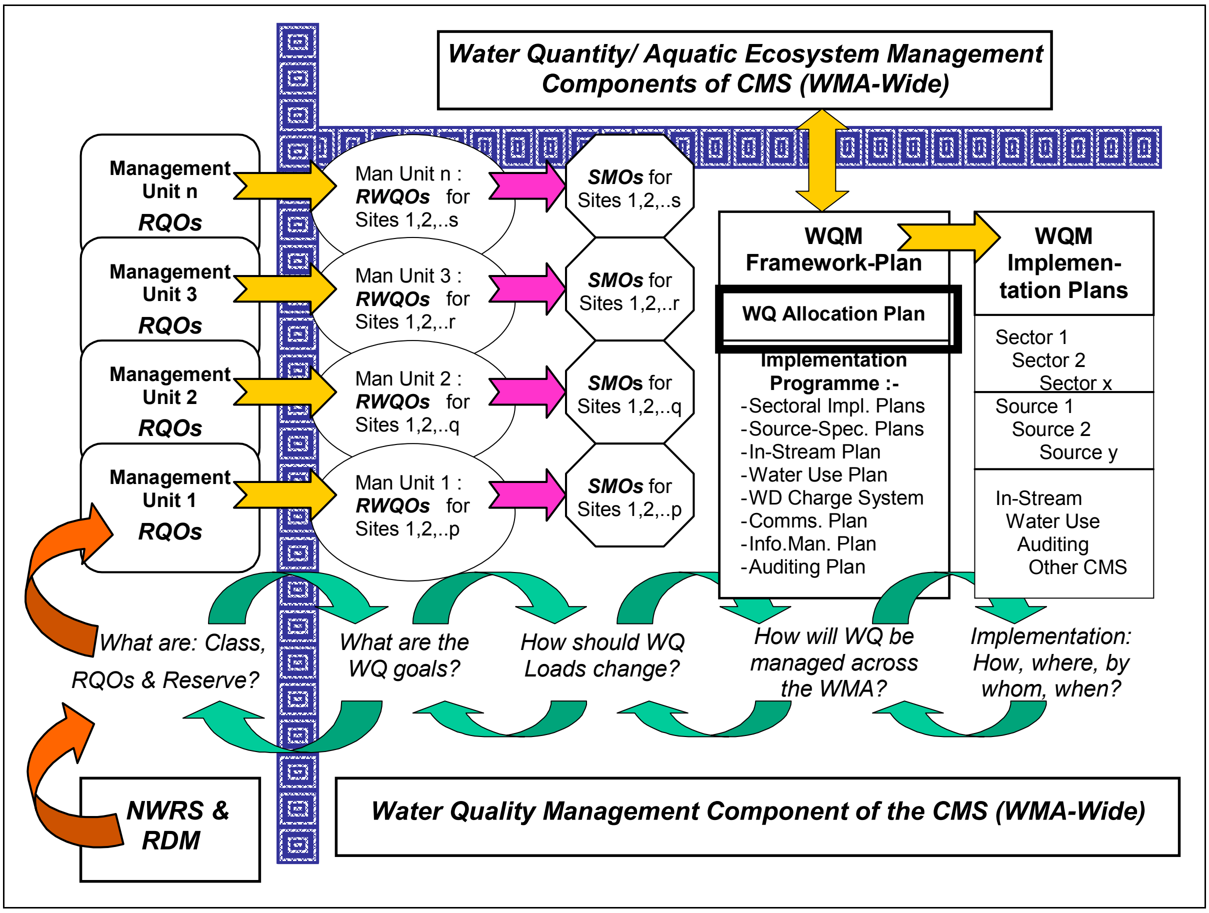


Figure 4 Conceptual Framework for Catchment Water Quality Management

In summary, the inputs to a Water Quality Allocation Plan are therefore the RWQOs for each management unit and the outputs are the waste loads allocated to different waste producing sectors and/or individual sources.

The procedures for setting Resource Quality Objectives and deriving the Resource Water Quality Objectives from them are therefore not components of a Water Quality Allocation Plan. The development of sectoral or source specific implementation plans are also not components of a Water Quality Allocation Plan and it is normally left to the sector of an individual source to show what measures they would implement to meet the requirements of the load allocated to them.

3.3 The Water Use Allocation Planning

The first draft of the Toolkit for water use allocation planning was available at the time of preparing this report (DWAF/DID, 2004) and it gives an indication of the strategic direction that the Department may follow in planning the allocation of water use. Water allocation, while founded on sound water resource management approaches, is regarded largely as a social, political, economic and legal process. The overarching philosophy and strategy which guided the development of the draft Toolkit was described in more detail in the document entitled: *A Draft Position Paper for Water Allocation Planning in South Africa: Towards a Framework for Water Allocation Planning*. For the Toolkit to be useful in a wide range of applications, it was designed to address three broad scenarios, namely (**Figure 5**):

- Catchments where water is freely available for the foreseeable future
- Catchments which are exhibiting some signs of stress and where licence applications may exceed the remaining resource available
- The compulsory licensing situation, i.e. closed or soon to be closed catchments

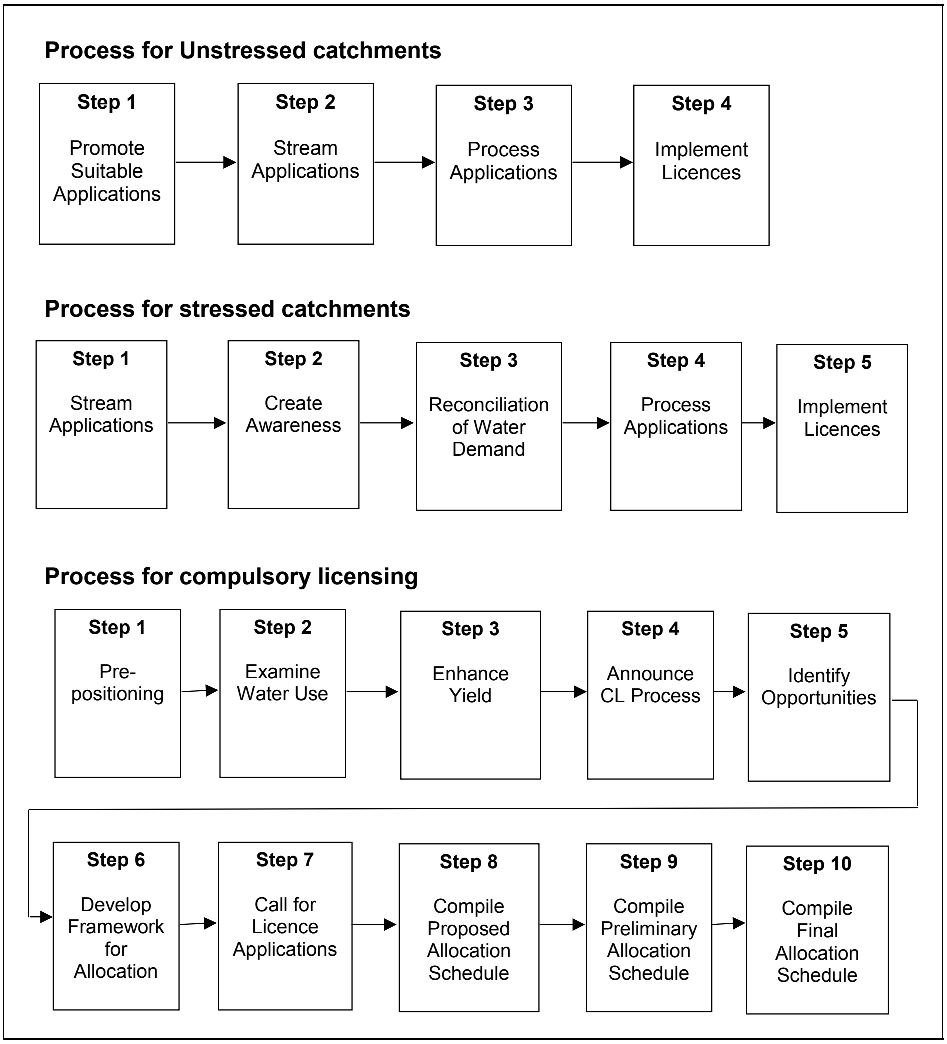


Figure 5 Processes for allocating water use in unstressed, stressed, and catchments where compulsory licensing is required (from DWAF/DID, 2004)

In terms of the compulsory licensing process, the Water Quality Use Allocation Plan fits into the Step 6 (Develop Framework for Allocation) and Steps 8 to 10 (Compile Allocation Schedule):

- The Framework for Allocation (Step 6) is the first, high-level attempt to reconcile supply and demand in the catchment. The analysis will be at a strategic level and will not strive for very high levels of accuracy. It will focus at a sector level as opposed to the individual user level necessary at the Allocation Schedule. The framework sets out the rules for the proposed/possible allocations and minimises the potential for appeals through agreeing to some objectives and criteria for allocation.
- The Water Allocation Schedule analysis different options to allocate water to sectors and to individual water users. It is an iterative process with ongoing public consultation. The process involves intensive technical analysis and it requires the determination of allocatable water, water required for the reserve, unallocated water, impacts on existing water use and the cut-off point where severe economic prejudice occurs.

The process clearly points towards a two-tiered approach to water allocation in cases where compulsory licences are required, the first tier being undertaken at a strategic level and focusing on water use sectors and the second tier focusing on individual users and local impacts.

3.4 Source Management in South Africa

The document, *Source Management in South Africa* (DWAF, 2003d), provides a comprehensive, focused and co-ordinated approach to manage sources of pollution in such a way as to limit their impact on the resource and to achieve optimal water resource management. The document describes:

- The principles and approaches that were used to develop an overall strategy;
- A functional strategy that defines the tasks undertaken by the Department and includes aspects such as source classification, best practice, water use authorisations, enforcement, source management plans and co-operative incentives;
- Source management programmes that address aspects such as source classification, best practice, water use authorisation, enforcement and multi-lateral agreements;
- An organisational strategy that addresses national and regional office organisation and responsibilities, and
- Strategies to enable and implement the overall source management strategy.

The strategy is a high level document that provides little technical guidance that can be incorporated into a water quality allocation framework. It does however provide a detailed description of the development of a Source Management Plan (SMP) at regional/CMA level. It describes the steps that should be followed to develop a SMP and provides a guide for selecting the most appropriate source management instrument for different sectors.

3.5 Resource Directed Water Quality Management

The final version of the report on *Resource Directed Water Quality Management* (DWAF, 2004) was available at the time of preparing this section of the report. The document contained the first suite of management instruments developed to make the Water Quality component of Resource Directed Measures operational in licences and to assist the DWAF with the evaluation and issuing of licences. The document provided an overview of the two main approaches adopted by the DWAF for managing water resources, namely Resource Directed Measures (RDM) and Source Directed Controls (SDC) as well as the broader context of the water use licensing process. It also provided a guideline which described a practical, consistent approach to the determination of RWQOs, by integrating the results of a Catchment Vision, Resource Classification and the Reserve, i.e. Resource Directed Measures, and to provide an approach to operationalising these RWQOs in the evaluation of licence applications through the allocatable resource.

In the document, allocatable water quality was defined as "The maximum worsening change in any water quality attribute away from its present value that maintains it within a pre-determined range (typically management objectives) reflecting the desired future state. If the present value is already at or outside the pre-determined range, this indicates that none is accessible and that either rehabilitation of the resource and/or reduced pollution loads relating to the affected attribute(s) is necessary. The attributes may be quantified by water quality objectives, criteria or targets (e.g. in-stream or in-aquifer resource quality objectives, or a target water quality range or criteria). These may be expressed in terms of concentrations or loads (i.e. linked to water quantity, and flow in particular)".

The document also provided guidance on how to calculate the allocatable water quality. The allocatable water quality was calculated as the RWQOs less the present state, i.e. RWQOs – present state. In this way, the allocatable water quality could be determined for each parameter of concern. The 'Allocatable water quality' may be expressed in terms of the units in which the respective variables are measured, or as 'Allocatable loads', which were derived from the 'target flow'. The confidence level in determining the allocatable water quality was based on the percentiles provided for the present state. The confidence in the allocatable loads was a function of the percentiles provided in the present state and the 'flow assurance'. The target flow was the flow for which loads were calculated and in this context, is the output of an instream flow requirement study. A simple spreadsheet was also provided that could be used to calculate the allocatable water quality.

3.6 The National Water Resource Classification System

The DWAF is currently developing a National Water Resource Classification System (NWRCS). At the time of preparing this report, the NWRCS was still under development. However, some of the concepts that were emerging from discussions (DWAF, 2005; DWAF, 2006a) were used to inform the development of a water quality allocation framework. Some of the relevant concepts are listed below. These may change as the NWRCS develops in the next few years but it is useful to consider in order to ensure early alignment between approaches and policies.

The NWRCS represents the first stage of the protection process, and as such, must be designed to facilitate a balance between protection and use of water resources. The following tenets were identified as important in the NWRCS (DWAF, 2005):

- Tenet 1: Equity, sustainability and optimal use - the reason for protection of resources is to maintain ecosystem integrity at a level that ensures the continued delivery of desired ecosystem goods and services for use.
- Tenet 2: Balance and trade-off - the chosen management class (MC) should balance protection of the resource with its utilisation in line with societal norms and values.
- Tenet 3: National interest and uniformity - the MC of a resource may produce solutions that are acceptable at a local level, but are sub-optimal when considered at a national level. Catchment-level decisions therefore need to be evaluated against national-level constraints.
- Tenet 4: Transparency - stakeholders should be involved both in the development of the NWRCS and in the process of classifying water resources.
- Tenet 5: Implementability - the NWRCS must be sufficiently user-friendly to be used, at reasonable cost, by trained DWAF/CMA staff at an operational level.
- Tenet 6: Interdependency of the hydrological cycle - the NWRCS needs to account for the inter-linkages between all ecosystems dependent on allocatable water (aquatic systems and terrestrial aquifer dependent systems); rivers, groundwater, lakes, wetlands and estuaries.
- Tenet 7: Legally defensible and scientifically robust - the NWRCS must be legally defensible and scientifically robust.
- Tenet 8: Scale - the scale at which the NWRCS is applied must be appropriate for the problem at hand.
- Tenet 9: Sustainability baseline and precautionary approach - it is recognised that there is a sustainability baseline that if crossed, could result in the non-delivery of the goods and services necessary for economic growth, poverty alleviation and equity. As there is a degree of uncertainty as to the exact position of this baseline, and as the risks exceeding the limits of sustainability are considerable, the precautionary principle will be applied.
- Tenet 10: Auditable and enforceable - the NWRCS needs to be auditable and enforceable to ensure that it is operationalised.
- Tenet 11: Lowest level of contestation and the highest level of legitimacy - given the strategic importance of the NWRCS, the principle of lowest level of contestation and highest level of legitimacy will be applied.
- Tenet 12: Utilisation of existing tools, data and information - the NWRCS will use existing tools, data and information wherever possible.

It was further recognised that:

- The methods developed to classify water resources must be consistent with the methods used for water use licensing and the allocation of water resources.

- The primary scale proposed for implementation of the NWRCS is the river basin (catchment), which provides a practical, understandable spatial unit within which economic, social, economic and ecological trade-offs can be made.
- The description of functional relationships between resource units needs to accommodate upstream-downstream linkages. This means that the conditions in the downstream reaches are, in part, dictated by the conditions in the upstream reaches. Resources cannot, therefore, be classified in isolation. To achieve a balance between socio-economic development and maintenance of ecosystems there is a need to understand within-catchment upstream-downstream linkages, how they affect and are affected by human activities and how they are linked by water flows (quantity and quality).
- The concept of an ecologically sustainable bottom-line was also described. The National Water Act stipulates that a water resource should be managed to ensure its sustainable utilisation. RDM policy states that this minimum level of health should be at least a D-Class condition. The approach that was proposed was to incorporate the method for determining upstream and downstream functional linkages in a process to predict the condition for resources (including the estuary) in a catchment by moving sequentially upstream using a D-Class as the base-line condition. This would require starting at the downstream end of the catchment, and working upstream in segments, at each stage determining conditions that would still meet the D-class target at the bottom end of the basin (**Figure 6**).

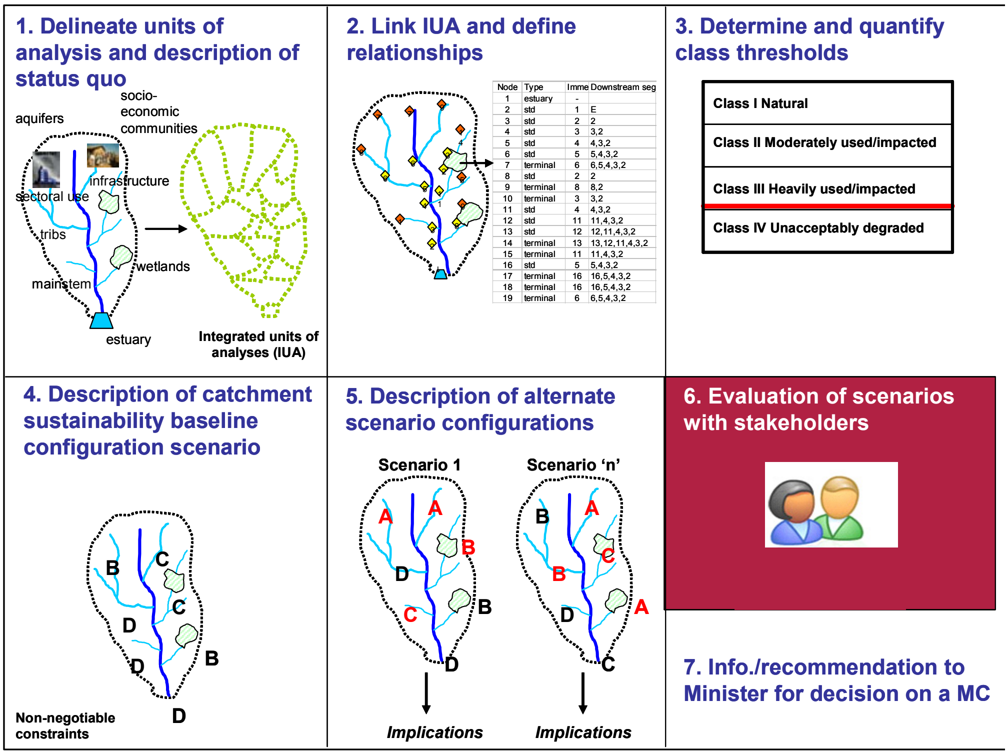


Figure 6 Diagram illustrating the proposed seven step classification system (DWAF, 2006). Steps 4 and 5 are relevant to this project because it implies the use of catchment scale modelling tools. In Step 4 a sustainable catchment configuration is determined that would meet a D class status at the estuary. In Step 5, alternative catchment configurations are considered and its implications are described, *inter alia*, on water quality.

- The Classification Process will involve the generation and testing of multiple options/alternatives (MCs) for economic development, which achieve utilisation objectives but still ensure protection. These scenarios may involve different combinations of resource condition, to arrive at an overall minimum protection level of Class-D, or may involve greater protection in some parts of the catchment to arrive at an overall condition that is better than the baseline.

The need to take upstream/downstream dependence into account and the need to evaluate alternate scenarios can only be addressed if simple, strategic level analytical tools or models are available to support decision making in the classification process.

4 CONCEPTUAL FRAMEWORK FOR WATER QUALITY USE ALLOCATION PROCEDURES

4.1 Description of the operating environment

Water quality use allocation is viewed as a component of a catchment water quality management strategy (DWAF, 2003a). This would require a two-tiered approach to water quality use allocation where the first tier is a broad high-level assessment of loads and allocating loads to sectors at a catchment to sub-catchment scale, and the second tier is a more detailed assessment of individual sources within sectors at a sub-catchment to river reach scale. Water quality use allocation can, however, also inform other processes such as the water resource classification process or the setting of resource water quality objectives (RWQOs).

4.2 Guiding principles

In DWAF (1999), some clarification was provided about the meaning of the terms principles, criteria etc. within the context of developing water resource management policies. It was stated that:

- A ***principle*** is a statement of a general rule as a guide for action
- A ***criterion*** is an element of a principle stated exactly so that any action may be judged by that principle
- An ***indicator*** is a quantitative, categorical or qualitative measure of the relevant criterion that allows an action to be judged as to whether or not it meets the criterion
- A ***standard*** is a value or a category of an indicator that has been accepted or declared to be a minimum standard of performance with respect to a relevant criterion.

The principles for the ***technical components*** of Water Quality Use Allocation are:

- Precautionary principle approach - this is a pro-active approach aimed at avoiding environmental impacts before they occur and has the purpose of preventing pollution. In water quality use allocation it could mean pro-active planning of the use of assimilative capacity and using a margin of safety to prevent unforeseen damage due to incomplete understanding of the potential impacts.
- Integrated and holistic approach - this principle entails an integration of traditional scientific realms and a holistic approach to the management of potential impacts on the environment. An objective of the Water Quality Use Allocation system is to give due consideration in the assessment and decision-making process to all aspects in order to seek a balance between environmental sustainability, economic development and social equity.
- Due consideration given to alternative options – the most sustainable option, known as the Best Practical Environmental Option (BPEO) should be implemented. In terms of Water Quality Use Allocation this principle entails considering alternative load reduction strategies and options to achieve the best practical environmental option to protect the water resource.

- Carrying capacity - this principle is aimed at ensuring that development does not exceed the natural carrying capacity of environmental systems. In terms of Water Quality Use Allocation, the objective should be to allocate waste loads within the capacity of the system to assimilate the loads.
- Equity and fairness - the allocation system should not create inequitable impacts on any sector of society, and the associated costs should be equitably distributed. The system should be applied to all waste-producing activities that impact on water resources, regardless of the nature of the discharge (for example, point vs. diffuse or surface vs. sub-surface). The system should, moreover, promote efficiency and equity in the provision of water quality.
- Simplicity - The tools being used should be understandable, both to the agency administering the system and to the impactors, and should not be difficult to implement, thereby ensuring its effectiveness and limiting the cost of implementation. This will contribute further to the financial viability and affordability of the system, and ultimately to its acceptance.

There are other principles that have more to do with the ***process*** being followed and these include aspects such as:

- Transparency – there should be transparency in determination of loads and decision-making about the allocation of loads.
- Consistency – the system should be consistent with national water resource management goals and objectives as well as goals and objectives for the water management area.
- Integration – the system should be integrated with water quality and pollution control strategies implemented by the DWAF.
- Affordability – the system should be affordable in terms of the administrative burden placed on the authorities as well as affordable in the sense that it should not place an unaffordable financial burden on the polluters to administer the system.
- Efficiency – the system should be efficient and should not place an unnecessary technical and administrative load on the licensing authorities.
- Acceptability – the process followed should be acceptable to the key role players.

4.3 Regulatory environment - What does the National Water Act say about a Water Quality Use Allocation Plan?

Section 9 of the National Water Act (Act 36 of 1998) specifies that a Water Allocation Plan be developed as part of a Catchment Management Strategy. The following is an extract from the NWA with the relevant section highlighted:

9. A catchment management strategy must -

(a) take into account the class of water resources and resource quality objectives contemplated in Chapter 3, the requirements of the Reserve and, where applicable, international obligations;

(b) not be in conflict with the national water resource strategy;

(c) set out the strategies, objectives, plans, guidelines and procedures of the catchment management agency for the protection, use, development, conservation, management and control of water resources within its water management area;

(d) take into account the geology, demography, land use, climate, vegetation and waterworks within its water management area;
***(e)* contain water allocation plans which are subject to section 23, and which must set out principles for allocating water, taking into account the factors mentioned in section 27(1);**
(f) take account of any relevant national or regional plans prepared in terms of any other law, including any development plan adopted in terms of the Water Services Act, 1997 (Act No. 108 of 1997);
(g) enable the public to participate in managing the water resources within its water management area;
(h) take into account the needs and expectations of existing and potential water users; and
(i) set out the institutions to be established.

Section 23 referred to in Section 9(e) of the NWA has statements about the determination of the quantity of water that may be allocated by responsible authorities:

23. (1) Subject to the national water resource strategy the Minister may determine the quantity of water in respect of which a responsible authority may issue a general authorisation and a licence from water resources in its water management area.
(2) Until a national water resource strategy has been established, the Minister may make a preliminary determination of the quantity of water in respect of which a responsible authority may issue a general authorisation and licence.
(3) A preliminary determination must be replaced by a determination under subsection (1) once the national water resource strategy has been established.
(4) A responsible authority must comply with any determination made under subsection (1) or (2).
(5) In making a determination under subsections (1) and (2) the Minister must take account of the water available in the resource.

Section 27(1) referred to in Section 9(e) specifies broadly what factors need to be taken into account when issuing licences:

27. (1) In issuing a general authorisation or licence a responsible authority must take into account all relevant factors, including -
(a) existing lawful water uses;
(b) the need to redress the results of past racial and gender discrimination;
(c) efficient and beneficial use of water in the public interest;
(d) the socio-economic impact -
(i) of the water use or uses if authorised; or
(ii) of the failure to authorise the water use or uses;
(e) any catchment management strategy applicable to the relevant water resource;
(f) the likely effect of the water use to be authorised on the water resource and on other water users;
(g) the class and the resource quality objectives of the water resource;
(h) investments already made and to be made by the water user in respect of the water use in question;
(i) the strategic importance of the water use to be authorised;
(j) the quality of water in the water resource which may be required for the Reserve and for meeting international obligations; and
(k) the probable duration of any undertaking for which a water use is to be authorised.
(2) A responsible authority may not issue a licence to itself without the written approval of the Minister.

In the development of regulations to give effect to the NWA the allocation plan referred to in Section 9 of the NWA refers to both **quantity** and **quality** (DWAF, 2003b).

4.4 Approach to water quality use allocation

A number of discrete steps were identified in the water quality use allocation framework illustrated in **Figure** 7. The components of a Catchment Water Quality Management Strategy are illustrated on the left and the components of Water Quality Use Allocation are illustrated on the right. The arrows indicate the interfaces and exchange of information between the two. Water Quality Use Allocation is generally focused on the constituents of concern in order to promote efficiency.

In a specific water resource management unit, the water resource classification process would set the management class which would inform the setting of resource quality objectives and from that, the resource water quality objectives. This process that is generally external to water quality use allocation, would set the water quality management targets for the constituents of concern.

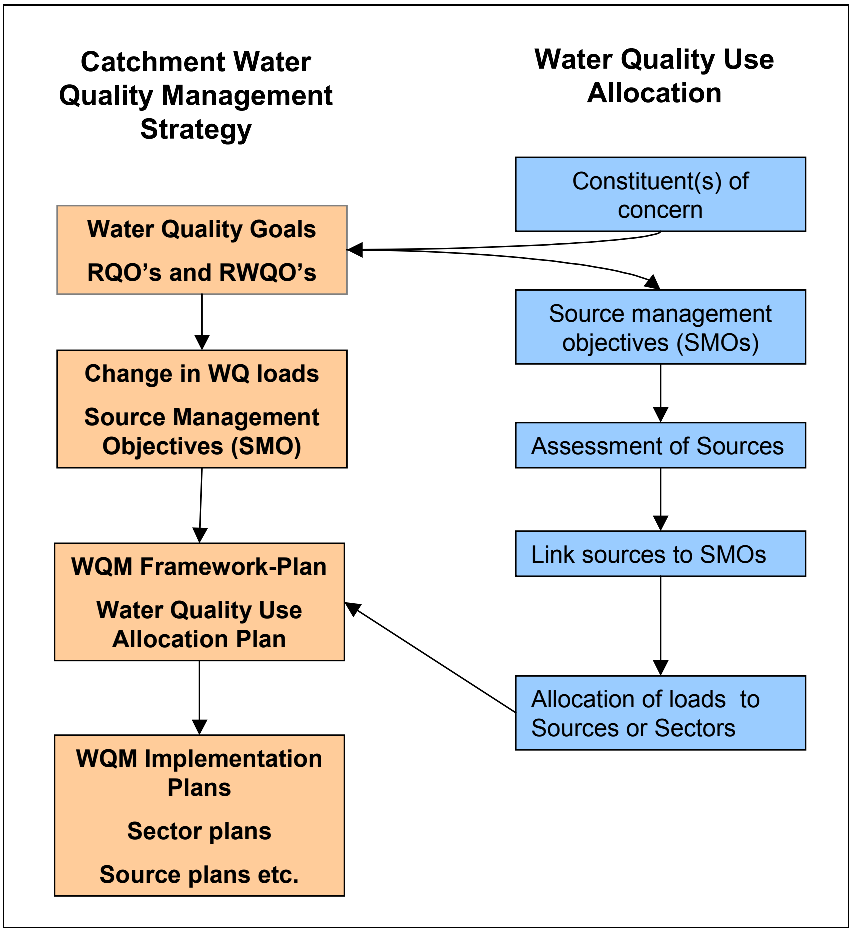


Figure 7 A framework for water quality use allocation

The next step is to determine the source management objectives that would ensure that the water quality management targets (or RWQOs) are achieved. This constitutes the total load that can be discharged after taking into consideration the natural background loads and any safety margins that should be added. The total load can be the sum of the point source loads and the non-point source loads. In the US's TMDL model, allocatable load is then viewed as the load that can be allocated between individual point source dischargers (Waste Load Allocations) and non-point source loads are lumped together with the natural background loads to form the Load Allocation. The underlying assumption being that it is more difficult to manage and permit non-point source loads. An alternative may be to view the allocatable load as the sum of the point and non-point source loads and then setting load targets for each component (point or non-point source). The underlying assumption is that a system is in place to also control or license non-point sources.

The next step is to assess the sources contributing to the loads. The assessment should include point and non-point sources. These loads then need to be compared to the total allocatable load. If the source loads are less than the total allocatable load, then there is scope to allow further loads to be discharged without exceeding the source management objectives. If the source loads exceed the total allocatable load, then source loads need to be curtailed in order to meet the source management objectives.

The next step is to distribute the loads (or load reductions) between the different sources. This can be done on a sector basis (municipal, agriculture etc.) or on an individual discharger basis depending on the complexity of the catchment and water resource management unit.

Water quality use allocation occurs at two tiers:

- Firstly, in an aggregated form, such as per user sector or per water resource management unit. This is the Water Quality Use Allocation Plan tier.
- Secondly, in a disaggregated and detailed form per individual discharger. This is the Water Quality Use Allocation Schedule tier.

The Water Quality Use Allocation Plan must identify the water quality constituents of concern and the extent to which the Plan incorporates water quality use allocation for those relevant constituents. The Plan must also specify the level of detail of the analysis that will be pursued for the water quality allocation (DWAF, 2006b).

4.5 Technical support for water quality use allocation

The degree of technical support is a function of the water quality stress in a catchment or sub-catchment.

A water quality *unstressed* situation

In a water quality unstressed situation

- the water quality requirements of the aquatic ecosystem and other water users are met,
- water quality trends are stable or if deteriorating, the rate of deterioration is such that user requirements would still be met in the short to medium-term, and

- the impact on water quality of known water use licence applications would not infringe on water user requirements.

In this situation, simple tools can be used to support the water quality use allocation process (**Figure 8**). These tools may entail an inventory of the sources and their loads, per water resource management area. Simple mass balances with conservative assumptions can be used to allocate loads to individual sources and to check if the source management objectives and resource water quality objectives are not exceeded. The tools can be based on database and spreadsheet applications.

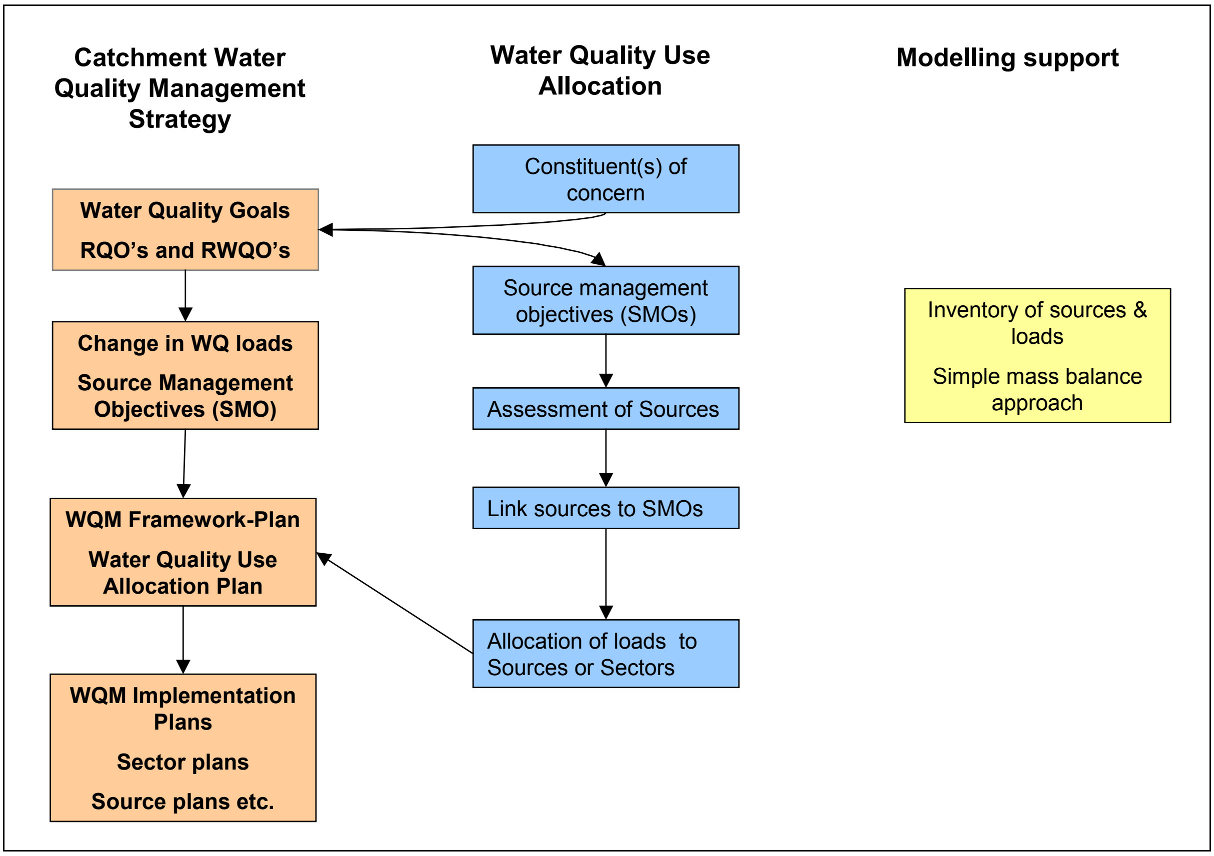


Figure 8 Technical support for water quality use allocation in a water quality unstressed situation

A potentially water quality *stressed* situation

In a potentially water quality stressed situation

- the water quality requirements of the aquatic ecosystem and other water users are met but there may be infrequent occasions when these requirements are not met due to unplanned events like floods, etc.
- water quality trends show a deterioration in quality and the rate of deterioration is such that user requirements may not be met in the short to medium-term, and

- the impact on water quality of known water use licence applications would infringe on water user requirements.

The technical support required in a potentially water quality stressed situation is more complex than a simple inventory and mass balances for the management units in the catchment (**Figure 9**). In this case, allocation scenarios need to be considered at a coarse scale in order to consider upstream/downstream dependencies and effects. This would probably entail a simple coarse catchment scale model (at least to a quaternary catchment scale) and a temporal scale that is equivalent to the water resource planning models commonly used in the Department of Water Affairs and Forestry, normally monthly. The model should be able to use flow data generated by the water resources planning models to drive the flow component of the water quality simulations. The model needs to accommodate loads from point as well as non-point sources and non-point source load calculations can be based on simple empirical models or export coefficients. Point sources can be lumped into sectors depending on the degree of information that is available. The model should be calibrated against observed water quality (and flow) data and it should be able to simulate the present status in the catchment as well as future states depending on the level of envisaged development in the catchment.

The modelling system (input data, model code, output visualisation software) needs to be maintained by collecting the required observed data, entering these into the model and verifying the model calibration on at least an annual basis.

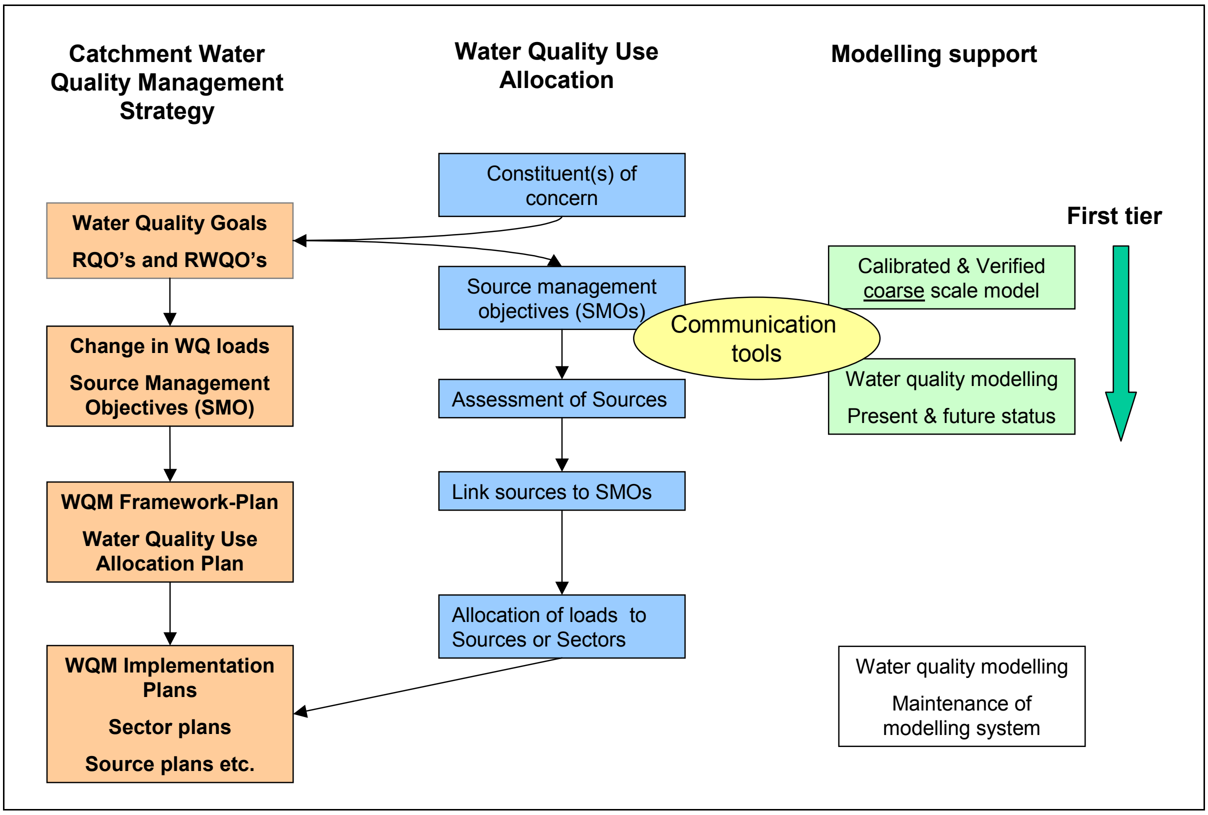


Figure 9 Technical support for water quality use allocation in a potentially water quality stressed situation

A water quality *stressed* situation

In a water quality stressed situation

- the water quality requirements of the aquatic ecosystem or other water users are not met and there is no allocatable water quality, and
- compulsory licensing is required to meet resource water quality objectives.

Two tiers of support are required in a water quality stressed situation (**Figure 10**):

- First tier support - a simple coarse catchment scale model (at least to a quaternary catchment scale) and a temporal scale that is equivalent to the water resource planning models commonly used in the DWAF, normally a monthly time-step. The model needs to accommodate loads from point as well as non-point sources, and non-point source load calculations can be based on simple empirical models or export coefficients. Point sources can be lumped into sectors depending on the degree of information that is available. The model should be calibrated against observed water quality (and flow) data and it should be able to simulate the present status in the catchment as well as future states depending on the level of envisaged development in the catchment.
- Second tier support - a finer scale model that can be set up for complex sub-catchments or river reaches. Whereas the coarse catchment scale model (Tier 1) would be set up for a whole catchment or sub-catchment, the fine scale model would only be set up for specific areas (quaternaries or river reaches) where the disaggregating of loads to individual users, and site specific estimates of the water quality impacts (e.g. sites of water abstraction, sensitive ecosystems, etc.) are important. The model would be more deterministic and focus on non-conservative substances such as nutrients, algal growth and/or bacteria and their decay or increase, as well as the influence of local environmental factors such as meteorology or river morphology. The temporal scale would be daily or sub-daily.

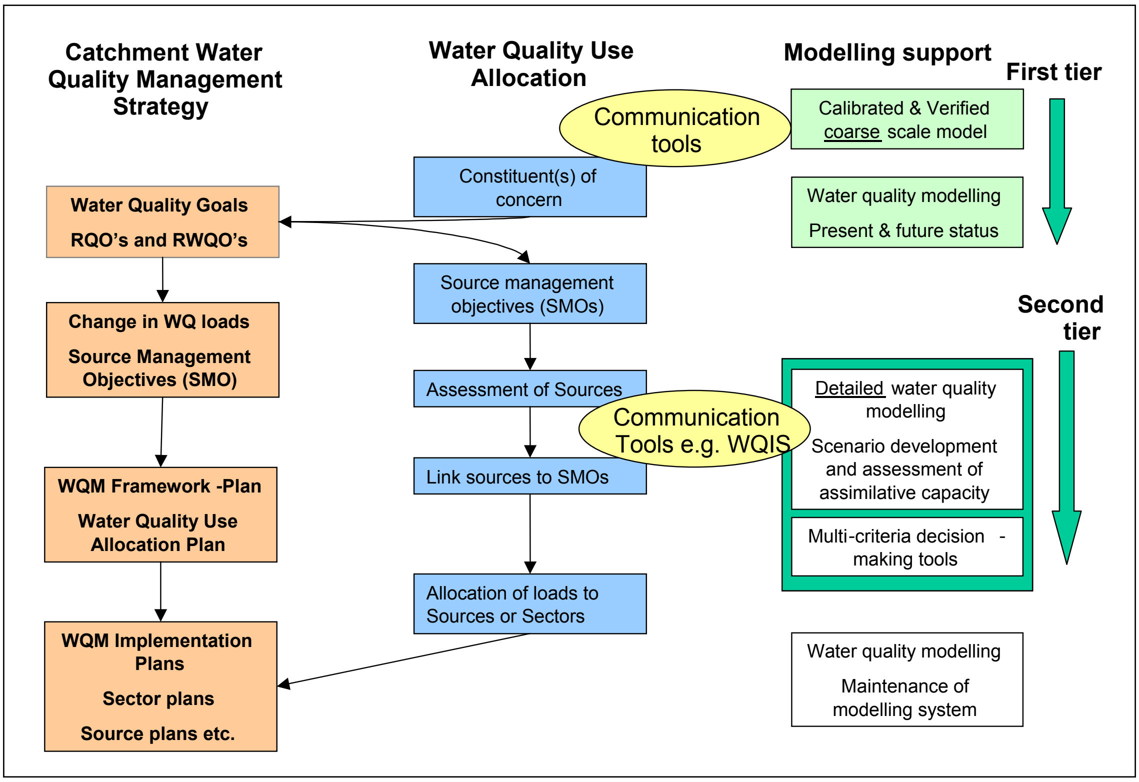


Figure 10 Technical support for water quality use allocation in a water quality stressed situation

The coarse and fine scale modelling systems (input data, model code, output visualisation software, etc.) need to be maintained by collecting the required observed data, entering these into the model and verifying the model calibration on at least an annual basis.

It is recognised that other support tools are also required in addition to the technical tools to support water quality use allocation in water quality stressed situations but these fall outside the brief of this project.

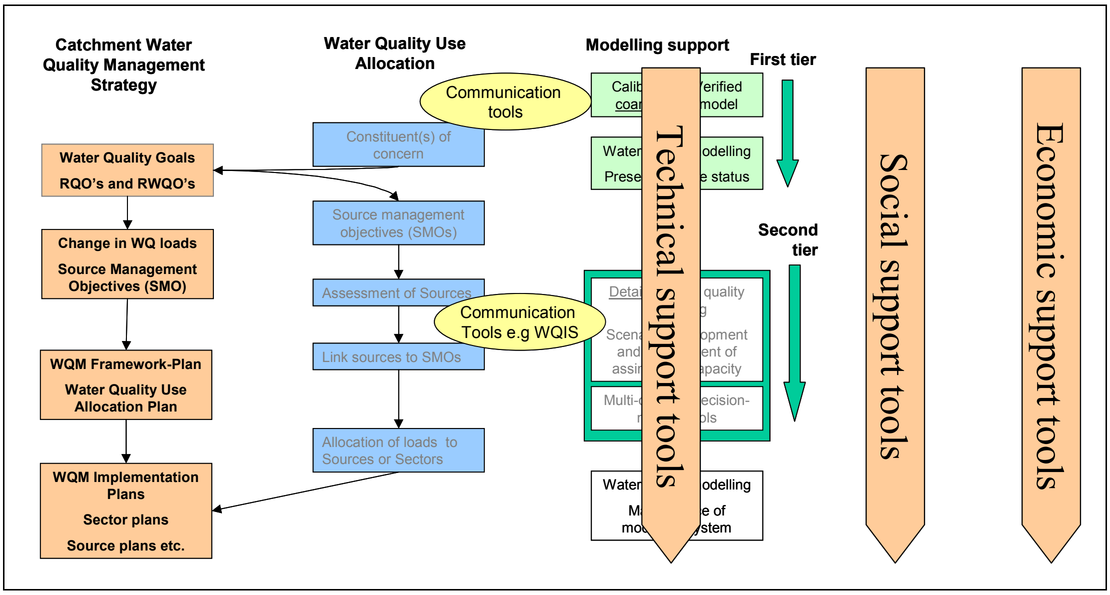


Figure 11 Other support tools that would be required to support water quality use allocation in water quality stressed situation.

4.6 Technical guidelines for water quality use allocation

The following guidelines are proposed to support water quality use allocation:

1. **Focus on water quality variables of concern** - water quality use allocation and the tools designed to support the process should focus on the water quality variables of concern. It may be valid to use coarse scale (spatial and temporal scales) modelling tools to support load allocations for conservative substances which lend themselves to mass balance type applications. However, non-conservative substances such as nutrients, bacteria, organic compounds and pesticides, may require more deterministic modelling tools with a finer spatial and temporal scale.

2. **Two tiers of modelling support** - in order to promote efficiency, two tiers of decision support should be applied to water quality load allocations. The decision on whether only the first tier or both tiers are appropriate should be based on the level of water quality stress in the catchment or in specific water resource management units. In an unstressed and potentially water quality stressed situation, coarse scale tools would be appropriate to allocate loads to sectors. In a water quality stressed situation, coarse scale tools should be used for allocating loads to sectors within sub-catchments (say quaternary scale), and finer-scale models should be used in complex sub-catchments to disaggregate the sector allocations to individual users.

3. **Link to water resource planning tools** - the coarse scale models should be compatible in terms of spatial and temporal scale to water resource planning models in order to promote integration of the flow and quality components of a Water Allocation Plan and Water Allocation Schedule.

4. **Application of good modelling practices** - modelling and data preparation procedures should be consistent with good modelling practices such as those advocated in the *Guidelines for models for water resource evaluation* (DWAF, 2003c) and the *Good Modelling Practice Handbook* (STOWA/RIZA, 1999).

   Guidelines for models for water resource evaluation (DWAF, 2003c) recommends the following:

   - Explicitness in model configuration (transparency)
   - Systematic calibration according to predominantly objective criteria
   - Systematic split-sample verification
   - Creative use of all available water quality data
   - Transfer, inference or regionalisation of model parameter values
   - Structured expert audit and peer review processes need to play a role
   - Increasingly sophisticated modelling for increasingly water quality stressed catchments
   - Provide modelling support through GIS-linked graphical user interfaces

   The *Good Modelling Practice Handbook* (STOWA/RIZA, 1999) recommends the following regarding systematic documentation of modelling

   - Management objectives
     - Scope of problem
     - Technical objectives that result from the management objectives
     - Level of analysis needed
     - Level of confidence needed
   - Conceptual model
     - System boundaries
     - Important time and spatial scales
     - Key processes
     - System characteristics
     - Source description
     - Available data sources
   - Choice of technical approach
     - Rationale for approach in context of management objectives
     - Reliability and acceptability of approach
     - Important assumptions
   - Parameter estimation
     - Data used for parameter estimation
     - Rationale for estimates in the absence of data
     - Reliability of parameter estimates
   - Uncertainty/Errors
     - Error/uncertainty in inputs, initial conditions and boundary conditions
     - Error/uncertainty in constituent loadings

    - Error/uncertainty in specifications of environment
    - Structural errors in specification (e.g. simplifications)
- Results
    - Tables of all parameter values used
    - Tables or graphs of all results used in support of management objectives or conclusions
    - Accuracy of results
- Conclusions of analysis in relation to management objectives
- Recommendations for additional analysis (if required)

5. **Rapid scenario development and evaluation -** the water quality allocation support tools should facilitate the rapid development and evaluation of waste load allocation scenarios. There are a number of ways to calculate how the waste loads can be allocated to sectors and/or individual users. There are also other considerations such as equity, acceptability and affordability that are taken into account. These calculations and considerations require technical tools that can accommodate the development and evaluation of different allocation scenarios. These should be linked to multi-criteria decision-making tools and procedures to help decision makers to select the most balanced allocation scenario that satisfies the requirements of economic development, social equity and environmental sustainability.

6. **User-friendly model outputs and stakeholder communication** - the tools to support water quality use allocation are technically quite complex and can be quite sophisticated water quality simulations models. The tools being used should be selected not only according to their ability to produce user-friendly output which the water quality modeller can interpret but also according to their ability to produce output that can be used in interactions with institutional stakeholders. This is especially important in situations where different allocation scenarios need to be evaluated in a workshop environment to ensure that the aims of cooperative governance and stakeholder acceptance are fulfilled.

5 DISCUSSION, RECOMMENDATIONS AND CONCLUSIONS

5.1 Discussion

The project reviewed a number of international approaches to water quality use allocations as well as policies and procedures that were developed or are being developed in South Africa that would inform the development of a framework for water quality use allocation.

The approach to water quality use allocation or waste load allocation was reviewed for the USA, Australia and the European Union. Although the approaches differed from country to country, a number of similarities could be identified. In all cases, an assessment was made of the present situation, constituents of concern were identified and water quality management targets were set for those constituents. The management targets were either set as maximum concentrations or as maximum loads. The next generic step was to determine an allocatable load after accounting for background concentrations or loads. A load was regarded as allocatable if the present situation was better than the management target or there was no allocatable load if the present situation was poorer than the management targets. If there was an allocatable load, the load was then allocated to different users. In general, not all the allocatable load was allocated to users. Either a margin of safety was built in and/or some of the allocatable load was held in reserve for future users. In general, the identification of constituents of concern and the setting of management targets were done through some consultative process. The determination of an allocatable load and developing scenarios to divide the allocatable load amongst different users or user sectors was largely a technical task. The final load allocation was again made through consultation with key stakeholders. In general, models of different levels of sophistication were used to support some of the consultative processes and all of the technical tasks.

Policies to support the implementation of the South African National Water Act were evolving continually and during the execution of this project, the project team attempted to keep up to date with these developments as they were completed. The team also took note of policies and tools that were still developing, especially where the underlying concepts and principles became stable and accepted by the DWAF. These formed the basis for distilling some guiding principles and developing the framework for water quality use allocation.

The water quality use allocation framework was based on the water quality component of a catchment management strategy and some of the common features of the international experience were incorporated into the structure. In essence, it involved assessing the catchment water quality status, identifying the variables of concern, obtaining the management targets that were set as part of the National Water Resource Classification System, determining the allocatable load after subtracting the natural background loads, and apportioning the allocatable load to point and non-point sources, and apportioning the point and non-point source loads to users sectors and eventually to individual users.

The degree of technical support required for this process was based on the degree of water quality stress in the catchment or water resource management unit. The degree of water quality stress was assumed to be a measure of whether management targets were fully met at catchment (no stress), or the present state was very close to the management targets (potentially stressed) or whether the present state was worse than the management targets (stressed).

In the case of a water quality unstressed catchment or water resource management unit, simple database and mass balance tools would be sufficient to support the water quality allocation process.

In the case of a potentially water quality stressed catchment, simple catchment water quality modelling tools would be sufficient to support the water quality allocation process.

In the case of a water quality stressed catchment, two tiers of modelling tools would be required to support the water quality allocation process. The first tier tools would include a simple catchment water quality model, and the second tier tools would include a more deterministic, finer scale model that will only be applied to problematic sub-catchments or river reaches.

A set of technical guidelines was developed to support the water quality use allocation process. These included:

- Focus on water quality variables of concern
- Two tiers of modelling support
- Link water quality tools to water resource planning tools
- Apply good modelling practices
- Rapid scenario development and evaluation, and
- User-friendly model outputs to facilitate stakeholder communication

5.2 Recommendations on future research

The following research needs have been identified to support water quality use allocation:

1. **Modelling research needs** – the core of a water quality use allocation process is a model that predicts the relationships between the condition of a river or reservoir, the pollutants being investigated and alternatives for load reductions or allocations. There is a need for a simple, catchment scale model that can be used for the first tier of water quality use allocations. Such public-domain models should interface with water resource planning models so that the water quality modelling can use the flow simulations that would form the basis of the Water Use Allocation Planning process. There is specifically a need for credible catchment scale models that can simulate nutrients and microbial water quality (non-conservative constituents). There is a need to maintain existing models so that the modelling software keeps track with upgrades in operating systems. There is a need to develop these tools using open source software to make it more widely available to model users. There is a need to promote applied technical support for the models and to provide appropriate training for new

users in water resource management agencies and the specialist service providers that support them.

2. **Allocation of loads to individual sources** – there are some twenty methods for allocating constituent loads to individual dischargers (Chadderton *et al.,* 1981). These include methods such as equal percent removal, equal effluent concentrations, equal cost of pollutant removed, etc. There is a need to investigate which of the methods are appropriate to South Africa given the primary objectives of equity and sustainability embedded in the National Water Act. Such an investigation should also give guidance to water quality managers on the suitability of alternative methods to local conditions, and how to apply them correctly.

3. **Appropriate export coefficients** – there is a need to develop export coefficients and/or loading functions for different South African land-uses in order to estimate coarse scale non-point source pollution loads at a quaternary catchment scale. Export coefficients are empirical estimates of the mass of a pollutant exported per unit area per unit time (usually annual) for a particular land-use. Loading functions calculate constituent loads by multiplying the estimated runoff with empirically determined parameters that describe the relationship between the constituent and flow. Nutrient loads are either estimated as the product of measured flows and concentrations or as a function of catchment properties. Estimating nutrient loads from catchment properties can either be by means of complex models or by means of unit area exports (export coefficients). Despite the advances in research on complex physically based models for nutrient transport, the export coefficients approach still plays an important role in regional and catchment scale management. The limited data requirements and their sensitivity to temporal changes in land-use and management practices make export coefficients attractive alternatives to complex models.

4. **Uncertainty analysis** – there is a need to incorporate uncertainty analysis into the water use allocation process. Decisions would often be taken in a data sparse environment introducing uncertainty in the data being used and in the model predictions. There is a need to build uncertainty into the modelling processes that would account for the uncertainty or inherent errors in model calculations, especially where the errors may accumulate from the flow simulations to the water quality simulation.

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