THUKELA WATER PROJECT DECISION SUPPORT PHASE

RESERVE DETERMINATION MODULE
THUKELA SYSTEM WATER QUALITY REPORT

March 2004

Prepared by: IWR SOURCE-TO-SEA
PO Box 122
Persequor Park
PRETORIA
0020

For: The Manager
National Water Resources Planning
Department of Water Affairs and Forestry
Private Bag X313
PRETORIA
0001

This report is to be referred in bibliographies as:

Department of Water Affairs and Forestry, South Africa. 2004. DWAF Report No. PBV000-00-10306. Thukela System Water Quality Report - Reserve Determination Study - Thukela River System. Prepared by IWR Source-to-Sea as part of the Thukela Water Project Decision Support Phase.

First draft: July 2003
Final draft: November 2003
Comments: October 2003
Comments from external reviewers: January 2004
Final report: March 2004

The report was prepared by:
P-A Scherman, WJ Muller[*] and H Malan[**]

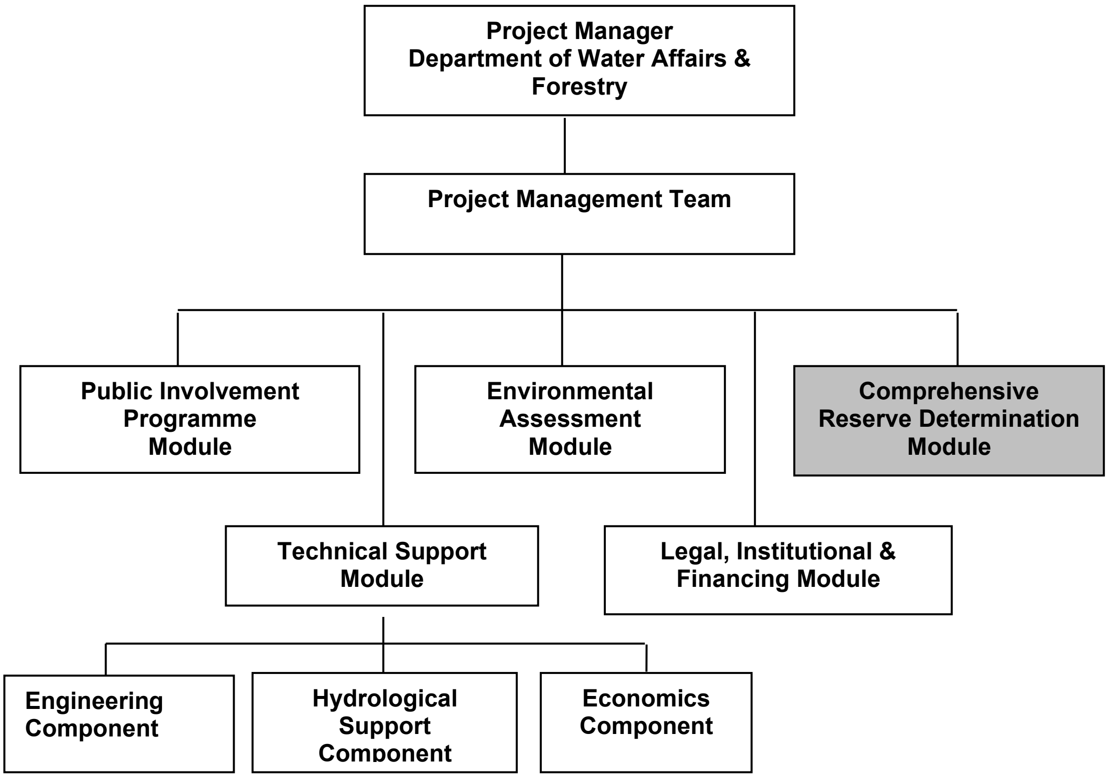
The water quality study was undertaken by:
P-A Scherman, WJ Muller[*] and H Malan[**], M Papo[***], N Valisa[*] and CG Palmer[*]
Coastal and Environmental Services
PO Box 934
GRAHAMSTOWN
6140

[*] Unilever Centre for Environmental Water Quality
Institute for Water Research
Rhodes University
PO Box 94
GRAHAMSTOWN
6140

[**] Freshwater Research Unit
Zoology Department
Rhodes Gift
University of Cape Town
7701

[***] Resource Quality Services (previously IWQS)
Department of Water Affairs and Forestry
Private Bag X313
PRETORIA
0001

STRUCTURE OF DECISION SUPPORT PHASE



DEPARTMENT OF WATER AFFAIRS & FORESTRY
NATIONAL WATER RESOURCES PLANNING

THUKELA WATER PROJECT DECISION SUPPORT PHASE
RESERVE DETERMINATION MODULE
THUKELA SYSTEM WATER QUALITY REPORT

IWR SOURCE-TO-SEA **MARCH 2004**

Approved for IWR Source-to-Sea by:

…………………………..	**………………………………..**
Greg Huggins	**Delana Louw**
Administrative Project Leader	**Technical Project Leader**

***Approved for the Project Management Team by*:**

…………………………..	**………………………………..**
TT Tlou PrEng	**RA Pullen PrEng**
Project Co-ordinator	**Study Leader**

Approved for National Water Resources Planning by:

…………………………..	**………………………………..**
NJ van Wyk PrEng	**JA van Rooyen**
Project Manager	**Director**

EXECUTIVE SUMMARY

The Executive Summary provides an overview of the report, and briefly presents the main sections of the report, as well as the major findings. Present state tables are presented per Quality Resource Unit, and problems encountered during the study are outlined.

The Thukela Reserve Determination study is made up of a number of modules and this report describes the process and results of the assessment conducted for the water quality component of the Ecological Reserve. The tasks addressed during this report are only those related directly to water quality. Water quality assessments focus primarily on magnitude of in-stream concentration (while flow assessments look at frequency, magnitude and duration), with toxicological studies and water quality modeling incorporating some degree of duration. The water quality approach is therefore still primarily a hazard, and not a risk-based approach.

Section 1 of the report introduces the approach followed during the study. The study was initiated using a particular set of methods (referred to as Approach 1 in the text), primarily based on the water quality methods of the RDM documents released in 1999, while revised methods became available during the study. An attempt was made to use best available methods, and upon a directive from DWAF Scientific Services, Approach 2 (based on documents released in 2002) was followed for the water quality assessment. A number of problems were encountered with the methods outlined in the 2002 documents, particularly regarding unclear (e.g. the nutrient method) and incomplete methods (e.g. methods for toxics and pH). A comparative assessment of the methods used (i.e. Approaches 1 and 2) is presented in Appendix A. Although modelling and toxicological information are not required by the revised water quality approach (DWAF, 2002a), both these tools were available and proved to be valuable during the Thukela study. Methods and results presented in this report are therefore according to DWAF (2002a), or Approach 2, with the use of additional modelling and toxicological tools.

The A – F classification system has been used throughout the Thukela study (therefore followed for Approach 1), while Approach 2 calls for a water resource classification of natural, good, fair and poor. Results for the water quality assessment are therefore presented using both classification systems.

Section 2 of the report presents the study area, describes current land-use activities, and defines Quality Resource Units (QRU). The area defined as the study area includes the main stem of the Thukela River, the Little Thukela, Bushmans, Sundays, Buffalo and Mooi rivers. Except for a few distinct areas - the Horn and Ngagane Rivers, tributaries of the Buffalo River above Newcastle; the Wasbank River which flows into the Sundays River; the Klip River which flows into the Thukela River at Ladysmith; and the Mandini / Sundumbili industrial complex near the Thukela estuary - there are few industrial and economic activities in the Thukela catchment. Land-use is therefore characterised by mining in the upper reaches of the Buffalo and Sundays rivers, with the remainder of the catchment being characterised by agriculture. Water quality issues are mainly driven by nutrients and agricultural land-use, with water abstractions being mostly for irrigation (subsistence crops, some commercial citrus plantations and large-scale fodder crops for cattle), urban / domestic water purposes and to satisfy water transfer requirements. Much of the resources of the Thukela River are currently being used to support requirements in other parts of the country. Careful planning for implementation of the Reserve should therefore be a priority.

Section 3 outlines the procedure by which Reference Condition and Present Ecological State are defined per QRU, **following the revised methods of DWAF (2002a)**. A brief synopsis of the method per water quality variable, is presented. Due to the dearth of data in certain areas, a number of additional sites were monitored weekly for a two-month period (August – September 2001), as prescribed in the RDM manuals of 1999. In-stream toxicity testing was conducted at selected sites - the only toxicity that was identified was using the *Selenastrum* algal inhibition test. Toxicity was seen in the Mandini Stream and Sundays River samples.

Note – water quality assessment

The methods followed for the water quality assessment were strictly according to DWAF, 2002a. During the assessment a number of problems were encountered, which were clarified with the team responsible for compiling the Water Quality methods manual. As methods are constantly being upgraded, this report does not provide recommendations regarding changes in methods.

At a meeting in July 2003, after the Thukela water quality assessment had been completed and the report compiled, a number of the methods were modified and updated. This process is part of finalizing water quality methods for use in future comprehensive Reserve assessments, with the latest version of methods dated September 2003. It is recommended that the Thukela data be used to test the new suite of methods, so as to evaluate the accuracy and sensitivity of all available methods. This evaluation should be conducted as a separate project, with the completion of this report not being dependent on the results.

Present Ecological State assessments are presented in the following tables per Quality Resource Unit. The results for the water quality assessment for the Thukela River are presented first, followed by each of the tributaries considered in the study from the most upstream tributary to the most downstream tributary.

Resource Unit A: Thukela River from Rugged Glen to Woodstock Dam

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	1	**RC**	V1H035 (1978-1985)
IFR number	-	**PES**	V1H036 (1995 – 2000)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		D	Lower Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		D	Lower Fair
Biotic community composition (invertebrates)		A/B	Upper Good
Overall site classification for WQ		**B**	**Good**

Resource Unit B: Thukela River from Driel Barrage to Spioenkop Dam

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	2 and 3	**RC**	V1H035 (1978 – 1985)
IFR number	1	**PES**	V1H026 (1998 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		D	Lower Fair
Overall site classification for WQ		**B/C**	**Lower Good**

Resource Unit C: Thukela River from Spioenkop Dam to confluence with Little Thukela

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	4	**RC**	V1H057 (1983 – 1988)
IFR number	2	**PES**	V1H057 (1998 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		B/C	Lower Good
Overall site classification for WQ		**B**	**Good**

Resource Unit D-E: Thukela River from confluence of the Little Thukela to the confluence with the Klip River

River	Thukela River	DWAF Water Quality Monitoring points	
QRU	5 and 6	RC	V1H001 (1977 – 1981)
IFR number	-	PES	V1H001 (1997 – 2001)
Water Quality Constituents		A - F system	Descriptive system
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		B/C	Lower Good
Overall site classification for WQ		**B**	**Good**

Resource Unit F: Thukela River from confluence of Klip River to confluence with the Bushmans River

River	Thukela River	DWAF Water Quality Monitoring points	
QRU	7 and 8	RC	No reference condition data
IFR number	4	PES	Collected water quality data, site 5
Water Quality Constituents		A - F system	Descriptive system
$MgSO_4$		C	Upper Fair
Na_2SO_4		C	Upper Fair
$MgCl_2$		A	Natural
$CaCl_2$		B	Good
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		D	Lower Fair
TIN		D	Lower Fair
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		B/C	Lower Good
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit G - H: Thukela River from the confluence of the Bushmans River to the confluence of the Buffalo River

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	9 and 10	**RC**	V6H002 (1977 – 1979)
IFR number	9	**PES**	V6H002 (1998 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		D	Lower Fair
Na_2SO_4		A	Natural
$MgCl_2$		C	Upper Fair
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A	Natural
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		C	Upper Fair
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit I: Thukela River from the confluence with Sundays River to Middledrift

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	11 + 12 (segments 39-51)	**RC**	No Reference condition data
IFR number	15	**PES**	Collected water quality data, site 1
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		D	Lower Fair
Na_2SO_4		A	Natural
$MgCl_2$		B	Good
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		B	Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		C/D	Fair
Biotic community composition (invertebrates)		B	Good
Overall site classification for WQ		**B/C**	**Lower Good**

Resource Unit J: Thukela River from Middledrift to the end of the rejuvenated foothills zone

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	12 (segment 52 – 73)	**RC**	V5H002 (1977 – 1982)
IFR number	16	**PES**	V5H002 (1996 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		A	Natural
$MgCl_2$		C	Upper Fair
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C/D	Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		C	Upper Fair
Biotic community composition (invertebrates)		C	Upper Fair
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit L - M: Little Thukela River from Injasuthi to the confluence with the Thukela River

River	Little Thukela River	**DWAF Water Quality Monitoring points**	
QRU	14 and 15	**RC**	V1H010 (1976 – 1981)
IFR number	3	**PES**	V1H010 (1996 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C/D	Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		D	Lower Fair
Biotic community composition (invertebrates)		B	Good
Overall site classification for WQ		**B/C**	**Lower Good**

Resource Unit N: Bushmans River from Elands Park to Wagendrift Dam

River	Bushmans River	**DWAF Water Quality Monitoring points**	
QRU	16	**RC**	V7H017 (1977 – 1984)
IFR number	-	**PES**	V7H017 (1996 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A	Natural
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		A/B	Upper Good
Overall site classification for WQ		**B**	**Good**

Resource Unit O: Bushmans River from Wagendrift Dam to Upper foothills

River	Bushmans River	**DWAF Water Quality Monitoring points**	
QRU	17	**RC**	V7H020 (1997 – 2001)
IFR number	5	**PES**	V7H012 (1996 – 2001)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		C	Upper Fair
Na_2SO_4		A	Natural
$MgCl_2$		B	Good
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		C	Lower Fair
Overall site classification for WQ		**B/C**	**Lower Good**

Resource Unit P: Bushmans River from lower foothills to confluence with the Thukela

River	Bushmans River	**DWAF Water Quality Monitoring points**		
QRU	18 and 19	**RC**	V7H020 (1997 – 2001)	
IFR number	6	**PES**	Collected water quality data, site 4	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		A		Natural
Na_2SO_4		A		Natural
$MgCl_2$		A		Natural
$CaCl_2$		A		Natural
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		A/B		Upper Good
TIN		B/C		Lower Good
Chl-a: phytoplankton		A		Natural
Chl-a: periphyton		E/F		Poor
Biotic community composition (invertebrates)		B		Good
Overall site classification for WQ		**B**		**Good**

Resource Unit Q: Sundays River from the Newcastle/Ladysmith Road Bridge to the end of the rejuvenated bedrock falls

River	Sundays River	**DWAF Water Quality Monitoring points**		
QRU	20	**RC**	V6H006 (1976 – 1978)	
IFR number	7	**PES**	V6H004 (1996 – 1999)	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		E/F		Poor
Na_2SO_4		C		Upper Fair
$MgCl_2$		A		Natural
$CaCl_2$		A		Natural
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C/D		Fair
TIN		B		Good
Chl-a: phytoplankton		-		-
Chl-a: periphyton		-		-
Biotic community composition (invertebrates)		C		Upper Fair
Overall site classification for WQ		**C**		**Upper Fair**

Resource Unit R: Sundays River from the start of the rejuvenated foothills to the confluence with the Thukela River, and PES assessment for the Wasbank River

River	Sundays River	**DWAF Water Quality Monitoring points**		
QRU	21	**RC**	V6H006 (1976 – 1978)	
IFR number	8	**PES**	Collected water quality data, site 3	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		E/F		Poor
Na_2SO_4		C		Upper Fair
$MgCl_2$		A		Natural
$CaCl_2$		B		Good
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		A		Natural
TIN		A		Natural
Chl-a: phytoplankton		A		Natural
Chl-a: periphyton		E/F		Poor
Biotic community composition (invertebrates)		B/C		Lower good
Overall site classification for WQ		**C**		**Upper fair**

River	Wasbank River	**DWAF Water Quality Monitoring points**		
QRU	-	**RC**	V6H006 (1976 – 1978)	
IFR number	-	**PES**	V6H003 (1995 – 2000)	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		E/F		Poor
Na_2SO_4		E/F		Poor
$MgCl_2$		A		Natural
$CaCl_2$		D		Lower Fair
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C/D		Fair
TIN		A/B		Upper Good
Chl-a: phytoplankton		-		-
Chl-a: periphyton		-		-
Biotic community composition (invertebrates)		-		-
Overall site classification for WQ		**C – C/D**		**Upper Fair – Fair**

Resource Unit S: Mooi River from the confluence of the Little Mooi River to the Mooi River Falls

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	22	**RC**	V2H005 (1977 – 1982)
IFR number	-	**PES**	V2H005 (1996 – 2000)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		C/D	Fair
Biotic community composition (invertebrates)		B/C	Lower Good
Overall site classification for WQ		**B**	**Good**

Resource Unit S-T: Mooi River, Segments 16 – 30

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	23	**RC**	V2H005 (1977 – 1982)
IFR number	10 and 11	**PES**	V2H002 (1996 – 2000)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		B-B/C	Good – Lower Good
Overall site classification for WQ		**B**	**Good**

Note: Chl-a samples were taken downstream of IFR 10 and between IFR 10 and 11.

Resource Unit T: Mooi River from the Mooi River Falls to the confluence with the Thukela River

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	24	**RC**	V2H005 (1977 – 1982)
IFR number	12	**PES**	V2H008 (1995 – 2000)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		C	Upper Fair
Na_2SO_4		A	Natural
$MgCl_2$		C	Upper Fair
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C/D	Fair
TIN		B	Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		D	Lower Fair
Biotic community composition (invertebrates)		-	-
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit U: Buffalo River from Utrecht/Ozisweni Road Bridge to the end of the lowland river zone

River	Buffalo River	**DWAF Water Quality Monitoring points**	
QRU	25	**RC**	No Reference condition data
IFR number	13	**PES**	V3H010 (1997 – 2000)
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		E/F	Poor
$MgCl_2$		A	Natural
$CaCl_2$		B	Good
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		E/F	Poor
TIN		D	Lower Fair
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		C/D	Fair
Overall site classification for WQ		**D**	**Lower Fair**

Resource Unit V: Buffalo River from the start of the rejuvenated bedrock zone to the confluence with the Thukela River

River	Buffalo River	**DWAF Water Quality Monitoring points**	
QRU	26	**RC**	V3H011 (1975 – 1979)
IFR number	14	**PES**	Collected water quality data, site 2
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		C	Upper Fair
$MgCl_2$		B	Good
$CaCl_2$		B	Good
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		E/F	Poor
TIN		D	Lower Fair
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		B	Good
Overall site classification for WQ		**C/D**	**Fair**

Section 4 presents the *Additional Tools* used during this study, i.e. toxicological data and flow-concentration modelling.

The use of catchment or site-specific toxicity testing using indigenous macroinvertebrates was demonstrated during the Olifants River study (DWAF, 2000) where toxicity information aided the interpretation of salinity data. As this study was initiated following Approach 1, which required toxicological data, site-specific toxicity data was available for use by the water quality team. The methods of DWAF (2002a) describe toxicity testing using in-stream macroinvertebrates as a useful additional tool for comprehensive and high confidence water quality Reserve assessments, such as the Thukela study. Toxicity testing using organisms from sites in the Thukela catchment was conducted to generate a classification table for Total Dissolved Solids (TDS) and Electrical Conductivity (EC).

Flow-concentration modelling integrates water quality and quantity, and predicts the water quality conditions likely to occur under a proposed IFR regime. This will ensure that in meeting the ecological Reserve with regard to *quantity*, the water *quality* component of the Reserve is also attained.

Water quality data for the Reference Condition (RC) and Present Ecological State (PES) at each IFR site were used to obtain flow-concentration relationships by plotting monthly median concentrations against monthly mean flow data, and the regression equation derived. These flow-concentration (Q - C) relationships were used to predict, for a given flow, what the expected in-stream concentration would be, and were used to set up a matrix of flows and associated predicted concentrations for identified water quality constituents. The appropriate matrix was used to convert the flow time-series to a time-series of expected concentrations for different flow scenarios. From the time-series of expected concentration under various flow regimes, concentration-exceedence curves were generated and the flow scenarios could be compared with regard to the changes in the concentrations of key water quality constituents under changing flow conditions.

The most important assumptions and provisos in this method are presented below:

- Use is made of monthly *median* values of concentrations and monthly *average* flow values, through which a trend-line is fitted. Unless there is measured water quality data for very low flows and very high flows, extrapolation (as occurs when converting to concentration time-series) is likely to be inaccurate.

- Concentration duration curves can be used to compare and rank some of the water quality consequences that will arise from different flow scenarios. Predicted concentration values derived in this way are, however, estimates.
- The modelling method is not suitable for chemical constituents that show an increase in concentration with increasing flow, e.g. pollutants from diffuse sources that wash off agricultural lands and into the river. This is because it cannot be assumed that if the flow in a river is decreased, the in-stream concentration of the pollutant will also decrease.

A full description of the theoretical basis for the modeling methods, including the use of monthly median or mean concentration or flow values, versus instantaneous values, is given in Malan and Day (2002a).

The following information is presented in the modeling report:

- The present water quality situation.
- The flow-concentration relationships (as shown by the Q - C graphs).
- The exceedence profiles and water quality consequences obtained at the IFR workshops (i.e. for the recommended Ecological Reserve flow, and Upper and Lower categories).
- The exceedence profiles and water quality consequences obtained at the Yield Scenario workshop (i.e. for the eight flow scenarios generated by the system modellers).
- Overall conclusions and comments, including whether the Ecological Reserve Category is likely to be attained for water quality under the proposed flow regime and under the **present-day loading of pollution**.

The final section of the report, *Section 5*, presents per IFR site what the water quality objectives or ecological specifications (ecospecs) should be, so as to meet the prescribed water quality Reserve, for the constituents used in the assessment. The ecospecs represent the maximum concentration that should not be exceeded. In the case of dissolved oxygen this is the minimum value.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AEV	Acute Effects Value
BOD	Biological Oxygen Demand
CEV	Chronic Effects Value
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
ERC	Ecological Reserve Category
IFR	In-stream Flow Requirement
IWQS	Institute for Water Quality Studies
OREWRA	Olifants River Ecological Water Requirements Assessment
PES	Present Ecological State
Q-C	Flow-concentration (modelling)
QRU	Quality Resource Unit
RC	Reference Condition
RDM	Resource Directed Measures
RQS	Resource Quality Services (previously IWQS)
RU	Resource Unit
SPATSIM	Spatial and Time Series Information Modelling
SRP	Soluble Reactive Phosphorous
TIN	Total Inorganic Nitrogen
T-SOFT	Time Series Display and Analysis Software
TSS	Total Suspended Sediment
TWQR	Target Water Quality Range
TWP	Thukela Water Project

1 INTRODUCTION

1.1 BACKGROUND

The Reserve Determination module (Module 3 of 5 for the Thukela Water Project Decision (TWP) Support Phase) is designed, *inter alia*, to meet the requirements of the National Water Act No 36 of 1998. As such the study has been guided by three major parameters. These are:

- The objectives of Chapter 3 of the National Water Act No 36 of 1998 for a comprehensive Reserve determination and the subsequent RDM protocols released by DWAF.
- The specific requirements of the Terms of Reference as supplied by Department of Water Affairs and Forestry (Tender WF7405).
- The needs of the Thukela Water Project and associated organs of the Department of Water Affairs and Forestry. These include broad based planning required to meet overall water resource management objectives in the catchment.

The Reserve Determination module involves quantification of the water resource required to meet objectives for the Thukela system under a series of flow scenarios that were defined during the course of the study. This need for a scenario-based approach was mooted to enable the TWP to make recommendations regarding water resource planning based on a suite of alternatives with regard to the needs of the Reserve. Out of the Reserve Determination study information will be made available in a manner that will allow the Project Management Team (PMT) of the TWP to make informed recommendations and decisions for planning and management. The specific objectives of this Reserve Determination module are therefore to:

- Assign an Ecological Reserve Category per IFR site;
- develop flow scenarios and evaluate these with the TWP and stakeholders;
- recommend one of these scenarios to represent the Ecological Reserve for the quality and quantity components for the river and estuary;
- determine the impact of the recommended Reserve on the allocatable yield;
- determine whether it is possible to supply the Reserve from existing and proposed schemes;
- to provide mitigation measures if it is not met / supplied;
- and design ecological specifications and a monitoring programme for the Ecological Reserve Category selected by DWAF.

The Reserve Determination module is made up of a number of studies and this report, DWAF report number PBV000-00-10306, describes the process and results of the assessment conducted for the water quality component of the Ecological Reserve. The tasks addressed during this report are only those related directly to water quality. Water quality inputs to other components, e.g. resource economics, are dealt with elsewhere. The objective of this Ecological Reserve assessment is therefore to provide quantified and descriptive information about the frequency, magnitude and duration of particular flows and concentrations of water quality constituents, which describe both the present state of the system and conditions for the selected Ecological Reserve Categories.

1.2 WATER QUALITY IN THE ECOLOGICAL RESERVE

One of the underlying principles of the National Water Act and the DWAF's water resource strategy is that of water resource protection to ensure long-term sustainable use for people. The provision of goods and services for people is dependent on functioning river systems, and the quality and quantity of services is dependent on the current status of a system and the degree of protection afforded that river system, i.e. its classification status. An impacted, or "workhorse", river provides fewer services to communities dependent on the river system than a pristine system, particularly in services related to water quality, i.e. assimilation or degradation and dilution of wastes. The Ecological Reserve determination for water quality is therefore a description of what the current water quality status is and the river's capacity to provide services such as waste assimilation, how much it has changed from its reference state, and what water quality status is needed to sustain a particular level of ecosystem health, or Ecological Reserve Category (ERC). Changes in water quality under different flow scenarios are also documented, so as to provide information toward meeting overall water resource management objectives in the catchment.

Although the Ecological Reserve approach assesses frequency, magnitude and duration of flow, the same is not true for water quality. Water quality assessments still focus primarily on magnitude (primarily the concentration of chemical constituents), with toxicological studies and water quality modelling incorporating some degree of duration. The water quality approach is therefore still primarily a hazard, and not risk-based, approach (DWAF, 2002a). Hazard can be described as a state that may result in an undesired event, whereas risk includes the *probability* of that event. Risk therefore results from the existence of a hazard and uncertainty about its expression or effect.

1.3 WATER QUALITY IN THE ECOLOGICAL RESERVE: THUKELA STUDY

The terms of reference for the water quality component of the Ecological Reserve for the Thukela catchment study area, prescribed that water quality be assessed at a comprehensive level. As the first project at which water quality was undertaken at a higher level of confidence, i.e. intermediate, was the Olifants River study of 1999 – 2001, methods were still undergoing development at the initiation of the Thukela study in July 2001. A review of water quality methods for the Ecological Reserve was undertaken for DWAF in 2001/2002, and once available, methods were incorporated into the Thukela study upon a directive from DWAF Scientific Services. As a result, the water quality **present state assessment** for the Thukela River was conducted following both approaches – firstly, the approach as outlined in the inception report submitted to DWAF at the outset of the Thukela project in 2001, and the methods available at the time (termed Approach 1), and secondly, the methods available once the review of water quality methods had taken place in 2002 (DWAF, 2002a), i.e. Approach 2.

The Thukela study also presented an opportunity to compare approaches and test the updated and modified methods of DWAF (2002a) using real data. This comparative assessment, including data gaps and general comments, is shown in Appendix A. As the terms of reference and inception report for the Thukela study called for best available methods to be used at all times, methods and results presented in this report are therefore according to DWAF (2002a), or Approach 2, with the use of additional modelling and toxicological tools.

The outline of approaches used, and the generic steps followed in each approach, is shown below.

1.3.1 Thukela water quality study: Approach 1

This water quality assessment was conducted following the methods prescribed in:

- The Resource Directed Measures (or RDM) protocols of DWAF (1999a), which outlined the approach to be taken for a comprehensive Reserve assessment for rivers; and
- the Olifants River Ecological Water Requirements Assessment (OREWRA) study and report produced by Palmer and Rossouw (DWAF, 2000a).

A comparison with Approach 2 is described in Appendix A, and the overall method according to DWAF (1999a) is shown below:

1. Delineate the geographic boundaries of the resource.
2. Determine the water quality reaches of the resource.
3. Determine reference conditions.
4. Assess the Present Ecological Status.
5. Select a future management class.
6. Assign the Reserve.
7. Design a monitoring system.

1.3.2 Thukela water quality study: Approach 2

This water quality assessment was conducted following the methods prescribed in:

- DWAF (2002a) i.e. *Assessing water quality in ecological Reserve determinations for rivers: Version 2, Draft 15.0, March 2002.* Methods contained within this manual were not complete, and note should therefore be made of the version used for the Thukela study. Although the manual is not appended to this report, excerpts from the manual are provided in Chapter 3 where necessary, and an electronic version of the manual is available as part of the electronic database of information for this study.
- Additional tools not prescribed in DWAF (2002a), i.e. the use of toxicological data and flow-concentration modelling.
- Expert judgement and specialist knowledge of the authors based on previous experience of water quality reserve assessments. This proved to be invaluable as updated methods of DWAF (2002a) were not yet complete.

Results are shown in this report, and the overall method according to DWAF (2002a) is shown below:

1. Initiate study and scoping: decide on geographic area of study domain and required level of confidence, and finalize list of water quality constituents to be assessed during the study.
2. Delineate Resource Units.
3. Site selection and information collection.
4. Determination of benchmarks: use the generic tables of water quality boundary values to determine the reference condition and present ecological state (re-benchmarking tables if necessary), and water quality input into the ecological importance and sensitivity assessment.
5. Describe ecological specifications for each category: qualitative and quantitative specifications.

The overlap between the two methods can be clearly seen (Table 1.1), but the results reported will be according to the **assessment method of Approach 2** and Section 1.3.2. Note that Table 1.1 is taken from the existing manuals regarding these methods. A step which is not shown here is that of assessing water quality consequences of different ERC flow scenarios.

Table 1.1 A comparison of the process followed by each approach

Approach 1	Approach 2
1. Delineate geographic boundaries of the resource.	1. Initiate study and scoping: Decide on geographic area of study domain and required level of confidence, and finalise list of water quality constituents to be assessed during the study.
2. Determine the water quality reaches of the resource, but assessments are done at the level of resource units.	2. Delineate Quality Resource Units. 3. Site selection and information collection.
3. Determine reference conditions. 4. Assess the present ecological status. 5. Select a future management class.	4. Determination of benchmarks: Use generic tables of water quality boundary values to determine the reference condition and present ecological state (re-benchmarking tables if necessary), and water quality input into the ecological importance and sensitivity assessment.
6. Assign the Reserve. 7. Design a monitoring system.	5. Describe ecological specifications for each category: qualitative and quantitative specifications.

It is important to note that source-directed controls will be recommended to solve water quality problems in the Thukela study area, and that the use of dilution to treat water quality problems will be a management decision. Therefore, if source-directed controls are not implemented under certain flow scenarios, it may be possible that the water quality Reserve will not be met. This issue will be expanded and emphasized in the relevant section of the report, i.e. Chapter 5.

1.3.3 Classification system

Although the classification system A - F has been used throughout the Thukela study (as according to DWAF (1999a)), Approach 2 (Section 1.3.2) calls for a water resource classification of natural, good, fair and poor. Results for the water quality assessment will be presented using both classification systems. Table 1.2 provides a comparative of these categories.

Table 1.2 The classification of river health and integrity (Kleynhans, IWR Source-to-Sea, *pers. comm.*)

	Categories	Classes	Ecological description
Management Classes	A	Natural	Modifications to the natural abiotic template and the characteristics of the biota are undetectable. The characteristics of the resource are completely determined by unmodified natural regimes. Even potential anthropogenic induced changes to the abiotic characteristics and anthropogenic risks to the well-being of biota are not measurable.
	A/B, B, B/C	Upper Good Good Lower Good	Modifications to the natural abiotic template and the characteristics of the biota may vary from small to moderate. The characteristics of the resource are largely determined by natural regimes while anthropogenic influences tend to play a small to moderate role. There is a small risk that the resource base may be exceeded. Consequently, the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a limited number of localities may be somewhat higher than expected under natural conditions. Temporally and spatially this may result in somewhat lowered abundances and frequency of occurrence of intolerant and moderately intolerant species. However, even in the short, medium and long term the resilience and adaptability of biota are not compromised. The impact of acute disturbances on the biota is effectively mitigated by the presence of sufficient refuge areas.

	Categories	Classes	Ecological description
	C, C/D, D	Upper Fair Fair Lower Fair	Modifications to the natural abiotic template and the characteristics of the biota may vary from moderate to large. The characteristics of the resource are partly determined by natural regimes but anthropogenic influences tend to play a major role. There is a moderate to large risk that the resource base may be exceeded. Consequently, the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a significant number of localities may be higher than expected under natural conditions. Temporally and spatially this may result in low abundances and frequency of occurrence of intolerant and moderately intolerant species, as well as a possible increase in the abundances and frequency of occurrence of tolerant species which may reach pest proportions. However, in the medium to long term the resilience and adaptability of biota are not compromised. The impact of local and acute disturbances are to an extent mitigated by some refuge areas.
	E, F	Poor	Modifications to the natural abiotic template and the characteristics of the biota may vary from large to completely dominant. The characteristics of the resource are almost completely determined by severe anthropogenic influences. There is a serious to critical risk that the resource base may be exceeded. Consequently, the risk to the well-being and survival of all but the most tolerant biota (depending on the nature of the disturbance) at almost all localities is serious to critical. Temporally and spatially this will result in the absence of intolerant and moderately intolerant species and very low abundances and frequency of occurrence of moderately tolerant species. Tolerant species tend to increase in abundance and frequency of occurrence and can reach pest proportions. On all temporal and spatial scales the resilience and adaptability of biota are compromised. The impact of local and acute disturbances are to an extent mitigated by some refuge areas

2 THE STUDY AREA

2.1 INTRODUCTION

The area defined as the study area is described in DWAF (2003a), and includes the main stem of the Thukela River, the Little Thukela, Bushmans, Sundays, Buffalo and Mooi Rivers.

The Thukela River is in KwaZulu-Natal and rises in the Drakensberg mountains, from where it flows eastwards and discharges into the Indian Ocean about 100km north-east of Durban. The Thukela River is the second largest river in South Africa with a Mean Annual Runoff (MAR) of 3 799 million m^3/annum (Tlou and Matji, and WRP Consulting Engineers, 2002). Significant tributaries are the Klip, Sundays, Buffalo, Little Thukela, Bloukrans, Bushmans and Mooi rivers. The Thukela catchment area is fairly sparsely populated, with significant towns being Ladysmith, Newcastle, Dundee, Colenso, Bergville, Estcourt and Mooi River. Except for a few distinct areas - the Horn and Ngagane Rivers, tributaries of the Buffalo River above Newcastle; the Wasbank River which flows into the Sundays River; the Klip River which flows into the Thukela River at Ladysmith; and the Mandini / Sundumbili industrial complex near the Thukela estuary - there are few industrial activities in the catchment. Land-use is characterised by coal mining (including defunct mines) in the upper reaches of the Buffalo and Sundays rivers, with the remainder of the catchment being characterised by agriculture. General water quality issues in the Thukela catchment are therefore mainly driven by nutrients and agricultural land-use, with water abstractions being mostly for irrigation (subsistence crops, some commercial citrus plantations and large-scale fodder crops for cattle), urban / domestic water purposes and to satisfy water transfer requirements. Acid-mine drainage does generate water quality issues in mining areas, such as the upper Buffalo and Sundays rivers. Generally there is little economic development in the Thukela catchment to stimulate development. Figure 2.1 is an overview of landcover for the Thukela catchment, showing forestry, mining, urban areas, tributaries and dams.

Water resources from the Thukela River are currently being used to support requirements in other parts of the country via Inter-basin Transfers. Careful planning for implementation of the Reserve should be a priority, as growth of areas such as the Upper Vaal water management area means that there will be an increase in demand for water supply from the Thukela system (Tlou and Matji, and WRP Consulting Engineers, 2002). Transfers from systems such as the Buffalo River will have water quality impacts in this system itself, as well as potential water quality issues in the receiving system, due to the degraded state of this river (see Section 2.3).

2.2 THE UPPER THUKELA CATCHMENT: AN OVERVIEW

This section contains a brief overview of the Upper Thukela catchment, focussing on water quality issues, and includes information drawn from the Internal Strategic Perspective (ISP) conducted for DWAF by Tlou and Matji, and WRP Consulting Engineers, in 2002. Other information sources are indicated where used. See Table 3.2 for additional information.

- There are no significant water quality problems in the upper part of the catchment, i.e. above or to the west of Ladysmith.
- The rapid development of settlements and increase in rural population above Spioenkop and Woodstock dams could lead to eutrophication and excessive organic load problems in the dams in future, as well as sedimentation due to erosion. This occurrence is dependent on land-use management and the provision of municipal services.
- Overstocking and over-grazing leads to erosion and sedimentation into water-courses. Sedimentation is based on qualitative and geomorphological assessments in this study as DWAF monitoring data does not include measurements of in-stream turbidity for most of the catchment.

- Large-scale irrigation, with related impacts on water quality e.g. eutrophication due to wide-spread use of fertilizers and ploughing down to the river bank, is seen in the lower section of the Upper Thukela catchment (personal observation, Scherman and Muller, July 2001).

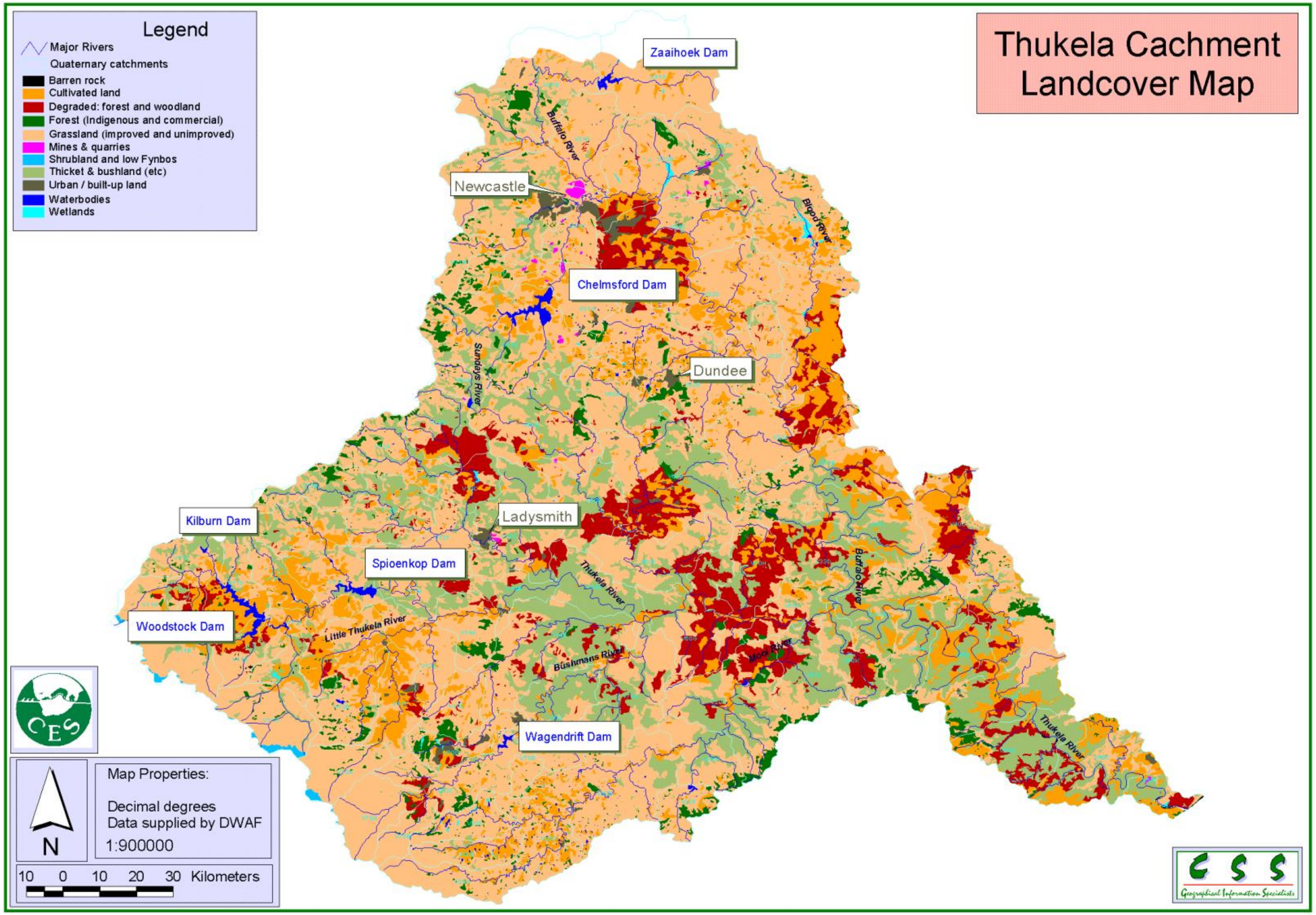


Fig 2.1 Landcover characteristics of the Thukela catchment

- The Ladysmith-Ezakheni area contributes to pollution of the Thukela River via the Klip River primarily, where high *Escherichia coli* and total coliforms have been measured (Tlou and Matji, and WRP Consulting Engineers, 2002).
- There has been a rapid growth in informal settlements around the Ladysmith area, therefore contributing to high organic loads. This is also valid for the Tugela Ferry and Wasbankspruit areas.
- Urban development and breakdown of municipal services (e.g. blocked sewers) in the Wasbankspruit area, has resulted in occasional high organic loads (Tlou and Matji, and WRP Consulting Engineers, 2002).
- Natural drainage from geological formations and drainage from coal mines also contain appreciable amounts of nitrates, phosphates and sulphates. Two dormant and six closed coal mines are located in the Wasbankspruit and Sundays River catchments. No coal mines are currently operating in the catchment.

2.3 THE LOWER THUKELA CATCHMENT: AN OVERVIEW

This section contains a brief overview of the Lower Thukela catchment, focussing on water quality issues, and includes information drawn from the Internal Strategic Perspective (ISP) conducted for DWAF by Tlou and Matji, and WRP Consulting Engineers, in 2002. Other information sources are indicated where used. See Table 3.3 for additional information.

- Overstocking of livestock is evident in the Mooi River catchment, and a number of piggeries in the area increase eutrophication levels.
- The most impacted area in the Thukela catchment is the Buffalo River catchment, particularly the upper catchment (Chapter 3 of this study).
- The Buffalo River is highly salinised along its length (mostly due to acid mine drainage); particularly in the upper catchment (Chapter 3 of this study).
- Half the urban population in the Thukela catchment is centered in Newcastle, Volksrust, Dannhauser and Charlestown areas along the Buffalo River.
- Iscor, Karbochem, AECI, and coal mining are the main industrial and mining activities in the Buffalo River and Thukela catchments.
- There are eight dormant and six closed coal mines in the *Upper Buffalo River* catchment (Tlou and Matji, and WRP Consulting Engineers, 2002).
- Ncandu, Horn, Ngagane and the Buffalo River (immediately upstream of its confluence with Ngagane) are the rivers most severely impacted by urban, industrial or mining developments in the Upper Buffalo River catchment, with the following primary water quality impacts evident (Tlou and Matji, and WRP Consulting Engineers, 2002).
  - High salinity levels from acid mine drainage.
  - Organic and faecal pollution due to raw sewage spillage from the western portion of Madadeni township.
  - Reports of sodium and flouride pollution (near the Ngagane – Buffalo River confluence, associated with Iscor).
  - Reports of taste and odour problems associated with chlorinated phenols (observed in the Horn and Ngagane rivers at Iscor's raw water intakes). These reports could not be verified as phenols are not monitored by DWAF.
  - The catchments are overstocked by about 40%, resulting in soil erosion and high turbidities.
- The *Middle Buffalo River* catchment has a large rural population. Consul Glass (located near Dundee in the Mzinyashane River catchment) is the most significant industrial development. Approximately six operating coal mines, 18 dormant coal mines and 17 closed coal mines are located in this section of the catchment (Tlou and Matji, and WRP Consulting Engineers, 2002).
- The Middle Buffalo River is about 70% over stocked with livestock.
- The Mzinyashane River system is the most severely affected by acid mine drainage from coal mining activates. The eutrophication of streams downstream of coal

mining areas is thought to be attributable to the increased nutrient loads coming from the coal mines.

- The rural population density of the *Lower Buffalo River* catchment is high, and the carrying capacity of the catchment for livestock is being exceeded. General degradation of catchment vegetation, leading to soil erosion and high in-stream turbidities, and organic pollution are the most prominent impacts on surface water quality.
- The main urban centres in the lower section of the Thukela catchment are Sundumbili, Mandini, Tugela Rail and smaller villages. The main industrial developments are the Sappi mill at Mandini and Isithebe Industrial Estates.
- The land-use activities and water quality implications of the Mandini area can be described as follows (Section 4.4.3 of this study): Large industrial area, including Sappi Tugela mill, Mandini, Tugela Rail and Sundumbili Sewage Treatment Works (STW), a textile and vegetable oil factory. Irrigation by sugar farmers takes places further downstream. Abstraction and discharge takes place in this area. Water quality conditions are Fair according to available water quality data. However, data confidence is low as this is a known area of impact, and available data does not seem to reflect these poor conditions. This is particularly important as biological data reflect the deteriorating water quality conditions (PES for fish: D category), even though evidence of rapid recovery can be seen at the John Ross bridge further downstream (Coke, 2001). The impact of Mandini Stream therefore seems localized, with dilution at times of high flows and requested compensatory flows from Spioenkop Dam upstream resulting in good recovery taking place in the Thukela River.
- Sappi's effluent discharge into the Tugela River, via the Mandini Stream, is characterized by high BOD, COD, suspended solids, sodium levels, colour problems and temperatures of up to 46°C. Reductions in dissolved oxygen (DO) downstream of Sappi's effluent discharge have been noted. Water is released from Spioenkop Dam on request to dilute Sappi wastewaters. Sappi monitor at three sites in the Thukela River downstream of the Mandini – Thukela River confluence, i.e. *John Ross bridge*, a point called *Ultimatum Tree* about 5-6 km downstream, and *Havelock Farm*, another 2-3 km toward the estuary, for Chemical Oxygen Demand (COD), Na, pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), temperature and colour. Unfortunately their database is limited, with monthly medians reported for the last 5 years. Results do not reflect the expected poor water quality conditions. For more information, see Section 4.4.3 of this study.
- The rural population density in the lower section of the catchment is the highest in the Thukela catchment. Livestock densities are the lowest in the catchment, and appear to be well within the carrying capacity of the catchment. Afforestation covers about 15% of this sub-catchment area (Tlou and Matji, and WRP Consulting Engineers, 2002).

3 THUKELA ECOLOGICAL RESERVE ASSESSMENT: WATER QUALITY - METHODS

3.1 INTRODUCTION

This section of the report follows the methods of DWAF (2002a), i.e. Approach 2, for delineating Quality Resource Units (QRU), and defining Reference Condition (RC) and Present Ecological State (PES) categories in terms of water quality, per Resource Unit and QRU. Toxicological data (Section 4.2 and Appendix E) and flow-concentration modeling (Section 4.3 and Appendices F-J) were also produced and undertaken, as they provided useful additional information for a comprehensive water quality Reserve assessment. Although the method manual used to undertake this study, i.e. DWAF (2002a), is not appended to this report, excerpts from the manual are provided where necessary and an electronic version of the manual is available as part of the electronic database of information for this study.

3.2 STEP 1: INITIATE STUDY AND SCOPING

In this phase the geographic study area and required level of confidence was determined, and the list of water quality constituents to be assessed during the study finalized.

The geographic area, i.e. the *Thukela catchment*, and an assessment at the *comprehensive level* was confirmed by the client. The area defined as the study area is described in DWAF (2003a), and includes the main stem of the Thukela River, as well as the Little Thukela, Bushmans, Sundays, Buffalo and Mooi rivers (Fig 2.1).

DWAF (2002a) provides methods for a number of water quality constituents that are assessed for an ecological Reserve water quality assessment. However, the methods are not yet complete and not all constituents could be assessed to provide a high confidence comprehensive Reserve assessment. Constituents, and instructions for use, are described in Section 3.4.2. For more detailed information see DWAF (2002a). Water quality constituents listed in DWAF (2002a) are shown below:

- Inorganic salts
- Nutrients (Total Inorganic Nitrogen (TIN), Soluble Reactive Phosphorous (SRP))
- Dissolved oxygen
- pH
- Turbidity
- Temperature
- Toxic substances
- Biotic community composition, i.e. macroinvertebrates
- Chlorophyll-a as an indicator of algal abundance

3.3 STEP 2: DELINEATION OF (WATER) QUALITY RESOURCE UNITS AND SITE SELECTION

As water quality is an integral component of sustaining river systems for efficient and effective use, Quality Resource Units (QRUs), or areas of homogeneous water quality, were identified for the Thukela study area. Quality and quantity resource units are determined during a Reserve assessment - while these may overlap and sometimes be defined by the same features e.g. a tributary, they are often not the exact same sections of the river. Note that all references to quality refer to *water* quality.

Note Water quality input to the Ecological Reserve project was based on IFR sites, contained within Resource Units. However, the methods of DWAF (2002a) for the quality

Reserve require data assessment at the level of QRUs. Results are therefore presented per QRU, contained within Resource Units.

The delineation of QRUs was based on the following information:

- 1:50 000 maps of the catchment, depicting land-use activities, point and diffuse sources of pollution, and catchment characteristics, such as towns, tributaries, dams, etc. Note that dam walls normally form the upstream boundary of a QRU, and the inflow point into the reservoir the downstream boundary (DWAF, 1999a; DWAF, 2002a). Towns, point sources and tributaries can define the boundary between QRUs.
- A site visit of the catchment and discussions with residents of the study area, including staff of DWAF regional offices and Tugela Mill, Sappi.
- Available water quality reports, e.g. the *Water quality situation assessment: Wasbank River catchment* (DWAF, 1999b).
- The working draft of the *Operating rules report* from the systems modellers on this project (DWAF, 2001): This document provides an indication of how dams are operated in the catchment, both for water availability and dilution purposes (e.g. Sappi Tugela Mill). This information assisted in giving some insight as to where identified water quality problems are managed by manipulating flows. Although the water quality study advocates the preferential management of point sources of pollution where possible, it is recognised that regional water resource managers do release water from dams for dilution purposes, e.g. the release of water from Spioenkop Dam for the dilution of Sappi Tugela return flows near Mandini, and releases from Ntshingwayo (Chelmsford) Dam to dilute factory spillages.
- Note that ecoregional information was being refined and therefore not available for the selection of Quality Resource Units.

Once QRUs had been delineated, water quality monitoring data available for the catchment was collected from the following sources for the present state assessment.

- DWAF monitoring points: All the DWAF water quality monitoring points in the Thukela catchment study area were identified, including points outside of the study area which may provide information on water quality conditions within the study area. Once the IFR sites had been selected for the upper and lower Thukela catchment, the DWAF monitoring points closest to the IFR sites were also identified. Water quality data was requested from the DWAF Hydrological Information System (HIS) database (now WMS) for each identified monitoring point. All data were screened (e.g. for length of data record and frequency of sampling) and only DWAF monitoring points with data of *adequate quality* (as prescribed by DWAF, 2002a) were used. See Appendix B for the DWAF monitoring points.
- Data from other sources, e.g. Umgeni Water and Tugela Mill, Sappi (see Appendix K for graphs of Sappi data).
- Additional water quality data collected for the purposes of this project (named *water quality (WQ) sites 1-6*): Upon screening the water quality data, a number of gaps in the dataset became obvious. Six points in the catchment were identified (a budget-dependent selection) for additional data collection. Additional monitoring consisted of weekly data for 2 months (mid-August to mid-October 2001), as per the requirements of the RDM documents (DWAF, 1999a). Water samples were collected and analysed for a specified list of constituents by Umgeni Water Services. The constituents were selected so as to match those currently monitored by DWAF and available at DWAF monitoring points. Sites sampled are shown in Table 3.1.
- Limited Polmon and water quality data available from DWAF regional offices.

Table 3.1 Additional sites in the Thukela study area monitored weekly for water quality during August and October 2001

Site code	Site description	Co-ordinates
WQ site 1	Thukela River around Jameson's Drift	28°46'22.7"S, 30°53'56"E
WQ site 2	Lower Buffalo River, around IFR 14	28°26'49"S, 30°36'00.4"E
WQ site 3	Lower Sundays River, around IFR 8	28°38'43"S, 30°12'49.5"E
WQ site 4	Bushmans River between Weenen and the Bushmans – Thukela confluence	28°46'02.8"S, 30°10'09.6"E
WQ site 5	Thukela River below the Klip - Thukela confluence, and upstream of the Thukela - Bloukrantz confluence	28°44'47.2"S, 30°08'42.3"E
WQ site 6	Klip River, below Ladysmith and upstream of the Klip - Thukela confluence	28°36'43"S, 29°54'12"E

Resource Units and QRU defined for the Upper and Lower Thukela catchments are seen in Tables 3.2 and 3.3 respectively. Note that the water quality descriptor provided on these tables is based on a screening exercise that was conducted *before* the present state assessment. Tables also show the DWAF monitoring points available, and those sourced for data for assessing RC and PES. The position of the QRUs is listed in relation to segment numbers and Resource Units, as used by the Water Quantity task group. In areas where no water quality data are available, neighbouring Quality Resource Units were amalgamated. Figure 3.1 and Figure 3.2 show QRUs graphically for the Upper and Lower Thukela catchments respectively.

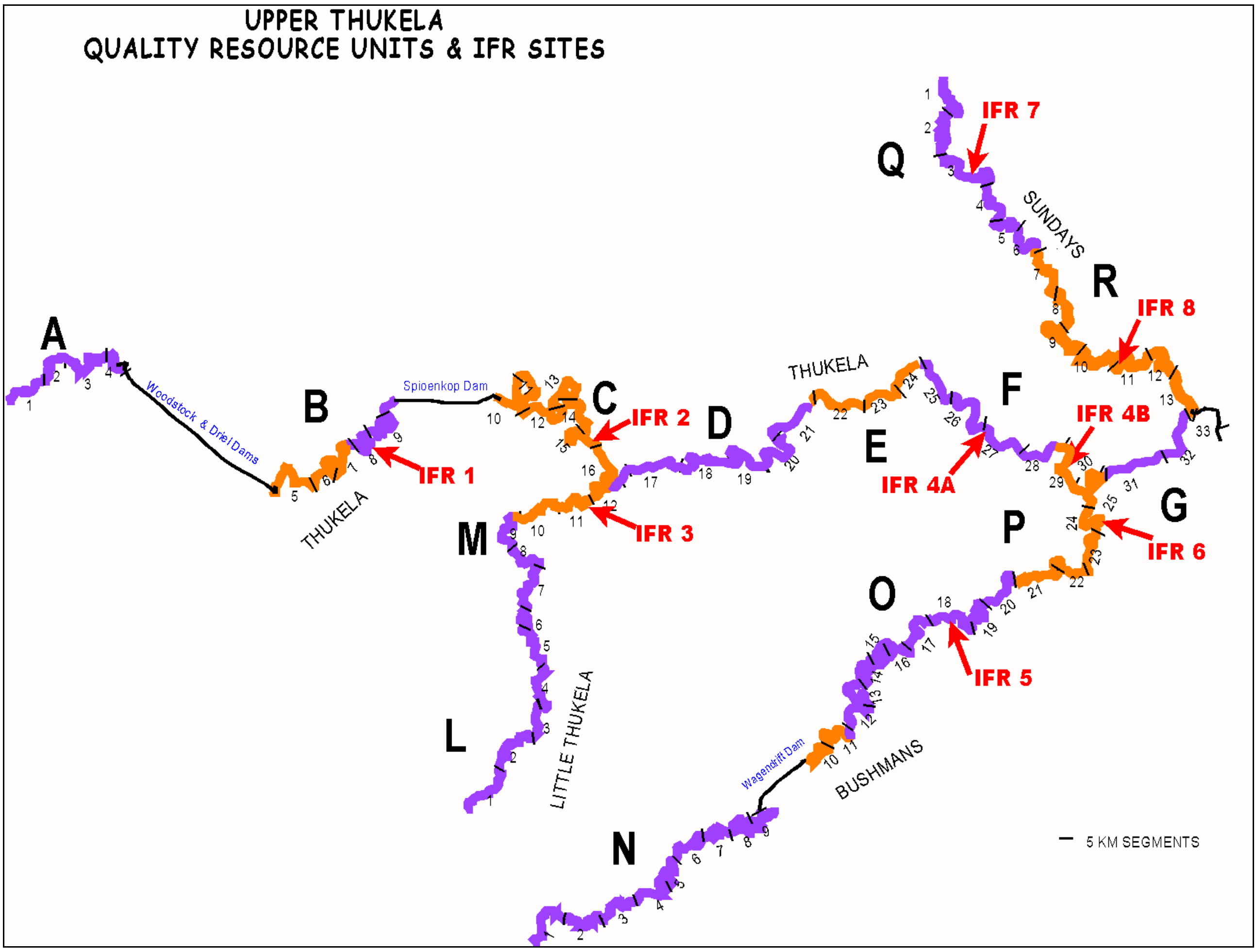


Fig 3.1 Quality Resource Units of the Upper Thukela catchment (colours used to differentiate between adjoining QRUs)

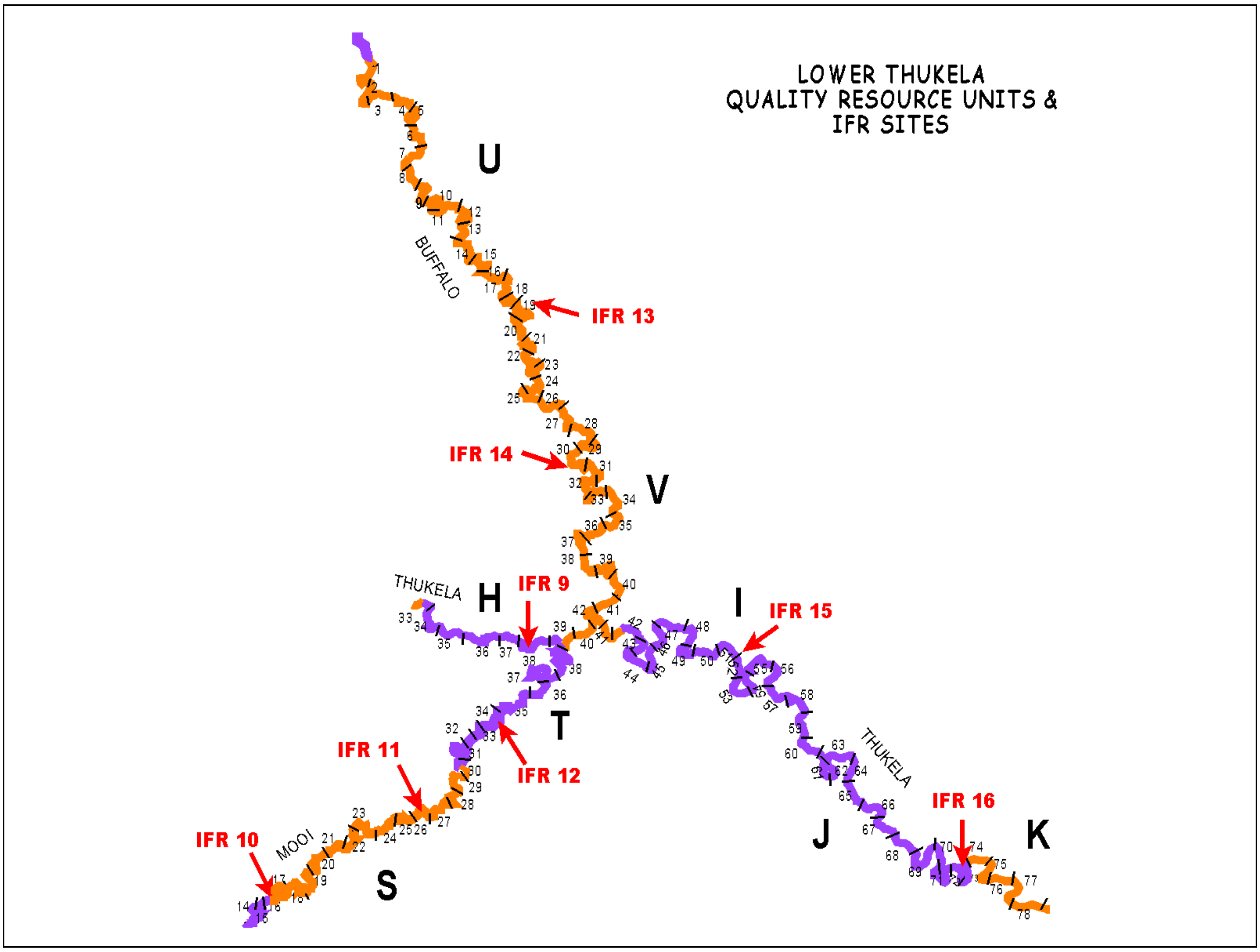


Fig 3.2 **Quality Resource Units of the Lower Thukela catchment (colours used to differentiate between adjoining QRUs)**

Table 3.2 Resource Units, QRUs and descriptive information for the Upper Thukela catchment

Upper Thukela River Catchment: Thukela River				
QRU no.	**Segment no. (RU)**	**Description**	**Monitoring point data available and used for assessing RC + PES**	**Land use activities and implications for water quality**
1	1-4 (A)	Rugged Glen to upstream of Woodstock and Driel Dams.	DWAF mon. points V1H035 (**RC**) and V1H036 (**PES**)	Little land use activity; some cultivated lands. Water quality conditions good.
2	5-7 (B)	Woodstock and Driel Dams to upstream of Bergville.	DWAF mon. point V1H058 (data not suitable).	Water is abstracted for irrigation (cultivated lands) and urban/domestic water purposes, and the water transfer sheme to the Sterkfontein Dam in the Vaal River system from the Woodstock and Driel Dams. Water quality conditions appear good, although data confidence not suitable for a present state assessment.
3	7-9 (B)	Bergville to upstream of Spioenkop Dam.	DWAF mon. points V1H026 (**PES**) and V1H031. *Combine QRUs 2 and 3*, and use V1H035 from QRU 1 for **RC**.	Irrigation (cultivated lands and orchards) and urban / domestic water use. Water quality conditions good. Water quality at V1H031 (on the Sand Spruit) is poorer than V1H026 (on Thukela), probably due to agricultural return flows - dilution at the confluence expected to improve quality.
4	10-16 (C)	Spioenkop Dam to upstream of Thukela - Little Thukela confluence.	DWAF mon. point V1H057 (**RC** and **PES**).	Main land use is crop production and cattle farming. Water quality conditions good.
5	17-20 (D)	Thukela - Little Thukela confluence to upstream of Colenso.	No water quality data. *Combine QRUs 5 and 6.*	Main land use is crop production and cattle farming.
6	21-24 (D, E)	Colenso to upstream of Thukela - Klip River confluence near Ladysmith.	DWAF mon. point V1H001 (**RC** and **PES**) at Colenso.	Urban / domestic water use and limited cultivated lands. Water quality conditions good. Slightly reduced water quality conditions during winter.
7	25-29 (F)	Thukela - Klip River confluence to upstream of the Thukela - Bloukrantz confluence.	There are no DWAF mon. points in this segment. DWAF data on the Klip River will therefore be used, i.e. V1H038 just upstream of Ladysmith, and WQ site 6 upstream of Thukela - Klip River confluence. It is important to acknowledge the dilution effects when the Klip and Thukela Rivers join. WQ site 5 data (**PES**) is also available for the stretch below the Klip confluence and above the Bloukrantz confluence with the Thukela River.	The Klip River brings water of reduced quality to the Thukela River. Urban run-off and discharge from industrial activities associated with Ladysmith drain into the Klip River, and subsequently into the Thukela River. However, quality is expected to be restored to some degree upon dilution at the confluence of the Klip and Thukela Rivers. Klip River: water quality conditions fair. Thukela River QRU: effect of Klip River input ameliorated upon dilution.
8	29-30 (F)	Thukela - Bloukrantz confluence to upstream of the Thukela - Bushmans confluence.	No water quality data. *Combine QRUs 7 and 8.*	This QRU has been separated from QRU 9 due to the large-scale citrus farming being undertaken at Tugela Estates, just downstream of the Thukela - Bloukrantz confluence.
9	31-33 (G)	Thukela - Bushmans confluence to upstream of Thukela - Sundays confluence.	No water quality data. *Combine with QRU 10.* There is also a significant short tributary called the Sikhehlengeni River in this reach.	Crop farming and some settlements.

QRU no.	Segment no. (RU)	Description	Monitoring point data available and used for assessing RC + PES	Land use activities and implications for water quality
Upper Thukela River Catchment: Little Thukela River				
14	1-9 (L, M)	Wonder Valley to upstream of Winterton.	No water quality data. *Combine with QRU 15*.	Crop production and irrigation.
15	10-12 (M)	Winterton to the confluence of the Little Thukela and Thukela Rivers.	DWAF mon. point V1H010 (**RC** and **PES**).	Irrigation of extensive cultivated lands and orchards, and urban / domestic water use. Water quality conditions fair. In winter some increase in TDS and nutrient levels are evident, which may become problematic.
Upper Thukela River Catchment: Bushmans River				
16	1-9 (N)	Elands Park to upstream of Wagendrift Dam.	DWAF mon. points V7H016 on the Ncibidwane River (a tributary of the Bushmans, joining it at segment 2), and V7H017 (**RC** and **PES**) on the Bushmans River, at the confluence with the Ncibidwane.	Settlements and subsistence cattle farming. Some cultivated lands and orchards. Water quality conditions good.
17	10-11 (O)	Wagendrift Dam to upstream of the Little Bushmans River - Bushmans River confluence (including Estcourt).	DWAF mon. points V7H018 and V7H012 (at Estcourt, **PES**) on the Little Bushmans River. V7R001 at the outlet of Wagendrift Dam (not suitable for **RC** or PES).	Irrigation and urban / domestic water use. Some industrial activity (e.g. Nestlé, Estcourt meat processing) at Estcourt. Water quality conditions fair. Quality somewhat reduced at Estcourt (V7H012), probably due to urban run-off and industrial activity.
18	12-20 (O, P)	Little Bushmans River - Bushmans River confluence to upstream of Weenen.	No water quality data. *Combine with QRU 19*.	Crop production and irrigation.
19	21-25 (P)	Weenen to the confluence of the Bushmans and Thukela Rivers.	There are no DWAF monitoring points in this segment. Use WQ site 4 (**PES**) data.	Crop production, irrigation and urban / domestic water use. Water quality conditions fair (limited data).
Upper Thukela River Catchment: Sundays River				
20	1-6 (Q, R)	Sundays River from the Ladysmith/Newcastle road to upstream of the Wasbank - Sundays River confluence.	DWAF mon. point V6H006 (above study area, **RC**) and V6H004 (segment 2, **PES**).	Informal settlements, subsistence crops and cattle farming. The Newcastle-Platberg Colliery is found in this QRU. Water quality conditions good above the study area - reduced to fair by segment 2, due to increasing sulphate levels and the presence of the colliery.
21	7-13 (R)	Wasbank - Sundays River confluence to the confluence of the Sundays and Thukela Rivers.	DWAF mon. point V6H003 on the Wasbank River, WQ site 3 (**PES**) on the lower Sundays River (around IFR 8). Use V6H006 for **RC** (as for QRU 20).	The water quality in this reach is largely affected by input from the Wasbank River. Primary land use in the Wasbank catchment area is agriculture (crop production, cattle and game farming, subsistence farming) and trading. The upper Wasbank River is affected mainly by acid mine drainage from defunct coal mines, and high salt loads are evident. Large informal and semi-formal settlements can be seen in the lower Wasbank catchment. Poor water quality is evident. Some cultivated lands downstream of the Wasbank-Sundays River confluence. Poor quality water coming in from the Wasbank River (V6H003), with high TDS and sulphate levels. TDS and Sulphate levels still elevated at the monitoring point on the Sundays River, where water quality is fair.

Table 3.3 Resource Units, QRUs and descriptive information for the Lower Thukela catchment

Lower Thukela River Catchment: Thukela River				
QRU no.	**Segment no. (RU)**	**Description**	**Monitoring point data to be used**	**Land use activities and implications for water quality**
10	34-39 (H)	Thukela - Sundays confluence to upstream of Thukela - Mooi River confluence.	DWAF mon. point V6H002 (**RC** and **PES**) at Tugela Ferry.	This area is rugged and remote, with little activity excluding some settlements and subsistence farming. Water quality conditions fair. Slightly elevated TDS, particularly in winter. Nutrient levels elevated, potential exists for eutrophication if levels continue increasing.
11	39-41 (H, I)	Thukela - Mooi River confluence to upstream of Thukela - Buffalo River confluence.	No water quality data. *Combine with QRU 12*. Use WQ site 1 (**PES**) at Jameson's Drift.	This area is rugged and remote, with little activity excluding some settlements and subsistence farming.
12	42-73 (I, J)	Thukela - Buffalo River confluence to upstream of the Mandini / Sundumbili industrial complex.	DWAF mon. point V5H002 (**RC** and **PES**) (segments 52 – 73).	This area is rugged and remote, with little activity excluding some settlements and subsistence farming. This QRU also includes the Tugela-Mhlathuze transfer scheme abstraction point. Water quality conditions fair (data confidence low).
13	74 - estuary at 78 (K)	Mandini / Sundumbili industrial complex to the Thukela estuary.	DWAF mon. point V5H002 (segment 73-74) and water quality data from Sappi Tugela. **Note** This QRU is not covered in the water quality report, as dealt with as part of the estuarine assessment.	Large industrial area, including Sappi Tugela mill, Mandini, Tugela Rail and Sundumbili Sewage Treatment Works. Irrigation by sugar farmers takes places further downstream. The DWAF mon. point is upstream of most of the impacts. Abstraction and discharge takes place in this QRU. Water quality conditions fair - additional data accessed for verification (data confidence extremely low as a known area of impact).

Table 3.3 Continued…

QRU no.	Segment no. (RU)	Description	Monitoring point data to be used	Land use activities and implications for water quality
Lower Thukela River Catchment: Mooi River				
22	1-15 (S)	Beginning of study area to upstream of Mooi River town.	DWAF mon. point V2H006 on the Little Mooi River and V2H005 (**RC** and **PES**) on the Mooi River.	Cattle farming, stud farms and irrigation. Site of Mooi-Mgeni Transfer Scheme, from the Mooi River to Midmar Dam. Water quality conditions good.
23	16-30 (S, T)	Mooi River town to upstream of Muden.	DWAF mon. point V2H002 (**PES**) at Mooi River town, and V2H004 on segment 26 (around IFR 11). Use V2H005 for **RC** (as for QRU 22).	Defunct textile mill (closed 1999/2000) in Mooi River town. Extensive nutrient enrichment evident around Mooi River town (July 2001), apparently due to irrigation of fodder crops right down to river's edge. Large cattle breeding (dairy) and citrus farming area. Water quality conditions fair - good. Elevated TDS levels in winter.
24	30-38 (S, T)	Muden to the confluence of the Mooi and Thukela Rivers.	DWAF mon. point V2H008 (**PES**) at Keate's Drift. Use V2H005 for **RC** (as for QRU 22 and 23).	Irrigation and farming activities, particularly the Mooi River Irrigation Scheme before the Mooi-Thukela River confluence. Mostly informal settlements and subsistence farming around Keate's Drift. Water quality conditions fair. Elevated TDS levels in winter.
Lower Thukela River Catchment: Buffalo River				
25		Above the study area, including the Newcastle industrial area, the Ncandu and Ngagane tributaries of the Buffalo River, Osizweni and Madendeni.	DWAF mon. points V3H009 on the Horn River, a tributary of the Ngagane River, and V3H027 on the Ngagane River. No **RC** point, therefore default to benchmark tables. Use V3H010 for **PES**.	Extensive industrial area, including coal mining, Iskor (increasing salt levels significant), Eskom power station, Karbochem (main impact is high COD levels), spillage from the Sewage Treatment Works into the Ngagane River. Ngagane River therefore heavily affected by pollution. Extensive formal settlements of Newcastle, Madendeni and Osizweni, with associated urban / domestic water usage and discharge impacts. Water quality poor, particularly in the Horn River. Some amelioration in the Ngagane River.
26	1-42 (U, V)	From the Utrecht - Ozisweni road bridge to the confluence of the Buffalo and Thukela Rivers (area includes IFR 13 and 14).	No DWAF monitoring data is available; use WQ site 2 (**PES**), around IFR 14. Use V3H011 (Blood River) for **RC**.	Settlements, some farming activities (cultivated lands). Water quality fair - poor, with high TDS and sulphate levels.

3.4 STEP 3: DETERMINATION OF BENCHMARKS: DATA COLLECTION, DEFINITION OF RC AND PES CATEGORIES

3.4.1 Introduction

Before benchmarks (i.e. the key quantitative values and qualitative, narrative descriptions that comprise the water quality component of the Ecological Reserve) and Reference Condition (RC), Present Ecological State (PES) categories and quality ecospecs can be determined, the following data assessment and manipulation must be undertaken.

- Check data length.
- Check for seasonality and uneven frequency of sampling – if so, conduct weighting procedure if required.
- Manipulate data to produce means, 5th and 95th percentiles.

3.4.2 Data assessment and manipulation

DWAF (2002a and b) provide details of procedures to undertake an ecological Reserve for water quality at three levels of confidence (low, medium and high or otherwise referred to as Rapid, Intermediate and Comprehensive) and for a range of water quality constituents. The data requirements and analysis for these water quality constituents are discussed. Data requirements vary depending on whether the assessment being undertaken is at a low, medium or high confidence level. As far as possible, the data requirements for the high confidence assessment were followed in this study.

Note that this report merely outlines the methods to be followed for each variable. Although the water quality report should be an independent report, it was not considered practical to include the methods manual within this document, but rather provide the manual electronically as part of the electronic database of information for this project. The benchmark table and method for the *nutrient assessment* is shown as an example of RC and PES assessment. Other excerpts (benchmark boundaries) from the methods manual (DWAF, 2002a) are shown where relevant, and are taken directly from the manual.

In general, the water quality data record for each monitoring point was assessed as to its suitability for inclusion in the water quality assessment process, either for Reference Condition (RC) or for Present Ecological State (PES). Data from the relevant RC monitoring point was analysed and a decision made as to whether the default benchmark boundary values provided in DWAF (2002a) needed to be adjusted. For example, if analysis of the RC data showed that the background levels of a given constituent were naturally high, the default boundary values would need to be adjusted. If the benchmark values were to be left unchanged, the analysis proceeded for the PES assessment using the appropriate water quality monitoring point data. If the benchmark tables required adjusting, this was done before the analysis for PES could be undertaken. A description of how to adjust the benchmark tables provided can be found in DWAF (2002a). When suitable RC data were not available (e.g. no suitable water quality monitoring point is available for the QRU), the PES assessment reverts to the default benchmark tables.

For the purpose of this study the A - F categories were retained for the assessments, as these categories can be readily converted to the Natural – Fair classification system (see Table 1.2).

Water quality data were obtained from the DWAF-HIS database (data now stored on the WMS database). The length of data record and frequency of sampling varied between water quality monitoring points, but the most recent data available was up to the beginning of 2001, i.e. the commencement of the water quality assessment for this study. There were areas where no water quality data was available. Under these conditions, the method of DWAF (1999a) allows for the weekly collection of two months of water quality data. As the water quality assessment had been initiated following these RDM protocols, these weekly data were available to the project team. Therefore, in resource units where the only data available were those collected during the course of this project, these data were used for determining present state, although with reduced confidence due to the small sample size and limited duration of sampling. These resource units (and quality resource units) are clearly indicated in the Results section (Section 3.4.3).

DWAF (2002a) requires that some water quality constituents be weighted for season before analysis is undertaken. An appropriate statistical method for achieving this was not however, specified. After discussion with a statistician (Radloff, Rhodes University, *pers. comm.*), it was decided to use a simple weighting procedure to adjust the median and percentile data. Data were weighted according to flow, i.e. a period of high flow and a period of low flow: all data were included in one or the other of these categories. The low flow period was April to September and the high flow period was October to March (Hughes, Rhodes University, *pers. comm.*). These low and high flow periods coincide with winter and summer months respectively.

DWAF (2002a) provides methods for assessing a number of water quality constituents which are considered important in an ecological Reserve water quality assessment. However, the methods are not yet complete and not all constituents could be assessed to provide a high confidence comprehensive Reserve assessment. Data analysis and interpretation of each of the constituents are described in Section 3.4.3; where constituents were not included in the analysis and assessment, it was due to insufficient information being provided in DWAF (2002a) to be able to undertake the assessment, or because the DWAF monitoring network does not include that variable, e.g. turbidity was not measured routinely in most of the Thukela catchment.

Inorganic salts

According to DWAF (2002a), a limited selection of inorganic salts should be analysed in preference to using either electrical conductivity (mS/m) or Total Dissolved Solids (mg/L), as the effects of these individual salts outweigh effects attributable to increasing salinity. These inorganic salts are, in order of increasing toxicity, $CaSO_4$, NaCl, $CaCl_2$, $MgCl_2$, Na_2SO_4 and $MgSO_4$. DWAF (2002b) describes how toxicity data from international databases were used to derive the upper boundary levels for the Natural, Good and Fair boundaries and the EWQRCalc Version 2.3 (2002) model was used to undertake the calculations of salts from ionic data. The EWQRCalc model was developed by Jooste (RQS) specifically to undertake water quality calculations for Reserve assessments. Within this model, the ionic water quality data (usually from DWAF but other sources of data can be used) are recalculated to provide salt concentrations (magnesium sulphate, sodium sulphate, magnesium chloride, calcium chloride, sodium chloride and sodium sulphate). These data and other water quality constituents (such as nutrients) are analysed and compared against provided benchmark boundary values to provide an overall assessment for the site being assessed. A major discrepancy between the method used in the model and the DWAF documentation provided to undertake assessments for nutrients (DWAF, 2002a) meant that the EWQRCalc model could only be used to undertake the Reserve assessment for salts. The discrepancy was the result of a weighting procedure required by the method (DWAF, 2002a), which was not incorporated in the EWQRCalc model. Boundary values for the A, B, C and D categories provided in EWQRCalc Version 2.3 (2002) were therefore used rather than the values in the benchmark tables of DWAF (2002a) – this was on recommendation from Jooste (RQS, *pers. comm.*) as the values in EWQRCalc Version 2.3 were more up to date. This spreadsheet (in Excel) was provided to the water quality team to undertake the water quality assessment. This model is currently still confidential and not available for general use. Although the EWQRCalc spreadsheet is not appended to this report (the spreadsheet is comprised of formulae in cells and calculations are formulated), an electronic version is available as part of the electronic database of information for this study.

Note that as TDS data were available, TDS data is used in combination with individual salts for flow-concentration modeling.

Confidence in the PES assessment is linked to the data record. A high confidence assessment can be undertaken if the data record contains at least 60 samples evenly distributed over a time period that is no longer than 5 years. Fewer data records results in a medium or low confidence assessment. Inorganic salt data are not weighted for seasonality before assessment.

In all the QRUs the benchmark table values were used for the inorganic salt assessment to derive the water quality category for the PES, implying that areas of naturally elevated salinity were not found in the study area.

Nutrients

The nutrients considered for the water quality assessment are Soluble Reactive Phosphorous (SRP) and Total Inorganic Nitrogen (TIN). These two constituents are considered important due to their role in algal growth and eutrophication. As such, seasonality is considered important and the data are weighted. Benchmark table values were adjusted where necessary to provide RC values. The benchmark tables and method for the RC and PES assessment, as taken from DWAF (2002a) are shown in the text boxes below to illustrate the method.

Table x: The benchmark class boundaries for nutrients. SRP should be used as the driver in the reference condition. (Based on SA Water Quality Guidelines for Aquatic Ecosystems (DWAF 1996), Water Quality Index ranges (Umgeni Water), and practical experience in the Umgeni Water Operation Area)

Category	Soluble Reactive Phosphorus, SRP, mg/ℓ	Total Inorganic Nitrogen, TIN, (Nitrate + Nitrite + Ammonia), mg/ℓ
Natural	<=0.005	<=0.25
Good	<=0.025	<=1
Fair	<=0.125	<=4
Poor	>0.125	>4

- The average concentration results for the last 3 years of data should be used to determine class.
- The data should be at least at a monthly frequency to account for seasonality. If there are more results in one season (summer/winter), than the other, the data should be weighted to take account of this imbalance.
- The SA Water Quality Guidelines for Aquatic Ecosystems (1996), the Umgeni Water, Water Quality Index ranges and practical experience in the Umgeni Water Operation Area were considered in drawing up these ranges.
- SRP should be used as the driver in determining class (as apposed to TP). TP is important in lakes – in principle it is TP – but in river TP less relevant because of movement through the system – any gap between SRP and TP is covered by the periphyton response variable.

Reference conditions: Nutrients

Low confidence

- Use the Natural boundary values in Table x modified by any available data.

Medium confidence

- Refer to Natural boundary in the benchmark table
- Compare UNIMPACTED data, or derived data, to Table x:
  - o The average concentration for last 3 years of data should be used.

- o The data should be monthly, and account for seasonality. If there are more results in one season (summer/winter), than the other the data should be weighted to take account of this imbalance.
- If necessary, calibrate Table x according to reference conditions by:
  - o Moving the hypothetical Natural or Protected boundary to the reference condition indicated by the site-specific data.
  - o Moving the Good boundary by half the value you changed the Natural or Protected : Good = (Fair–Reference)0.5 + Reference

High confidence

- Refer to Natural boundary in the benchmark table.
- Compare UNIMPACTED data, or derived data, to Table x:
  - o The average concentration for last 3 years of data should be used.
  - o The data should be two-weekly, and account for seasonality. If there are more results in one season (summer/winter), than the other the data should be weighted to take account of this imbalance.
- If necessary, calibrate Table x according to reference conditions, as follows:
  - o New Natural boundary = average of the data record.
  - o New Good boundary = Old Good + ((new natural – old natural)/2).
  - o New Fair boundary = Old Fair + ((new good – old good)/2).

Present state classification: Nutrients

Low confidence

- Collect SRP and TIN data from the past 1-3 but not more than 5 years.
- Calculate the 95^{th} percentile (95% of values less than this value)
- Use either Table x, or Table x modified for the *Reference Conditions* to relate the nutrient concentration to a PES class.

Medium confidence

- Collect SRP and TIN data monthly results over 3 years.
- Calculate the 95^{th} percentile.
- Use either Table x, or Table x modified for the *Reference Conditions* to relate the nutrient concentration to a PES class.

High confidence

- Collect SRP and TIN data - two-weekly results over 3 years.
- Calculate the 95^{th} percentile.
- Use either Table x, or Table x modified for the *Reference Conditions* to relate the nutrient concentration to a PES class.

Note that the method for adjusting the benchmark table for the Reference Condition for a high confidence assessment is different to that described in DWAF (2002a), as the description provided was incorrect. After discussions with Jooste (RQS) and Rossouw (Ninham Shand), the adjustments described in Table x were undertaken. The PES data were then compared to the adjusted benchmark table values and a category assigned accordingly.

Dissolved oxygen

Many aquatic organisms are sensitive to a lack of oxygen, hence the importance of including an assessment of dissolved oxygen in a water quality assessment. However, the DWAF-HIS data does not contain routine dissolved oxygen information and therefore an assessment of this water quality constituent could not be undertaken. Although spot samples were taken at a few sites during field surveys, the data was considered inadequate for an assessment to be conducted.

pH
The benchmark table in DWAF (2002a) provides category boundaries for only the Good and Fair categories – see text box below. Determining RC and PES for pH was problematic due to the change in analytical methods by DWAF in the late 1980s, resulting in an anomaly in monitoring data.

The benchmark class boundaries for pH

Category	pH
Good	6.5 – 8.0
Fair	5.0 – 9.0

Turbidity
Turbidity is used as a measure of suspended solids and is considered important both due to its ability to scatter light, resulting in reduced photosynthesis in a water body, and its ability to interfere with feeding and foraging (and subsequent growth and reproduction) of aquatic organisms (DWAF, 2002a). However, the method for use in an ecological Reserve assessment for water quality has not yet been developed: there are no category boundary values provided, possibly because the relationship between turbidity and category has not yet been established. Although turbidity data were not available from the DWAF monitoring network, assessments of turbidity were not undertaken as part of additional monitoring as data would merely have provided comparative information between sites. Sediment loads in rivers are expressed qualitatively based on information provided by the team geomorphologist.

Temperature
Temperature is an important physical water quality component affecting aquatic organisms in a variety of ways. Daily and seasonal temperature fluctuations can be large and, in addition, organisms have a wide range in tolerance to temperature changes. Although the method described in DWAF (2002a) is incomplete, it does specify that assessment of water temperature should only occur if a thermal impact is expected to occur, e.g. downstream of a dam or downstream of known thermal effluents. Some of the QRUs were downstream of dams but details of releases were not specified in the DWAF operations document (DWAF, 2001), although some of the dams were capable of bottom releases. However, along with there being no method specified to assess RC and PES, nor any values in the benchmark table, there were also insufficient data (or no data) to undertake temperature assessments for this study. Measurements of ambient water temperature should be included in any future monitoring programme.

Toxic substances
The *South African Water Quality Guidelines for Aquatic Ecosystems* (DWAF, 1996) lists a number of water quality constituents and provides water quality criteria, e.g. Target Water Quality Ranges (TWQR), for these constituents. These water quality constituents need to be considered when there is a low biotic response (e.g. biomonitoring results which reflect poor water quality) (DWAF, 2002a) or an inventory of effluent discharges indicating that there may be water quality issues that should be considered. The boundary values in the benchmark tables are described as values extrapolated from Chronic Effect Values (CEV) and Acute Effect Values (AEV) as described in DWAF (1996) – see text box below. However, no values are provided, and it is not clear how the extrapolations are to be undertaken. The relationship between the boundary category values (i.e. the description provided in the benchmark table, DWAF, 2002a) and the TWQR, CEV and AEV (provided in DWAF, 1996) is not explicit. In addition to these inadequacies of the method, there is no description of how to undertake the RC assessment, nor is there adequate information to undertake a PES

assessment. For these reasons, toxic substances were omitted from the water quality assessment, and qualitative information provided where available.

The benchmark class boundaries for (toxic substance). Values not available at time of preparing this report.

Boundary	Concentration of (toxic substance)
Natural	100% species protection extrapolated from 95% CEV
Good	95% species protection based on 95%CEV
Fair	100% species protection extrapolated from 95% AEV

Biotic community composition

Biomonitoring data provides a recognised measure of water quality and general river health using the presence/absence of selected *macroinvertebrate taxa* (family level identification). The advantage of using macroinvertebrates is that they are able to provide an integrated response to water quality over time, and respond to pulses of changing water quality (which are missed by only collecting chemical samples intermittently) as well as constituents which are not monitored. The method describes how to derive RC and use these to adjust the benchmark table values if necessary – see the benchmark table in the text box below. The PES assessment is then compared against the benchmark table values. However, the high confidence assessment requires that three or more sites per unimpacted site (for RC) and resource unit (for present state) should be surveyed, and for three non-high flow seasons. These data requirements could not be fulfilled during this project.

The benchmark class boundaries biotic composition (SASS). The ASPT should be the combined data from all biotopes present at a site as described in Dickens and Graham (in press).

Class boundary	Range of ASPT Scores
Natural	7
Good	6
Fair	5

Data provided by Dickens and Bokwe (2002) were therefore used to provide information regarding the biotic community composition; no new data were collected on any of the catchment visits. The PES category provided by Dickens and Bokwe (2002) were used to provide an overall QRU assessment.

Chlorophyll-*a* as an indicator of algal abundance

Using only the nutrient analyses from the water quality database may provide an incorrect assessment of the nutrient status of a river. Low concentrations of nitrogen, phosphorous or both suggest that nutrient levels and eutrophication in the stream are low – however, these dissolved nutrients may be bound in the active growth of plants (algae), indicating that eutrophication may in fact be present. Algae (both free-floating phytoplankton and periphyton found on substrates) are the main cause of water quality problems associated with eutrophication. Chlorophyll-*a*, a photosynthetic pigment found in algae, provides a sensitive assessment of the algal biomass present in a water body, and is the most widely used indicator of algal biomass in South Africa.

Chlorophyll-*a* should be used as an indicator of algal abundance when there is evidence of nutrient enrichment, e.g. through the presence of phytoplankton or periphyton. If chlorophyll-

a data are readily available they should be used. If not, samples should be collected during a site visit and the data compared to the benchmark table values to provide an assessment of the present ecological state, although the confidence of the assessment will be low due to the small sample size. See the text box below for the benchmark table.

Chlorophyll-*a* assessments were not included in the RDM protocols, and only a single field survey to collect samples for chlorophyll-*a* analysis from selected QRUs was undertaken in June 2002, once the methods of DWAF (2002a) were being followed. Sites for chlorophyll-*a* analysis were selected on the basis of outcome of discussions at a Thukela specialist meeting held in October 2001, and the analysis of water quality data using the DWAF (1999a) method that showed inconsistencies between predicted nutrient categories and personal observations. Where the water quality data did not reflect the PES of the biota (i.e. macroinvertebrates and fish), a spot sample of phytoplankton and periphyton was taken for chlorophyll-*a* analysis. Knowledge of land-use in the catchment was also used to refine the selection of sampling sites (limited time and budget). Samples were analysed by Dr W Froneman of the Department of Zoology and Entomology at Rhodes University – see Appendix C for the report produced by Dr Froneman.

Although only one set of chl-*a* data were available, it proved invaluable in assessing the nutrient status of the rivers and sites sampled.

The benchmark class boundaries for Chlorophyll a as an indicator of algal abundance

Boundary	Indicator	Concentration	Reference
Natural (Oligotrophic)	Phytoplankton Chlorophyll *a*	<10 µg/L	Walmsley & Butty (1980), Walmsley (1984)
	Periphyton[1] Chlorophyll *a*	< 3 mg/m^2	Biggs (1995) cited in EPA (2000)
Good (Mesotrophic)	Phytoplankton Chlorophyll *a*	10-20 µg/L	Walmsley & Butty (1980), Walmsley (1984)
	Periphyton Chlorophyll *a*	3-25 mg/m^2	Biggs (1995) cited in EPA (2000)
Fair (Eutrophic)	Phytoplankton Chlorophyll *a*	20-30 µg/L	Walmsley & Butty (1980), Walmsley (1984)
	Periphyton Chlorophyll *a*	25-260 mg/m^2	Biggs (1995) cited in EPA (2000)
Poor (Hypertrophic)	Phytoplankton Chlorophyll *a*	> 30 µg/L	Walmsley & Butty (1980), Walmsley (1984)
	Periphyton Chlorophyll *a*	> 260 mg/m^2	Biggs (1995) cited in EPA (2000)

In-stream toxicity
Toxicity testing is an important technique for monitoring toxic pollution in aquatic ecosystems. Chemical and physical tests are not sufficient to assess the effects of pollution on the biota, and chemical interactions and complex interactions with the aquatic organisms also need to be considered. Different species of aquatic organisms are not equally susceptible to the same toxic substances, so many different organisms from different trophic levels should be used for toxicity testing. Toxicity tests should also include both short-term or acute tests, and longer or chronic toxicity tests. Acute toxicity tests therefore provide information on the short-term effect of a substance, while chronic toxicity tests provide information on the long-

term effects of a substance, usually after one tenth of the life span of the organism. Toxicity testing using living organisms is used as a rapid method of demonstrating the toxic effect of a substance (Umgeni Water Services, 2002 – full report in Appendix D).

In-stream toxicity tests should be undertaken for an intermediate or comprehensive ecological Reserve assessment (DWAF, 2002a) (these are referred to as medium or high level of confidence assessments in DWAF, 2002a). The method does not provide benchmark values nor sufficient detail for an adequate toxicity assessment.

However, spot water samples were taken from selected sites in May 2002 (i.e. during low flows) and analysed by Umgeni Water Services for acute toxicity using *Daphnia pulex* (water flea), a fish (the guppy *Poecilia reticulata*) and an algal inhibition test using *Selenastrum.* Samples were also analysed for sub-lethal toxicity using the AMES test by the CSIR's Toxicity Testing Laboratory. The selection of sites were based on areas in the catchment where the poorest water quality conditions exist, based on the results of the ERC workshop held in October / November 2001.

Fish have been regarded as good test species for the assessment of aquatic toxicity because of their ecological and economic importance. The guppy species, *Poecilia reticulata* used by the Umgeni Water Hydrobiology laboratory, is a small, live bearing, fresh water fish. It breeds regularly and may be kept in relatively small aquaria. It is also widely used as a test species. The method used at the laboratory is suitable for the determination of acute toxicity to *Poecilia reticulata* by pollution from chemical substances, industrial effluents, sewage effluents and surface or ground waters.

Daphnia pulex are small freshwater crustaceans that have been used for many years to assess toxicity. They are recommended as standard toxicity tests organisms (EPA 1993). *Daphnia* are valuable as test organisms because of their sensitivity to toxic substances, ease of identification, culturing and handling, ubiquitous distribution, tolerance to laboratory conditions and extensive use in toxicity testing. *Daphnia* reproduce parthenogenetically and hence clones with very little genetic variability are produced, with reproducible testing results. The method used is for the determination of acute toxicity to *Daphnia* by pollution from chemical substances, industrial effluents, sewage effluents and surface or ground waters.

Phytoplankton are the primary producers in the aquatic community and are therefore the base of aquatic food chains. As such, bioassays using algae are valuable for determining the primary productivity of a water body. The algae may be used to predict the potentially toxic effects of a substance on the aquatic environment. *Selenastrum capricornutum* is a planktonic green algae, usually unicellular in culture. Chlorophyll-*a* is used as an algal biomass indicator, thus the growth potential of *Selenastrum capricornutum* may be measured by analysis for the presence of the pigment chlorophyll-*a.* The method is used for the determination of the growth inhibition effect of potentially toxic substances (chemicals, industrial effluents and sewage effluents) on the growth of freshwater algae (Umgeni Water Services, 2002 – full report in Appendix D).

The AMES *Salmonella* mutagenicity test is a plate incorporation assay, which uses *Salmonella typhimurium* tester strains TA98 and TA100. TA98 detects frame shift mutagens and TA100 detects base-pair substitution mutagens (CSIR report, 2002 – full report in Appendix D). These tests therefore identify sub-lethal mutagenic effects.

Detailed reports can be found in Appendix D. Sites sampled were as follows:

- Sundays River just below the Wasbank confluence. S: 28° 32' 54'', E: 30° 07' 10''.
- Little Thukela River around Winterton. S: 28° 47' 40'', E: 29° 32' 38''.
- Horn River. S: 27° 53' 26'', E: 29° 57' 40''.
- Buffalo River below Ngagane confluence. S: 27° 42' 29'', E: 30° 06' 59''.
- Mandini Stream. S: 29° 10' 20'', E: 31° 25' 20''.

- Thukela River just below Mandini confluence. S: 29° 10’ 44’’, E: 31° 26’ 11’’.

The only acute toxicity was identified was using the *Selenastrum* algal inhibition test. Toxicity was found in the Mandini Stream and Sundays River samples using this test.

3.4.3 Results

Results for the Present Ecological State assessments are presented in Tables 3.4 to 3.22. The results for the water quality assessment for the Thukela River are presented first, followed by each of the tributaries considered in the study from the most upstream tributary to the most downstream tributary. In each of the tables, *A - F system* refers to the category derived under the *A, B, C, D* classification system (DWAF, 1999a) and *Descriptive system* refers to the category derived under the *Natural, Good, Fair, Poor* classification system (DWAF, 2002a). QRU refers to the Quality Resource Unit considered, while the monitoring points as well as the years of the data record considered for the data assessment associated with the QRU are listed. Results are shown on the basis of RUs.

DWAF (2002a) does not provide a method to derive an overall water quality assessment category. These have been provided for each resource unit and are based on consideration of the individual water quality constituents and professional judgment. The method of achieving an overall water quality category is therefore qualitative, and generally follows the method prescribed in DWAF (2000a), i.e. first considering the status of the systems drivers, mediated by the nutrient status, and finally incorporating any toxic constituents noted or measures of in-stream toxicity. The responses of the biota to water quality conditions are also considered. Categories per variable were derived using the benchmark boundary tables of DWAF (2002a) – see Section 3.4.2 for benchmark tables, and the electronic database of information for this study for the methods manual (DWAF, 2002a) and the EWQRCalc Version 2.3 spreadsheet used for the assessment of inorganic salts. All raw data, i.e. DWAF and other data sources, including data collected during the project (Sites 1-6), are available as part of the electronic database.

Resource Unit A: Thukela River from Rugged Glen to Woodstock Dam

Table 3.4 shows the PES categories for RU A. A large sample size (n=208) resulted in a high confidence assessment for inorganic salts and nutrients. The benchmark boundary values for SRP were changed, but not for TIN. The chlorophyll-*a* analysis and the biotic community composition provided a low confidence assessment due to the small sample size. There are no temperature issues in this resource unit and absence of temperature data therefore does not affect confidence in the water quality assessment.

Table 3.4 PES categories and overall site assessment for RU A

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	1	**RC**	V1H035 (1978-1985), n=70
IFR number	-	**PES**	V1H036 (1995 – 2000), n=208
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		D	Lower Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		D	Lower Fair
Biotic community composition (invertebrates)		A/B	Upper Good
Overall site classification for WQ		**B**	**Good**

Resource Unit B: Thukela River from Driel Barrage to Spioenkop Dam

Table 3.5 shows the PES categories for RU B. A large sample size resulted in a high confidence assessment for inorganic salts and nutrients. The benchmark boundary values for SRP were changed, but not for TIN. No chlorophyll-*a* analysis was undertaken for this resource unit. The biotic community composition provided a low confidence assessment due to the small sample size. This resource unit is downstream of the dam: scour releases and bottom releases from Driel Barrage may result in water quality issues, such as changes in DO, temperature and turbidity. However, there are only limited temperature data available (insufficient to make an adequate assessment) and no data available for DO or turbidity.

DWAF water quality monitoring point V1H058 was identified in the initial screening as suitable for reference condition assessment (due to length of data record, and position of the monitoring point). However, analysis of the data revealed that nutrients were in higher concentrations than V1H026, as a result of intense agricultural land-use. As a result, it was deemed more appropriate to use monitoring point V1H035 for the reference state assessment. DWAF (2002a) does not provide details of the approach to use under these circumstances and the decision was based on professional judgement.

Table 3.5 PES categories and overall site assessment for RU B

River	Thukela River	**DWAF Water Quality Monitoring points**		
QRU	2 and 3	**RC**	V1H035 (1978 – 1985), n=69	
IFR number	1	**PES**	V1H026 (1998 – 2001), n=93	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		A		Natural
Na_2SO_4		A		Natural
$MgCl_2$		A		Natural
$CaCl_2$		A		Natural
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C		Upper Fair
TIN		A/B		Upper Good
Chl-a: phytoplankton		-		-
Chl-a: periphyton		-		-
Biotic community composition (invertebrates)		D		Lower Fair
Overall site classification for WQ		**B/C**		**Lower Good**

Resource Unit C: Thukela River from Spioenkop Dam to confluence with Little Thukela River

Table 3.6 shows the PES categories for RU C. High confidence can be placed in the inorganic salt and nutrient analysis. Both SRP and TIN benchmark values were adjusted. No chlorophyll-*a* analysis was undertaken for this resource unit. From the operating rules document (DWAF, 2001) it is not clear whether bottom releases are possible and whether water quality impacts may arise from potential bottom releases. In any event, no DO, turbidity or temperature data were available. Low confidence is placed in the biotic community composition assessment for its use in the water quality assessment as only limited data were available.

Table 3.6 PES categories and overall site assessment for RU C

River	Thukela River	**DWAF Water Quality Monitoring points**		
QRU	4	**RC**	V1H057 (1983 – 1988), n=152	
IFR number	2	**PES**	V1H057 (1998 – 2001), n=155	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		A		Natural
Na_2SO_4		A		Natural
$MgCl_2$		A		Natural
$CaCl_2$		A		Natural
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C		Upper Fair
TIN		A/B		Upper Good
Chl-a: phytoplankton		-		-
Chl-a: periphyton		-		-
Biotic community composition (invertebrates)		B/C		Lower Good
Overall site classification for WQ		**B**		**Good**

Resource Unit D-E: Thukela River from confluence of the Little Thukela to the confluence with the Klip River

Table 3.7 shows the PES categories for a combined assessment of RUs D and E. These units were combined due to insufficient water quality data being available to assess these RU and QRUs, separately. Assessments for inorganic salts and nutrients are provided with high confidence due to a good water quality data record. The benchmark values for SRP needed to be adjusted, but not for TIN. No chlorophyll-*a* analysis was undertaken. Low confidence was placed in the biotic community composition, due to the lack of adequate data. There is no evidence of a thermal impact in either of these resource units and lack of temperature data therefore did not affect the overall site assessment.

Table 3.7 PES categories and overall site assessment for RU D and RU E

River	Thukela River	**DWAF Water Quality Monitoring points**		
QRU	5 and 6	**RC**	V1H001 (1977 – 1981), n=91	
IFR number	-	**PES**	V1H001 (1997 – 2001), n=64	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		A		Natural
Na_2SO_4		A		Natural
$MgCl_2$		A		Natural
$CaCl_2$		A		Natural
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C		Upper Fair
TIN		A/B		Upper Good
Chl-a: phytoplankton		-		-
Chl-a: periphyton		-		-
Biotic community composition (invertebrates)		B/C		Lower Good
Overall site classification for WQ		**B**		**Good**

Resource Unit F: Thukela River from confluence of Klip River to confluence with the Bushmans River

Table 3.8 shows the PES categories for RU F. There were no water quality data for a reference condition assessment and the default benchmark table values were used. Additional data for a present state assessment were collected from the site as prescribed by DWAF (1999a). However, the confidence in the assessment is low as only a limited sample size, taken over an 8-week period during low flows, was available. The data were analysed in the manner prescribed by DWAF (2002a). The overall water quality assessment for RU F is Upper Fair (C) as a result of high SRP, TIN and high SO_4 values.

Table 3.8 PES categories and overall site assessment for RU F

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	7 and 8	**RC**	No reference condition data
IFR number	4	**PES**	Collected water quality data, site 5, n=8

Water Quality Constituents	**A - F system**	**Descriptive system**
$MgSO_4$	C	Upper Fair
Na_2SO_4	C	Upper Fair
$MgCl_2$	A	Natural
$CaCl_2$	B	Good
NaCl	A	Natural
$CaSO_4$	A	Natural
SRP	D	Lower Fair
TIN	D	Lower Fair
Chl-a: phytoplankton	A	Natural
Chl-a: periphyton	-	-
Biotic community composition (invertebrates)	B/C	Lower Good
Overall site classification for WQ	**C**	**Upper Fair**

Resource Unit G-H: Thukela River from the confluence of the Bushmans River to the confluence of the Buffalo River

Table 3.9 shows the PES categories for a combined assessment of RUs G and H. These were combined due to insufficient water quality data being available to assess these RUs and QRUs, separately. The assessments for inorganic salts and nutrients could only be undertaken at a medium confidence level due to a lack of data. The default benchmark table values were used for the PES assessment.

Table 3.9 PES categories and overall site assessment for RU G and RU H

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	9 and 10	**RC**	V6H002 (1977 – 1979), n=78
IFR number	9	**PES**	V6H002 (1998 – 2001), n=34

Water Quality Constituents	**A - F system**	**Descriptive system**
$MgSO_4$	D	Lower Fair
Na_2SO_4	A	Natural
$MgCl_2$	C	Upper Fair
$CaCl_2$	A	Natural
NaCl	A	Natural
$CaSO_4$	A	Natural
SRP	C	Upper Fair
TIN	A	Natural
Chl-a: phytoplankton	-	-
Chl-a: periphyton	-	-
Biotic community composition (invertebrates)	C	Upper Fair
Overall site classification for WQ	**C**	**Upper Fair**

Resource Unit I: Thukela River from the confluence with Buffalo River to Middledrift

Table 3.10 shows the PES assessment for RU I. There were no water quality data for a reference condition assessment and the default benchmark table values were used. Data for a present ecological state assessment were obtained by collecting additional data. However, the confidence in the assessment is low as only a limited sample size, taken over an 8-week period during low flows, was available. The data were analysed in the manner prescribed by

DWAF (2002a). Magnesium sulphate and SRP values were high, although uncertainty exists about the validity of the Mg results: the method used to obtain $MgSO_4$ salt from the ion data is known to be inadequate and results obtained using EWQRCalc Version 2.3 should therefore be interpreted with caution (Jooste, *pers. comm.*). The water quality data included DO data, and these placed the PES for DO in an Upper Good (A/B) category.

Table 3.10 PES categories and overall site assessment for RU I

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	11 + 12 (segments 39-51)	**RC**	No Reference condition data
IFR number	15	**PES**	Collected water quality data, site 1, n=8
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		D	Lower Fair
Na_2SO_4		A	Natural
$MgCl_2$		B	Good
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
DO		A/B	Upper Good
SRP		C	Upper Fair
TIN		B	Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		C/D	Fair
Biotic community composition (invertebrates)		B	Good
Overall site classification for WQ		**B/C**	**Lower Good**

Resource Unit J: Thukela River from Middledrift to the end of the rejuvenated foothills zone

Table 3.11 shows the PES categories for RU J. It should be noted that although this is a separate RU from the previous one, the QRUs for the two RUs overlap. However, the data describing the water quality for the two RUs is different, due to position of the water quality monitoring point. High confidence can be placed in the assessment for inorganic salts and nutrients. The benchmark values were adjusted for both SRP and TIN. No temperature issues are expected in the RU, and therefore lack of temperature data did not affect the confidence in the assessment. The confidence in the biotic community composition assessment was low. The overall PES category assessment is Upper Fair as a result of reduced water quality due to increased SRP, presence of periphyton and a reduced biotic community composition assessment.

Table 3.11 PES categories and overall site assessment for RU J

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	12 (segment 52 – 73)	**RC**	V5H002 (1977 – 1982), n=116
IFR number	16	**PES**	V5H002 (1996 – 2001), n=83
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		A	Natural
$MgCl_2$		C	Upper Fair
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C/D	Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		C	Upper Fair
Biotic community composition (invertebrates)		C	Upper Fair
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit L-M: Little Thukela River from Injasuthi to the confluence with the Thukela River

Table 3.12 shows the PES categories for RU L and RU M. Analysis of inorganic salt and nutrient data resulted in a high confidence assessment, however, it must be noted that two resource units and two quality resource units were combined in order to undertake the assessment. This was due to insufficient data to assess the two RUs and QRUs separately. The benchmark values for SRP and TIN were adjusted to provide the PES assessment. Low confidence was placed in the analysis of chlorophyll-*a* data. Biotic community composition information was available for both RU L and RU M and these were averaged to provide the overall assessment.

Table 3.12 PES categories and overall site assessment for RU L and RU M

River	Little Thukela River	**DWAF Water Quality Monitoring points**		
QRU	14 and 15	**RC**	V1H010 (1976 – 1981), n=111	
IFR number	3	**PES**	V1H010 (1996 – 2001), n=61	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		A		Natural
Na_2SO_4		A		Natural
$MgCl_2$		A		Natural
$CaCl_2$		A		Natural
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C/D		Fair
TIN		A/B		Upper Good
Chl-a: phytoplankton		A		Natural
Chl-a: periphyton		D		Lower Fair
Biotic community composition (invertebrates)		B		Good
Overall site classification for WQ		**B/C**		**Lower Good**

Resource Unit N: Bushmans River from Elands Park to Wagendrift Dam

Table 3.13 shows the PES categories for RU N. Inorganic salt and nutrient analysis resulted in a high confidence assessment due to sample size. The benchmark values for SRP were adjusted, but not for TIN. No temperature problems are anticipated in this resource unit and therefore the lack of temperature data did not affect the assessment. Analysis of chlorophyll-*a* data resulted in a low confidence assessment as there was only a single sample; however, high SRP values (resulting in an Upper Fair PES category) is reflected by the periphyton which is placed in a Poor PES category. The increased nutrient levels did not appear to affect the biotic community composition (PES category is Good).

Table 3.13 PES categories and overall site assessment for RU N

River	Bushmans River	**DWAF Water Quality Monitoring points**	
QRU	16	**RC**	V7H017 (1977 – 1984), n=126
IFR number	-	**PES**	V7H017 (1996 – 2001), n=63
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A	Natural
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		A/B	Upper Good
Overall site classification for WQ		**B**	**Good**

Resource Unit O: Bushmans River from Wagendrift Dam to Upper foothills

Table 3.14 shows the PES categories for RU O. Analysis of the inorganic salt and nutrient data resulted in a medium confidence assessment, due to a small sample size (less than 60 data points as required by DWAF (2002a)). Benchmark values for SRP were adjusted, but not for TIN. The resource unit (and QRU) is downstream of Wagendrift Dam: according to DWAF (2001) bottom releases are possible from this dam, therefore there may be water quality issues (temperature, DO and turbidity) associated with such releases. However, there was insufficient data in the data record to adequately assess this impact (no DO or turbidity data and a small sample size for temperature, n = 27). The biotic community composition is in an Upper Fair PES category.

Table 3.14 PES categories and overall site assessment for RU O

River	Bushmans River	**DWAF Water Quality Monitoring points**	
QRU	17	**RC**	V7H020 (1997 – 2001), n=49
IFR number	5	**PES**	V7H012 (1996 – 2001), n=37
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		C	Upper Fair
Na_2SO_4		A	Natural
$MgCl_2$		B	Good
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		C	Upper Fair
Overall site classification for WQ		**B/C**	**Lower Good**

Resource Unit P: Bushmans River from lower foothills to confluence with the Thukela River

Table 3.15 shows the PES categories for RU P. There were no suitable water quality monitoring points for assessment of reference condition and a decision was made to use the same reference condition monitoring point as for RU O (QRU 17). Water quality data had been collected as per DWAF (1999a) and these were used for a low confidence PES assessment. As for RU O, benchmark values for SRP were adjusted, but not for TIN. A single sample provided the analysis for chlorophyll-*a* analysis resulting in a low confidence assessment, although periphyton analysis indicated elevated nutrients. DO and biotic community composition assessments provided low confidence (small sample size), although indicate a Good PES category.

Table 3.15 PES categories and overall site assessment for RU P

River	Bushmans River	**DWAF Water Quality Monitoring points**	
QRU	18 and 19	**RC**	V7H020 (1997 – 2001)
IFR number	6	**PES**	Collected water quality data, site 4, n=8
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		A/B	Upper Good
TIN		B/C	Lower Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		B	Good
Overall site classification for WQ		**B**	**Good**

Resource Unit Q: Sundays River from the Newcastle/Ladysmith Road Bridge to the end of the rejuvenated bedrock falls

Table 3.16 shows the PES categories for RU Q. The assessment of PES is medium confidence due to a small sample size (n=46). The benchmark values were adjusted for SRP but not for TIN. The overall PES category of Upper Fair was ascribed to increased SO_4 levels and increased SRP levels, probably due to coal mining in the upper Sundays River catchment e.g. the Newcastle-Platberg Colliery. The reduced water quality assessment was reflected by the PES assessment for biotic community composition, which is in an Upper Fair category.

Table 3.16 PES categories and overall site assessment for RU Q

River	Sundays River	**DWAF Water Quality Monitoring points**	
QRU	20	**RC**	V6H006 (1976 – 1978), n=61
IFR number	7	**PES**	V6H004 (1996 – 1999), n=46
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		C	Upper Fair
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C/D	Fair
TIN		B	Good
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		C	Upper Fair
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit R: Sundays River from the start of the rejuvenated foothills to the confluence with the Thukela River

Table 3.17a shows the PES categories for RU R. It should be noted that the reference condition monitoring data for RU R was the same as for RU Q. This was due to a lack of adequate reference condition water quality monitoring point in this resource unit. Data analysis were undertaken with low confidence (as 8 data points had been collected as per DWAF, 1999a). The benchmark values for SRP were adjusted, but not for inorganic salts or TIN. Analysis of chlorphyll-*a* resulted in a low confidence assessment as only a single sample was analysed. The biotic community composition (PES category of a B/C) did not reflect the overall water quality PES assessment of C, which is largely a result of increased SO_4 levels and high periphyton growth. A present state assessment was conducted for the Wasbank River, Table 3.17b, to show the quality of water entering the Sundays River upstream of the IFR site. Sulphate and SRP levels are elevated, resulting in a present state classification of a C – C/D (upper fair – fair) category.

Table 3.17a PES categories and overall site assessment for RU R

River	Sundays River	**DWAF Water Quality Monitoring points**		
QRU	21	**RC**	V6H006 (1976 – 1978), n=61	
IFR number	8	**PES**	Collected water quality data, site 3 n=8	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		E/F		Poor
Na_2SO_4		C		Upper Fair
$MgCl_2$		A		Natural
$CaCl_2$		B		Good
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		A		Natural
TIN		A		Natural
Chl-a: phytoplankton		A		Natural
Chl-a: periphyton		E/F		Poor
Biotic community composition (invertebrates)		B/C		Lower good
Overall site classification for WQ		**C**		**Upper fair**

Table 3.17b PES categories and overall site assessment for the Wasbank River

River	Wasbank River	**DWAF Water Quality Monitoring points**		
QRU	-	**RC**	V6H006 (1976 – 1978), n=61	
IFR number	-	**PES**	V6H003 (1995 – 2000), n=103	
Water Quality Constituents		**A - F system**		**Descriptive system**
$MgSO_4$		E/F		Poor
Na_2SO_4		E/F		Poor
$MgCl_2$		A		Natural
$CaCl_2$		D		Lower Fair
NaCl		A		Natural
$CaSO_4$		A		Natural
SRP		C/D		Fair
TIN		A/B		Upper Good
Chl-a: phytoplankton		-		-
Chl-a: periphyton		-		-
Biotic community composition (invertebrates)		-		-
Overall site classification for WQ		**C – C/D**		**Upper Fair – Fair**

Resource Unit S: Mooi River from the confluence of the Little Mooi River to the Mooi River Falls

RU S and RU T are divided into three Quality Resource Units (QRU 22, QRU 23 and QRU 24). Results presented in Tables 3.18 – 3.20 reflect these QRUs. These RUs and QRUs have different IFR sites associated with them: IFR 10 is in RU S and IFR 11 is in RU T.

Table 3.18 shows the PES categories for RU S. Inorganic salt and nutrient analysis resulted in high confidence assessment (due to sample size). Benchmark values for SRP were adjusted but not for TIN. The elevated SRP levels were reflected in the chlorophyll-*a* analysis for periphyton, although this was a single sample and low confidence was placed in this assessment. However, the biotic community composition was at a Lower Good PES category, and, along with the increased nutrient levels, resulted in an overall Good PES category.

Table 3.18 PES categories and overall site assessment for RU S

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	22	**RC**	V2H005 (1977 – 1982), n=158
IFR number	-	**PES**	V2H005 (1996 – 2000), n=209
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		C/D	Fair
Biotic community composition (invertebrates)		B/C	Lower Good
Overall site classification for WQ		**B**	**Good**

Resource Unit S-T: Mooi River, Segments 16 – 30

Table 3.19 shows the PES categories for a combined assessment of RUs S and T, including IFR sites 10 and 11. The reference conditions for the previous QRU (i.e. QRU 22) was used for this assessment. The inorganic salt and nutrient assessment was undertaken with high confidence due to the sample size. Benchmark values for SRP were adjusted but not for TIN. The elevated SRP values were reflected in the chlorophyll-*a* analysis for periphyton, which was also high (PES was in a Poor category), although confidence is low as it was the result of a single spot sample. The assessment of biotic community composition was taken from combined data from RU S and segments 26-29 of RU T (Dickens and Bokwe, 2001). The overall PES category of Good was largely a result of the elevated SRP and periphyton levels.

Table 3.19 PES categories and overall site assessment for RU S and RU T

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	23	**RC**	V2H005 (1977 – 1982), n=158
IFR number	10 and 11	**PES**	V2H002 (1996 – 2000), n=94
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		A	Natural
Na_2SO_4		A	Natural
$MgCl_2$		A	Natural
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C	Upper Fair
TIN		A/B	Upper Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		B-B/C	Good – Lower Good
Overall site classification for WQ		**B**	**Good**

Note: Chl-*a* samples were taken downstream of IFR 10 and between IFR 10 and 11.

Resource Unit T: Mooi River from the Mooi River Falls to the confluence with the Thukela River

Table 3.20 shows the PES categories for RU T. Inorganic salt and nutrient assessment were undertaken with medium confidence. Benchmark values for SRP were adjusted but not for TIN. The elevated SRP values were reflected in the chlorophyll-*a* analysis for periphyton, which is in the same Upper Fair – Fair PES category, although confidence is low because it was the result of a single spot sample. The biotic community composition data of Dickens and Bokwe (2001) was with particular reference to Segments 26 – 29 (i.e. IFR 11) - no data are available for further downstream. The overall assessment of PES category of Upper Fair is due to elevated nutrient levels.

Table 3.20 PES categories and overall site assessment for RU T

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	24	**RC**	V2H005 (1977 – 1982), n=158
IFR number	12	**PES**	V2H008 (1995 – 2000), n=67
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		C	Upper Fair
Na_2SO_4		A	Natural
$MgCl_2$		C	Upper Fair
$CaCl_2$		A	Natural
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		C/D	Fair
TIN		B	Good
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		D	Lower Fair
Biotic community composition (invertebrates)		-	-
Overall site classification for WQ		**C**	**Upper Fair**

Resource Unit U: Buffalo River from Utrecht / Ozisweni Road Bridge to the end of the lowland river zone

Table 3.21 shows the PES categories for RU U. No reference condition data could be sourced for this RU, therefore the default benchmark tables were used. Inorganic salt and nutrient analysis was undertaken with high confidence and the elevated levels of these constituents was reflected by the biotic community composition (PES category Fair). In particular, the inorganic salt assessment appears to be a result of elevated SO_4 concentrations. The overall PES assessment results in a Lower Fair category, a result of the overall assessment of poor water quality and biota.

Table 3.21 PES categories and overall site assessment for RU U

River	Buffalo River	**DWAF Water Quality Monitoring points**	
QRU	25	**RC**	No Reference condition data
IFR number	13	**PES**	V3H010 (1997 – 2000), n=140
Water Quality Constituents		**A – F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		E/F	Poor
$MgCl_2$		A	Natural
$CaCl_2$		B	Good
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		E/F	Poor
TIN		D	Lower Fair
Chl-a: phytoplankton		-	-
Chl-a: periphyton		-	-
Biotic community composition (invertebrates)		C/D	Fair
Overall site classification for WQ		**D**	**Lower Fair**

Resource Unit V: Buffalo River from the start of the rejuvenated bedrock zone to the confluence with the Thukela River

Table 3.22 shows the PES categories for RU V. As there are no appropriate water quality monitoring points in the Buffalo River, V3H011 on the Blood River was used to assess reference condition. Benchmark values for SRP were adjusted but not for TIN. Water quality data had been collected as per DWAF (1999a) and these were used for a low confidence PES assessment. A single chlorophyll-*a* analysis of periphyton reflected the increased nutrient levels (both SRP and TIN, although only SRP was in Poor category). The increased nutrient levels and increased inorganic salts (particularly $MgSO_4$ and Na_2SO_4) did not appear to have a large impact on the biotic community composition, where the PES category was Good.

Table 3.22 PES categories and overall site assessment for RU V

River	Buffalo River	**DWAF Water Quality Monitoring points**	
QRU	26	**RC**	V3H011 (1975 – 1979)
IFR number	14	**PES**	Collected water quality data, site 2
Water Quality Constituents		**A - F system**	**Descriptive system**
$MgSO_4$		E/F	Poor
Na_2SO_4		C	Upper Fair
$MgCl_2$		B	Good
$CaCl_2$		B	Good
NaCl		A	Natural
$CaSO_4$		A	Natural
SRP		E/F	Poor
TIN		D	Lower Fair
Chl-a: phytoplankton		A	Natural
Chl-a: periphyton		E/F	Poor
Biotic community composition (invertebrates)		B	Good
Overall site classification for WQ		**C/D**	**Fair**

4 ADDITIONAL TOOLS

4.1 INTRODUCTION

Aquatic organisms have both physico-chemical and flow habitat requirements. There are three main kinds of data which are useful in quantifying these requirements: chemical data which describe in-stream chemical conditions; toxicogical data which describe the tolerances of organisms and their in-stream responses to changing chemical concentrations; and biomonitoring data which describe the distribution and composition of communities (Scherman et al., 2003). All three of these information types were used during the Thukela ecological Reserve study, as shown in Section 3 of this report. The usefulness of catchment or site-specific toxicity testing using indigenous macroinvertebrates was demonstrated during the Olifants River study (DWAF, 2000) where toxicity information aided the interpretation of salinity data. As this study was initiated following Approach 1 (Section 1.3.1), site-specific toxicity data was available for use by the water quality team. The methods of DWAF (2002a) describe toxicity testing using in-stream macroinvertebrates as a useful additional tool for comprehensive and high confidence water quality Reserve assessments, such as the Thukela study.

Flow assessments, and the development of methods for these assessments, are vital to effective water resource management. Developments in this field have focused primarily on the quantity of water required to maintain ecosystem integrity, while there has been little development regarding water quality models that relate changing water quality conditions to an altered or reduced flow regime, and ultimately to changes in biotic communities. However, if the National Water Act is to be implemented, there is a requirement for methods for providing qualitative and quantitative Resource Quality Objectives for a suite of water quality constituents (Scherman et al., 2003). Malan and Day (2002a, b) of the University of Cape Town, South Africa, have developed a simple flow-concentration model for use in rivers, which integrates with hydrological tools used in ecological Reserve assessments.

Section 4 therefore considers tools not specifically required by the revised methods of DWAF (2002a), but both toxicological data and flow-concentration modeling have proved invaluable for determining the water quality implications of a recommended flow regime. These tools are therefore used in an attempt to provide a more ecologically relevant and predictive input to assess the water quality component of environmental assessments.

4.2 TOXICITY TESTING

Toxicity tests are undertaken to define a concentration-response relationship between a driving water quality parameter and ecosystem health. In this study the selected water quality parameter was salinity (using the surrogates Total Dissolved Solids (TDS) and Electrical Conductivity (EC)) using sodium chloride as toxicant due to the primary land-use activities in the Thukela catchment, i.e. agriculture. Salinity is considered as a system variable that regulates essential ecosystem processes (Palmer and Scherman, 2000). In addition, TDS is a good reflection of water quality consequences of the natural geology of an area, as high salinities can also naturally occur.

Acute (96-hour) and short-term sub-lethal (10-day) toxicology experiments were undertaken in recirculating artificial streams using site-specific indigenous invertebrates following a standard protocol (DWAF, 2000b). Test organisms were selected based on a number of factors (DWAF, 2000b), with the determining factor often being the availability of organisms in high enough numbers for repeated or duplicated testing. Indigenous invertebrates were collected from reference sites (or least impacted sites) and experiments undertaken at the artificial stream laboratory of the Unilever Centre for Environmental Water Quality (then the Centre for Aquatic Toxicology), at the Institute for Water Research in Grahamstown. The laboratory-based experiments undertaken used dechlorinated tap water as experimental diluent (or medium) due to practicalities of transporting river water to the laboratory.

Experimental details are summarised in Table 4.1. More information can be found in DWAF (2000b) and Appendix E.

Table 4.1 Details of toxicology experiments undertaken during the Thukela project

River and collection (reference) site	Diluent	Toxicant	Test organism	Experimental design
Bushmans River - Weenen Nature Reserve (Upper catchment)	Dechlorinated tapwater	Sodium chloride	*Euthraulus elegans* (Leptophlebiidae) *Afronurus peringueyi* (Heptageniidae)	Regression
Mooi River – caravan park at Mooi River town (Lower catchment)	Dechlorinated tapwater	Sodium chloride	*Euthraulus elegans* (Leptophlebiidae)	Regression
			Tricorythus discolor (Tricorythidae)	Replicated

The boundaries between categories A - E/F were defined using the experimental end-points shown in Table 4.2.

Table 4.2 Categories boundaries defined by toxicity data. This table is used as a guideline and professional judgment is used to refine boundaries (Scherman et al., 2003)

Category	Boundary descriptor (maximum allowable level)
A	Reference condition (natural state) or below measurable short-term chronic toxicity*, i.e. < lower 95% confidence limit of the short-term chronic LC_1
B	Inferred short-term chronic toxicity, i.e. the lower confidence limit of the short-term chronic LC_5
C	Measured short-term chronic toxicity, i.e. short-term LC_1 or LC_5
D	Measured acute toxicity, i.e. acute LC_1
E/F	Greater than acute LC_1

* short-term chronic: 10 days.

The toxicity tests undertaken for the purposes of these studies measure an extreme biological end-point, i.e. mortality, and are of relatively short duration (10 days). For this reason, the lower confidence intervals of LC_1 of sub-lethal exposures (10-day exposures) are used to define boundaries between categories. This is in line with the DWAFs protective approach to aquatic resources. The way in which toxicity data can be used most effectively in water resource management is currently under discussion (Jooste, RQS, *pers. comm.*) (Scherman et al., 2003).

Table 4.3 is the classification table for Total Dissolved Solids (TDS) and Electrical Conductivity (EC) based on laboratory-generated toxicity data using macroinvertebrates from the Thukela River system. Confidence in the data is shown on a scale of 1-5, with 5 being the highest level of data confidence. Appendix E shows toxicity results obtained. Although four organisms were tested, only the results for the mayflies *Afronurus peringeyi* and *Euthraulus elegans* were used to define categories due to high confidence in these results.

Table 4.3 Classification table for TDS and EC based on toxicity data from *Afronurus peringeyi* (Heptageniidae) from the Bushmans River (Upper Thukela catchment), and *Euthraulus elegans* (Leptophlebiidae) from the Mooi River (Lower Thukela catchment)

Category	TDS (mg/L)	EC (mS/m)	Level of confidence in the data
A	< 200	< 30	2
B	200- 600	30- 90	2
C	600 – 1000	90 – 150	4
D	1000 – 1900	150 – 300	4
E	> 1900	> 300	4

Table 4.3 shows that a B category for TDS extends from 200 – 600 mg/L. However at some sites on the system (especially the Sundays and Buffalo rivers) it may be more valid to set a B category of 200 – 400 mg/L (i.e. more conservative). This is because, due to mining, the salt problems in these areas are sulphate-based, and the natural levels of sulphate throughout the catchment are very low (i.e. under 10 mg/L, DWAF (2003b). In addition, sulphate is generally acknowledged to be more toxic than NaCl at equivalent concentrations (Palmer and Scherman, 2000).

Although the method of DWAF (2002a) uses a range of inorganic salts rather than an integrated measure of salinity to classify the PES, such as TDS or EC, the information provided by in-stream toxicity testing was used extensively during the modelling phase. The modelling phase of the project (Section 4.3) serves to integrate water quality and quantity, and provides input to the IFR and scenario modeling workshops regarding ecological consequences of water quality conditions under various flow regimes.

4.3 MODELLING: INTEGRATION OF WATER QUALITY AND QUANTITY

4.3.1 Introduction

This section of the report describes the methods used and results obtained from water quality modelling carried out as part of the Thukela Reserve water quality project. The term *water quality modelling* is used to describe techniques employed to obtain quantitative predictions of what the concentration of chemical constituents in a given river reach would be under given conditions of flow (e.g. a proposed IFR flow regime). The concentration of in-stream chemical constituents, as well as the values of physical constituents may vary significantly with changes in flow. In addition, aquatic biota respond not only to the hydraulic habitat and amount of water supplied, but also to the quality of that water. Thus it is important that the water quality conditions likely to occur under a proposed IFR regime also be predicted and reported in a quantitative manner. This will ensure that in meeting the ecological Reserve with regard to *quantity*, the water *quality* component of the Reserve is also attained.

4.3.2 Outline of the approach used

Water quality data for the Reference Condition (RC) and Present Ecological State (PES) at each IFR site were used to obtain flow-concentration relationships by plotting monthly median concentrations against monthly mean flow data, and the regression equation derived. These flow-concentration (Q-C) relationships were used to predict, for a given flow, what the expected in-stream concentration would be, and were used to set up a matrix of flows and associated predicted concentrations for identified water quality constituents. The appropriate matrix was used to convert the flow time-series to a time-series of expected concentrations for different flow scenarios. From these time-series, concentration-exceedence curves were generated and the flow scenarios could be compared with regard to the expected changes in the concentrations of key water quality constituents under changing flow conditions.

4.3.3 Assumptions and approximations in the approach

There are some important assumptions in the modelling method that need to be taken into account when interpreting results. A full discussion of these aspects is given in Malan and Day (2002a).

- Low confidence is expressed in the quantitative predictions obtained using flow-concentration and time-series water quality modeling, as in-stream concentrations are inherently variable and affected by factors other than flow. The modelling method used is a simple approach and is aimed at providing an ***estimate*** of predicted water quality.
- Use is made of monthly *median* values of concentrations and monthly *average* flow values, through which a trend-line is fitted. Unless there is measured water quality data for very low flows and very high flows, extrapolation (as occurs when converting to concentration time-series) is likely to be inaccurate.
- It is important to note that all predictions of water quality made in this report assume that pollution loads will remain the same as present day loads.
- Concentration exceedence curves can be used to compare and rank some of the water quality consequences that will arise from different flow scenarios. Caution should however be used to make exact quantitative predictions from the curves (e.g. to conclude that under a B category flow, TDS will be above (say) 300 mg/L ***exactly*** 50% of the time is erroneous). **Values given in this report are estimates**.
- The water quality experienced by aquatic biota at a given site is composed of many different constituents. The effect of altered flow on many of these constituents (e.g. dissolved oxygen or temperature) cannot be predicted using the modelling approach used in this study.
- *The modelling method is not suitable for chemical constituents that show an increase in concentration with increasing flow*, e.g. pollutants from diffuse sources that wash off agricultural lands and into the river. It cannot be assumed that if the flow in a river is decreased, the in-stream concentration of the pollutant will also decrease. This will depend on site-specific factors. For key sites at which water quality is critical it may be necessary to carry out further studies. This would entail setting-up a detailed catchment run-off model that takes into account the pollution generated per unit area of land and resultant instream concentrations under different flow scenarios. Such an activity is outside of the capabilities of the Q-C modeling method which is a simple screening tool.

4.3.4 Methods and data sources used

Water quality modelling was carried out in the following manner:

Flow-concentration modelling
Flow-concentration (Q-C) modelling was used to estimate the concentration of a particular chemical constituent that would be expected to occur in a river reach at a given flow. This technique is described in detail in Malan and Day (2002a, b) and Malan et al. (2003).

Reference Condition water quality was inferred from either historical data or from an un-impacted site using the procedure described in the RDM manual of DWAF (1999a). For each IFR site, present day water quality was assessed using data from the *nearest* DWAF monitoring site. Where possible, the data used for Q-C modelling were the same as those used in the water quality assessment of Section 3.4.3. At two sites, IFR 11 in the Mooi River and IFR 13 in the Buffalo River (RC only), the purposes of modelling required that different data sets be used. This information, in addition to the water quality monitoring station that was used to derive the RC and PES, and the time period of data used, is noted in Table 4.4.

Simulated flow data used in the water quantity determinations of the IFR as supplied by the hydrologist for the project, were used for modelling. Monthly mean flows were calculated using data from the entire dataset.

Monthly mean flow values (natural flows: simulated flows; other flows: outputs of the yield model) were correlated with median monthly concentration values for each variable. *Median* water quality values were used since concentrations can range widely and a single extreme event can alter the mean significantly. It is therefore statistically correct to use median values. However, *mean* discharge values were used as this is the convention in the field of hydrology. Correlation of concentration and flow values was carried out separately for the RC and PES. The water quality constituents examined included TDS, sulphate (SO_4^{-2}), total phosphorus (TP), soluble reactive phosphorus (SRP), total inorganic nitrogen (TIN) and fluoride (F). The chemical constituents modelled per site depended on the availability of data and the perceived water quality problems at that site. Where specific water quality issues were identified (e.g. elevated sulphate levels in the Buffalo and Sundays rivers) and data were available, the constituents of concern were also modelled.

Graphs were then plotted of concentration versus flow and a regression line drawn through the data points. The "best fit" was chosen by using the relationship (in Microsoft Excel) that yielded the highest value of the coefficient r^2. This relationship was used to predict the concentration that would arise from a given flow. For each IFR site and for each recommended monthly flow, the median concentration and 95% confidence intervals of each chemical constituent was predicted using the appropriate regression relationship. The median concentration of each water quality variable was predicted for each month under the prescribed IFR base flow regime. These calculations were carried out separately for both Maintenance and Drought flows. Predictions were made for base-flows, rather than total flow (which would include floods and any excess flow in the system). Therefore, in the case of TDS, sulphate and other chemical constituents that show a decrease in concentration with increased flow, the predictions from Q-C modelling represent the *worst case scenario*. By examining the predicted concentrations, the expected assessment category for each month under the IFR flow regime could be derived. These values were examined with regard to the criteria used for defining assessment categories for each variable as described in DWAF (2002a), Section 3.4.3 and Table 4.3.

Information that can be obtained using flow-concentration modelling
Using flow-concentration modelling, depending on the availability and reliability of data at each IFR site, the following information can be obtained:

- Flow-concentration relationships for the key water quality constituents.
- Estimates of how many months of the year, under the proposed IFR base flow, the water quality Reserve would be attained with regard to the various water quality constituents modelled (TDS, nutrients), as well as the likely assessment category.
- In what month the worst water quality would be likely to occur and what concentrations could be expected.

Table 4.4 Sources of water quality data used for Q-C modeling

IFR Site	Water quality data		Comments
	RC	PES	
1 – Thukela River	V1H035Q01 1978 – 1986	V1H026Q01 1995 – 2000	Between Woodstock and Spioenkop Dams.
2 – Thukela River	V1H057Q01 1983 - 1988	V1H057Q01 1995 – 2000	Downstream of Spioenkop dam, and upstream of the Klip River confluence.
3 – Little Thukela River	V1H010Q01 1976 - 1981	V1H010Q01 1993 - 2000	Periods of no flow during winter.

IFR Site	Water quality data		Comments
	RC	PES	
4 – Thukela River	None	None	Downstream of Klip River confluence. No appropriate monitoring site. No modelling undertaken.
5 - Bushmans River	None	None	No appropriate monitoring site. No modelling undertaken.
6 – This site was omitted from the IFR workshops (Louw, *pers comm.*)			
7 - Upper Sundays River	V6H006Q01 1976 - 1982	V6H004Q01 1994 - 2000	Just upstream of the Wasbank River confluence.
8 - Lower Sundays River	None	None	No appropriate monitoring site. No modelling undertaken.
9 – Thukela River	V6H002Q01 1977 - 1982	V6H002Q01 1995 - 2000	Downstream of Sundays River confluence, and upstream of Buffalo and Mooi rivers.
10 - Mooi River	V2H005Q01 1977 – 1982	V2H002Q01 1995 – 2000	Just downstream of confluence with Little Mooi River.
11 - Mooi River	V2H005Q01 1977 – 1982	* V2H004Q01 1994 – 1998	Middle section of Mooi River. Same RC used as for IFR 10.
12 - Lower Mooi River	V2H005Q01 1977 – 1982	V2H008Q01 1995 – 2000	Lower Mooi River, just above the confluence with the Thukela River. Same RC used as for IFR 10.
13 – Buffalo River	* V3H011Q01 1975 - 1979	V3H010Q01 1995 - 1999	
14 - Lower Buffalo River	None	None	No appropriate monitoring site. No modelling undertaken.
15 - Thukela River	None	None	No appropriate monitoring site. No modelling undertaken
16 - Thukela River	V5H002Q01 1977 – 1982	V5H002Q01 1995 – 2000	

* Indicates when water quality data from a different DWAF monitoring point was used than in the water quality assessment (Section 3.4.3, Tables 3.2 and 3.3). Length of data record used differed per application.

4.3.5 Production of concentration profiles

The software package T-SOFT (*Time Series Display and Analysis Software*, developed by Hughes et al., 2000) was used to transform time-series of flow to time-series of concentration at each IFR site. The regression equation that had been derived at each site using Q-C modelling was used for this transformation. A transformation matrix was set up such as that shown for IFR 1 (Table 4.5). This table shows, for a given flow value, the corresponding predicted median TDS concentration that could be expected under the current pollution loads. Due to the inaccuracies in extrapolating to flows for which no observed TDS values were available, the transformation matrix covered only up to the approximate highest discharge for which observed TDS data were available, i.e. the 1:10 year flood flows. Floods equal to or larger than this (i.e. greater than 120 m^3/sec, the highest flow value in Table 4.5) would all be set at 37.7 mg/L TDS, the corresponding salinity concentration. Additional justification for this step is the fact that TDS concentrations decrease as flow is increased. Thus it is during periods of low flow, rather than during floods, that water quality problems resulting from high salinity are likely to occur.

Table 4.5 Transformation matrix used to convert flow (m^3/s) to TDS concentration (mg/L) for PES at IFR 1

Flow	TDS (mg/L)	Flow	TDS (mg/L)
0.50	74.4	18.05	67.3
1.00	74.2	24.63	64.9
1.48	74.0	29.00	63.3
2.09	73.8	36.86	60.5
3.88	73.0	45.04	57.7
4.69	72.7	59.60	53.1
5.74	72.2	75.00	48.7
6.66	71.9	90.00	44.7
8.48	71.1	100.00	42.2
11.92	69.7	120.00	37.7

Total Dissolved Solids (TDS) was the most common water quality variable that was modeled, since it is a conservative constituent that is usually highly correlated with flow, and is regularly monitored as part of the DWAF monitoring network. TDS is also a good indicator of overall salinity conditions, although no longer required for a present state assessment according to DWAF (2002a). Selected inorganic salts and nutrients were also modelled where appropriate. This depended on whether the constituent was likely to be problematic (i.e. reach significant concentrations) and how close the relationship between flow and instream concentration was. Constituents that exhibited a regression coefficient (r^2) greater than, or equal to 0.60, and that were considered to be of use in making predictions of water quality, were modelled further. The cut-off value of 0.6 (for 10 degrees of freedom, $\alpha(2)$, $p>0.003$) was chosen arbitrarily In some cases, the concentration of a constituent varied little with flow (e.g. TIN at IFR 1), and the Q-C line yielded an almost horizontal line Although in such cases r^2 is low, there is a high predictability in the modeling (because for all flows, concentration is more or less constant). From examination of such data, if the 95% confidence interval around the regression line (assessed using expert judgement) was small, time-series modelling was carried out (although the results, as to be expected, usually showed very little difference between flow scenarios; e.g. TDS at IFR1). The water quality constituents that were modelled included TDS, sulphate, magnesium sulphate, and the nutrients, Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorous (SRP).

A range of flow scenarios, as generated by the water quantity team and output of the yield model (see DWAF 2004 for more information), were examined and the water quality implications, including whether the quality Reserve would be met, were assessed. Concentration exceedence curves were prepared and the flow scenarios ranked according to the perceived impact on water quality. In addition, an examination was made of the percentage time that the water quality variable would be in each assessment category.

The flow scenarios assessed consisted of two groups: Firstly, those that were generated using the IFR model and were the product of the specialists' (i.e. invertebrates, riparian vegetation, fish and geomorphology specialists) recommendations. These were considered at the IFR workshop, and included the recommended Ecological Reserve category, the category above (Upper Reserve category) and the category below (Lower Reserve category). In situations where a D category scenario was recommended, only this and the upper Reserve category (i.e. C) were modelled.

The second group of scenarios (eight in total) were those considered at the Yield Scenario Workshop. These flow scenarios were generated as part of an examination of the yield of the Thukela catchment by the system modeller for the project. For all except Scenario 8, the present day (2000) quantity demands on the system were assumed. For Scenario 8 the demands likely to be made on the system due to the level of development in 2015 were applied. The scenarios vary in the volume of Mean Annual Runoff (MAR) that is represented, with Scenario 1 having the highest (3 054 million m^3) and Scenario 8 the lowest (2 501 million m^3) flows. Scenarios 1 to 3 represent the main IFR scenarios (Upper, Recommended and Lower). Scenario 7 represents the present day flow in the system (du Toit, WRP, *pers. comm.*). The flow scenarios that were examined are described fully in DWAF (2004). Descriptions are provided in the text box below.

Scenario descriptions

Scenario Number	Description
1	Current (2000) level of development in the catchment, with flows set to improve the PES to a better state than the recommended EC. This was abandoned as it was considered unrealistic.
2	Current (2000) level of development in the catchment, using the flows set for the recommended EC. These flows are generally lower than those set for Scenario 1, as they were intended to maintain the recommended EC. An interesting point is that when the flows for this scenario were modelled, the ecological conditions at a number of the IFR sites improved, i.e. the EC achieved would be better than the PES.
3	The current level of development with flows set to achieve a lower than recommended EC. Recommended flows are generally lower than for Scenarios 1 and 2.
4	Current level of development with flows set to achieve the EC at all sites apart from IFR 4. As this scenario still included floods that could not be provided, it was considered unrealistic, and was abandoned.
5	Current level of development, with flows set to achieve the EC at all sites apart from IFR 4. Floods that could not be met were removed and in some cases drought periods were increased.
6	Current level of development with flows set to achieve an EC lower than that recommended. Floods that could not be provided were removed and in some cases drought periods were increased.
7	Current level of development and flows. Flows with more efficient operating rules for the dams.
8	A 2015 level of development with no IFRs provided. The developments included are Spring Grove Dam, increased transfer from Driel Dam, Middledrift transfer and the proposed Fairbreeze transfer. This scenario is a worst case for the ecology.

4.3.6 Production of stress profiles

By using experimentally derived toxicological data it is possible to relate the concentration of a chemical constituent (e.g. NaCl) in an aquatic system to the stress experienced by the aquatic biota due to this stressor (Palmer and Rossouw, 2001; O'Keeffe et al., 2002; Scherman et al., 2003). This approach was used in the Olifants and Breede River Reserve studies. It is most suited to salts and has not been developed to assess the effect of nutrient concentrations on aquatic biota. In the Thukela catchment nutrients, rather than salts, are generally the pollutants of concern. In addition, the use of stress profiles still requires development before they become a robust tool for evaluating flow scenarios. Therefore stress profiles were not constructed for the Thukela catchment and attention was rather given to producing concentration profiles of not only TDS, but of other chemical constituents as well.

4.3.7 Water quality assessment categories

As outlined in Section 1.3, the national method for setting water quality assessment categories was reviewed and modified during the course of the Thukela study, by which stage a considerable amount of modelling had already been carried out for TDS and sulphate, following Approach 1 (Section 1.3.1). Approach 2 (i.e. DWAF, 2002a) does not consider TDS or anions (e.g. sulphate), but rather individual salts (e.g. $MgSO_4$ or Na_2SO_4). Furthermore, assessment categories had not been defined for sulphate under Approach 1. Associated with each approach is a classification system for defining ecological state, i.e. the A – F system associated with Approach 1, and the descriptive system associated with Approach 2. Table 4.6 therefore shows boundary concentrations and assigned categories using both the A - F system and the descriptive system (i.e. natural – poor) for the nutrient descriptors Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorous (SRP).

Table 4.6 Boundary concentrations and categories for TIN and SRP

Total Inorganic Nitrogen (TIN)		
Concentration (mg/L)	**Descriptive system**	**A - F system**
0.25	Natural	A
0.5	Upper good	A/B
0.75	Good	B
1.0	Lower good	B/C
2.0	Upper fair	C
3.0	Fair	C/D
4.0	Lower fair	D
> 4.0	Poor	E/F

Soluble Reactive Phosphorous (SRP)		
Concentration (mg/L)	**Descriptive system**	**A - F system**
0.005	Natural	A
0.012	Upper good	A/B
0.02	Good	B
0.025	Lower good	B/C
0.058	Upper fair	C
0.091	Fair	C/D
0.125	Lower fair	D
> 0.125	Poor	E/F

Note that in the case of nutrients, the assessment method for determining PES according to Approach 2 (i.e. DWAF, 2002a) makes use of *weighted annual 95th percentiles*, whereas the modelling method uses *monthly median values* (as previously required by Approach 1, i.e. DWAF, 1999).

Assessment categories and classification descriptors for TDS are shown in Table 4.3, and were derived using site-specific toxicological information. Modelling of individual salts was carried out only at sites where data were available, and where elevated salinity was considered to be an issue.

4.4 MODELLING RESULTS

4.4.1 General comments and Q-C relationships

The Q-C (flow-concentration) plots for all IFR sites that could be modelled are shown in Appendix F, and the regression equations summarised in Appendix G. As is expected from the dilution effect at high flows, TDS, sulphate, and individual salts showed a slight to marked decrease with increasing flow at all sites. The response of nutrients, on the other hand, was a lot more variable. In general, the relationship between SRP and flow was poor, and this constituent was not used to prepare concentration time-series. TIN concentrations were negatively correlated with flow at some sites (e.g. IFR 3), and only weakly correlated at others (e.g. IFR 16). At sites where the r^2 value was above 0.65, TIN concentration decreased with increased flow and thus time-series modelling of TIN could be carried out.

Increases in nutrients with increasing discharge have been attributed to the disturbance of benthic sediments at high flows, with the concomitant release of nutrients into the water column, as well as increased wash-off from banks during rainfall events (Malan and Day, 2002b). Total Suspended Sediment (TSS) loads also increase with flow and is considered a problem in certain areas of the catchment (e.g. the Sundays River). Due to lack of data, this constituent could not be examined quantitatively in this project.

The predicted median concentration and the 95% confidence intervals (calculated from the appropriate regression equation) expected to arise each month of the recommended IFR, is shown in Appendix H. These values are reported for each site and each water quality constituent that could be modelled, for the Upper, Recommended and Lower Ecological Reserve flow regimes, and for both Maintenance and Drought flows. These tables therefore show when (i.e. what month) the worst water quality (i.e. highest concentrations) is likely to occur and what concentrations are likely to be found, under the recommended flow regime. Predicted concentrations are not reported for high flows. Although concentrations of the various water quality constituents could be predicted for flood periods, extrapolation to high flow values is likely to be inaccurate. For most constituents it is the periods of low flow that are likely to exhibit the worst water quality.

The complete set of flow-concentration transformation matrices for all the IFR sites is shown in Appendix I and Appendix J presents the concentration exceedence curves produced for each site, under each flow scenario. Note that where the results for different flow scenarios are stated as being equivalent, this is in water quality terms only. Variations can be seen in terms of the volume and timing of flow. In general, it was found that the water quality consequences became progressively worse with decreasing MAR. Thus scenario 1 usually resulted in the best water quality (lowest concentration of constituents) and scenario 8 the worst. For this reason, and to make reading the exceedence curves easier, in many cases only scenarios 1, 5 and 8 have been converted to concentration time-series.

4.4.2 Results for individual IFR sites

Water quality modelling results are presented in the following manner per IFR site.

- The present water quality situation. Note that Approach 1 refers to the method of DWAF (1999a), while Approach 2 refers to the revised methods as required by DWAF (2002a). See Section 1.3 for more information.
- The flow-concentration relationships (as shown by the Q-C graphs).
- The exceedence profiles and water quality consequences obtained at the IFR workshops (i.e. for the recommended Ecological Reserve flow, and Upper and Lower categories).
- The exceedence profiles and water quality consequences obtained at the Yield Scenario workshop (i.e. for the eight flow scenarios generated by the system modellers).
- Overall conclusions and comments, including whether the Ecological Reserve Category is likely to be attained.

The Q-C graphs and exceedence curves that were obtained for IFR 1 are shown in the text as an illustration of the results that were obtained. Figures for the other sites are shown in the relevant appendices. To aid understanding of the text below, reference should be made to the flow profiles generated by the yield model (DWAF 2004).

The overall PES assessment for each IFR site is shown using both Approach 1 and Approach 2, except for the sites where additional data was collected (n=8). The water quality PES assessment for these sites was conducted using Approach 2 only, as this method allows for assessments based on minimal data. Although this report therefore focuses on the assessment conducted using Approach 2 (i.e. DWAF, 2002a), and results per IFR site refer to this approach, both sets of overall water quality assessments are shown for most sites to demonstrate the differences between the approaches.

IFR 1 (Bergville, Thukela River)

Present water quality situation

This site is situated between Woodstock and Spioenkop Dams. It should be noted that periods of no, or very low flow occur at this site due to abstractions for irrigation and urban / domestic use. Water transfers also take place from the Woodstock and Driel Dams to the Sterkfontein Dam on the Vaal River system. Water quality impacts are also evident from releases from abattoirs in the area and sludge scouring from Driel barrage. Sludge scouring causes reduced dissolved oxygen concentrations and increased sediment loads.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B category	B/C category, i.e. Lower Good (Table 3.5)

The application of revised methods for assessing water quality therefore drops the water quality PES by half a category. Some increase in TIN and TDS can be seen under low flow conditions. However, inorganic salts (and therefore TDS levels) remain within an A category and are not problematic. A chlorophyll-*a* assessment conducted during June 2002 (lowest flows are traditionally July – August), indicated that periphyton levels for the stretch of river above the IFR site, is in a Lower Fair (D) category. SRP is in an Upper Fair (C) category and the SASS score is a D. This low score for macroinvertebrates may be due to lack of habitat and possibly to the presence of filamentous algae (Thirion, RQS, *pers. comm.*).

The recommended water quality component of the ERC for that reach of the Thukela River is a B/C category, meaning that current water quality conditions should be maintained.

Flow-concentration relationships

Median monthly water quality data for the RC and PES were derived from stations V1H035 and V1H026 respectively. The Q-C relationship was examined for TDS, TIN and SRP. In general, the concentration of all the modelled water quality constituents did not change greatly with altered flow. This is likely to be a result of mixing in the upstream Woodstock dam. The Q-C plots of TDS versus flow are shown in Fig 4.1 as an example of Q-C graphs – graphs for the entire set of water quality constituents for this site, and plots for all other IFR sites are shown in Appendix F. It can be seen that the PES concentration of TDS is only slightly higher than that expected under natural conditions. Concentration time-series were prepared for TDS and TIN at this site, but not for SRP as this constituent increased slightly in concentration with flow and the points were scattered. The Q-C regression equation for each constituent and the value of r^2 are given in Appendix G. It can be seen from Appendices F and G that that the confidence interval around the PES TIN regression line is small, and therefore the confidence in the predictions is high and the regression equation can be used for the generation of concentration time-series. The monthly range of concentrations expected under the Reserve Categories C and D, and Maintenance and Drought flow regimes is shown in Appendix H.

Fig. 4.1 **Q-C plots for TDS (mg/L) at IFR 1. The RC (~) and the PES (□) are shown, as well as the regression lines through the points. The 95% confidence interval for the PES is shown as dotted lines. Flows are shown in m^3/sec.**

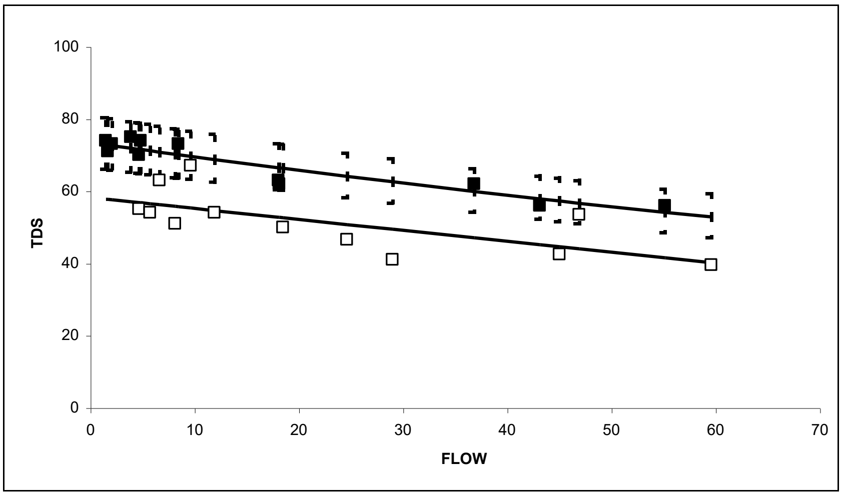
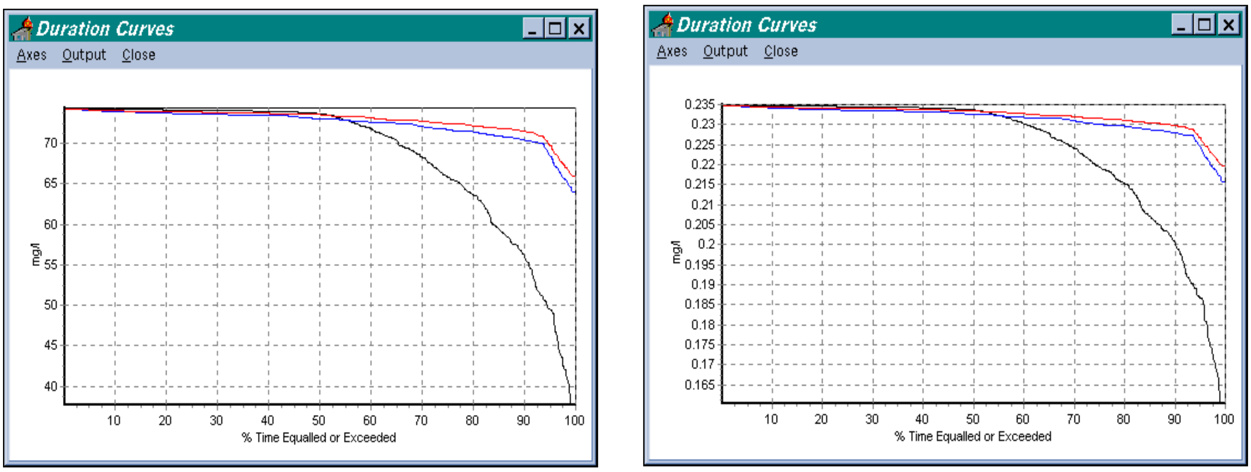


Fig. 4.2 **Exceedence curves for TDS (left) and TIN (right) for IFR 1: Black = present day flow, blue = C Reserve Category flow regime, red = D Reserve Category flow regime.**



Results from the IFR workshop

At the IFR workshop, the consequences to the aquatic biota of a C or D category flow regime were evaluated. The flow time-series that represent present day, category C, and category D flow regimes were therefore converted to concentration time-series using the appropriate flow-concentration matrix (Appendix I). An example of exceedence curves is shown in Fig 4.2 – curves for all other sites are shown in Appendix J. The results for TDS (Fig 4.2) show that under category C and D flow scenarios, the median concentration is not likely to go below approximately 65 mg/L, whereas under the present day flow it does so approximately 23% of the time. The maximum concentrations that can be expected under all flow regimes are similar. Nevertheless, TDS levels are low at this site and the difference between the flow scenarios (with regard to the effect on TDS) is not likely to cause a change in assessment category for salts.

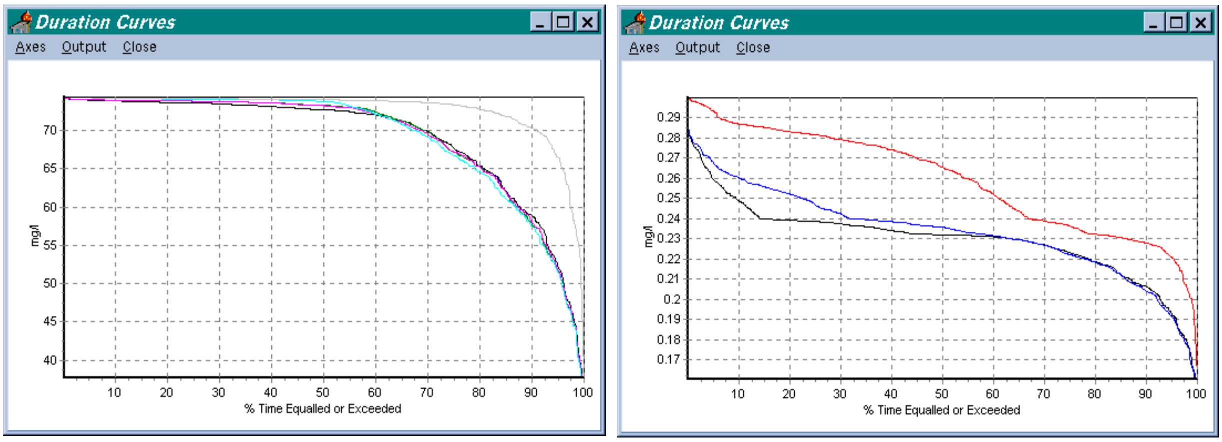
A similar situation is shown in the figure for TIN. Under category C and D low flow scenarios, the periods of very low concentrations of TIN (lower than 0.3 mg/L) that currently happen under the present flow regime would no longer occur (except under flood/high flow conditions). Despite this, the overall predicted concentrations of TIN are low and thus it is considered that there is no significant difference with regard to the water quality consequences between the different flow scenarios.

Results from the Yield Scenario workshop

The different flow scenarios that were generated by the yield model were compared for TDS and TIN. These results are presented in Fig. 4.3. There is little difference between flow scenarios, except for scenario 8. This scenario, which represents the lowest MAR, would be expected to result in higher concentrations of both TDS and TIN. Despite this, under all scenarios, TDS remains less than 100 mg/L, i.e. an A category, and TIN will stay below a median value of approximately 0.3 mg/L, i.e. within a Natural or Upper Good category. Under scenario 8, median TIN values will move to well within an Upper Good category (i.e. out of the natural range) roughly 60% of the time, 20% of the time under scenario 5, and 10% of the time under scenario 1.

SRP could not be modelled, because the concentration of this constituent tends to increase with flow at this site. SRP is currently in an Upper Fair category (C).

Fig. 4.3 Exceedence curves for TDS (left) for IFR 1 obtained from the Yield Scenarios: black = scenario 1, blue = scenario 2, red = scenario 3, yellow = scenario 4, dark green = scenario 5, pink = scenario 6, turquoise = scenario 7, grey = scenario 8. TIN (right): black = scenario 1, blue = scenario 5, red = scenario 8



Conclusion

All flow scenarios will satisfy the water quality ERC for salinity and TIN, however SRP will have to be improved through management practises. If improved management practises are not implemented, the overall water quality status will be at a B/C to C category for scenario 8, under Approach 2 (DWAF, 2002a) and B to B/C for scenario 8, under Approach 1 (DWAF, 1999a) (due to elevated SRP levels). The new method therefore drops the PES a half a category. *Under flow scenario 8, the overall water quality ERC of a B/C is not likely to be achieved without the control of SRP loading.*

IFR 2 (Skietdrift, Thukela River)

Present water quality situation

This site is downstream (approximately 40 km) of the Spioenkop dam and upstream of the Klip River confluence. Land use in this area is primarily crop production and cattle farming. Conditions are relatively stable for most water quality constituents.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B category	B category, i.e. Good (Table 3.6)

TDS levels increase slightly at low flows, but levels remain within an A category and are not problematic. TDS and inorganic salts are all in a natural (A) category, TIN in an A/B (Upper Good) category, and SRP in a C or Upper Fair category. The recommended water quality component of the ERC for that reach of the Thukela River is a B category, using both sets of assessment methods.

Flow-concentration relationships

Median monthly water quality data used for modelling, were derived from stations V1H057 (1983-1988 and 1996-2001 for RC and PES respectively). This monitoring site was not ideal for water quality modelling as it is at the outfall of Spioenkop Dam; is a distance upstream from the IFR site, and might therefore not reflect the real water quality situation. There are however no sites that are closer, or that are considered to be more representative of the water quality. Flow-concentration plots were prepared for TDS, TIN and SRP (Appendix F). Similar results were obtained to those for IFR 1. The concentration of most modelled chemical constituents showed little change in concentration with flow, and the plots are virtually horizontal lines. This was true for both RC and PES, and is most likely due to mixing in the upstream Spioenkop Dam. It was considered that TDS and TIN could be used to make predictions under different flows. The concentration of SRP on the other hand, was unpredictable when plotted against flow and was not modelled further. Present day levels of TIN were found to be lower than the RC, indicating an improvement in the water quality that is released from Spioenkop Dam.

Results from the IFR workshop

Concentration time-series analysis at this site was carried out using TDS. It was not considered necessary to model other constituents since TIN concentrations are low at this site and are largely independent of flow. The low predictability of SRP, because of the poor correlation between SRP and flow, did not allow further modelling of this constituent.

The results from concentration time-series analysis (Appendix J) showed that under the different flow scenarios (B, C and D category Reserve flow scenarios), there is no significant difference in the predicted TDS concentrations (concentrations will not exceed 75 mg/L). Time-series modelling for TIN is likely to exhibit similar results. It should be kept in mind however, that this IFR site is a distance downstream of the monitoring site from which the data was taken. The actual IFR site is likely to exhibit more of a response with flow and, in addition, because of the agricultural activity in this part of the catchment, nutrient levels are likely to be slightly higher.

Results from the Yield Scenario workshop

As can be seen from the exceedence curve (Appendix J), under all yield scenarios, median TDS levels should remain below roughly 80 mg/L, i.e. in an A, or natural category. In the case of SRP, the present day concentrations of this constituent place it in a C (Upper Fair) category. Under scenario 2, higher flows are present during the dry season (when water quality can be expected to be the worst). From expert judgement (as time-series modelling could not be carried out), the SRP would probably improve to a B/C (or Lower Good) category during the dry season. Under scenario 5 (similar to 6), there are reduced flows in the dry season, with conditions being poorer than present for about 50% of the time – however, it is not expected that SRP should drop below a C. Scenarios 7 (present) and 8 are similar, so conditions are expected to stay the same, i.e. SRP will stay in a C category. The PES for TIN is an A/B (Upper Good) category. Under scenario 2, it will probably improve to an A category during the dry season. Under scenarios 5 and 8, TIN would not be expected to change much from an A/B category.

Conclusion

The concentrations of TDS are not expected to increase significantly under any of the proposed flow scenarios. Consequently, this constituent will remain in an A or natural category. Under scenario 2, SRP and TIN are expected to improve, thereby resulting in an

A/B water quality category. Scenarios 5 (+6) and 7 (+8) will all result in a B category for the water quality component of the ERC for this site, as conditions are mostly similar to present state. *Therefore, the recommended water quality Reserve category of B for this site will be attained under all flow scenarios.*

IFR 3 (Little Thukela River)

Present water quality situation
As little data is available for this area, two Resource Units (RU L and RU M) and two Quality Resource Units (QRU 14 and 15) were combined for this assessment. Land use in the area is primarily agricultural, with extensive irrigation of cultivated lands and urban / domestic water use. Periods of no flow are encountered, and although toxicity tests conducted by Umgeni Water Services in May 2002 using *Daphnia*, algae and fish as test organisms (see Appendix D) did not indicate in-stream toxicity, pesticide use has been reported in the Winterton area (regional DWAF personnel, *pers. comm.*). This claim remains unsubstantiated, and no evidence of in-stream toxicity was seen.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
C category	B/C category, i.e. Lower Good (Table 3.12)

A chlorophyll-*a* assessment conducted during June 2002 indicated that periphyton levels for the stretch of river above the IFR site, is in a Lower Fair or D category, with SRP in a Fair (C/D) category. Some increase in phosphate and TIN can be seen under low flow conditions. The PES category for this section (set following Approach 2 of DWAF, 2002a) is a B/C, i.e. lower good, mainly due to elevated periphyton and SRP levels. (RU L: PES = A/B category, and RU M: PES = C category). The water quality PES of C previously set for this site (using Approach 1) was based on reports of pesticide use. Improved nutrient assessment methods and in-stream toxicity results indicate a better water quality state than previously perceived.

Flow-concentration relationships
Median monthly water quality data for modelling were derived from station V1H010, the only DWAF monitoring point on the Little Thukela River (1976 – 1982 for RC, and 1995 to present for PES). As Winterton (a likely source of pollution) is situated between the IFR site and monitoring station, the data may not be representative of the water quality at the site, and confidence in the assessment is low.

Both TDS and TIN showed a negative correlation with flow at this site (Appendix F). TDS is a conservative variable and shows a reasonably high correlation with flow (r^2 = 0.79). There was also a strong correlation between TIN concentration and flow (r^2 = 0.822), while SRP could not be used for time-series analysis due to the poor correlation with flow.

TDS levels were only slightly higher than those recorded for the RC; TIN concentrations were elevated compared to the RC, and those for SRP were more or less the same as those for the RC. This indicates a possibility that the RC data are not completely representative of non-impacted conditions, and that even during the late 1970's there were elevated phosphate levels in the Little Thukela River. A definitive conclusion cannot be made without further investigation. As there are no other monitoring sites on the Little Thukela River, it was decided to use V1H010 despite the high SRP levels, rather than extrapolating from a RC site on a different tributary.

Results from the IFR workshop
TDS and TIN were modelled at this site. The flow scenarios that were modelled were present-day, flows representative of ERCs B/C, C/D and D, and natural.

The concentration exceedence curves (Appendix J) showed that the expected concentrations and durations for TDS under all the flow regimes representing the different ERCs, were very similar. TDS under category B/C, C/D and D flows will be slightly lower than present during the low flow period and slightly higher than at present during high flows. Despite this, all TDS values are very low and a move out of an A (or natural) category is not expected. The concentration exceedence curves for TIN show a similar pattern to TDS. TIN concentrations under categories B/C, C/D and D flows will be slightly lower than present during the low flow period (A/B to a B category) and slightly higher than at present during high flows.

Results from the Yield Scenario workshop
The results of concentration time-series analysis show that under high flow conditions (i.e. when the lowest levels of TDS and TIN occur) there will be no difference in the expected concentrations under the different flow scenarios. It is, however, during the dry season that differences will occur. This is a consequence of the fact that for the Little Thukela River, the volumes of water assigned to each flow scenario differ only during the dry season, with scenario 1 providing the highest flow and scenario 8 the lowest. Despite this, in the case of TDS there is a maximum difference of only 10 mg/L between scenarios. Thus all scenarios are likely to fall within the 95% confidence interval (see the Q-C plot for TDS at this site), and it is considered that the difference between scenarios is not statistically significant. Furthermore, the levels of TDS are low at this site (within an A or natural category) and no change in assessment category resulting from implementation of one of the new flow scenarios is envisaged.

Scenarios 1, 5 and 8 were modelled for TIN. Again, little difference is expected under these scenarios, with TIN expected to stay within a good (A/B – B) category and median monthly values not likely to exceed approximately 0.7 mg/L. Conditions should improve slightly under scenarios 5 and 6 compared to the present situation, as times of no-flow at this site will be avoided. No modelling could be carried out for SRP, but from expert judgement it is predicted that a similar situation would be expected. SRP would therefore improve from a C/D or Fair category under scenarios 5 and 6 (see flow curves in DWAF 2004).

Conclusion
Water quality is not expected to deteriorate under any of the scenarios, including scenario 8 as it is similar to present state. Conditions should improve under scenarios 5 and 6 in the dry season (as periods of no flow are avoided). *The implication is that the recommended water quality Reserve category will be met under all scenarios, and that conditions should not deteriorate from the present B/C category for the water quality component of the ERC under any scenario.*

IFR 4 (Zingela, Thukela River)

Present water quality situation
Water quality modelling was not carried out at this site, as there is no nearby monitoring station in this section of the Thukela River, i.e. downstream of the Klip River and upstream of the confluence with the Bloukrans River. However, it should be noted that **water quality from the Klip River is poor**, with elevated nutrients and sulphates (and other water quality constituents) from industrial activity at Ladysmith and general agricultural land use in the Klip River catchment. Periphyton and nutrient levels in the Klip River were classified as being in a Poor category. A reduction in flow in the Thukela River will result in reduced dilution of the Klip River input and may well result in poorer water quality at IFR 4.

The PES category for this section of the Thukela River (set following Approach 2 of DWAF, 2002a) is a C, i.e. Upper Fair (Table 3.8), mainly due to elevated TIN and SRP levels, and the concentration of sulphate salts.

Results from the IFR workshop
Limited data were collected in the Thukela River (QRUs 7 and 8) (*site 5*) for August and September (2001). This is during the period of lowest flows, and therefore when the worst water quality can be expected. The flow scenarios that were evaluated were those for flow categories B, B/C and C/D. Using expert judgement it was predicted that TDS would stay within an A or natural category for both category B and B/ C flows, while it would move into a B category (see TDS toxicity table in Section 4.2) under flow scenario C/D. It should be noted that these predictions are tentative because of the lack of data and consequent lack of water quality modeling.

Results from the Yield Scenario workshop
Sulphate, SRP and TIN were evaluated qualitatively as no modeling could be carried out. It is expected that sulphate would improve from an Upper Fair to Lower Good (B/C) category under scenario 3, as more water is available during the dry season, and SRP and TIN could improve to a C (Upper Fair) category. However, changes are not expected to be significant enough to cause an improvement in overall water quality. It should be noted that these predictions, as above, are tentative (due to low confidence in the supporting data (8 data points).

No change in water quality category is expected under scenarios 6 and 7, while scenario 8 is likely to result in higher sulphate concentrations and an increase in nutrients due to reduced flows during the wet season. A decrease in overall category to a C/D would therefore be expected.

Conclusion
From a qualitative assessment of the data (in the absence of modeling) it can be concluded that water quality is expected to stay the same as at present under scenarios 3, 6 and 7, and is expected to drop half a category under scenario 8. *The implication is that the recommended water quality Reserve category of a C should be met under most scenarios, but that management of the Klip River input will be required to prevent a C/D water quality category developing under scenario 8.*

IFR 5 (Bushmans River)

Present water quality situation
No water quality modelling was carried out at this site, as there is no DWAF monitoring station in this section of the Bushmans River (downstream of the confluence with the Little Bushmans River). Water quality PES at this site is a category B/C (Lower Good) due to elevated SRP concentrations (C category) as a result of upstream industrial activity at Estcourt and agricultural land-use. This RU is downstream of Wagendrift Dam. As bottom releases are possible from this dam DWAF (2001), there may be water quality issues (temperature, DO and turbidity) associated with such releases. However, there was insufficient data in the data record to adequately assess this (no DO or turbidity data and a small sample size for temperature, n = 27). The biotic community composition is in an Upper Fair (C) PES category.

The PES category for this section (set following Approach 2 of DWAF, 2002a) is a B/C, i.e. Lower Good. The recommended water quality component of the ERC for that reach is therefore a B/C category.

Results from the IFR workshop
Limited data were collected in the Bushmans River (*site 4*) for August and September (2001). This is during the lowest flows, therefore when the worst water quality can be expected. The overall site assessment is shown in Table 3.14. Scenarios evaluated qualitatively were those for flow categories B/C and C/D. Limited TDS data from *site 4* were used for this assessment, and give an *estimate* of the concentration of TDS that could be expected under

the low flow months of the different flow scenarios. The estimates were based on the assumption that the salinity loading would remain the same as during August/September 2001, but that the flow (and hence dilution capacity) would be reduced during times of low flow. At present, TDS is in an A or natural category, but would be within a B or Good category under both flow scenarios (based on the toxicity table in Section 4.2).

Results from the Yield Scenario workshop
Available information suggests that there may be water quality impacts associated with Estcourt's sewage effluent, of which a large component is industrial effluent (Tlou and Matji, and WRP Consulting Engineers, 2002). Erosion would also be expected due to overgrazing. The assessment is made based on professional judgment only, since modeling could not be conducted. The confidence in the predictions is therefore low.

Under all scenarios in the wet season, water quality PES conditions would remain as at present, i.e. B/C overall category. Implementation of flow scenarios 5 and 6 is likely to lead to deterioration in water quality during the dry season, and may drive the water quality component of the ERC to a C category.

Conclusion
From a qualitative assessment of the data (in the absence of modeling) it can be concluded that the *recommended water quality Reserve category of a B/C would probably not be met under scenarios 5 and 6*. Under these scenarios, source-directed controls would be required to improve the conditions of phosphates and other quality-related issues in the catchment.

IFR 6 (Thukela River)

No water quality modelling was carried out at this site, as there is no nearby monitoring station. In addition, flow scenarios were not generated for this site (Louw, IWR Source-to-Sea, *pers. comm.*).

IFR 7 (Upper Sundays River)

Present water quality situation
This site is in Resource Unit Q and is upstream of the Wasbank River confluence. Water quality issues are related to mining in the area, e.g. Newcastle-Platberg Colliery. Although problems require point-source management and are therefore not flow-related, low flows obviously exacerbate water quality issues, e.g. elevated sulphate levels. Magnesium sulphate is in a Poor (E/F) category (although Mg does naturally occur at high levels (Dallas and Day, 1993)), and sodium sulphate is a C category. Natural drainage and drainage from coalmines result in high levels of nitrates, phosphates (SRP is in a C/D category) and sulphates (see Section 2.2 and Table 3.16). These conditions are reflected in the SASS monitoring, which was an Upper Fair or C category. Overgrazing also results in high erosion further upstream – due to the site being at the mouth of the gorge, high turbidities were not seen in-stream (Wadeson, *pers. comm.*).

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B/C category	C category, i.e. Upper Fair (Table 3.16)

The recommended water quality component of the ERC for this reach of the Sundays River is a B/C category, meaning that source-directed controls will be required to improve the current water quality status.

Flow-concentration relationships
Monitoring station V6H006 (1976-1982), which is a site located in the upper Sundays River catchment, was used to estimate the RC water quality. PES was determined using data from

V6H004. This site is relatively close to the IFR site, is upstream of the Wasbank River input, and is therefore considered to be representative of the expected water quality conditions at the IFR site.

Q-C plots were prepared for TDS, TIN, SRP, fluoride (based on anecdotal information about potential impacts of fluoride), total sulphate and magnesium sulphate. Magnesium sulphate and sulphate were examined as they are considered problematic in this reach of the river (Table 3.16). Insufficient data were available to model sodium sulphate.

Fluoride levels were found to be well below the Chronic Effect Value of 1.5 mg/L and within the Target Water Quality Range of 0.75 mg/L (DWAF, 1996). In addition, the levels of this constituent appeared to be largely independent of flow. Although TDS levels remain low (A category according to DWAF, 1999a), they are elevated compared to other reaches of the Thukela system and are negatively correlated with flow. As expected, total sulphate and magnesium sulphate exhibit similar trends to TDS. Although the regression coefficient for SRP is above 0.65, this constituent increases with flow and could not be used for making predictions about water quality. TIN levels were found to be independent of flow - a horizontal (or zero slope) flow-concentration plot was obtained, and the data points were scattered. No RC data were available for sulphate, but for the other constituents it could be seen that present day levels were elevated compared to least-impacted conditions.

Results from the IFR workshop

As TDS and sulphate showed good concentration-flow relationships, these constituents were used for time-series analyses for this site. It was not possible to model other constituents as none exhibited a strong (decreasing) relationship with flow. The flow categories that were modelled were present day, Ecological Reserve Category B/C, C/D, and natural.

The TDS exceedence curves for the different scenarios showed that both present day conditions and those under the flow scenarios B/C and C/D, are elevated compared to natural (Appendix J). Although TDS levels were similar under both the new flow scenarios, TDS levels under the B/C category scenario will be slightly lower than under the C/D category scenario, as the former will supply more water most of the year compared to the C/D flow scenario. Despite the differences between the water quality consequences of present day, B/C and C/D flows, the predicted differences were within the 95% confidence interval, and were not considered to be significant. As the B assessment category for TDS is wide (ranging from 200-600 mg/L (see Table 4.3), a change in assessment category for TDS is not expected.

No RC data were available for sulphate, but expected concentrations for the present day and under the two flow scenarios were modelled. Similar results were obtained from time-series modelling of this water quality constituent as for TDS.

Results from the Yield Scenario workshop

Flow scenarios for this site are virtually indistinguishable except during the low-flow portion of the hydrograph. This is reflected in the results of concentration time-series modelling, which reveals differences in expected concentrations of water quality constituents only under conditions of low-flow (Appendix J). In the case of TDS, for scenario 7 (and 8) flows, median TDS levels will be expected to exceed 200 mg/L, i.e. move into a B or Good category, for approximately 10% of the time. Under the other scenarios, however, TDS will remain in an A category. Magnesium sulphate forms a large proportion of the TDS in this reach of the Sundays River. Although TDS remains in an A or B category for all flow scenarios, magnesium sulphate is in a Poor category (E/F) for over 60% of the time under all scenarios (because expected concentrations will be higher than 37 mg/L, i.e. the boundary value for a D category). Although only scenarios 1, 5 and 8 were modelled in the case of this salt, similar results can be expected as for TDS. Thus, magnesium sulphate concentrations for all scenarios except for 7 and 8 would be similar, and implementation of flow scenario 7 or 8 would lead to higher concentrations during the dry season.

Conclusion
Under scenario 7 conditions would remain as at present. Under scenarios 5 and 6, (which represent more water in the dry season), magnesium sulphate conditions would stay Poor, while TDS would probably remain in an A category. SRP and TIN would remain as present. Overall water quality would not improve under scenarios 5 and 6 due to the elevated sulphate levels. *The recommended water quality Reserve of category B/C will not be met under any scenarios unless sulphate pollution and coalmine drainage in this catchment is addressed.*

IFR 8 (Sundays River)

Present water quality situation
Water quality modelling was not carried out at this site, as there is no nearby monitoring station in this section of the Sundays River. IFR 8 is positioned below where the Wasbank River enters the Sundays River, bringing water of poor quality, specifically increased TDS and sulphate levels from mining activities in the upper catchment. A reduction in flow in the Sundays River will result in less dilution of the Wasbank River input, and may well result in poorer water quality at IFR 8.

Table 3.17a shows an assessment of water quality conditions for the site on the Sundays River, using limited weekly data for August and September 2001. Periphyton and magnesium levels at this site were classified as E/F or Poor. The revised methods used to assess water quality, i.e. Approach 2 of DWAF (2002a), indicated a present state category of a C category. The recommended water quality component of the ERC of C was set for this site.

Table 3.17b shows an assessment of water quality conditions in the Wasbank River, using data from DWAF monitoring point V6H003. The PES category for the Wasbank River (according to the methods of DWAF, 2002a) is a C – C/D, i.e. Upper Fair - Fair, mainly due to elevated sulphate and SRP levels.

Results from the IFR workshop
Limited data were collected in the Sundays River (*site 3*) for August and September (2001), i.e. lowest flows and when the worst water quality conditions can be expected. These results were used to give an *estimate* of the concentrations of sulphate and TDS levels, and concentrations of suspended solids that could be expected under the low flow months of the different flow scenarios. The calculations were based on the assumption that the loading of these constituents would remain the same as during August/September 2001, but that the flow (and hence dilution capacity) would be reduced. This approach is not valid for nutrients, and probably not for suspended solids.

The scenarios that were evaluated qualitatively (i.e. using expert judgement) were those for flow categories C and D. The limited data from *site 3* used for this assessment give only an *estimate* of the concentrations that could be expected under the low flow months of the different flow scenarios. TDS levels are likely to deteriorate significantly under C and D flow categories, as would sulphate levels. It is expected that suspended solids levels are likely to exceed the Target Water Quality Range as defined in DWAF (1996).

Results from the Yield Scenario workshop
Scenarios 6 and 8 are equivalent to present state in terms of flow, and so no changes are anticipated in water quality. During the dry season, scenario 6 provides slightly more water than present, but probably not enough to improve the category, particularly as this is a low confidence site.

Conclusion
Water quality is expected to remain within the present assessment category under flow scenarios 6 and 8. *The implication is that the recommended water quality reserve of a C category should be met under all scenarios. It is however important to note that limited data was used for this assessment, and that management of the Wasbank River catchment area will be required so as to reduce threats to the Sundays River system.*

IFR 9 (Tugela Ferry, Middle Thukela River)

Present water quality situation
This site is in the middle section of the Thukela River, downstream of the confluence with the Sundays River and upstream of the Mooi River. Results from the revised water quality assessment method of DWAF (2002a) indicate that there are elevated magnesium levels in this reach, although the possible cause for this could not be identified. The predicted high levels of magnesium salts ($MgSO_4$: D / Lower Fair, and $MgCl_2$: C / Upper Fair category) may be an error due to the application of the EWQRCalc model Version 2.3 (as required by the new water quality method of DWAF, 2002a) used to define benchmark values for inorganic salts, which appears to over-estimate magnesium sulphate concentrations (Jooste, RQS, *pers. comm.*). This potential over-estimation leads to a lower confidence in the data.

SRP levels are elevated compared to RC and are in an Upper Fair (C) category - possibly due to input from the Sundays River catchment, as well as from the Bloukrans catchment which (although not investigated in this project) has been reported to show elevated TDS, sulphate and phosphate levels (Tlou and Matji, and WRP Consulting Engineers, 2002). Although no data were available, turbidity is expected to be a problem due to degradation of the landscape related to overgrazing and erosion.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B category	B/C category, i.e. Lower Good (Table 3.9)

The recommended water quality component of the ERC for this reach of the Thukela River is a B/C category.

Flow-concentration relationships
Water quality monitoring site V6H002 was used as the modelling data source for both the RC (1977- 1982) and the PES (1995-2000) for IFR 9. This station is reasonably close to the IFR site and therefore should be representative of the water quality in that reach. Present day concentrations of TDS changed quite markedly with altered flow for this site, and were reasonably well correlated (r^2= 0.840). For this reason, TDS was used for the time-series analysis and to provide the water quality consequences of the different flow scenarios. Nutrients were not used for time-series analysis as they increased with flow and did not show a strong correlation. Sulphate is elevated at this site (due to pollution from the Sundays River) although the concentrations are not excessive. Sulphate was used for time-series modelling for the yield scenarios only.

Results from the IFR workshop
The exceedence curve for TDS shows that present day levels are much higher than natural levels. For both of the recommended flow scenarios (C and D Reserve category), TDS levels would be relatively similar. The D category flows would, as expected, lead to slightly higher levels of TDS than the C category flows (D category flows would lead to TDS levels roughly 25mg/L higher than C category flows).

During low flows all scenarios would lead to similar TDS levels (around a maximum of 410 mg/L). However, there is a considerable difference in the predicted TDS levels for both scenarios compared to present day levels in the wetter portion of the hydrological cycle.

TDS levels under flow scenarios C and D will be up to approximately 70 mg/L higher when compared to the present day situation.

Whichever scenario is selected, it is important to note that water of poor quality originates from the Sundays River. Therefore if water quality is not improved in this tributary and the volume of flow is reduced, the dilution capacity at the IFR site will be reduced and water quality will deteriorate.

Results from the Yield Scenario workshop
Time-series modelling was conducted for sulphate and TDS. In the case of TDS, modelling shows that under all scenarios, median TDS will remain in a B (Good) category, i.e. it will remain below 600 mg/L. There are some small differences between the flow scenarios. Flow scenario 8 is expected to result in the highest concentrations and flow scenario 1 in the lowest. In the middle portion of the hydrograph, median TDS levels under scenario 8 are expected to be up to roughly 80mg/L higher than under scenario 1.

Modelling shows that under all flow scenarios, median sulphate concentrations will be in an Upper Fair (C) category (i.e. above 25 mg/L) for approximately 40% of the time under flow scenario 8, approximately 30% of the time under flow scenario 5 and 10% under flow scenario 1. SRP and TIN could not be modelled at this site, and therefore could only be examined qualitatively. SRP is in an Upper Fair (C) category and is likely to stay the same under all flow scenarios. Similarly, TIN is in a Natural (A) category, and will remain the same for all flow scenarios.

Conclusion
Water quality will remain in a B/C category under all scenarios, meaning that recommended water quality Reserve category of a B/C for this site will be attained under all flow scenarios.

IFR 10 (Mooi River)

Present water quality situation
This site is on the upper Mooi River at Mooi River Town and is just downstream of the confluence with the Little Mooi River. There are no perceived major water quality problems in this area, except for nutrient enrichment at Sierra Ranch downstream from the IFR site, as shown by high periphyton chlorophyll-a values (category E/F; Table 3.19). Present state data shows that TDS is in an A or Natural category, sulphate levels are not elevated relative to the RC, but nutrient levels are elevated compared to RC and a cause for concern (SRP is in an Upper Fair or C category). Note that although the assessment in Table 3.19 uses monitoring data from V2H002 to derive the PES water quality, a different site, namely V2H005 was used for Q-C modeling. However, the description of water quality for the site is similar.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B/C category	B category, i.e. Good (Table 3.19)

Flow-concentration relationships
Water quality data used for modelling were derived from station V2H005, i.e. 1977 - 1982 and 1995 – present, for the RC and PES respectively. The station used to derive the PES is close to the IFR site and is considered to be representative of the water quality in that reach. TDS, sulphate, SRP and TIN were plotted against flow at this site. TDS was the only water quality variable that showed a reasonably good correlation with flow, and was used for time-series modelling.

Results from the IFR workshop

The exceedence curves show that all three Reserve flow scenarios (category B, C and D flows) yielded results similar to the TDS concentrations currently found in the Mooi River in that reach. Whilst current TDS concentrations (and those predicted under the three flow regimes) are slightly higher than occurred under natural conditions, the overall TDS levels are low at this site and will remain within an A category.

Results from the Yield Scenario workshop

Under all flow scenarios, median TDS values are expected to remain below 100 mg/L, i.e. in a Natural or A category. Sulphate is not anticipated to be problematic under any flow scenario. However, since SRP did not show a close correlation with flow, only qualitative predictions can be made as to the likely effect of different flow scenarios and thus conclusions regarding this variable are tentative. In the wet season, under flow scenarios 5 and 6, it is expected that SRP levels should stay as present, i.e. within in a C or Upper Fair category. Dry season flows under scenarios 5 and 6 will reduce the times of stagnant water, and therefore should improve the poor periphyton conditions at these times. For flow scenario 8, SRP conditions may worsen slightly, but probably not enough to change the category.

Conclusion

Flow scenarios 7 (present) and 8 are not expected to result in changes to the water quality status of the system, but flow scenarios 5 and 6 should improve the nutrient and periphyton status. TDS is expected to remain low under all flow scenarios. *Therefore, it is expected that the recommended water quality Reserve category of B for this site will be attained under all flow scenarios.*

IFR 11 (Mooi River Falls, Mooi River)

Present water quality situation

This site is in the middle section of the Mooi River, and is in the same Quality Resource Unit (T) as IFR 12. The IFR site is situated just below the gorge, and present state conditions are quite different to the upstream section of this resource unit. Information is presented only for the water quality immediately surrounding the IFR site, where water quality conditions are substantially better than further upstream. There are no major water quality problems in this area, except for some increase in TDS during periods of low flow, with monthly medians up to over 150 mg/L, although this is still within an A category according to the TDS toxicity tables generated for this project (Table 4.3).

The recommended water quality component of the ERC for that reach of the Mooi River is a A/B category (DWAF, 2003b).

Flow-concentration relationships

Water quality data used for modelling were derived from station V2H005 (1977-1982) for the RC and V2H004 (1995-present) for the PES, respectively. The monitoring station used for PES is close to the IFR site and is considered to be representative of the water quality for that reach. Flow-concentration plots were prepared for TDS, sulphate, TIN and SRP. As expected, TDS concentration was negatively correlated with flow. Sulphate levels were poorly correlated with flow, and there was a slight increase in concentration with flow. Sulphate levels however, are not elevated at this site compared to the RC, and this may be a reflection of natural background variation. SRP concentrations were scattered when plotted against flow and could not be used for time-series modelling. The present-day concentration of TIN in this reach appears to have decreased compared to the late 1970's (the period used to derive the RC). Present-day levels of TIN are low and appear to be independent of flow. As a result, at this site, time-series modelling was carried out using only TDS.

Results from the IFR workshop

Overall the TDS levels are somewhat higher at this site than upstream (although not excessively). Time-series water quality modelling yielded similar results to IFR 10 in that TDS concentrations for all flow scenarios (B, B/C and C/D) were similar and slightly elevated during high flows (up to roughly 30 mg/L higher than present day). At low flows, TDS concentrations will be lower than (Reserve category B and B/C flows), or the same as (Reserve category C/D flows) the present day situation. Nevertheless, under all flow scenarios, median monthly TDS values are expected to remain within an A or Natural category.

Results from the Yield Scenario workshop

The exceedence curves for TDS are similar for all flow scenarios except for flow scenario 8. Under all flow scenarios, median TDS values should remain below 100 mg/L, i.e. in a Natural or A category. However, under flow scenario 8, TDS levels will remain at the maximum, i.e. approximately 75 mg/L for about 90% of the time, compared to 70% of the time under the other flow scenarios. Despite this, because of the overall low TDS conditions, flows under scenario 8 are not expected to impact or change the water quality category for TDS.

Time-series modelling could not be conducted for sulphate. From expert judgement it was concluded that sulphate is not anticipated to be a problem under any flow scenarios. A qualitative examination of how the SRP and TIN concentration vary with flow was also carried out (since modelling could also not be carried out for these constituents). These constituents are within a Lower Good (B/C) and Natural (A) category respectively. In the wet season, flow scenario 8 represents less water than at present, however, this is not expected to lower the SRP category. In the dry season, flow scenario 8 is similar to present, but conditions (particularly SRP) are expected to improve under flow scenarios 5 and 6, particularly flow scenario 5. However, the SRP category was set based on Q-C modelling, meaning that there is a moderate confidence in this category. Although SRP may improve to a B category, the overall water quality status will remain at an A/B or Upper Good category.

Conclusion

All scenarios will maintain water quality in an A/B category, with SRP conditions improved under flow scenario 5 in the dry season. *Therefore, the recommended water quality Reserve category of A/B for this site will be attained under all flow scenarios.*

IFR 12 (Keate's Drift, Mooi River)

Flow scenarios were not generated for this site (Louw, IWR Environmental, *pers. comm.*) and concentration time-series modelling was therefore not carried out. Flow-concentration modelling was conducted to evaluate flow relationships, using monitoring point V2H008 (1995-present) to derive the PES, and V2H005 for the RC. TDS and sulphate were both negatively correlated with flow (Appendix F), and TIN and SRP poorly correlated with flow.

IFR 13 (Upper Buffalo River)

Present water quality situation

The most impacted area in the Thukela catchment is the Buffalo River catchment, particularly the upper catchment. As the activities in the area directly above the designated Thukela Reserve study area will have an impact on water quality, water quality conditions in the Ncandu, Horn and Ngagane catchments were evaluated during this study. This area is extensively industrial, with coalmining, power generation and chemical manufacturing taking place. Sewage treatment facilities are also present, and organic and faecal pollution due to raw sewage spillage from the western portion of Madadeni township, occurs. These activities impact upon the quality of the Horn and Ngagane Rivers, and therefore upon the Buffalo River. The Horn River is in a particularly poor condition, specifically as concerns TDS (medians for winter and summer are 571 and 134 mg/L respectively) and sulphate levels (medians for winter and summer are 321 and 55.4 respectively). Some amelioration is expected upon entering the Ngagane River, with further improvements in water quality expected when the Ngagane River enters the Buffalo River. The Buffalo River is highly salinised along its length (as compared to levels elsewhere in the Thukela catchment), but particularly in the upper catchment.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
C category	D category, i.e. Lower Fair (Table 3.21)

The overall present state category of a D is largely due to the elevated magnesium and sodium sulphate levels (Poor or E/F category), as well as the nutrients that are in an E/F or Poor state for SRP, and a Lower Fair or D category for TIN. This is substantiated by an invertebrate category of C/D. These conditions are related to extensive industrial and mining activities in the upper catchment, as well as large urban populations. Overgrazing also results in extreme erosion and high turbidities.

The recommended water quality component of the ERC for this reach of the Buffalo River is a C category, meaning that source-directed controls will be required to improve the current water quality status.

Flow-concentration relationships

The IFR site is substantially further down the river from the Ngagane – Buffalo River confluence. Data used for modelling for the RC and PES, were derived from stations V3H011 (1975-1979) and V3H010 (1995-2000), respectively. V3H010 is just a short distance upstream from the IFR site and is considered to be representative of the water quality that is currently found in that reach. DWAF monitoring station V3H011 is on the Blood River, a tributary of the Buffalo River that joins below the IFR site. It was necessary to derive reference water quality data for modelling from a different river because the Buffalo River has been impacted for a considerable length of time, and no unimpacted RC data were available from sites on the main stem of the river. *Note that the present state assessment shown in Table 3.21 defaults to the benchmark tables for RC.*

All water quality constituents that were plotted for IFR 13 showed a negative correlation with flow. This was the case even for nutrients, perhaps indicating that these enter the river course as point - rather than diffuse - sources of pollutants. Sulphate levels fluctuate from about 30 to approximately 80 mg/L at low flows, which is substantially above the estimates of 5-15 mg/L for other sites on the Thukela system not affected by sulphate pollution. The strongest concentration-flow relationships were found for TDS, sulphate and TIN. These constituents were therefore used for time-series modelling.

Results from the IFR workshop

The PES TDS concentration is considerably higher than under natural conditions, indicating that salinity is considerably increased in this river reach. It should be noted, however, that a site on the Blood River was used to model RC data. These may possibly be lower than would have occurred naturally at IFR 13 in the Buffalo River, although salinity levels in the Thukela catchment in general appear to be relatively low.

The flow scenarios considered at the IFR workshop were the flows representing present day, as well as the recommended ERC of C and D. Under flow scenarios C and D, similar levels of TDS are likely to occur during low flows (reaching up to roughly 450 mg/L) as presently occurs. During the rest of the hydrological cycle (during medium- and high-flows), under scenarios C and D, TDS will be elevated compared to the present state. The predicted difference in TDS concentration between present day and category D is quite considerable (up to approximately 170 mg/L).

Similar results were recorded for sulphate. The maximum monthly median concentration under all flow regimes, unless there is amelioration of pollution sources, will be roughly 90mg/L. Note also that under a C or D flow regime, sulphate levels are unlikely to drop much below 35 mg/L, whereas under the current situation they do roughly 15% of the time. A similar pattern to TDS and sulphate is exhibited by TIN, in that although the highest concentrations of this nutrient will not be elevated, the length of time that these levels are likely to occur will be increased.

Results from the Yield Scenario workshop
It is expected that the water quality conditions that will arise from each of the eight flow scenarios (including present day) will be virtually identical (Appendix J) since the flow scenarios are very similar. The results of time-series modelling for TDS indicate that this variable will be in a B category (concentrations between 200-600mg/L) for all flow scenarios, including present day. Only during floods does the TDS level improve to a natural or A category (i.e. concentrations less than 200 mg/L). Note that this assumes the validity of the TDS-toxicity table (Table 4.3). The toxicity table is based on NaCl, whereas TDS in this part of the catchment is, to a large extent composed of sulphate. Sulphate is generally acknowledged to be more toxic than NaCl at equivalent concentrations (Palmer and Scherman, 2000). Should the lower good boundary be reduced to 400 mg/L, TDS will be in a Fair category (i.e. above 400 mg/L) for approximately 30% of the time.

Magnesium sulphate concentrations will be in a Poor (E/F) category (i.e. greater than 38 mg/L) for about 80% of the time under all scenarios. As the flow scenarios are very similar, it is not expected that the nutrient status at this site is likely to change. The high loads of SRP and TIN at this site, unless there is remediation of pollution, are likely to keep these constituents in a Poor and Lower Fair category respectively. Under flow scenario 8, periods of no-flow will occur. In the case of SRP, during the dry season, scenario 5 flows may be expected to improve conditions marginally, and flow scenario 8 will worsen conditions marginally, but it is not likely to change the status from Poor.

Conclusion
Under scenarios 5, 6 and 7 conditions are expected to remain as at present. As there are times of no flow under scenario 8, overall water quality conditions would be expected to deteriorate further. *Therefore, the recommended water quality Reserve category of C for this site will be not be attained under any flow scenario.*

IFR 14 (Lower Buffalo River)

Present water quality situation
No water quality modelling was carried out at this site, as there is no nearby monitoring station. An assessment was made based on professional judgment and limited data, and confidence is low.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
C category	C/D category, i.e. Fair (Table 3.22)

The water quality conditions in this part of the river are improved compared to the upstream section of the Buffalo River. This is shown by a B category for macroinvertebrates. The overall PES category of a C/D is mainly due to elevated TIN (D or Lower Fair category) and SRP (E/F or Poor category) levels and the concentration of magnesium sulphate salts (E.F or Poor category). Periphyton results are also in a Poor category. Results suggest that the biota may have acclimated to fair, but stable, water quality conditions.

The recommended water quality component of the ERC for this reach of the Buffalo River is a C category, meaning that source-directed controls will be required to improve the current water quality status.

Results from the IFR workshop
Limited data were collected in the Buffalo River (*site 2*) for August and September 2001 (lowest flows, therefore when the worst water quality can be expected). Scenarios evaluated qualitatively were those for flow categories B/C and C/D. Limited TDS and sulphate data from *site 2* were used for this assessment, and give an *estimate* of the concentrations that could be expected under the low flow months of the different flow scenarios. It is expected that TDS levels would probably deteriorate from a B category to a C/D and D category under flow scenarios B/C and C/D respectively (based on the toxicity table in Section 4.2). Substantial increases in sulphate salts and sediment loads (overstocking and erosion lead to high in-stream turbidities) are expected under these scenarios.

Results from the Yield Scenario workshop
During the wet season, all scenarios are equivalent to present state; no changes are therefore predicted. During the dry season, scenario 5 provides slightly more water, but probably not enough to improve the water quality category, particularly as this is a site where there is low confidence in the water quality data. During the dry season, implementation of flow scenario 8 would probably lead to elevated concentrations of sulphate and nutrients (particularly periphyton), as periods of virtually no flow occur. This is likely to change the overall water quality PES to a D category.

Conclusion
Water quality is expected to stay the same as present under scenarios 5, 6 and 7, and is expected to drop half a category under scenario 8. *The implication is that the recommended water quality reserve of a C category will not be met under any flow scenario, and that management of the upper Buffalo catchment will be required.*

IFR 15 (Jameson's Drift, Lower Thukela River)

Present water quality situation
Available information and local knowledge of the area indicate that over-grazing; settlements and erosion are the primary water quality problems in the area. No water quality modelling was carried out at this site, as there is no nearby monitoring station. An assessment was made based on professional judgment and limited data, and confidence is low.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B category	B/C category, i.e. Lower Good (Table 3.10)

The PES category for this section, i.e. B/C or Lower Good category, is mainly due to SRP (C or Upper Fair category) and periphyton status (C/D or fair category). Magnesium sulphate is in a D (or Lower Fair) category, but other salts are in a Natural or A category. The predicted high levels of magnesium may be an error due to the application of the EWQRCalc model Version 2.3 (as required by the new water quality method of DWAF, 2002a) used to define benchmark values for inorganic salts, which appears to over-estimate magnesium sulphate concentrations (Jooste, IWQS, *pers. comm.*).

The recommended water quality component of the ERC for this reach of the Thukela River is a B/C category.

Results from the IFR workshop
No assessment was conducted for this site.

Results from the Yield Scenario workshop
Limited data were collected at IFR 15 (*site 1*) for August and September 2001 (lowest flows, therefore when the worst water quality can be expected) - an overall site assessment is shown in Table 3.10.

During the wet season, water quality conditions under all scenarios (particularly flow scenarios 3 and 6) would improve slightly, but probably not sufficiently to improve overall water quality status. Data confidence is however low.

Conclusion
Water quality is expected to stay the same as present under all flow scenarios. Improvements during the wet season will probably not be sufficient to improve overall status, without source-directed controls and improved management of sulphate and phosphate sources in the catchment. *The recommended water quality Reserve category of B/C will be met under all scenarios.*

IFR 16 (Lower Thukela River)

This site is on the lower Thukela River, above the Mandini industrial area. Water quality data used for this site were taken from V5H002, the most downstream station on the Thukela River. Much of the data from this station was also used in water quality modelling for the Thukela estuary, and some overlap can be expected.

Present water quality situation
As this IFR site is above the Mandini industrial area, only land-uses above the IFR site will be assessed. Turbidities are high at this point – Sappi have experienced severe turbidity problems at their raw water intake (Tlou and Matji, and WRP Consulting Engineers, 2002). The rural population density in this area is also the highest in the Thukela catchment.

Elevated magnesium sulphate and magnesium chloride levels are depicted as E/F and C categories respectively. Other salts are in a Natural (A) category. SRP is in a Fair or C/D category, and periphyton in an Upper Fair or C category.

The PES for water quality is shown below:

Approach 1 (DWAF, 1999a)	Approach 2 (DWAF, 2002a)
B category	C category, i.e. Upper Fair (Table 3.11)

The recommended water quality component of the ERC for this reach of the Thukela River is a C category.

Flow-concentration relationships
For the purpose of water quality modelling, 1977-1982 data from V5H002 was used for the RC assessment, and 1995-2001 for the present state assessment. Both SRP and TIN increased with flow at this site - this is possibly a consequence of the intensive sugar farming in the area that leads to diffuse-sources of nutrient-based pollution. Only TDS was suitable to use for time-series modelling at this site, and even then the correlation between flow and concentration was not very high ($r^2 = 0.685$).

Results from the IFR workshop
The flow time-series that were converted to TDS concentration time-series were for flow representing present day, and for Reserve categories B/C, C/D and D. TDS concentrations predicted under all these flow scenarios were very similar. During low flows TDS concentrations will be similar to current levels, and median monthly concentrations should not exceed roughly 360 mg/L. During high flows, however, TDS concentrations under the three Reserve flow scenarios will be considerably higher than at present. At present a

concentration of higher than 220 mg/L occurs in the system at this site roughly 65% of the time, whereas under a D category flow scenario this will occur roughly 90% of the time.

Results from the Yield Scenario workshop
TDS concentrations during medium- and high-flows would be expected to be similar for all scenarios except for scenario 8. Under flows represented by scenario 8, predicted concentrations of TDS would be expected to be higher throughout the entire hydrological year. The other scenarios differ only at low flows where the usual ranking of scenarios could be expected (i.e. the water quality consequences became progressively worse with decreasing MAR; thus scenario 1 TDS levels are lower than scenario 2 etc.). Under all scenarios, including the present state, TDS levels vary between an A or B category.

In the absence of Q-C modelling, the effect of the different flow scenarios on the other water quality constituents could only be described qualitatively. Under flow scenarios 3 and 6, conditions would be expected to stay the same as a present, as these flows are similar to the present day flows. Flow scenario 8 would result in reduced dilution capacity and elevated sulphate and SRP levels in the wet season. Periphyton levels would probably also be elevated. In the dry season, flow scenario 8 is not expected to make much difference to overall water quality conditions. Although TIN could not be modelled, it is currently in an A/B category, and is not expected to deteriorate under any of the flow scenarios. Therefore, it is estimated that under flow scenarios 3 and 6 conditions would probably stay the same as present, but under flow scenario 8 conditions would worsen to a C/D (fair) category.

Conclusion
Under flow scenarios 3 and 6, water quality PES will remain in a C category. Under scenario 8, overall water quality status will drop to a C/D category. *The* recommended *water quality Reserve category of C is therefore likely to be met under all scenarios.*

4.4.3 Results for the Thukela estuary

As this information was submitted to the Thukela Estuarine Team, some overlap can be expected with the estuaries report, as well as with IFR 16 results shown above.

Present water quality situation
RU J includes IFR 16, and is the reach above that including the estuary (RU K). RU J includes the gauging weir V5H002, thereby providing some routinely monitored water quality data. RU K, i.e. below IFR 16 to the Thukela estuary, falls into two Quality Resource Units. The QRU of relevance here, and potentially having the greatest impact on the estuary, is QRU 13 (segments 74 – 78), or the Mandini / Sundumbili industrial complex to the Thukela estuary.

The land-use activities and water quality implications can be described as follows: Large industrial area, including Sappi Tugela mill, Mandini, Tugela Rail and Sundumbili Sewage Treatment Works (STW), a textile and vegetable oil factory. Irrigation by sugar farmers takes places further downstream. Some of the impacts are only evident from the Sappi Tugela Mill data, as their monitoring points are at John Ross bridge and further toward the Thukela estuary - however, limited constituents are monitored. Abstraction and discharge takes place in this QRU. Water quality conditions are fair (data confidence extremely low as a known area of impact) according to available water quality data. However, biological data reflects the deteriorating water quality conditions (PES for fish: D category) even though evidence of rapid recovery can be seen at the John Ross bridge (Coke, 2001).

The only in-stream and downstream data available for use was from Sappi Tugela. Sappi monitors at three points in the Thukela, i.e. *John Ross bridge*, a point called *Ultimatum Tree* about 5-6km downstream, and *Havelock Farm*, another 2-3km toward the estuary. Unfortunately their database is limited, with monthly medians reported for the last 5 years. The constituents they monitor include COD, Na, pH, EC, DO, temperature and colour. A number of figures are included in Appendix K to show the trends in selected constituents at the different monitoring points. Attempts to access nutrient data, or more extensive data, were not successful.

Discharge-concentration (Q-C) modelling

Discharge-concentration modelling (i.e. determining the mathematical relationship between concentration and flow) was carried out for the following water quality constituents:

TDS, pH, ortho-phosphate, nitrates and nitrites, ortho-silicate, COD.

Data from IFR 16 (i.e. V5H002) were used to model all constituents apart from COD. This was firstly because there were no data to indicate that IFR 16 water quality was not representative of the area below Mandini for these constituents (although, alternatively, there is little data to indicate that IFR 16 water quality is representative of the area below Mandini, particularly as this is an area of known industrial impacts). Secondly, the DWAF data set was more complete and reliable than that from Sappi and thirdly, the available discharge data were for IFR 16. The different data sources were compared for individual water quality constituents in order to assess if the V5H002 data were very different from that of the lower reaches (Table 4.7). No flow data were available for closer to the estuary. Data from Sappi (Havelock site) were used to model COD, since this variable was not measured by DWAF. The Q-C method is described in Malan and Day (2002a). The Q-C method is not suitable for making predictions of temperature or DO, and so these constituents could not be modelled.

The results from Q-C modelling are summarised in Table 4.8. The modelling exercise was the most successful for the conservative constituents TDS and ortho-silicate, but was less successful for nutrients. The data points for combined nitrate and nitrite in particular were scattered. The Q-C plots for each variable are shown in Fig 4.4. Ortho-phosphate, combined nitrate and nitrite, and ortho-silicate increase with discharge (at least in the low flow portion of the range). This indicates that these constituents enter the system as diffuse pollutants (there is extensive sugar cane farming around the area). The Q-C method cannot be used for predicting in-stream concentration in situations where non-point sources are the major contributor (Malan and Day, 2002a); this is because if flow is reduced in the system, it does not necessarily mean that the concentration of the constituents will also decrease. Such pollutants can only be modelled using a catchment run-off model that involves extensive collection of data (for example, determining the load of each constituent generated per unit area, for each different land-use). The Q-C method can be used for making predictions of substances that *decrease* with increased discharge due to the effect of dilution. At IFR 16, these constituents are TDS, pH and COD. Of these three constituents, only TDS exhibited an r^2 value higher than 6.0 (Section 4.3.5) and could be used to make predictions of water quality. This variable was therefore used to convert discharge time-series to time-series of salinity in order to compare and rank the different flow scenarios with regard to their water quality consequences.

Concentration time-series modelling

Eight different flow scenarios (Table 4.9) were generated by the hydrologists and system modeller for evaluation. These scenarios, along with the MAR at IFR 16 that they represent, are shown below (Hughes, Rhodes University, *pers. comm.*):

Table 4.7 Comparison of the water quality for IFR 16 and below Mandini (i.e. river water entering the Thukela estuary). Concentrations expressed as mg/L (RC = reference condition, TIN = total inorganic nitrogen)

Water quality variable	IFR 16 (DWAF V5H002)		Sappi Havelock *		CSIR data (once-off sampling)		Water quality guidelines **	Comment
	Median annual PES	Max . monthly median PES	Median annual PES	Max. /min . monthly median PES	30/05/1996 $	21/08/2001 $$		
EC	30	42 (Sept)	23	39 (Aug)	30	no data	Specified in terms of RC.	Data do not show that EC is elevated below Mandini, compared to IFR 16.
pH	8.2	8.6 (Sept)	7.8	8.0 (May)	7.8	7.1	Specified in terms of RC.	Data do not show that pH is significantly altered below Mandini compared to IFR 16.
DO	No data		6.0	8.6 (Max) 3.8 (Min)	12.5	6.0	Minimum allowable level (lethal 1 day) ≈ 3.6	Sporadic episodes of low DO levels may well occur below Mandini.
Ortho-phosphate	0.021	0.032 (Jan)	No data		0.038	0.023	>0.025 = eutrophic	Phosphate levels elevated both at IFR16 and in lower reaches
Nitrate and nitrite	0.09	0.1 (July)	No data		<0.048	0.02	0.5 – 2.5 = mesotrophic (TIN)	Difficult to assess if nitrate and nitrite are elevated below Mandini, as data are limited.
Ortho-silicate	5.8	6.3 (Apr)	No data		5.2	3.3	Not in guidelines	Data do not show that this variable is elevated below Mandini.
COD	No data		17.1	48.1	< 5.0	no data	Not in guidelines	Difficult to assess if this variable is a concern.
Temperature	No data		24.7	27.9 (Feb, Mar) 19.6 (Jun, Jul)	20	22	Specified in terms of RC.	Difficult to assess if this variable is a concern.
TSS	No data		No data		31	20	Specified in terms of RC.	Difficult to assess if this variable is a concern.

* This is the most downstream site monitored by Sappi.
** DWAF (1996) South African water quality guidelines. Volume 7: Aquatic ecosystems.
$ Archibald (1996) Tugela estuarine flow requirement workshop. CSIR (KwaZulu-Natal), CSIR project no. JEA02/010/19960601.
$$ Taljaard, CSIR, *pers. comm.*

Table 4.8 Summary of Q-C modelling trends for IFR 16 on the Thukela River. The source and time-period used for RC and PES discharge and water quality data is shown. For each variable, the trend in concentration with increasing discharge is shown as well as type of relationship (linear, power etc.) and the regression coefficient r^2. The accuracy of the simulation is given by the correlation coefficient between simulated and measured PES values. All concentrations expressed as mg/L

IFR site	Water quality data		Discharge data		Water quality variable	RC Q-C relationship		Comments		
	RC	PES	RC	PES		Q-C trend	r^2	Q-C trend	r^2	
16	V5H002 ‘77-’82 n=116	V5H002 ’95 – ’01 n=119	Simulated data for V5H002	Simulated data for V5H002	TDS	↓ (power)	0.73	↓ (exponential)	0.69	Correlation between measured and simulated values good.
					NO^{3-} and NO^{2+}	scattered	0.18	↑ then↓ (polynomial)	0.58	Not suitable for making predictions of water quality.
					PO_4^{2-}	scattered	0.21	↑ (linear)	0.39	Wash-off effect in summer and point-source effect in winter. Not suitable for making predictions of water quality.
					SiO_4^{4-}	slight ↑	0.51	slight ↑	0.63	RC and PES very similar. Not very much variation with Q.
					pH	↓ (power)	0.87	↓ (log)	0.52	PES higher than RC. Possibly an artifact due to changing measurement techniques?
					COD	No data		↓ (linear)	0.28	Correlation between measured and simulated to low for further modelling.

Q: discharge C: concentration RC: Reference condition PES: Present Ecological State.

Fig 4.4 Q-C plots for various water quality constituents at IFR 16 (Thukela River)

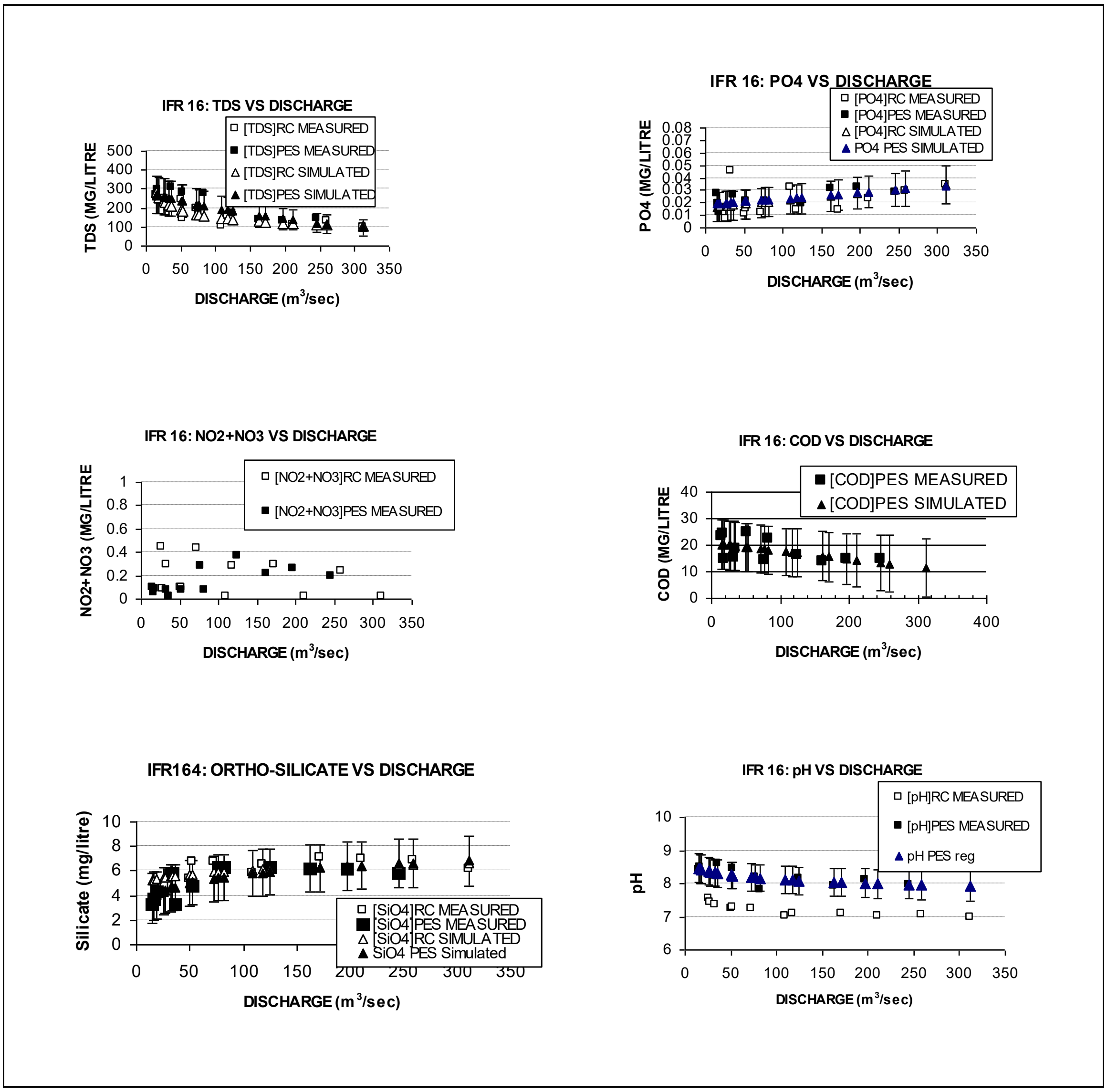


Table 4.9 Flow scenarios, and the MAR at IFR 16 that they represent, as generated by the project hydrologist

Scenario		MAR ($m^3 \times 10^6$)
1	Natural	3754
2	Present day (1995)	2756
3	Worst case 1	1788
4	Worst case 2	1669
5	River Reserve category A	2495
6	River Reserve category B	2258
7	River Reserve category C	2057
8	River Reserve category D	1915

The concentration of TDS expected under the different flow scenarios was used to rank the flow scenarios. From an examination of the Q-C plot for this constituent, the flow time-series matrices were set up representing discharge and predicted TDS concentration. These were used in the computer software T-SOFT to convert flow time-series to concentration time-series.

Matrix 1: compiled using the Q-C plot for the RC and was used to transform the natural flow time-series.
Matrix 2: compiled using the Q-C plot for the PES and was used to transform all other time-series (apart from natural).

Figure 4.5 shows the TDS exceedence curve for natural and present day flow scenarios. As is to be expected, TDS levels are considerably higher under the present day flow regime compared to under the natural flow regime. Figure 4.6 shows the TDS concentration duration curve that is expected to arise from the implementation of Worst case 1 and Worst case 2 flow scenarios. It can be seen that there is very little difference between the two scenarios.

Figure 4.7 shows the TDS concentration duration curve that is expected to arise from implementation of the following flow scenarios: Present day, Reserve category A, Reserve category B, Reserve category C, Reserve category D, and Worst case 1. There is not a large difference in expected salinity levels between many of the scenarios. River Reserve category D would appear to be the worst (in that the highest concentrations for the longest period of time would be expected), and is closely followed by the Worst case scenario. The best water quality is to be expected under the Reserve category A flow scenario, since, for example, a concentration of equal to, or greater than 280 mg/L TDS is to be expected only 8% of the time. Under a discharge regime characteristic of a D category River, a concentration greater than 280 mg/L would be expected approximately 38% of the time. Note that due to the approximations used to generate concentration time-series, the duration percentages are not exact but can be used to rank flow scenarios.

Seasonal variation of water quality
Figure 4.8 and 4.9 shows seasonal plots of present-day discharge and nutrient concentration. Nitrogen levels are highest during the summer rainfall months. Phosphate levels on the other hand are high during the summer months (due to wash-off from surrounding lands), but are also high during the low-flow months. This latter effect is likely to due to the in-stream loading. Any flow scenario that results in reduced flows (compared to natural) during the winter is likely to result in impaired water quality, because concentrations of most water quality constituents, but especially ortho-phosphate, will be elevated.

Table 4.10 shows the monthly predicted median TDS and COD levels under the different flow scenarios (Reserve categories A, B, C, D and worst case 1 and 2). The 95% confidence limits are also indicated. Descriptive explanations of how pH, inorganic nitrogen, ortho-phosphate and silicates are likely to change seasonally are also given. The results for TDS and COD are also shown graphically in Figure 4.10 and 4.11. The figure shows that the highest levels of TDS and COD will, like ortho-phosphate occur during the low flow season, namely winter.

Mass-balance calculations
It was hoped that by determining all the nutrient loads entering the Thukela at Mandini, rough estimates of the in-stream nutrient concentrations in this reach could be calculated. However, no data could be obtained from Sappi or other effluent producers in the Mandini area concerning end-pipe concentration of pollutants. Only limited nutrient loads were reported in DWAF (1994). In addition, no exact discharge data were available for Mandini (both abstraction and discharge takes place in this reach). Thus mass-balance calculations could not be carried out.

Fig 4.5 **TDS exceedence curve for natural (black line) and present day (blue line) scenarios**

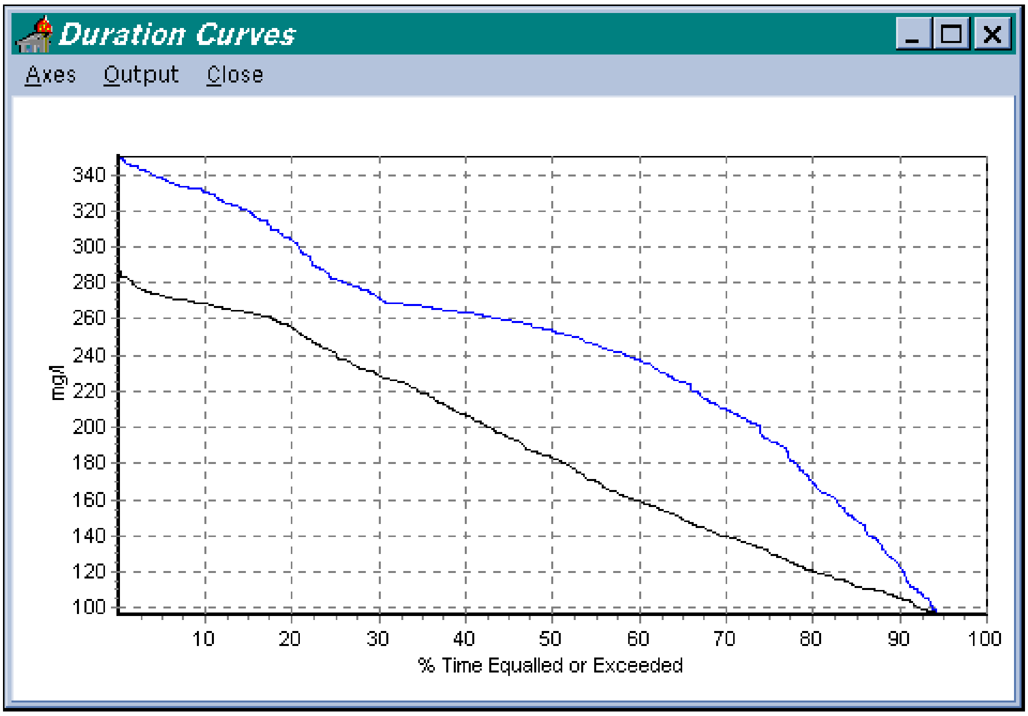


Fig 4.6 **TDS exceedence curve for the flow scenarios Worst case 1 and Worst case 2**

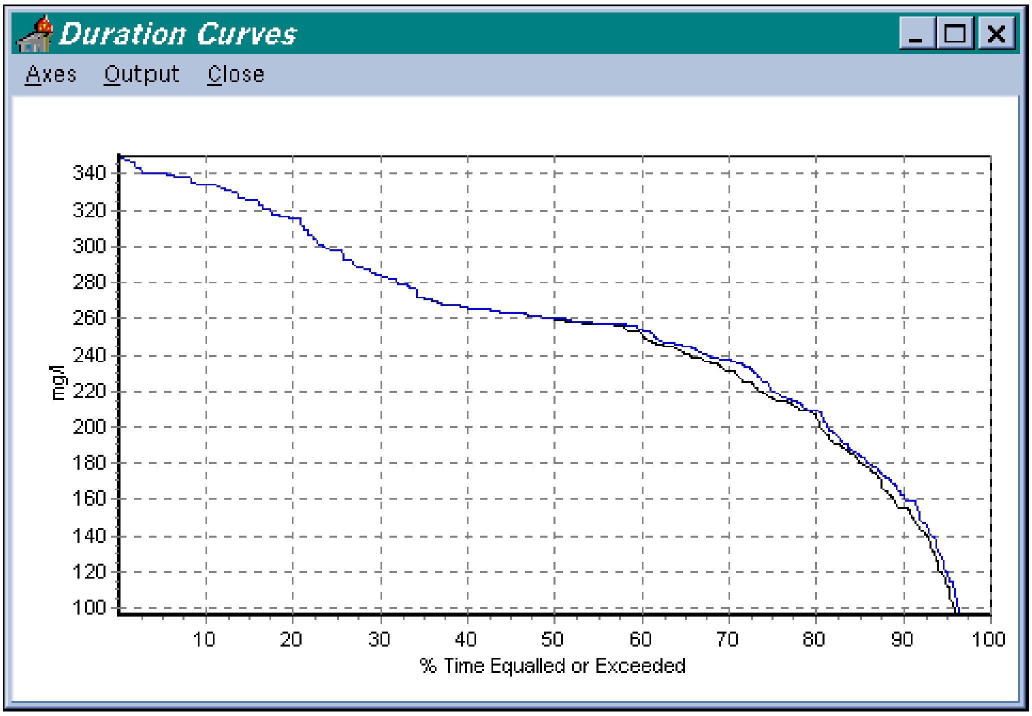


Fig 4.7 **TDS exceedence curve for the flow scenarios present day (black), Reserve category A (blue), Reserve category B (red), Reserve category C (yellow) and Reserve category D (green)**

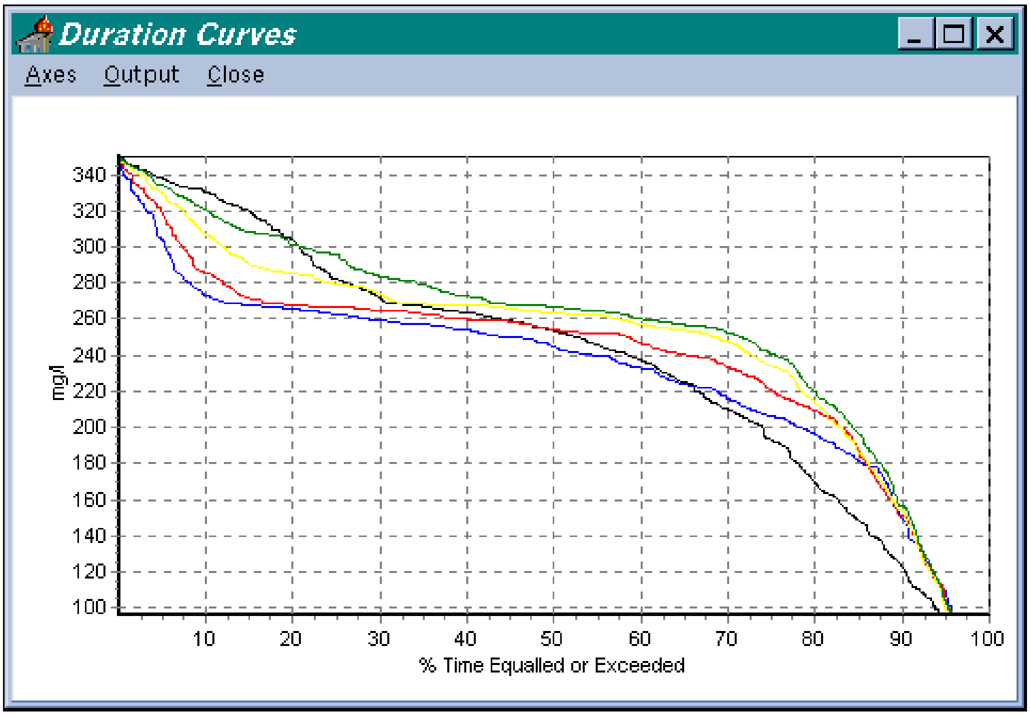


Fig 4.8 **Seasonal variation of discharge: NO_2 and NO_3**

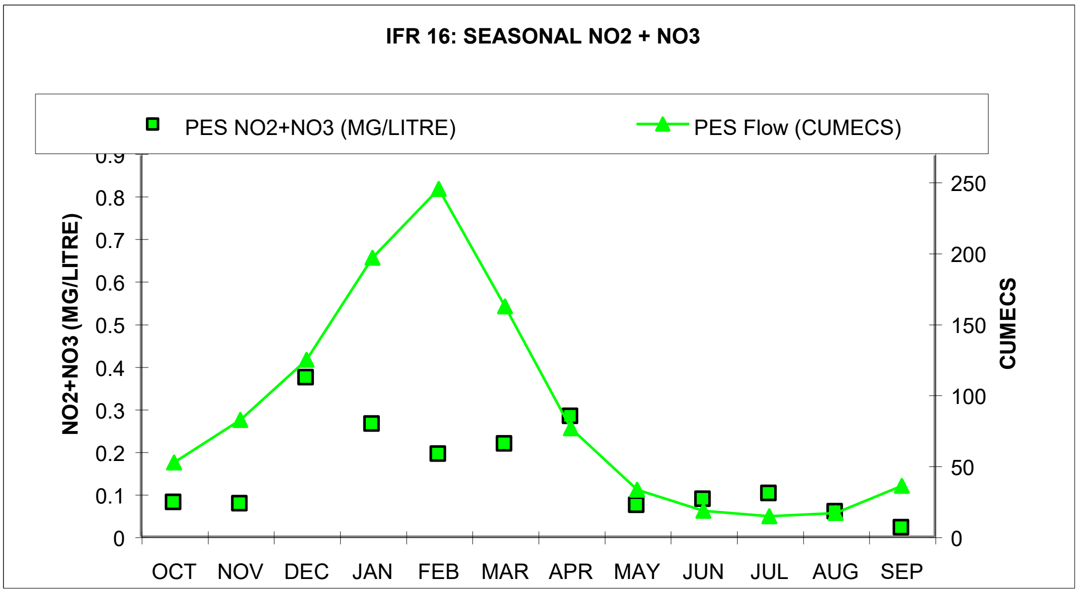


Fig 4.9 **Seasonal variation of discharge: PO_4**

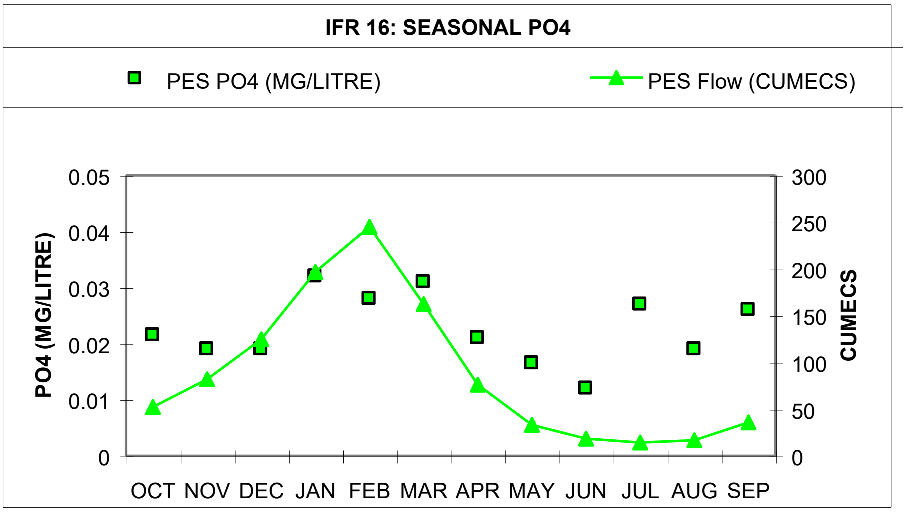


Fig 4.10 **Seasonal concentration of TDS under different flow scenarios**

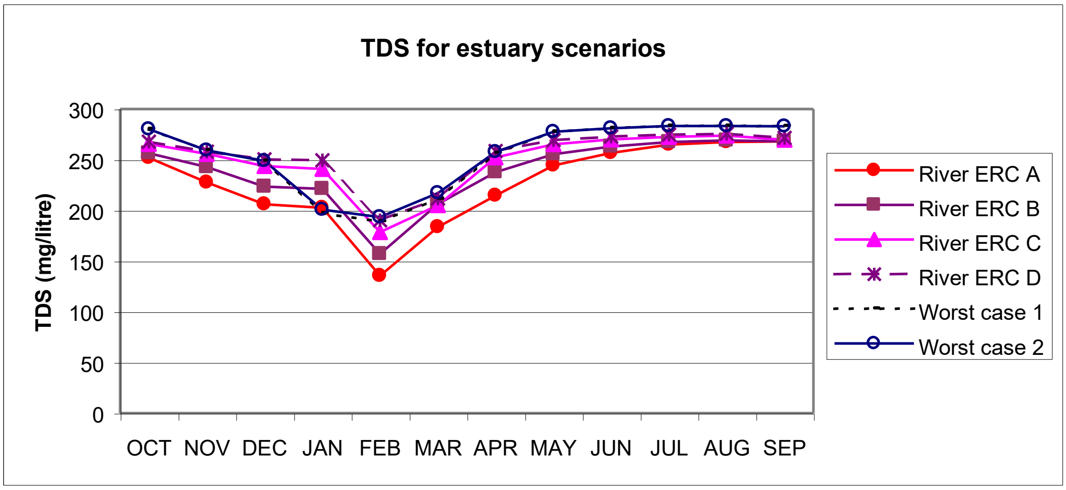


Fig 4.11 **Seasonal concentration of COD under different flow scenarios**

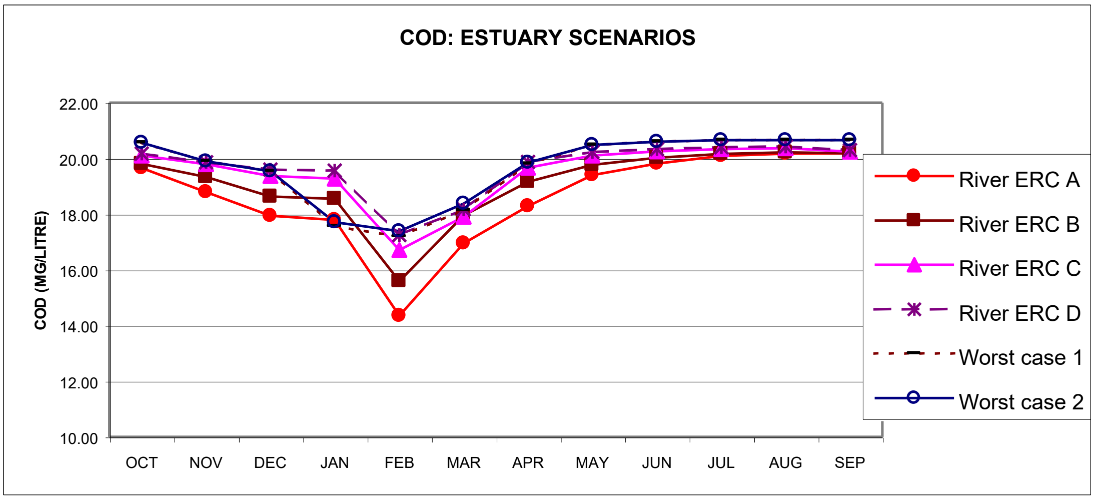


Table 4.10 Predicted monthly concentration and 95% confidence intervals for each estuary scenario

TDS												
Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
River ERC A	252	228	206	203	136	184	215	244	257	265	267	268
Upper 95% conf. limit	344	309	280	275	188	250	292	333	350	362	366	367
Lower 95% conf. limit	160	146	132	130	83	117	138	156	163	158	169	169
River ERC B	256	243	223	221	157	206	238	255	263	267	269	268
B Upper 95% conf. limit	350	330	304	301	215	280	323	349	359	366	368	367
B Lower 95% conf. limit	163	155	143	143	99	132	152	162	166	169	170	169
River ERC C	265	256	244	341	179	205	252	265	270	272	274	270
C Upper 95% conf. limit	363	349	332	328	243	279	344	363	370	373	375	369
C Lower 95% conf. limit	168	162	155	154	114	132	160	168	170	172	172	170
River ERC D	268	258	250	249	190	212	258	269	273	275	276	272
D Upper 95% conf. limit	366	352	341	340	259	288	353	369	374	377	378	372
D Lower 95% conf. limit	169	164	159	159	122	136	164	170	172	173	173	171
Worst case 1	280	259	249	197	189	211	256	277	281	283	283	283
WC1 Upper 95% conf. limit	384	354	339	568	257	287	350	281	386	389	389	389
WC1 Lower 95% conf. limit	176	164	158	156	121	135	163	174	176	177	177	177
Worst case 2	280	259	249	201	193	217	258	277	281	283	283	283
WC2 Upper 95% conf. limit	384	354	339	273	263	295	352	381	386	389	389	389
WC2 Lower 95% conf. limit	176	164	158	129	124	139	163	174	176	177	177	177
COD												
Month	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
River ERC A	19.66	18.87	17.93	17.79	14.35	16.95	18.29	19.39	19.81	20.09	20.17	20.18
River ERC B	19.81	19.33	18.63	18.54	15.60	17.95	19.15	19.77	20.02	20.16	20.22	20.18
River ERC C	20.10	19.79	19.37	19.27	16.71	17.90	19.66	20.10	20.25	20.33	20.36	20.24
River ERC D	20.17	19.86	19.60	19.56	17.24	18.17	19.87	20.23	20.34	20.40	20.42	20.30
Worst case 1	20.56	19.90	19.54	17.56	17.19	18.13	19.81	20.48	20.59	20.66	20.65	20.65
Worst case 2	20.56	19.90	19.54	17.71	17.39	18.38	19.85	20.48	20.59	20.66	20.65	20.65
PH												
PH decreases slightly with increasing flow. But not likely to exceed limits of approximately 7.8-8.8.												
$NO_2 + NO_3$												
No clear relationship between concentration of $NO_2 + NO_3$ and discharge. But highest concentrations will occur during periods of lowest flow.												
PO_4												
Not possible to predict resultant concentrations for this constituent as it shows a positive trend with flow. But highest concentrations will occur during periods of lowest flows.												
Silicates												
Not possible to predict resultant concentrations for this constituent as it shows a positive trend with flow. But highest concentrations will occur during periods of lowest flows.												

Conclusions

1. Water quality modelling using the Q-C method was of limited use at this IFR site because many of the constituents are from diffuse, rather than point-sources. They increase with increased flow due to wash-off rather than showing a dilution effect and do not have a strong correlation with flow. This makes predictions of water quality expected under a given flow inaccurate.
2. The concentration of TDS was used to rank the flow scenarios according to their likely impacts on water quality. Results from this showed that there was only a little difference between scenarios with regard to this variable. River Reserve Category D was the worst scenario, very closely followed by Worst case 1 and 2. The flow scenario represented by Reserve categories A and B would yield the least impacted water quality *with regard to TDS* (excluding natural). This is an interesting result since the Present day scenario represents a higher proportion of the MAR than these two highest Reserve categories. It is likely to be a result of the fact that the recommended discharge during the winter months (when flow is low and concentration of TDS high) is slightly higher for Reserve categories B compared to Present day.
3. It is important to note that although TDS was used to evaluate the scenarios, this constituent is not of particular concern since the levels are not excessively high in the lower part of the Thukela system. It is the nutrients, especially ortho-phosphate, which are a concern in this reach.
4. Although quantitative values cannot be given for many of the water quality constituents, the worst water quality is likely to occur during the winter when flow is at a minimum. Therefore any reduction of flow during this period is likely to exacerbate the current water quality impacts.

4.5 CONCLUSION: MODELLING

An important principle to follow when considering water quality and the Reserve process is that the recommended environmental flows should be those that satisfy the requirements of the aquatic biota with regard to hydraulic habitat. Flows should not be recommended to dilute pollutants to a level acceptable to the biota. If they are, it should be stated clearly that this is a management decision and that the *extra* water required for dilution is not part of the Ecological Reserve. The predicted consequences of the recommended flow regime (in the absence of pollution control) should therefore be quantified as far as is possible using water quality modelling.

5 OBJECTIVES OR QUALITY ECOSPECS

5.1 INTRODUCTION

This section of the report will list, per IFR site, the water quality objectives or Ecological specifications (ecospecs) in order to meet the water quality component of the recommended ERC, for the constituents used in the assessment. Quality ecospecs will therefore be listed per IFR site based on the recommended ERC. **Note that ecospecs are only provided for constituents covered by the revised methods of DWAF (2002a).**

5.2 RESULTS: QUALITY ECOSPECS

Results are presented as tables per IFR site. Quality ecospecs are related to attaining the recommended water quality category of the overall ERC, and are presented as 95th percentiles, i.e. values not to be exceeded more than 5% of the time, for inorganic salts and dissolved oxygen; and 50th percentiles for nutrients, i.e. TIN and SRP. Biotic community composition (invertebrates) should not drop below the indicated values. Percentiles should be calculated within the framework of the current assessment method, i.e. using the PES monitoring point as shown on the table for the relevant IFR site (e.g. Table 5.1 relates to IFR 1), and the most recent 3 to 5 years of data, equivalent to a minimum of 60 data points. This approach is consistent with the monitoring programme recommended for water quality. Present state categories per water quality constituent are shown as additional information.

Table 5.1 Quality Ecospecs for IFR 1

IFR 1: Recommended water quality component of the ERC – B/C or Lower Good category

PES for water quality: B/C or Lower Good category

River	Thukela River	**DWAF Water Quality Monitoring points**		
QRU	2 and 3	**RC**	V1H035 (1978 – 1985)	
IFR number	1	**PES**	V1H026 (1998 – 2001)	
Water Quality Constituents		**Present state**		**Quality ecospecs**
$MgSO_4$		A		16 mg/L
Na_2SO_4		A		20 mg/L
$MgCl_2$		A		15 mg/L
$CaCl_2$		A		21 mg/L
NaCl		A		45 mg/L
$CaSO_4$		A		351 mg/L
SRP		C		≤ 0.058 mg/L
TIN		A/B		≤ 0.5 mg/L
Chl-a: phytoplankton		-		(good) 10-20 µg/L
Chl-a: periphyton		-		(fair) 25-260 mg/m^2
Biotic community composition		D		(fair) ASPT = 5
Dissolved oxygen		-		(good) 6 mg/L
pH *		-		(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-		(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Note (This note is valid for all IFR sites)
No benchmark tables or boundary values exist for the following constituents, according to the revised methods of DWAF (2002a).

- *KCl. Although Table 3 of DWAF (2002a) provides benchmark boundaries for KCl, these values are inaccurate and this table was not used during the assessment (Jooste, RQS, pers. comm.).*

- *Individual ions, i.e. Mg, SO_4, Cl, K, Ca, Na. It is recommended that Target Water Quality Ranges and CEV values in DWAF (1996) be used in the absence of boundary values.*
- *Turbidity.*
- *Temperature.*
- *Toxicity, i.e. complex effluents and toxic substances not previously listed.*

Table 5.2 Quality Ecospecs for IFR 2

<u>IFR 2:</u> Recommended water quality component of the ERC – B or Good category

PES for water quality: B or Good category

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	4	**RC**	V1H057 (1983 – 1988)
IFR number	2	**PES**	V1H057 (1998 – 2001)
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		A	16 mg/L
Na_2SO_4		A	20 mg/L
$MgCl_2$		A	15 mg/L
$CaCl_2$		A	21 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		C	≤ 0.058 mg/L
TIN		A/B	≤ 0.5 mg/L
Chl-a: phytoplankton		-	(natural) < 10 µg/L
Chl-a: periphyton		-	(good) 3-25 mg/m^2
Biotic community composition		B/C	(good) ASPT = 6
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Table 5.3 Quality ecospecs for IFR 3

<u>IFR 3:</u> Recommended water quality component of the ERC – B/C or Lower Good category

PES for water quality: B/C or Lower Good category

River	Little Thukela River	**DWAF Water Quality Monitoring points**	
QRU	14 and 15	**RC**	V1H010 (1976 – 1981)
IFR number	3	**PES**	V1H010 (1996 – 2001)
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		A	16 mg/L
Na_2SO_4		A	20 mg/L
$MgCl_2$		A	15 mg/L
$CaCl_2$		A	21 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		C/D	≤ 0.091 mg/L
TIN		A/B	≤ 0.5 mg/L
Chl-a: phytoplankton		A	(natural) < 10 µg/L
Chl-a: periphyton		D	(poor) > 260 mg/m^2
Biotic community composition		B/C	(good) ASPT = 6
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

As the present state has improved using the methods of Approach 2, current conditions are sufficient to satisfy the Reserve. SRP and chlorophyll-a conditions could however be improved to a C category, i.e. ≤ 0.091 mg/L and 25 – 260 mg/m^2 respectively, by improved management practices.

Table 5.4 Quality ecospecs for IFR 4

IFR 4: Recommended water quality component of the ERC – C or Upper Fair category

PES for water quality: C or Upper Fair category

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	7 and 8	**RC**	No reference condition data
IFR number	4	**PES**	Collected water quality data, site 5
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		C	28 mg/L
Na_2SO_4		C	38 mg/L
$MgCl_2$		A	15 mg/L
$CaCl_2$		B	57 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		D	≤ 0.091 mg/L
TIN		D	≤ 4 mg/L
Chl-a: phytoplankton		A	(natural) < 10 µg/L
Chl-a: periphyton		-	(fair) 25-260 mg/m^2
Biotic community composition		B/C	(good) ASPT = 6
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Table 5.5 Quality ecospecs for IFR 5

IFR 5: Recommended water quality component of the ERC – B/C or Lower Good category

PES for water quality: B/C or Lower Good category

River	Bushmans River	**DWAF Water Quality Monitoring points**	
QRU	17	**RC**	V7H020 (1997- 2001)
IFR number	5	**PES**	V7H012 (1996 – 2001)

Water Quality Constituents	**Present state**	**Quality ecospecs**
$MgSO_4$	C	28 mg/L
Na_2SO_4	A	20 mg/L
$MgCl_2$	B	30 mg/L
$CaCl_2$	A	21 mg/L
NaCl	A	45 mg/L
$CaSO_4$	A	351 mg/L
SRP	C	≤ 0.058 mg/L
TIN	A/B	≤ 0.5 mg/L
Chl-a: phytoplankton	-	(good) 10 – 20 µg/L
Chl-a: periphyton	-	(good) 3-25 mg/m^2
Biotic community composition	C	(good) ASPT = 6
Dissolved oxygen	-	(good) 6 mg/L
pH *	-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *	-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Note: source-directed controls of Estcourt's sewage effluent (of which a large proportion is industrial), is recommended, as data confidence is low and conditions may move into a C category during the dry season.

Table 5.6 Quality ecospecs for IFR 7

IFR 7: Recommended water quality component of the ERC – B/C or Lower Good category

PES for water quality: C or Upper Fair category

River	Sundays River	**DWAF Water Quality Monitoring points**	
QRU	20	**RC**	V6H006 (1976 – 1978)
IFR number	7	**PES**	V6H004 (1996 – 1999)

Water Quality Constituents	**Present state**	**Quality ecospecs**
$MgSO_4$	E/F	D: 37 mg/L #
Na_2SO_4	C	B: 38 mg/L #
$MgCl_2$	A	15 mg/L
$CaCl_2$	A	21 mg/L
NaCl	A	45 mg/L
$CaSO_4$	A	351 mg/L
SRP	C/D	C: ≤ 0.058 mg/L #
TIN	B	≤ 0.75 mg/L
Chl-a: phytoplankton	-	(good) 10 – 20 µg/L
Chl-a: periphyton	-	(fair) 25 - 260 mg/m^2
Biotic community composition	C	(good) ASPT = 6
Dissolved oxygen	-	(good) 6 mg/L
pH *	-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *	-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

\# source-directed controls of mining activities in the area, and improved land practices to reduce overgrazing and erosion, will be required.

Table 5.7 Quality ecospecs for IFR 8

IFR 8: Recommended water quality component of the ERC – C or Upper Fair category

PES for water quality: C or Upper Fair category

River	Sundays River	**DWAF Water Quality Monitoring points**	
QRU	21	**RC**	V6H006 (1976 – 1978)
IFR number	8	**PES**	Collected water quality data, site 3

Water Quality Constituents	**Present state**	**Quality ecospecs**
$MgSO_4$	E/F	D: 37 mg/L #
Na_2SO_4	C	38 mg/L
$MgCl_2$	A	15 mg/L
$CaCl_2$	B	57 mg/L
NaCl	A	45 mg/L
$CaSO_4$	A	351 mg/L
SRP	A	≤ 0.005 mg/L
TIN	A	≤ 0.5 mg/L
Chl-a: phytoplankton	A	(natural) < 10 µg/L
Chl-a: periphyton	E/F	(fair) 25 - 260 mg/m^2 #
Biotic community composition	B/C	(good) ASPT = 6
Dissolved oxygen	-	(good) 6 mg/L
pH *	-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *	-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

\# source-directed controls of mining and poor land-use practices in the Wasbank catchment area will be required. As this site is below the confluence with the Wasbank River, source-directed controls will reduce threats to the Sundays River system, particularly at times of low flow. Data confidence is however low.

Table 5.8 Quality ecospecs for IFR 9

IFR 9: Recommended water quality component of the ERC – B/C or Lower Good category

PES for water quality: B/C or Lower Good category

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	9 and 10	**RC**	V6H002 (1977 – 1979)
IFR number	9	**PES**	V6H002 (1998 – 2000)

Water Quality Constituents	**Present state**	**Quality ecospecs**
$MgSO_4$	D	37 mg/L
Na_2SO_4	A	20 mg/L
$MgCl_2$	C	36 mg/L
$CaCl_2$	A	21 mg/L
NaCl	A	45 mg/L
$CaSO_4$	A	351 mg/L
SRP	C	≤ 0.058 mg/L
TIN	A	≤ 0.5 mg/L
Chl-a: phytoplankton	-	(good) 10 – 20 µg/L
Chl-a: periphyton	-	(good) 3-25 mg/m^2
Biotic community composition	C	(good) ASPT = 6
Dissolved oxygen	-	(good) 6 mg/L
pH *	-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *	-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Note: Elevated Mg levels may be an error (see Section 4.4.2, IFR 9), as a cause could not be isolated.

Table 5.9 Quality ecospecs for IFRs 10 and 11

<u>IFRs 10 + 11:</u> Recommended water quality component of the ERC – B or Good category

Note: This assessment reverts to Table 3.19, i.e. RUs S and T, which include IFR sites 10 and 11. The modeling undertaken for IFR 10 used data from a monitoring point closer to the IFR site (V2H005 for RC and present state), while the present state assessment refers to the resource units, rather than a single point. IFR 11 (Section 4.4.2) refers to a point below the gorge, where water quality has improved (category A/B), but is not representative of conditions in the reach.

PES for water quality: B or Good category

River	Mooi River	**DWAF Water Quality Monitoring points**	
QRU	23	**RC**	V2H005 (1977 – 1982)
IFR number	10 + 11	**PES**	V2H002 (1996 – 2000)
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		A	16 mg/L
Na_2SO_4		A	20 mg/L
$MgCl_2$		A	15 mg/L
$CaCl_2$		A	21 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		C	≤ 0.058 mg/L
TIN		A/B	≤ 0.5 mg/L
Chl-a: phytoplankton		-	(natural) < 10 µg/L
Chl-a: periphyton		-	(fair) 25-260 mg/m^2
Biotic community composition		B – B/C	(good) ASPT = 6
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Note: Chlorophyll-a conditions are a concern further downstream at Sierra Ranch (category E/F for periphyton) and should be improved to a C category, i.e. 25 – 260 mg/m^2, by improved management practices. Improved land practices would also serve to improve SRP conditions at this site.

Table 5.10 Quality ecospecs for IFR 13

IFR 13: Recommended water quality component of the ERC – C or Upper Fair category

PES for water quality: D or Lower Fair category

River	Buffalo River	**DWAF Water Quality Monitoring points**	
QRU	25	**RC**	No Reference Condition data
IFR number	13	**PES**	V3H010 (1997 – 2000)
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		E/F	C: 28 mg/L #
Na_2SO_4		E/F	C: 38 mg/L #
$MgCl_2$		A	15 mg/L
$CaCl_2$		B	57 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		E/F	C/D: ≤ 0.091 mg/L #
TIN		D	C: ≤ 2 mg/L #
Chl-a: phytoplankton		-	(good) < 10 - 20 µg/L
Chl-a: periphyton		-	(fair) 25 – 260 mg/m^2 #
Biotic community composition		C/D	(fair) ASPT = 5
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.
\# source-directed controls, particularly on acid mine drainage and sewage disposal, will be required.

Table 5.11 Quality ecospecs for IFR 14

IFR 14: Recommended water quality component of the ERC – C or Upper Fair category

PES for water quality: C/D or Fair category

River	Buffalo River	**DWAF Water Quality Monitoring points**	
QRU	26	**RC**	V3H011 (1975 – 1979)
IFR number	14	**PES**	Collected water quality data, site 2
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		E/F	C: 28 mg/L #
Na_2SO_4		C	B: 33 mg/L #
$MgCl_2$		B	30 mg/L
$CaCl_2$		B	57 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		E/F	C/D: ≤ 0.091 mg/L #
TIN		D	C; ≤ 2 mg/L #
Chl-a: phytoplankton		A	(natural) < 10 µg/L
Chl-a: periphyton		E/F	(fair) 25 – 260 mg/m^2
Biotic community composition		B	(good) ASPT = 6
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.
\# source-directed controls of mining and industrial activities in the upper catchment and improved land practices will be required. Data confidence is low.

Table 5.12 Quality ecospecs for IFR 15

IFR 15: Recommended water quality component of the ERC – B/C or Lower Good category

PES for water quality: B/C or Lower Good category

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	11 and 12	**RC**	No reference condition data
IFR number	15	**PES**	Collected water quality data, site 1
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		D	37 mg/L
Na_2SO_4		A	20 mg/L
$MgCl_2$		B	30 mg/L
$CaCl_2$		A	21 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		C	≤ 0.058 mg/L
TIN		B	≤ 0.75 mg/L
Chl-a: phytoplankton		A	(natural) < 10 µg/L
Chl-a: periphyton		C/D	(fair) 25-260 mg/m^2
Biotic community composition		B	(good) ASPT = 6
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

Note: Data confidence is low. Note that elevated Mg levels may be an error (see Section 4.4.2, IFR 15), as a cause could not be isolated.

Table 5.13 Quality ecospecs for IFR 16

IFR 16: Recommended water quality component of the ERC – C or Upper Fair category

PES for water quality: C or Upper Fair category

River	Thukela River	**DWAF Water Quality Monitoring points**	
QRU	25	**RC**	V5H002 (1977 – 1982)
IFR number	16	**PES**	V5H002 (1996 – 2001)
Water Quality Constituents		**Present state**	**Quality ecospecs**
$MgSO_4$		E/F	D: 37 mg/L #
Na_2SO_4		A	20 mg/L
$MgCl_2$		C	B: 30 mg/L #
$CaCl_2$		A	57 mg/L
NaCl		A	45 mg/L
$CaSO_4$		A	351 mg/L
SRP		C/D	≤ 0.091 mg/L
TIN		A/B	≤ 0.5 mg/L
Chl-a: phytoplankton		A	(natural) < 10 µg/L
Chl-a: periphyton		C	(fair) 25 – 260 mg/m^2
Biotic community composition		C	(fair) ASPT = 5
Dissolved oxygen		-	(good) 6 mg/L
pH *		-	(good) 6.5 – 8.0
Toxic substances (e.g. heavy metals, and including ammonia) *		-	(good) 95% species protection based on 95% CEV (DWAF, 1996)

* method incomplete.

\# source-directed controls, and improved land practices will be required.

6 CONCLUSION

This document reports on the water quality status of the Thukela River catchment assessed during the TWP Reserve study. Water quality is generally not the driver of the overall ecostatus of rivers in the study area, as parameters such as geomorphology and the status of the riparian vegetation are more instrumental in determining the health of the river. Water quality is generally good, with a number of areas of concern. The mining and industrial activities in the upper catchments of the Sundays and Buffalo rivers and their tributaries, result in high levels of salinity (sulphate-based salinity, which has more impact on aquatic biota than sodium-based salinity) along the length of the rivers, particularly the Buffalo River. The Lower Buffalo River is affected as salts are not broken down biologically but move through the system until they are flushed out. Nutrient enrichment is also evident at various sites in the catchment, with most systems being periphyton-dominated. The industrial centre of Mandini-Sundumbili is of particular importance as in-stream water quality data does not reflect the poor biological conditions known to occur in this area.

Source-directed controls of both industrial and mining activities, and improved land-use management to reduce enrichment of water systems and to prevent land degradation, are vital to effective water resource management in the Thukela catchment. In-stream flows were therefore never recommended by this study to dilute wastes or to address anthropogenic impacts.

The Thukela water quality study proved to be problematical as it took place during the development of new water quality methods. The study was initiated using a particular process (referred to as Approach 1 in the text), primarily based on the water quality methods of the RDM documents released in 1999, while revised methods became available during the study. An attempt was made to use best available methods, and upon a directive from DWAF: Scientific Services, Approach 2 (based on documents released in 2002) was followed. A number of problems were encountered, and a comparison of the methods is detailed in Appendix A. Although modelling and toxicological information are not required by the revised water quality approach (DWAF, 2002a), both these tools proved to be valuable during the Thukela study.

It is hoped that the application and use of untested methods midway during a Reserve study, with the associated problems and potential legal ramifications, will provide a valuable lesson for future Reserve studies, particularly in the field of water quality. It is vital that the new directorate formed to oversee and direct Reserve studies, D: Resource Directed Measures, perform a vital liaison and communication role in method development.

The Thukela study has therefore proved to be an opportunity to assess whether the information provided by the revised water quality methods is of value to the RDM Directorate of DWAF for the issuing of licenses. Liaison with the department is currently underway to ensure that the information produced by a water quality Reserve assessment is of use to management. The primary focus of the study is, however, to provide ecological specifications for water quality, linked to Ecological Reserve categories set for each site. This link will ensure the integrated nature of quality and quantity, and the concurrent management of these parameters.

7 REFERENCES

Archibald A. (1996) Tugela estuarine flow requirement workshop. CSIR (KwaZulu-Natal). CSIR project no. JEA02/010/19960601.

Coke M. (2001) Reserve Determination Module: Present state report – Appendix E: Fish. ERC workshop, October / November 2001.

Department of Water Affairs and Forestry (1994) Vaal augmentation planning study: Tugela-Vaal transfer scheme: Water quality. DWAF Report No. PC 000/00/12894. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (1996) South African water quality guidelines. Second edition, Volume 7: Aquatic ecosystems. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (1999a) Resource directed measures for protection of water resources. Volume 3: River ecosystems, Version 1.0. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (1999b) Water quality situation assessment: Wasbank River catchment. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (2000a) Water Quality: Olifants River ecological water requirements assessment. Draft report prepared by Palmer, CG and Rossouw, N. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (2000b) A protocol for acute toxicity testing using selected riverine invertebrates in artificial stream systems. Version 1.0. Produced by Scherman P-A, Palmer CG, Centre for Aquatic Toxicology, Institute for Water Research, Rhodes University, Grahamstown, for DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (2001) Operating rules report: First draft. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (2002a) Assessing water quality in ecological reserve determinations for rivers: Version 2, Draft 15.0, March 2002. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Department of Water Affairs and Forestry (2002b) Hazard-based water quality ecospecs for the ecological reserve in fresh surface water resources. A technical support document to the Ecological Water Quality Reserve. First Draft, First Edition, August 2002. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Dickens C. and Bokwe T. (2002) Reserve Determination Module: Present state report - Macroinvertebrates. ERC workshop, October / November 2001.

Department of Water Affairs and Forestry, South Africa. 2003a. DWAF Report No. PB V000-00-10302. Resource Unit Report - Reserve Determination Study - Thukela River System. Prepared by IWR Source-to-Sea as part of the Thukela Water Project Decision Support Phase.

Department of Water Affairs and Forestry, South Africa. 2003b. DWAF Report No. PB V000-00-10303. Ecological Reserve Category Report - Reserve Determination Study - Thukela River System. Prepared by IWR Source-to-Sea as part of the Thukela Water Project Decision Support Phase.

Department of Water Affairs and Forestry, South Africa. 2004. DWAF Report No. PB V000-00-10309. Thukela System Ecological Scenario Report - Reserve Determination Study - Thukela River System. Prepared by IWR Source-to-Sea as part of the Thukela Water Project Decision Support Phase

Du Toit A. (*pers. comm.*) Consulting Engineer, WRP Consulting Engineers, PO Box 564, Pietermaritzburg 3245, South Africa.

EWQRCalc Version 2.3 (2002). A model developed by Dr Sebastian Jooste (RQS, DWAF) to calculate salt concentrations from ion data; the model is only available from Dr Jooste.

Hughes D. (*pers. comm.*) Hydrologist, Institute for Water Research, Rhodes University, PO Box 94, Grahamstown 6140, South Africa.

Hughes D. A., Forsyth D. and Watkins D. A. (2000) An integrated software package for the analysis and display of hydrological or water resources time series data. WRC Report No. 867/2/00. Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

Jooste S. (*pers. comm.*) Scientist, Resource Quality Services (previously Institute for Water Quality Studies), DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Louw D. (*pers. comm.*) Technical Manager, Thukela Water Project: Reserve determination module, IWR Source-to-Sea, PO Box 122, Persequor Park 0020, South Africa.

Malan H. L. and Day J. A. (2002a) Development of numerical methods for predicting relationships between stream flow, water quality and biotic responses in rivers. WRC Report No. 956/1/02. Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

Malan H. L. and Day J. A. (2002b) Linking discharge, water quality and biotic responses in rivers: a literature review. WRC Report No. 956/2/02. Water Research Commission, PO Box 824, Pretoria 0001, South Africa.

Malan H. L., Bath A., Day J. and Joubert A. (2003) A simple flow-concentration modelling method for integrating water quality and water quantity in rivers. Water SA 29 (3).

O'Keeffe, J., Hughes D., Tharme, R. (2002) Linking ecological responses to altered flows, for use in environmental flow assessment: the flow stressor-response method. Verh. Internat. Verein. Limnol. 28: 84-92.

Palmer C. G. and Scherman P-A. (2000) Application of an artificial stream system to investigate the water quality tolerances of indigenous, South African, riverine invertebrates. WRC Report No. 686/1/00. Water Research Commission, PO Box 824, Pretoria, South Africa.

Palmer C. G. and Rossouw J. N. (2001) Olifants river ecological water requirements assessment: Water quality. DWAF Report No. PB 000-00-5999. DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Radloff S. (*pers. comm.*) Professor and Head of Statistics Department, Rhodes University, PO Box 94, Grahamstown 6140, South Africa.

Ramkooar S. (*pers. comm.*) Chemist, Tugela Mill, Sappi Kraft, Private Bag x6034, Mandeni 4490, South Africa.

Scherman P-A., Muller W. J. and Palmer C. G. (2003) Links between ecotoxicology, biomonitoring and water chemistry in the integration of water quality into environmental flow assessments. River Research and Applications 19:1-11.

Taljaard S. (*pers. comm.*) Scientist, CSIR, PO Box 320, Stellenbosch 7599, South Africa.

Thirion C. (*pers. comm.*) Scientist, Resource Quality Services (previously Institute for Water Quality Services), DWAF, Pvt Bag X313, Pretoria 0001, South Africa.

Tlou and Matji, and WRP Consulting Engineers (2002) Eastern Region Internal Strategic Perspective. Thukela Water Management Area. Starter document, September 2002.

USEPA (1991) Methods for measuring the acute toxicity of effluent and receiving waters to freshwater and marine organisms. EPA 600/4-90/027.

Wadeson R. (*pers. comm.*) Environmental Consultant, Postnet Suite 79, Private Bag x9118, Pietermaritzburg 3200, South Africa.