THUKELA WATER PROJECT DECISION SUPPORT PHASE

RESERVE DETERMINATION MODULE
MAIN REPORT

March 2004

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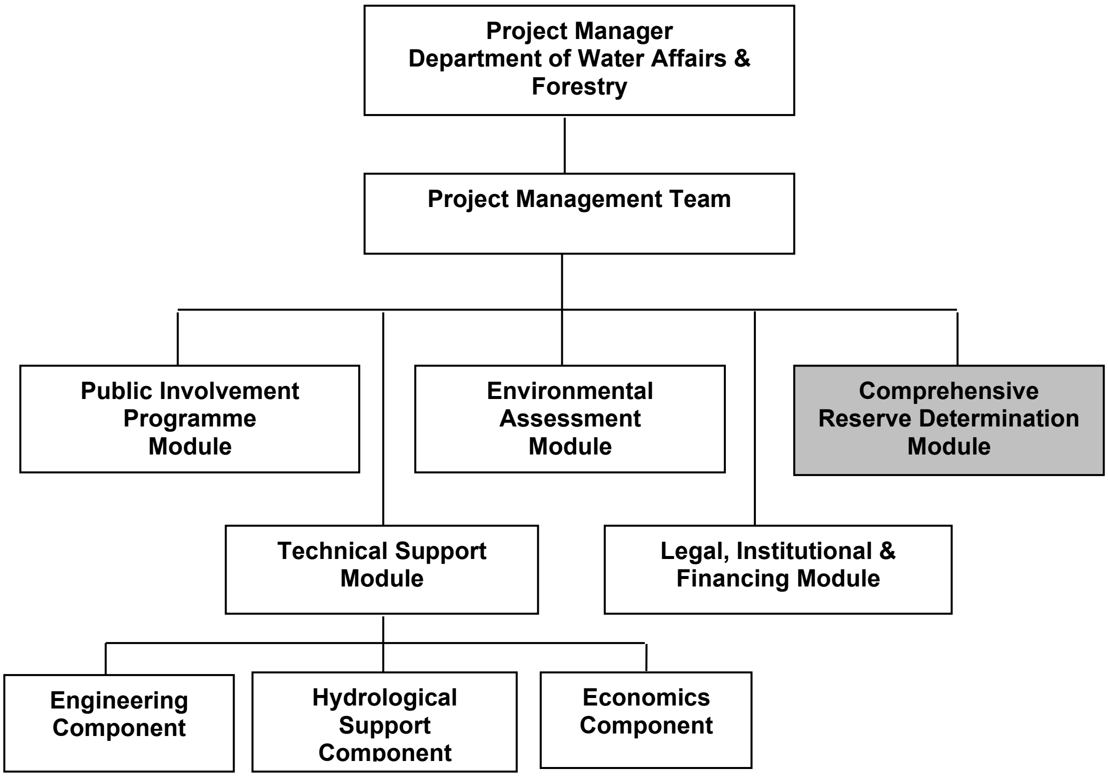
STRUCTURE OF DECISION SUPPORT PHASE



DEPARTMENT OF WATER AFFAIRS & FORESTRY
NATIONAL WATER RESOURCE PLANNING

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

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

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EXECUTIVE SUMMARY

BACKGROUND

The Thukela Reserve Study was initiated in the year 2001 with a view to supporting the then imminent implementation of the Thukela Water Project (TWP). The TWP was at that stage the most likely option to be constructed to augment water supplies to the Vaal River System by 2011. It was later found that water requirement projections in the Vaal River System were not being realised as previously expected and work on preparing the TWP for implementation was slowed down accordingly. Despite this change, the Department: Water Affairs and Forestry (DWAF) decided to complete the Ecological Reserve Determination in the Thukela River Catchment.

OBJECTIVES

This report serves as a summary of the Thukela Reserve Determination study. Each of the specialist reports are summarised according to methods used and results. The findings emphasise the impacts that the selected flow regime scenarios are expected to have on the broader environment in the Thukela River Basin. A recommendation is made regarding, what is believed to be, the most acceptable Ecological Reserve flow regime.

The major objectives of the Thukela Reserve Study were to:

- Generate a set of Ecological Reserve flow scenarios and test these scenarios.
- Determine the impact of the scenarios on the available yield.
- Determine the impact of the scenarios on the aquatic ecology.
- Determine the economic impact of selected scenarios. This included an evaluation of the impact on the Thukela Marine Bank.
- Determine the impact of selected scenarios on the goods and services delivered by the riverine system.

STUDY APPROACH

The study commenced during March 2001 and will continue until December 2003. The project is within the brief (as amended from time to time), on budget and on time.

The Reserve Determination study is comprised of a number of interrelated studies and modules.

Basic Human Needs Reserve (BHNR)

The BHNR component used demographic information to derive recommendations. Central to this process was the estimation of the population living within a 5km buffer, which were regarded as being primarily dependent on run of river for their water supplies. It was recommended that an amount of 60 litres per capita per day constitute the BHNR. This is close to that which was estimated to be abstracted from groundwater for those not proximate to the river, and was deemed sufficient to allow for all basic needs as defined in the *National Water Act* (NWA), 1998. This volume would also allow some water for uses such as minor subsistence irrigation of vegetables and other crops. A volume of 16.55 million cubic metres per annum is currently required from the river for the BHNR. This increases to just under 20 million cubic metres per annum in the year 2015, which is still a small component of the total Mean Annual Runoff of the river of around 3800 million cubic metres per annum.

Groundwater

Groundwater was addressed at a scoping level only and a recommendation and Terms of reference for future work was made.

ECOLOGICAL RESERVE

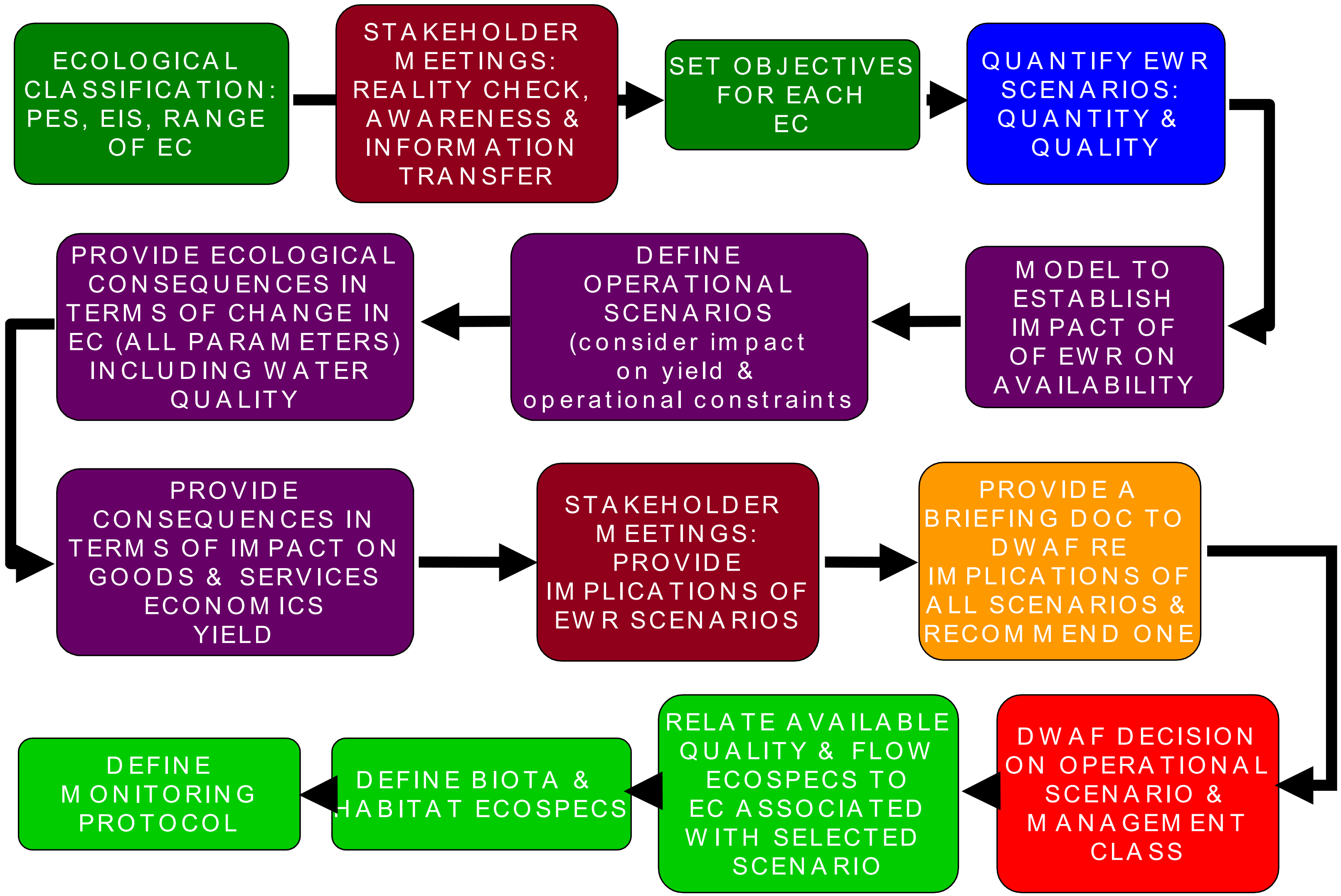
The determination of the ecological component of the Thukela Reserve Study was a sequential process, consistent with the Resource Directed Measures (RDM) protocols (see Figure on page v for a process diagram). The initial task was the delineation of the study area (Thukela and its major tributaries) into Resource Units (RUs) and the estuary. The RUs were then examined by specialists and determined a reference condition for each unit and the estuary, as well as the Present Ecological State (PES). The specialists suggested Ecological Categories (EC) (termed Ecological Reserve Category during the course of the study) for each of the RUs. Once the PES and EC were determined the Thukela Reserve Determination team set about developing flow scenarios at specific sites on the river called Instream Flow Requirement (IFR) sites. Please see second Figure (page vi) attached for the location of these sites in the Thukela River Basin.

Scenarios are alternative possible flow regimes which will result in different river states (Ecological Categories) at any IFR site. It was deemed important to consider the full range of implications of these scenarios on the broader social and ecological environment. An optimised scenario which would have minimal impact on water users and the ecology, was devised. Each of these scenarios was also tested to determine their effect on water quality and the overall resulting state of the river and estuary.

In summary, the process included the following steps and results: (Chapter 9)

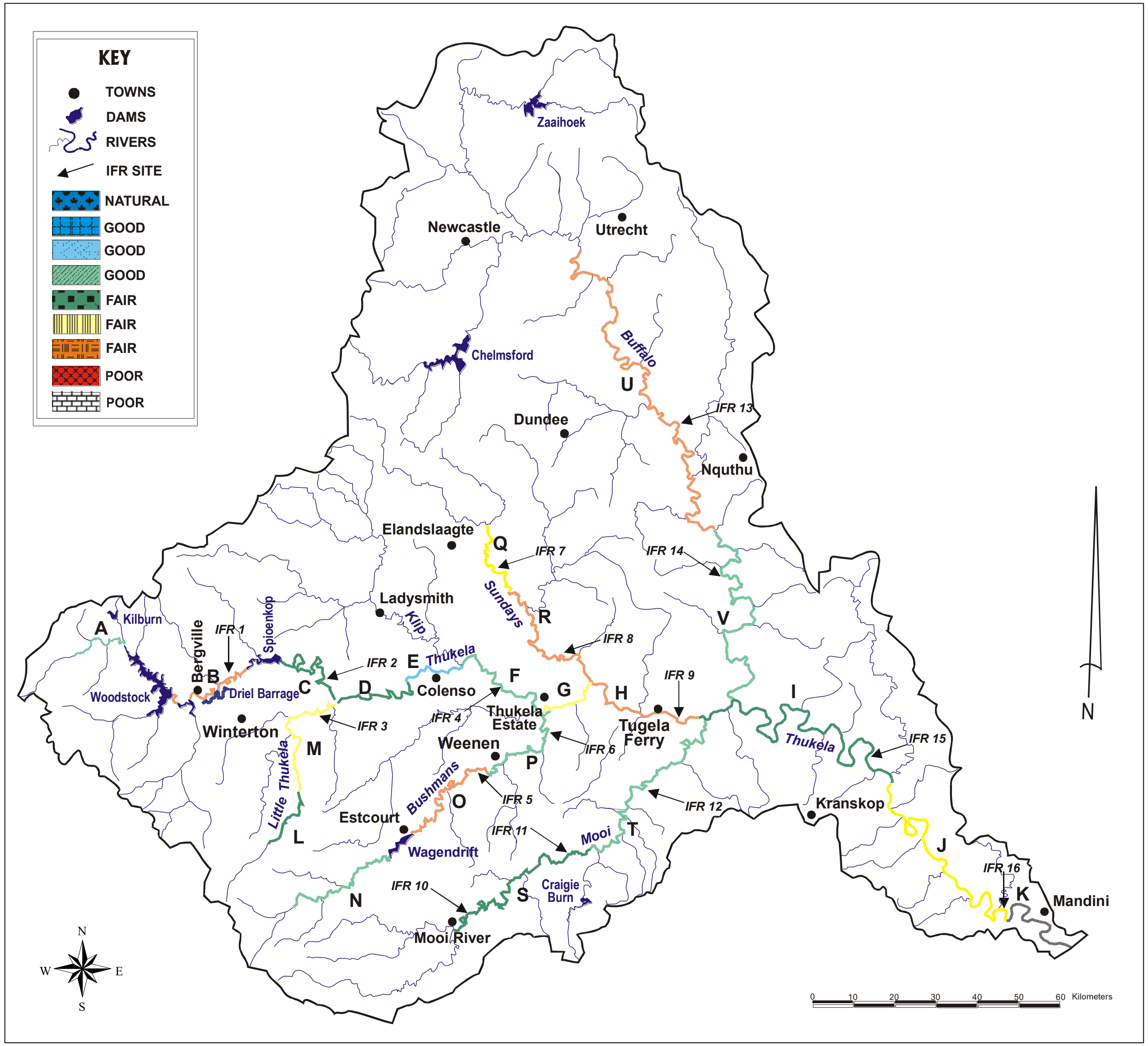
- The Water Resources Yield Model (WRYM) was run using three IFR scenarios to achieve:
  - The recommended EC (Scenario 2),
  - an EC higher than that suggested (Scenario 1), and
  - one that would result in an EC lower than that suggested by the specialists (Scenario 3).
- The results of the modelling indicated that the three scenarios would result in a range of impacts on the yield of the water resource and would have impacts on the water users in the Thukela River Catchment.
- A review and optimisation of the IFR scenario assumptions and the practical operation of river system was undertaken, and Scenarios 4, 5 and 6 were devised.

Diagram illustrating the sequential nature of the process followed for the Thukela Reserve Study

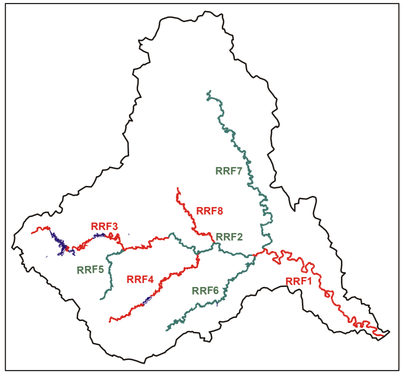


Study area

MAP OF THE STUDY AREA



Study area map



- The WRYM model was again run using the new scenarios.
- An evaluation of the ecological and yield impacts indicated that Scenario 5 had minimal ecological impacts and Scenario 6 had minimal impacts on the yield. The specialists optimised the proposed ecological water requirement flow regime (especially flood requirements), and another iteration was entered into, which resulted in the formulation of a ninth scenario.
- Scenarios 7 and 8 were described as baselines (i.e. current and future conditions with absolutely no IFRs supplied), against which all the other scenarios could be compared.
- Scenario 9 was then evaluated in detail. This scenario used Scenario 6 input for areas where there were no ecological problems, and Scenario 5 where the EC was not being met when Scenario 6 was applied. The flooding regime was also checked and optimised.

MODELLING RESULTS

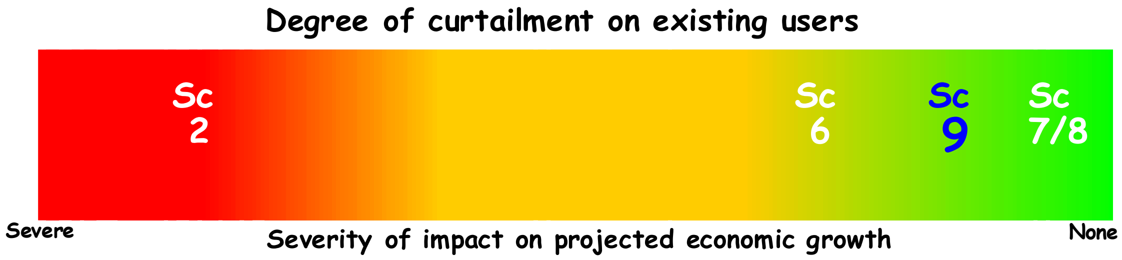
Yield modelling results indicated that water users in the Bushmans and Buffalo River catchments are the only ones that will not be impacted under all the Ecological Reserve scenarios from 2 to 9. Under Scenario 2, there would be curtailments in water supplies to water users, even some severe reductions in the level of assurance of supply, in all of the remaining sub-catchments in the Thukela River System. Scenario 6 has a slightly diminished impact on water availability, but is still not free of unacceptable impacts on water users in certain areas. Scenario 9 proved to have a relatively small impact on the Tugela-Vaal transfer, with slightly larger impacts on the users in the Little Thukela and Sundays River systems. Both rivers are uncontrolled and water use is more than the sustainable water resource availability.

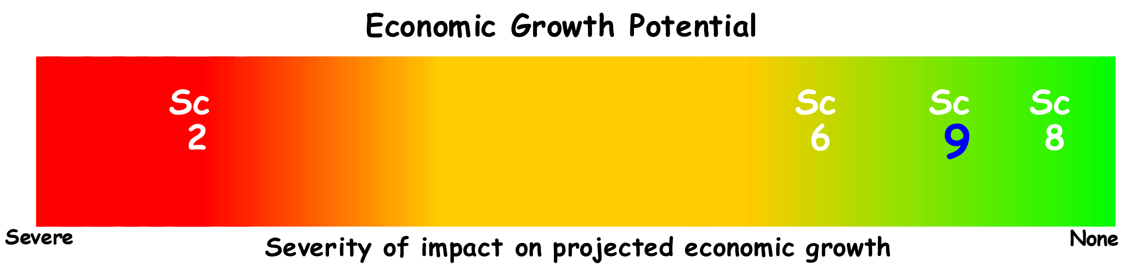
CONTEXT OF IMPACTS ON WATER USERS

In order to provide a broader suite of contextual information and to aid the decision- making process, a set of studies aimed at determining the economic impacts of the scenarios was undertaken. This had three major components:

- Goods and Services: A set of Goods and Services at a subsistence level are provided by the riverine system to local inhabitants. Economists and ecologists examined the critical goods and services provided by the river and examined the direction of change (either positive or negative) associated with scenarios and estimated the magnitude of the change in benefits and costs that may be experienced within the Thukela catchment under the relevant scenario.
- A second more 'traditional' market economic study attached values to the various sectors of the regional economy and looked at the impact of each of the scenarios on each of these sectors within each sub-catchment.
- The economic impact of different flow scenarios on the Thukela Marine Bank was examined by evaluating the link between flow and reported commercial catches of prawns and key fish species. The impact of a number of the scenarios on the value of the catches was estimated.

RESULTS
The following traffic light diagrams show the relative impacts of each scenario against the criteria components considered. Note that red illustrates an unacceptable situation for ecology and green an acceptable condition. The scale refers to the number of IFR sites.





PUBLIC INVOLVEMENT
In addition to the study criteria listed above, a robust Public Involvement Programme (PIP) supported the Thukela Reserve Determination Study. The process was designed to ensure that representatives of relevant stakeholders are adequately consulted in evaluating the various scenarios and in the selection of a Reserve for the future management of the Thukela system. There have been a series of structured and well documented interactions with the stakeholders. These have included the following:

- First round of eight River Reach Forum (RRF) meetings in eight parts of the Thukela River Basin. These were open public forums where people were thoroughly informed regarding the Reserve Determination process. This empowerment to participate in the Reserve Study also included field visits to the Thukela River.
- Second round of River Reach Forum meetings.

- First Stakeholder Reference Group (SRG) Meeting in Ladysmith. This forum was made up of elected representatives of the RRF's. Information provided at the SRG meeting was conveyed back to stakeholders via public newsletters.
- Second Stakeholder Reference Group Meeting to present preliminary results.
- Third Stakeholder Reference Group Meeting to present the recommendations contained in this document.

PIP team representatives stationed in Ladysmith and Mtunzini regularly visited key roleplayers to keep them informed of progress on the study. These team members also responded to queries raised by stakeholders during the course of the study.

RESERVE RECOMMENDATION

After consideration of the original scenarios, and bearing in mind the aim of recommending a Reserve flow regime to DWAF, it became apparent that it was possible to develop a scenario that both optimised flow requirements for sustainability of the resource and had the least potential impact on all sectors.

Scenario 9 appears to achieve a compromise between satisfying all in-basin user meeting. most ecological objectives and causing the least negative impact on the economy of the area and on the delivery of riverine Goods and Services.

The recommendation is that Scenario 9 and the resulting Ecological Categories at each IFR site and the estuary be accepted as a Preliminary Reserve and as the basis for future planning. The evaluation of a Reserve for a water abstraction licence at any point in the Thukela River System can now be determined by extrapolating the flow regime up or downstream from an existing IFR site.

ECOSPECS AND MONITORING

The last task within this study was to specify the Ecospecs (the ecological component of Resource Quality Objectives) and to provide a monitoring programme to measure compliance of the relevant Ecological Category. The monitoring programme consists of a baseline phase (one year) as well as a long term phase (5 years). The monitoring programme was designed during a specialist meetings and the results documented. The information should allow for DWAF to plan and budget for monitoring. Very broad estimates of cost for the baseline phase for both the river and the estuary is R1.3 million and for one year of the long-term monitoring, R530 000.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AEAM	Adaptive Environmental Assessment
AEV	Acute Effected Values
ASPT	Average Score Per Taxon
BBM	Building Block Methodology
BHNR	Basic Human Needs Reserve
BIODSS	Compliance Biomonitoring Decision Support System
BMDSS	Baseline Monitoring Decision Support System
CEV	Chronic Effected Values
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EA	Enumerator Area
EC	Ecological Category
Ecospec	Ecological specification
EIS	Ecological Importance and Sensitivity
EHI	Estuarine Health Index
ERC	Ecological Reserve Category
EWR	Ecological Water Requirements
FAII	Fish Assemblage Integrity Index
FS-R	Flow Stressor Response
GGP	Gross Geographic Product
HDI	Historically Disadvantaged Individual
HIS	Hydrological Information System
IFR	Instream Flow Requirement
KZN	KwaZulu Natal
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
MSL	Mean Sea Level
NWA	National Water Act
PES	Present Ecological State
Q-C	Concentration discharge
QRU	Quality Resource Unit
RC	Reference condition
RD	Reserve Determination
RDM	Resource Directed Measures
RDP	Reconstruction and Development Programme
REC	Recommended Reserve Category
RQO	Resource Quality Objective
RRF	River Reach Forum
RU	Resource Units
Sc	Scenario
SCM	Source Control Measures
SI	Socio/Cultural Importance
SRG	Stakeholder Reference Group
SRP	Soluble Reactive Phosphorous
TDS	Total Dissolved Solids
TIN	Total Inorganic Nitrogen
TOR	Terms of Reference
TPC	Threshold of potential concern
TSOFT	Time Series Delay and Analysis Software
TWPDSP	Thukela Water Project Decision Support Phase
TWP	Thukela Water Project
TWQR	Target Water Quality Ranges
VAPS	Vaal Augmentation Planning Study
WMA	Water Management Area

WRYM	Water Resources Yield Model

CPUE	Catch per Unit Effort
DEAT	Department of Environmental Affairs and Tourism
EI	Emigration Index
GGP	Gross Geographic Product
GLM	General Linear Model
KZN	KwaZulu-Natal
MCM	Marine and Coastal Management
MER	Marine and Estuarine Research
NI	Nursery Index
NMLS	National Marine Linefish System
NUTIA	Nutrient Index of the Adult stage
NUTIL	Nutrient Index of the Larval stage
PMT	Project Management Team
RI	Recruitment Index
TWPDSP	Thukela Water Project Decision Support Phase
WRYM	Water Resources Yield Model
WRP	Water Resource Planning

LIST OF OLD AND NEW RESERVE TERMINOLOGY

TERMINOLOGY: EXPLANATIONS AND CHANGES

Below follows explanations of the terms used in the document. Please note that some of the terms have changed following a DWAF workshop during April 2003. All new terms are in bold. Note that the Thukela reports consist of old terms.

PRESENT ECOLOGICAL STATE (PES):
The term remains unchanged.

INSTREAM FLOW REQUIREMENTS (IFR):
Also referred to as the "ecological flow component of the Reserve". The flow patterns (magnitude, timing and duration) required to maintain a riverine ecosystem in a particular condition. This term was specifically used for rivers only**.**

ECOLOGICAL WATER REQUIREMENTS (EWR):
This term should now be more widely used for both rivers and estuaries when one is referring to both quantity and quality requirements. When one only refers to rivers quantity, the term IFR can still be used.

NOTE: AT NO STAGE DURING THE PROCESS DOES ONE REFER TO AS THE RESERVE. THIS IS A SCENARIO BASED APPROACH AND ONLY WHEN A DECISION IS MADE ON WHICH SCENARIO WILL BE ACCEPTED BY DWAF, CAN ONE REFER TO THE RESERVE

ECOLOGICAL RESERVE CATEGORY (ERC):.
This referred to the range of possible states in which the river could be and still be deemed sustainable at different levels. One of those categories were referred to as the Recommended ERC which will be the category recommended based on ecological factors.

ECOLOGICAL CATEGORY (EC):
This term replaces the term ERC which was incorrect as it refers to a Reserve which has not yet been determined at the stage when one is using the term. One of the range of ECs selected will still be referred to as the Recommended option (from an ecological viewpoint).

ECOLOGICAL RESERVE SCENARIOS:
This term referred to different IFRs determined for different ERCs, i.e. the different flow requirements required to maintain the river in different ecological states.

ECOLOGICAL WATER REQUIREMENT SCENARIOS (EWRS):
This term has the same meaning as above but is now relevant for different EWRs determined for different ECs.

OPERATIONAL SCENARIOS:
Remains an unchanged term. This term refers to scenarios devised when constratins such as the availability of water, impact on the users, size of outlets are also considered.

OTHER TERMS

Assurance	Percentage of time at which a flow is equalled or exceeded.
ASPT	Average Score per Taxon. A derived variable used in invertebrate biomonitoring. Calculated by dividing the SASS4 Score by the number of SASS4 taxa.
Biota	A collective term for all the organisms (plants, animals, fungi and bacteria) in an ecosystem.
Biotope	The place in which a certain assemblage of organisms live.
Benthic	Bottom-dwelling biota. (See biota.)
Biomonitoring	The use of biota to assess the ecological "health" of an area. Biomonitoring is used by the Department of Water Affairs and Forestry in the National Rivers Health Programme.
Drought flow	The minimum flow required to facilitate the survival of the riverine ecosystem in a particular condition, and over short, infrequent periods when users are subject to water restrictions. (See MAINTENANCE FLOW.)
Ecospecs	The ecological component of RQO. The quantity and quality components of the Ecospecs component of RQO can be, but are not necessarily the same as the Reserve. The requirements of the other components of RQO could override the Reserve Requirements and in those cases, the results will be different.
EIS	Ecological Importance and Sensitivity. The ecological importance of a river is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity (DWAF, 1999 - Volume 3).
Embeddedness	Closely enclosed, as if in a matrix (e.g. pebbles embedded in silt).
Endemic	Occurring in a specified locality, not introduced.
Freshet	Flow pulse.
Habitat	The place in which a plant or animal lives. (See BIOTOPE.)
Habitat Integrity	The maintenance of an integrated composition of physicochemical and habitat characteristics on a temporal and spatial scale that is comparable to the characteristics of natural habitats of the region.
Invertebrate	An animal without a backbone - includes insects, snails, sponges, worms, crabs and shrimps.
Low Flow	The low flow component of the flow regime, determined graphically from time series of flows.

Maintenance flow — The flow required to meet the requirements of the riverine ecosystem at a particular site and maintain the resource base in a particular condition, or Ecological Class, during "normal" climatic years, as opposed to during "drought" years. The distinction between "normal" and "drought" was based on an examination of flow duration curves.

Marginal habitats — Habitats on the edge of the river.

PES — Present Ecological State. A state indicating the degree to which present conditions of an area have been modified from natural (undeveloped) conditions. Factors that are considered in the classification include the extent of flow and water quality modification, inundation, streambed condition, riparian condition and proportion of exotic biota. Values range from category A (largely natural) to category F (critically modified).

Reserve — The quantity and quality of water required (a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be (i) relying upon; (ii) taking water from; or (iii) being supplied from, the relevant water resource; and (b) to protect aquatic ecosystems under the National Water Act, 1998 (Act No. 36 of 1998) in order to secure ecologically sustainable development and use of the relevant water resource.

Resource quality — The quality of all the aspects of a water resource including (a) the quantity, pattern, timing, water level and assurance of instream flow; (b) the water quality, including the physical, chemical and biological characteristics of the water; (c) the character and condition of the instream and riparian habitat; and (d) the characteristics, condition and distribution of the aquatic biota.

Resource Quality Objective — Quantitative and auditable statements about water quantity, water quality, habitat integrity and biotic integrity that specify the requirements (goals) needed to ensure a particular level of resource protection.

Resource Unit — A length of river channel along which the structural characteristics are uniform. Reach boundaries were defined by changes in channel structure, slope, streambed, valley floor width and bank material.

Riparian — Pertaining to the river bank.

Riparian habitat — The physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas.

SASS4 — South African Scoring System version 4. A rapid method of assessing water quality, based on the presence of aquatic invertebrate families, each of which have been assigned a sensitivity value. The values are summed to provide a Total Score, and then divided by the total number of taxa to provide an Average Score per Taxon.

Segment	A length of river channel along which there is no significant change in the flow or sediment load. Segment boundaries were defined by major tributary junctions.
Sociological assessment	The sociological assessment was restricted to the dependence of people and communities on a healthy riverine ecosystem. Specific aspects considered included their reliance on the river for providing riparian plants, animals, natural foods, thatching, medicinal, cultural and food plants and pools for bathing. It did not include commercial or subsistence farming.
SI	Social Importance. Specific methods to determine social importance have not yet been determined. During the IERM, a simple set of questions is asked to determine the dependency of people on a healthy functioning river and also to assess the cultural and tourism potential. This provides some measure of the importance with low confidence.
Taxon (plural: TAXA)	General term for a taxonomic group in a formal system of nomenclature, whatever its rank. A taxonomic group refers to the systematic ordering and naming of plants and animals according to their presumed natural relationships. For example, the taxa Simuliidae, Diptera, Insecta and Arthropoda are examples of a family, order, class and phylum respectively.
WR90	A six volume report that summarises the surface water resources of South Africa as of 1990. Water Research Commission Report No 298/1-6/94.
Scenarios	(Scenarios are a set of flow regimes intended to have specific outcomes linked to the Reserve. Scenarios specify amount of water requirements (and water quality consequences), when it is required and where it is required).

1 THE THUKELA RESERVE DETERMINATION STUDY: INTRODUCTION AND BACKGROUND

1.1 BACKGROUND

In 1994 the Department of Water Affairs and Forestry (DWAF) initiated the Vaal Augmentation Planning Study (VAPS) to determine the respective merits of alternative water resource development options to augment supplies to the Vaal River. These options were to follow implementation of Phases 1A and 1B of the Lesotho Highlands Water Project. The subsequent Thukela Water Project (TWP) feasibility study was initiated by DWAF in 1997 to confirm the VAPS results and to examine the feasibility of transferring water from the Thukela River System to the Vaal River System. A number of investigations have since been undertaken to investigate the feasibility of various water supply options (BKS, 2001), including a series of Instream Flow Requirement (IFR) assessments (DWAF, 2000c). The Thukela Water Project has comprised the Thukela Water Project Feasibility Study, and the Thukela Water Decision Support Phase (TWPDSP). The TWPDSP was set up following the TWP Feasibility Study, in order to supply additional information to decision makers. The Thukela Reserve Determination (RD) study, which is the subject of this report, was initiated in support of the TWPDSP. Studies identified as necessary to provide a greater level of confidence in the feasibility of the TWP were:

- The RD study (Consultant: IWR Source-to-Sea and IWR Catchment Consultants).
- Additional environmental assessment of issues that emerged from the Feasibility Study (Consultant: Environmental Assessment Technologies).
- Hydrological Systems Analysis (Consultant: WRP).
- Public Involvement Programme (Consultant: ACER Africa).

These studies were supported by a dedicated project management component (Consultants: BKS and Tlou & Matji). The RD study encompassed a team of some 40 specialists and included the following organisations.

- IWR Source-to-Sea
- IWR Catchment Consultants
- Institute for Water Research (Rhodes University)
- Coastal and Environmental Services
- University of Port Elizabeth
- University of Cape Town
- CRUZ (University of Zululand)
- Council for Scientific and Industrial Research
- Laughing Waters
- Institute for Natural Resources (University of Natal)
- Economic Project Evaluation (EPE)
- Water Resource Planning (WRP)
- Southern Waters
- Streamflow Solutions
- Umgeni Water Services
- Integrated Environmental Assessment

The team was supported by input from DWAF. In particular, the following have been instrumental in providing guidance and support.

- Directorate National Water Resources Planning
- Directorate Resource Directed Measure (RDM)
- KwaZulu Natal Regional Office

1.2 STUDY AREA

The Thukela River is a principal river of the KwaZulu-Natal province in South Africa and is ranked as the second largest river by volume in the country. Historically, the Thukela (in isiZulu, Thukela means "something that startles") marked the southern boundary of Zululand. The total drainage basin of more than 29,000 square kilometres covers most of western KwaZulu-Natal. It rises as a stream on the 3,050-metre high Mont-aux-Sources plateau near the merger point of the Lesotho - Free State province borders. Its upper course, which lies within Royal Natal National Park in the Northern Drakensberg, hurtles down a series of waterfalls as it drops a total of 948m. The river then cuts through the Thukela Gorge at the foot of the escarpment (about 1,500m above sea level) and is soon joined by many tributaries, passes through the Ladysmith Basin, and, below Colenso, becomes narrow and deep. At Jameson's Drift it enters the wide, open Thukela Trough, at the eastern end of which it cuts deeply through a great block of sandstone, to issue on to the coastal plain.

The major tributary of the Thukela is the Buffalo. Other smaller but important tributaries include the Bushmans, Mooi, Little Thukela, Klip, Sundays and Blood Rivers.

The total population of the catchment is approximately 1.56 million. This includes several hinterland towns serving farming areas, such as Estcourt, Bergville, Mooi River and Dundee. The largest urban area is the Newcastle/Madadeni conurbation, which has a population of nearly 300 000. The second largest is Ladysmith/Ezakheni, with 105 000. The catchment also includes the districts of Msinga, Nkandla and Nquthu which, despite being predominantly rural, are nevertheless heavily settled, having a combined population of close to 500 000 people.

The majority of land is used for agriculture, with relatively large areas of grassland. There is a small amount of forestry in this catchment that can be found in the southern and eastern areas. The agriculture includes large areas of beef and dairy pastures, some sugar cane near the coast and around Weenen (both dry land and irrigated), vegetables and nuts, and some citrus farming on the coast near Mandini. The majority of irrigation uses sprinkler irrigation systems, but centre-pivot irrigation is also used in the western areas (especially around the Thukela River).

Rainfall is strongly seasonal in this catchment with in excess of 80% of rain occurring as thunderstorms during the period from October to March. The peak rainfall months are December to February in the inland areas, and November to March at the coast. Mean annual precipitation (MAP) ranges from in excess of 1500mm in the west, to 750mm at Ladysmith, to over 1000mm at the coast. The overall MAP is about 840mm. Mean annual runoff (MAR) figures are in excess of 600mm in the west (40% of MAP), 80mm (11% of MAP) in the central (Ladysmith) area and 180mm (18% of MAP) at the coast. The overall MAR is 130mm (18% of MAP). The MAR of the Thukela is estimated at 3799 million cubic metres per annum.

The area investigated for the purposes of the RD study includes the main Thukela River and the downstream sections of the Little Thukela, Bushmans, Sundays, Mooi and Buffalo Rivers (see Figure 1.1). Specialist work was undertaken at study sites known as Instream Flow Requirements (IFR) sites. A total of 16 IFR sites were selected in the river, and the estuary was investigated as a separate unit.

1.3 LEVEL OF THIS STUDY

The study was designed to follow, as far as practically possible, a Comprehensive Reserve Determination approach (See Chapter 2) to allow for the highest confidence possible. The guidelines for RD studies as set out by DWAF were followed as far as possible. To date, the Thukela RD study represents the most comprehensive of all Reserve Determinations, based on the suite of components addressed. The comprehensive approach required that a stakeholder involvement programme was included. The individual components were addressed at different levels, based on data availability and the importance of the component within the study area.

The major components/tasks addressed within the study are presented in Table 1.1. For each, the present project status, the level of detail, and the specialist fields in which capacity building took place, are indicated.

Additional components incorporated into the study were:

- A comprehensive stakeholder awareness programme.
- An economic study that included an examination of the Ecological Goods and Services of the Thukela system, and a formal market economic study. The Goods and Services component was considered critical in generating an understanding of the linkage between the largely rural marginal communities, and human dependence on the resource base (sustained by the health of the river).

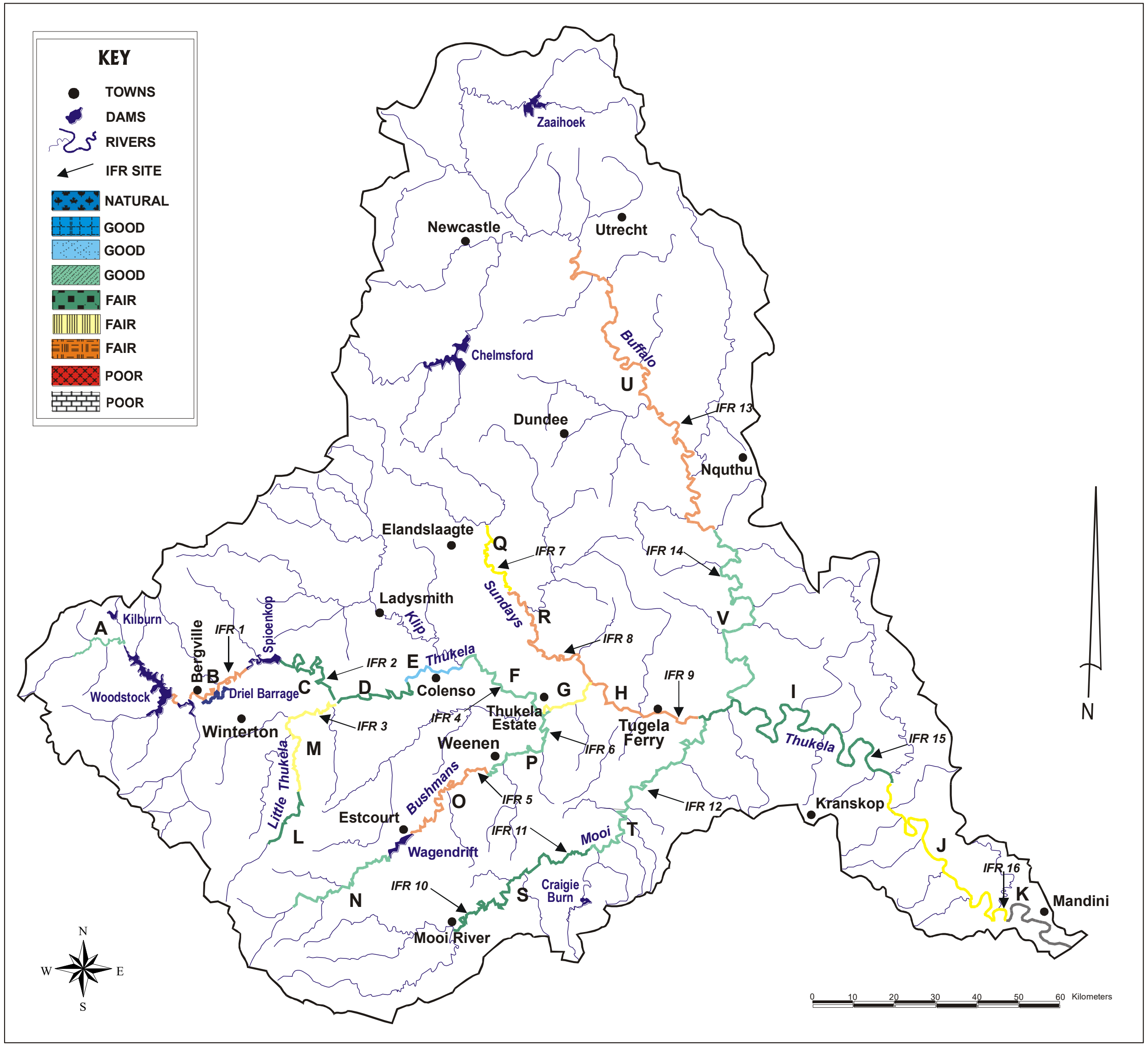
A study of the Thukela Marine Bank was important as it was proposed that there were a link between river flows and catches of prawns and certain fish species on the Bank, and that the potential impact of the Reserve needed to include this as a consideration.

Table 1.1 Components/Tasks addressed within the study

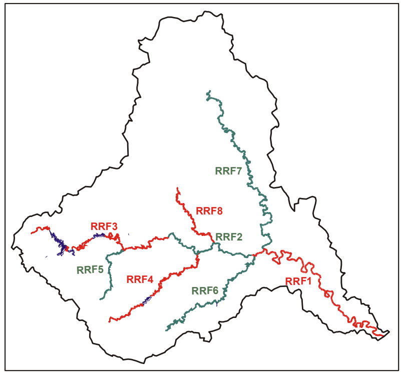
Study components	Level	Capacity Building
Project Management	Comprehensive	Yes
Basic Human Needs Reserve	Comprehensive	Yes
Ecological Water Requirement scenarios (River quantity and quality)	Comprehensive	Hydrology, water quality, aquatic invertebrates, geomorphology
Ecological Water Requirement scenarios (Estuary quantity and quality)	Intermediate - Comprehensive	Macro-invertebrates, vegetation, estuarine dynamics, sediment transport
Groundwater assessment	Scoping	-
Economic evaluation	-	Yes
Goods and Services evaluation	-	Yes
Thukela Marine Bank economic study	-	-
Stakeholder process	Comprehensive	Yes
Ecospecs and monitoring	Comprehensive	Hydrology, water quality, aquatic invertebrates, geomorphology, macro-invertebrates, vegetation, estuarine dynamics, sediment transport
Capacity building	Comprehensive	-

Fig 1.1 Study area

MAP OF THE STUDY AREA



Study area map



1.4 STUDY OBJECTIVES

The study objectives were to use the Reserve Determination methodology to determine a range of Ecological Water Requirements and Operational Scenarios for the Thukela River system, and to examine the consequences of each of these scenarios to the system's ecology, Goods and Services, and economics. Stakeholder viewpoints regarding these scenarios were to be integrated into the final scenario recommendation.

1.5 PROCESS

The following process was followed in order to address the objectives:

- The Basic Human Needs Reserve was recommended.
- A comprehensive ecological study was undertaken to determine the Present Ecological State of each study section of the river (or Resource Unit), and to recommend Ecological Categories for each of the Resource Units, including the estuary.
- This set the scene for the consideration of a set of Ecological Water Requirement (EWR) scenarios for each of the Resource Units. The EWR scenarios are linked to the recommended Ecological Categories.
- A set of EWR scenarios was generated for testing, through the application of a water yield model for the catchment. Each scenario represents a possible flow regime, intended to have specific outcomes (these are linked to the Reserve). Scenarios specify how much water is required, where and when, and take cognisance of the likely water quality consequences.
- Based on the impacts of the EWR scenarios, a set of flow scenarios called Operational Scenarios was generated and tested. These scenarios are realistic, as impacts on users and constraints such as outlet sizes of dams are considered. Decision makers will select one of these scenarios as the Reserve.
- The likely impact of the Operational Scenarios on the available yield was determined.
- The likely impact of the Operational Scenarios on the aquatic ecology was determined.
- The likely economic impact of selected Operational Scenarios was determined. This included an evaluation of the impact on the Thukela Marine Bank.
- The likely impact of selected Operational Scenarios on the Goods and Services delivered by the riverine system was determined.
- The information resulting from the former steps was provided in a user-friendly format to stakeholders, and included a recommendation for their consideration.

An additional requirement of the study was the application of specialist and technical capacity building throughout the project, with an emphasis on Historically Disadvantaged Individuals (HDIs) (see Table 1.1 and Chapter 18 for further information).

1.6 PROGRAMME

The study was initiated during March 2001 and will be finalised by December 2003. The project is within the brief (as amended from time to time), both on budget and time.

2 PROJECT PROCESS

2.1 OVERVIEW AND OBJECTIVES

A project plan, based on a well-designed process, was required to ensure successful completion of the project on brief, on time and within budget. The process was designed during the initial stages of the Reserve Determination (RD) study, and was incorporated into a project plan. During the study period minimal deviation from the accepted plan was required. The Thukela Project plan, as designed, formed the basis for a revised eight-step Resource Directed Measures (RDM) process.

2.2 RDM PROCESS

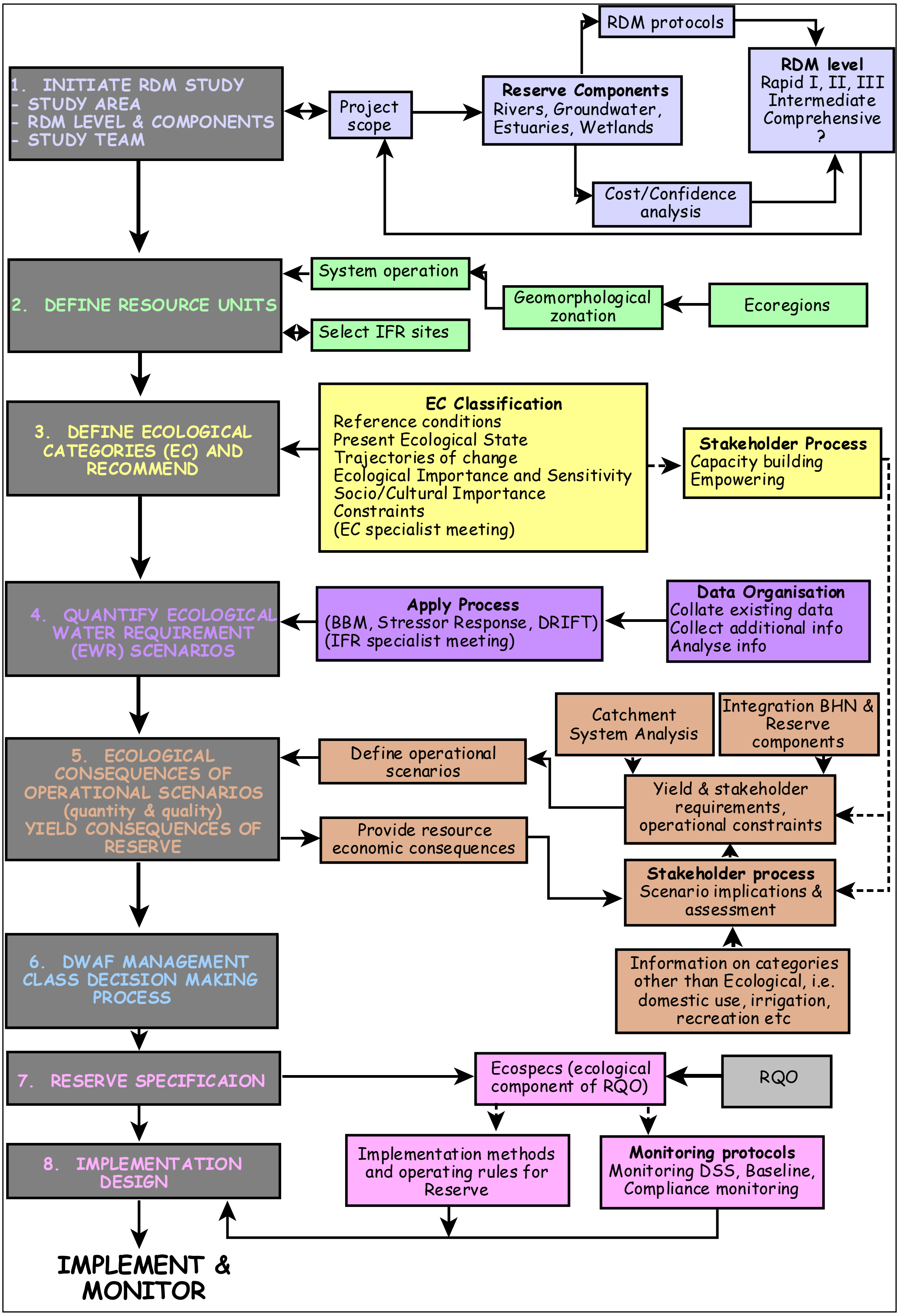
The 1999 RDM process (DWAF, 1999, vol 3) was used as a guide to determine the design of the RD project process and plan. The 1999 process was however found to be overly theoretical in some instances and not necessarily applicable to a study of such diversity and magnitude. Where this was deemed to be a problem the intent of the 1999 RDM process borne in mind but a more practical approach, relevant to the Thukela was devised. The present RDM process is presented in Figure 2. 1.

2.3 TERMINOLOGY

During the three-year period of this study, Reserve terminology changed constantly. This posed a problem of consistency within reporting of this study. It was decided that all reports bar the main and the briefing document will reflect the accepted terminology as at the start of the study. Most of the terminology changes took place during the last year (2003 of the project). A list of the terminology changes is provided in the front of the document.

Fig 2.1 The revised RDM process.

Major steps/tasks are shown in grey blocks. Smaller steps are shown in different colours. Each of the colours is used to link to one or more specific steps.



2.4 THUKELA PROJECT PROCESS

The Thukela project process and key tasks are sequentially described below. The inter-relationship between tasks is described in Figure 2.2. The key tasks and their sequences are provided in Figure 2.3.

- Groundwater: A groundwater scoping study was undertaken to investigate the groundwater component of the Reserve. Due to a lack of available methodologies, as well as the impression that the groundwater component of baseflows within the RD study area was minimal, this level was deemed appropriate.
- River divisions: The study area was divided into Resource Units (RUs). RUs are sections of river sufficiently different from each other to warrant their own Reserve requirements. Various tools are required to delineate these Units. Within each RU, or in as many as practically possible, IFR sites are selected.
- Basic Human Needs: The Basic Human Needs Reserve was determined.
- Ecological Classification: An Ecological Classification was undertaken, requiring the determination of Present Ecological State (PES) for the major components (water quality, geomorphology, hydrology, riparian vegetation, habitat integrity, fish and aquatic invertebrates). Using criteria such as Ecological Importance, trajectory of change, and likelihood of being able to address the problems, a range of Ecological Categories (ECs) are derived. One of these ECs will be the Recommended EC (REC) from an ecological viewpoint.
- IFR Scenarios: IFR scenarios were generated to test through the application of a yield model. Each scenario represents a possible flow regime, intended to have specific outcomes linked to the Reserve. Scenarios specify how much water is required, where and when, and take cognisance of the likely water quality consequences.
- Operational Scenarios: Based on the impacts of the IFR scenarios, a set of flow scenarios, called Operational Scenarios, were generated and tested. These scenarios are realistic flow scenarios as impacts on users and constraints such as outlet sizes of dams are considered. Decision makers will select one of these scenarios as the Reserve.
- Likely impacts of Scenarios:
  - Yield: The likely impact of the Operational Scenarios on the available yield was determined. Note that the yield modelling and the assessment of impact on yield were a separate hydrological study.
  - Ecology: The likely impacts of the Operational Scenarios on the aquatic ecology of the river and the estuary were determined.
  - Economics: The likely economic impacts of selected Operational Scenarios were determined. This included an evaluation of the impact on the Thukela Marine Bank.
  - Goods and Services: The likely impacts of selected Operational Scenarios on the Goods and Services delivered by the riverine system were determined.
- Reporting and consultation: The information resulting from the former steps was provided in a user-friendly format to stakeholders, and included a recommendation for their consideration. Note that the stakeholder process was not managed through the RD consultant.
- Recommendation of the scenario: All the consequences of the different flow scenarios and the stakeholder results were assessed and a recommendation of the scenario that could be accepted as the Reserve was presented to DWAF.
- Ecospecs: The Ecospecs (the ecological component of the Resource Quality Objectives, defined in terms of flow, quality, biota and habitat) for the Reserve were defined.
- Monitoring programme: A Reserve monitoring programme was designed.

An additional requirement of the study was the application of specialist and technical Capacity Building throughout the project, with an emphasis on Historically Disadvantaged Individuals (HDIs).

Fig 2.2 The TWP RD project plan, showing overall timing per year, specialist tasks and subtasks, and interaction between tasks

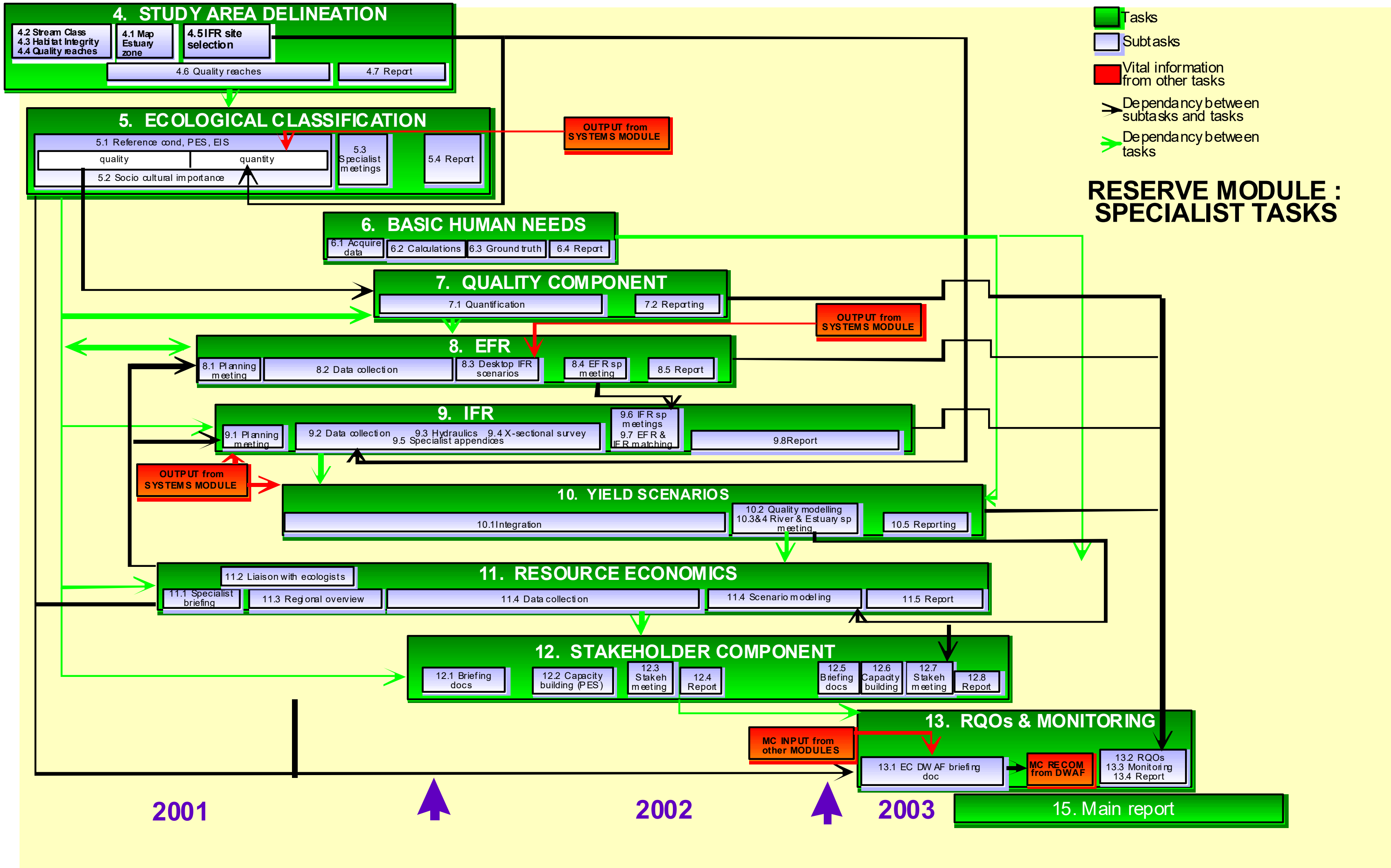
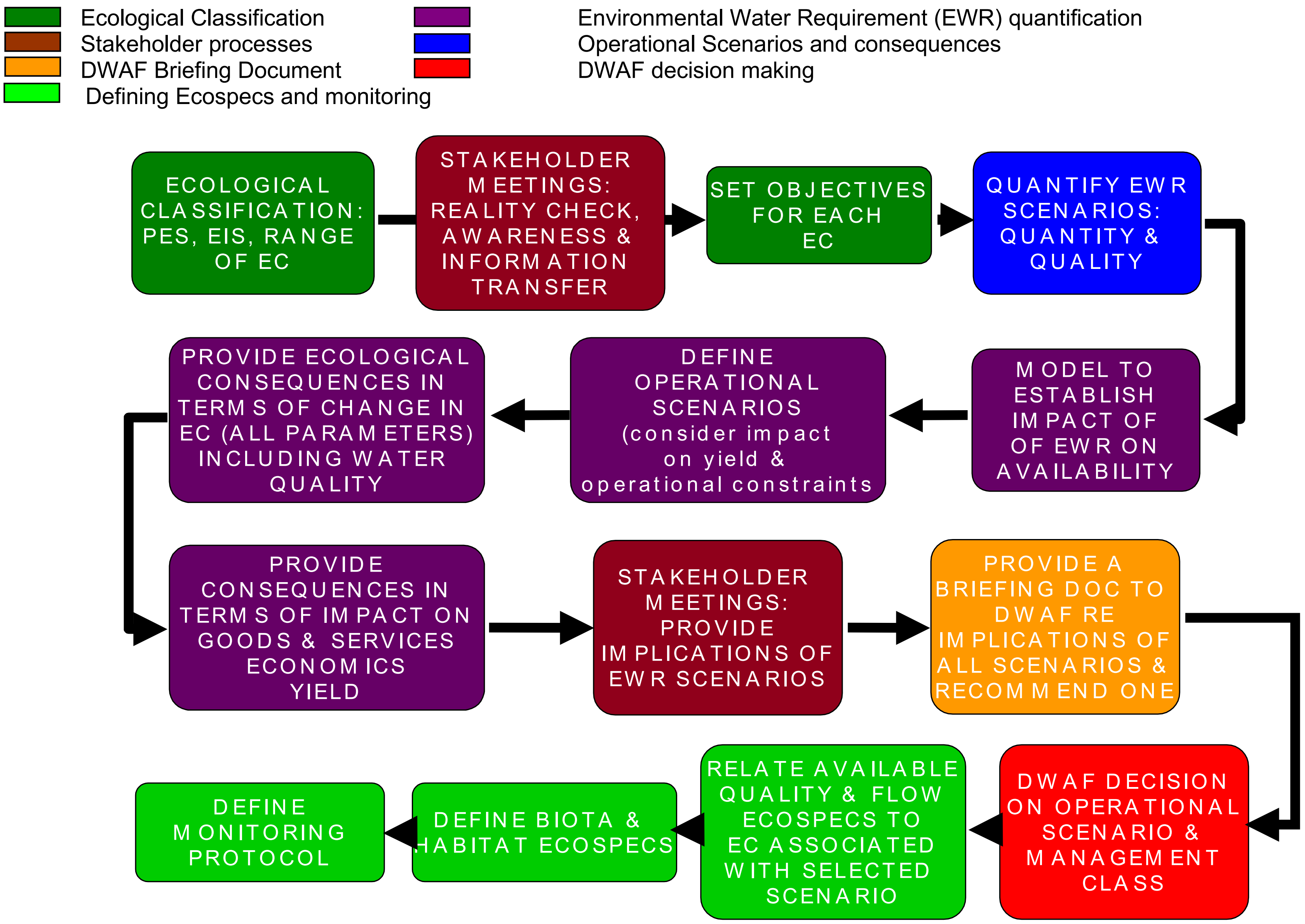


Fig 2.3 Diagram illustrating the sequential nature of the process followed for the Thukela Reserve Study



3 DELINEATION OF THE STUDY AREA: QUANTITY AND QUALITY RESOURCE UNITS

Note: This chapter is a summary of report DWAF Report No PBV000-00-10302 (DWAF 2003a).

3.1 OVERVIEW

The Thukela system is the second largest South African river (in terms of Mean Annual Runoff (MAR)), and the main stem of the Thukela River alone is approximately 500km long. In order to study this extensive system, it is necessary to divide it into manageable units on the basis of physical and biological criteria. The major units are termed Resource Units (RUs) and are measured at a scale of kilometers. Each RU is delineated on the basis of having sufficiently different physical or biological characteristics to set it apart from the other RUs and to warrant its own RD. Within the Resource Units, IFR sites are selected, and these form the study sites at which the quantity component of the Ecological Reserve is determined. These are measured at a scale of meters.

The purpose of this chapter is to
- Describe the process followed to define the RUs;
- present the RUs;
- describe the process followed to select IFR sites within the RUs.

3.2 METHODOLOGY

3.2.1 Determination of Quantity Resource Units (RUs)

The breakdown of a catchment into RUs for the purpose of determining the Reserve for rivers is done primarily on a biophysical basis, according to the occurrence of different ecological regions (eco-regions) within the catchment, as supplied by DWAF. Since the endpoint of a RD is an ecological one, the idea is to divide the catchment into individual units which are relatively homogenous (from end to end) on an ecological basis, to ensure that the Ecological Reserve is set on the basis of appropriate terms (DWAF, 1999, vol. 3).

The breakdown into RUs on the basis of ecoregions and/or geohydrological response units could then be further resolved into smaller RUs which are suited to management requirements (DWAF 1999, vol 3). This may be necessary, for example, where large dams and/or transfer schemes occur in the area. Different modes of management or operation for different river reaches also result in biophysical differences in river reaches, and should be considered.

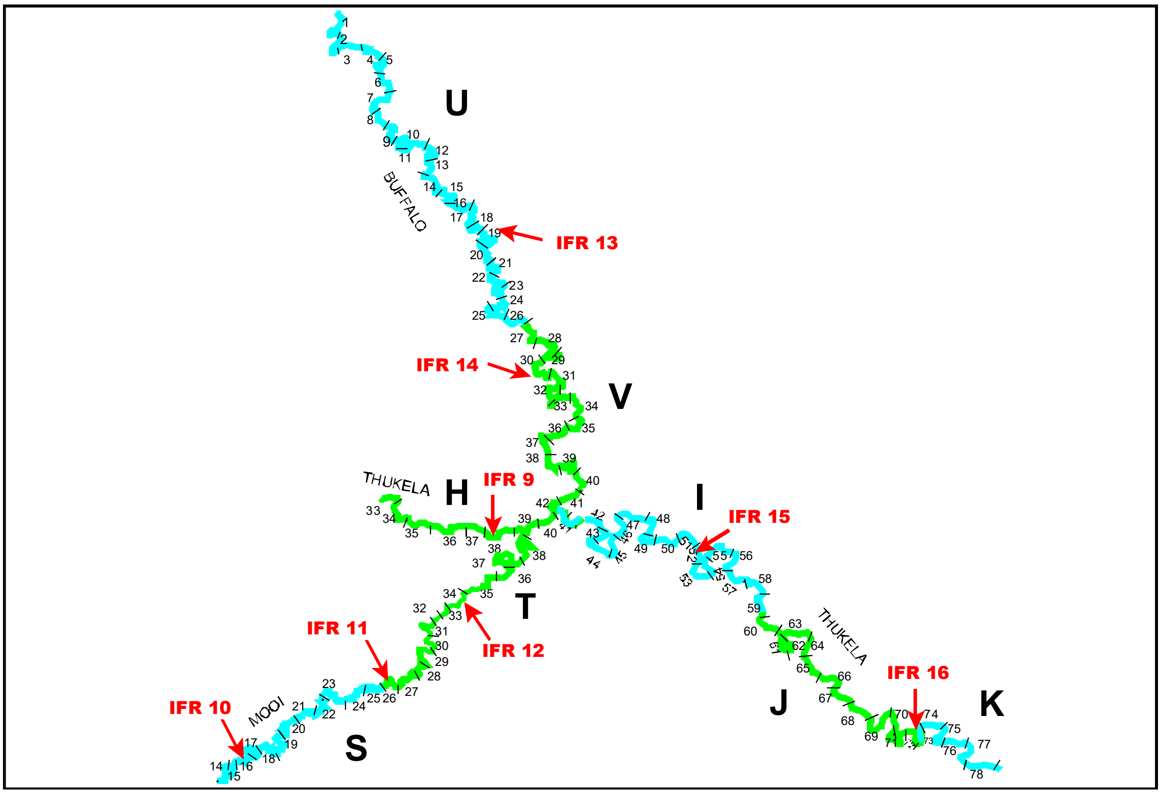
The determination of RUs takes into account a variety of factors, including the results of the Habitat Integrity Assessment. As overlaying all the data does not necessarily result in a logical and clear delineation, expert judgement, a consultative process and local knowledge is required to finally determine the RUs. The practicalities of dealing with numerous units within one study must also be considered to determine a logical and practical suite of RUs.

Thus, the following were considered when selecting the RU:
- Ecoregions (as provided by RQS, DWAF).
- Geomorphological classification (described hereinafter).
- Hydrology and Operation of the management systems.
- Habitat integrity.
- Local knowledge and expert judgement.

The RUs are illustrated in Figure 3.1 and 3.2.

Fig 3.1 Upper Thukela Reserve study area

Fig 3.2 Lower Thukela Reserve study area



3.2.2 Determination of Quality Resource Units (QRUs)

The river sections which are homogenous in terms of water quality, form water quality sub-units. Each RU may have more than one Quality Resource Unit (QRU). The selection of

QRUs is influenced by activities in the catchment, the availability of water quality data, and the length of the data series.

The following process is used to select the QRUs:

- Determine the location of DWAF water quality monitoring points, and their proximity to IFR sites.
- Determine the availability of water quality data.
- Assess the quality of data (e.g. length of data series).
- Identify sites in the study area requiring additional water quality data collection.
- Identify catchment characteristics e.g. tributaries, dams.
- Identify catchment activities, land-use, and sites with potential water quality problems.
- Access information on the "system operational rules" (e.g. dam management) of the catchment, and identify potential effects of these on water quality.
- Assess additional data collection from catchment excursions and evaluate the QRUs already identified.

The following QRUs were identified. Tables 3.1 and 3.2 describe the position of QRUs relative to RUs, and provide information per QRU.

Table 3.1 Resource Units, QRUs and 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**
Q1	1 - 4 (A)	Rugged Glen to upstream of Woodstock and Driel Dams.	DWAF mon. points V1H035 (RC) and V1H036 (PES)
Q2	5 - 7 (B)	Woodstock and Driel Dams to upstream of Bergville.	DWAF mon. point V1H058 (data not suitable).
Q3	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.
Q4	10 - 16 (C)	Spioenkop Dam to upstream of Thukela - Little Thukela confluence.	DWAF mon. point V1H057 (RC and PES).
Q5	17 - 20 (D)	Thukela - Little Thukela confluence to upstream of Colenso.	No water quality data. *Combine QRUs 5 and 6.*
Q6	21 - 24 (D, E)	Colenso to upstream of Thukela - Klip River confluence near Ladysmith.	DWAF mon. point V1H001 (RC and PES) at Colenso.
Q7	25 - 29 (F)	Thukela - Klip River confluence to upstream of the Thukela - Bloukrans 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 Bloukrans confluence with the Thukela River.
Q8	29 - 30 (F)	Thukela - Bloukrans confluence to upstream of the Thukela - Bushmans confluence.	No water quality data. *Combine QRUs 7 and 8*.
Q9	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.

Upper Thukela River Catchment: Little Thukela River			
QRU no.	**Segment no. (RU)**	**Description**	**Monitoring point data available and used for assessing RC + PES**
Q14	1-9 (L, M)	Wonder Valley to upstream of Winterton.	No water quality data. *Combine with QRU 15*.
Q15	10-12 (M)	Winterton to the confluence of the Little Thukela and Thukela Rivers.	DWAF mon. point V1H010 (RC and PES).
Upper Thukela River Catchment: Bushmans River			
Q16	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.
Q17	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 (RC due to settling in dam).
Q18	12-20 (O, P)	Little Bushmans River - Bushmans River confluence to upstream of Weenen.	No water quality data. *Combine with QRU 19*.
Q19	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.
Upper Thukela River Catchment: Sundays River			
Q20	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).
Q21	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).

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

Lower Thukela River Catchment: Thukela River			
QRU no.	**Segment no. (RU)**	**Description**	**Monitoring point data to be used**
Q10	34-39 (H)	Thukela - Sundays confluence to upstream of Thukela - Mooi River confluence.	DWAF mon. point V6H002 (RC and PES) at Tugela Ferry.
Q11	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.
Q12	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).
Q13	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 section, as dealt with as part of the estuarine assessment.

Lower Thukela River Catchment: Mooi River			
QRU no.	**Segment no. (RU)**	**Description**	**Monitoring point data to be used**
Q22	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.
Q23	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).
Q24	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).
Lower Thukela River Catchment: Buffalo River			
Q25		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 V3H011 (Blood River) for PES.
Q26	1-42 (U, V)	From the Utrecht - Osizweni 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 for RC.

3.2.3 Zonation of the Estuary

The estuary is treated as one Resource Unit. The estuary is delineated by the geographical boundaries, as follows:

- *Downstream boundary* - the estuary mouth.
- *Upstream boundary* - the extent of tidal influence, i.e. the point where tidal variation in water levels can still be detected.
- *Lateral boundaries* - the 5m contour above Mean Sea Level (MSL) along each bank.

3.2.4 Determination of IFR sites

IFR sites are critical points within individual RUs and must meet certain criteria. A sequential process is followed to determine the IFR sites. The criteria considered in selection of sites include:

- The locality of a gauging weir with good quality hydrological data.
- The locality of the proposed developments.
- The locality and characteristics of tributaries.
- The habitat integrity/conservation status of the different river reaches.
- The reaches in which social communities depend on a healthy river ecosystem.
- The suitability of the sites for follow-up monitoring.
- The habitat diversity for aquatic organisms, marginal and riparian vegetation.
- The suitability of the sites for accurate hydraulic modelling throughout the range of possible flows, especially low flows.
- Accessibility of the sites.
- Those areas or sites which could be critical for ecosystem functioning, for example, a riffle in which flow ceases during periods of low or no flow (as cessation of flow constitutes a break in the functioning of the river, and those biota dependent on this habitat and/or on continuity of flow will be adversely affected). Thus, a critical area comprises habitat which may be adversely affected by diminishing or zero flow. Pools are thus not considered critical, as they are still able to function as refuge habitats during periods of no flow.
- The locality of geomorphological 'reaches', and representative reaches within these.

There are a number of rules attached to each of these criteria, which are detailed in King *et al*, 1998.

The sites were selected on the basis of the aerial habitat assessment video and ground-truthed through site visits. Seventeen sites were selected, nine in the Upper Thukela and eight in the lower Thukela (Figure 3.1 and 3.2). The following sites are existing sites for which some level of relevant information was already available.

- IFR 1
- IFR 2
- IFR 4A
- IFR 4B
- IFR 5
- IFR 6
- IFR 9
- IFR 10
- IFR 11
- IFR 12

4 BASIC HUMAN NEEDS RESERVE (BHNR)

Note: This chapter is a summary of report DWAF Report No PBV000-00-10305 (DWAF 2003d).

4.1 OVERVIEW AND OBJECTIVES

The "Reserve Determination" Module (Module 3 of 5 for the Thukela Water Project Decision Support Phase) is designed, *inter alia*, to meet the requirements of the National Water Act (NWA) No 36 of 1998. In terms of the NWA, the Basic Human Needs Reserve (BHNR) is one component of the Reserve. The other component is referred to as the Ecological Reserve.

The objectives were to investigate the requirements to satisfy the BHN of the study area.

4.2 METHODS

The BHNR has been generated following a number of steps. The first of these steps was to use demographic data supplied by the Directorate Water Services: DWAF as a basis for analysis. The base information supplied by DWAF was adjusted data from the 1996 census. This data source utilised information that had been collected at an enumerator area (EA) level. The EA is the most fine-grained demographic information available. EAs are the building blocks of the census and EA data is often aggregated into census district information for the purposes of public consumption and broad-based planning. Using EA level data a "fine grained" demographic profile of the Thukela catchment was generated.

The EA data for the purposes of this study was further broken down to reflect the likely direct users of the surface water resources of the Thukela. This involved demarcating a 5km buffer zone on either side of the Thukela and its major tributaries. For the purposes of this exercise, and in keeping with the Thukela Reserve Determination Study, the relevant river reaches were those defined as the Thukela, Little Thukela (Injasuthi), Bushmans (Mchezi), Buffalo (Mzinyathi), Sundays and Mooi Rivers.

The 5km buffer zone was used to estimate the numbers of people who would be likely to be reliant on the flow in the relevant river reach. It was assumed that people outside of this area, although they might be making use of water from the rivers via a formal urban supply or a community water supply scheme, would in the main be using springs, minor streams or groundwater. It should be noted that virtually all major urban settlements in the Thukela catchment fall within the 5km buffer.

This part of the exercise involved demarcating the EAs within the buffer zone. The percentage of the area of each EA within the buffer zone was used to calculate the number of people within each EA residing within the buffer zone. For example, where 60% of the area of the EA fell within the buffer zone it was deemed that 60% of the population would be within the buffer zone.

The data was further analysed to estimate the population above and below the IFR sites identified for the study. This gives an indication of the amount of water that would need to pass certain IFR sites in order to meet the needs downstream.

4.3 RESULTS

The analysed data are presented in the following tables. Tables 4.1 and 4.2 are based on the entire population of the Thukela catchment, i.e. in that area greater than the 5km buffer zone already discussed. Tables 4.1 and 4.2 consider the likely water needs of the population of the catchment in its entirety. Scenarios are presented for the currently accepted RDP norm of 25ℓ per capita per day, as well as more liberal allowances of 60ℓ and 100ℓ per day[1]. In addition, the population growth is projected to 2020. It should be noted that accurately projecting population growth is problematic given the uncertainty around the impact of HIV/AIDS. Figure 4.1 illustrates the population within the Thukela Catchment. In order to err on the side of caution, a 1.5% per annum growth rate in population growth has been allowed for. Current estimates are that many rural areas, and the Thukela catchment is predominately rural, will have a zero or even a negative growth rate over the medium term.

Table 4.1 Annual potential BHNR in the entire catchment expressed in million cubic metres (MCM)

Year	**2001**	**2005**	**2010**	**2015**	**2020**
Population	**1 567 246**	**1 663 418**	**1 791 973**	**1 930 464**	**2 079 658**
Water use at 25ℓ per capita per day	14.30	15.17	16.35	17.61	18.97
Water use at 60ℓ per capita per day	34.32	36.42	39.24	42.27	45.54
Water use at 100ℓ per capita per day	57.20	60.71	65.40	70.46	75.90

Table 4.2 examines the total population of the catchment in more detail. In Table 4.3 the population in the catchment is disaggregated into four logical categories of settlement. These are rural villages (18.6% of the population of the catchment), scattered rural settlement (55.9%), urban (19.9%) and peri-urban (5.6%). Growth rates are applied to each of these categories, based on current, settlement-based, projections. These projections consider a fairly high growth rate of 2% for the urban and peri-urban areas over the next 20 years. A lower growth rate starting at 1.5% and declining to nil is considered for the rural areas. This is both in keeping with trends towards urbanisation and taking into account the expected impacts of AIDS. Figures for the total catchment differ fairly substantially from those presented in Table 4.1. By the year 2020 the more fine-grained analysis predicts a population of 1.87 million people, whereas the coarse-grained analysis as summarised in Table 4.1 predicts a population of 2.07 million.

Table 4.2 Analysis of water demand by settlement type

Year	**2001**	**Water need in MCM per annum**	**2010**	**Water need in MCM per annum**	**2020**	**Water need in MCM per annum**
Settlement	**Population**		**Population**		**Population**	
Rural village	291214	2.66	329723	6.02	338049	12.34
Scattered rural	876548	8.00	944524	8.62	944524	8.62
Urban	312478	22.81	380909	27.81	464326	33.90
Peri urban	87066	3.18	106133	5.81	129375	9.44
Total population	**1567306**		**1761289**		**1876274**	
Total water needs		**36.64**		**48.25**		**64.30**

Table 4.2 allows for different water demand and consumption levels. A per capita allowance of 200ℓ/c/d has been allowed for urban areas. The peri-urban areas start with an allowance of 100ℓ/c/d at present, growing to 200ℓ/c/d per person per day by the year 2020. This would be consistent with a "high road" scenario assuming electrification and growth in prosperity in these areas, leading to the purchase of appliances using larger volumes of water such as washing machines. Rural villages start with 25ℓ/c/d, increasing to 50ℓ/c/d per person per day by the year 2010 and 100ℓ/c/d by 2015. This again assumes growth in prosperity and village

1 The Reconstruction and Development Programme (RDP) defined 25ℓ per person per day as an initial supply of water that should be made available to all people within South Africa. Community water supply schemes were largely designed around this target.

electrification. Scattered rural areas retain a 25ℓ/c/d allocation for the entire period under consideration. This is based on the assumption that they will probably never have house connections and the experience shows that the effort involved in transporting water from stand pipes or protected springs caps consumption at about 25ℓ/c/d.

Fig 4.1 Population distribution in the Thukela WMA

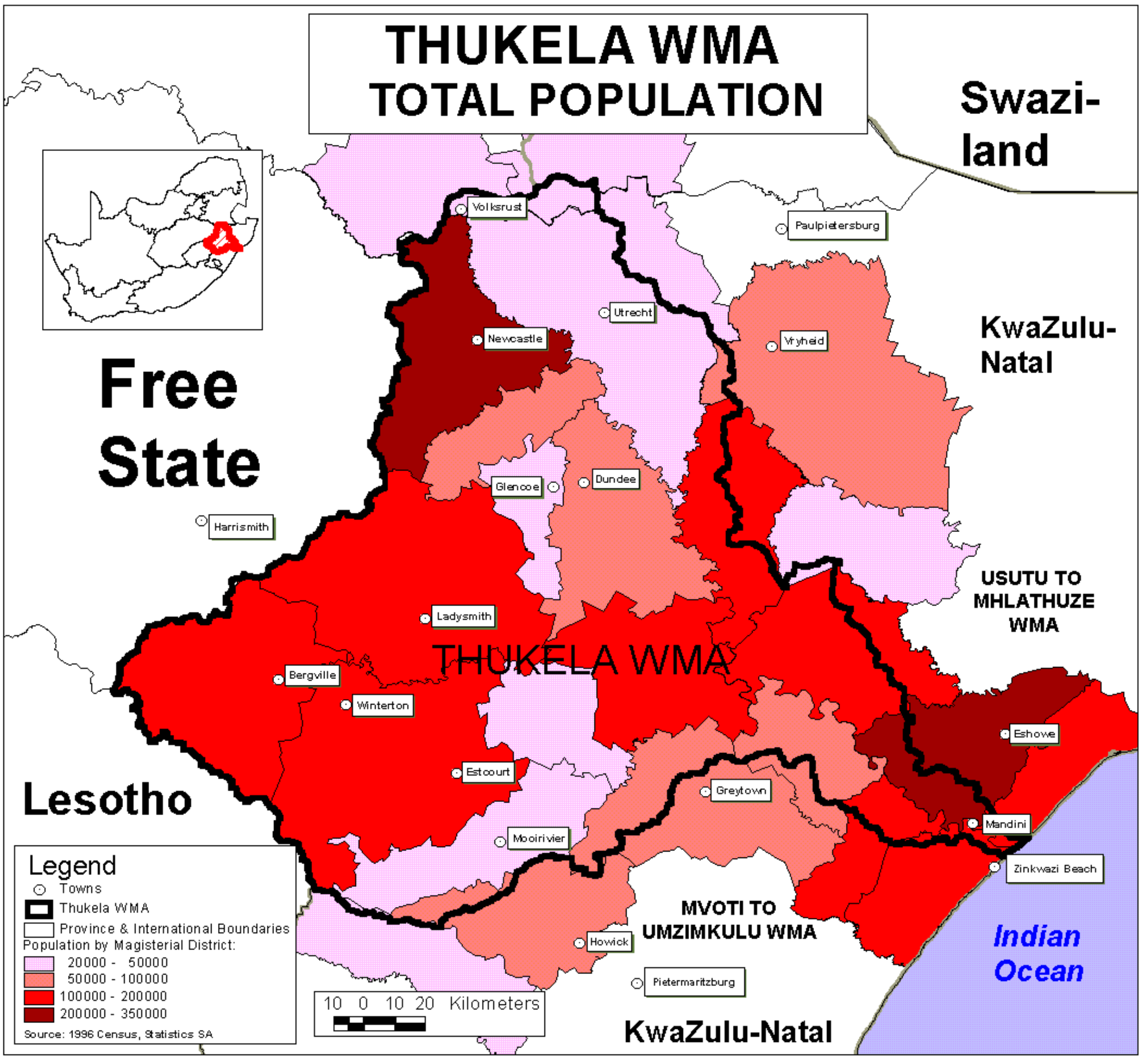


Table 4.3 presents the summarised estimates for the areas within the 5km buffer zone as already defined. The total population living within the 5km buffer zone in 2001 is calculated to be 715281 or 45.6% of the total population of the catchment. A per capita allowance of 200ℓ/c/d has been allowed for urban areas. The peri-urban areas start with an allowance of 100ℓ/c/d at present increasing to 200ℓ/c/d per person per day by the year 2020. Rural villages start with 25ℓ/c/d increasing to 50ℓ/c/d per person per day by the year 2010 and 100ℓ/c/d by 2015. Scattered rural areas retain a 25ℓ/c/d allocation for the entire period under consideration.

Table 4.3 Water demand for 5km buffer zone (expressed in million cubic meters per annum)

Year	2001	Annual water need	2010	Annual water need	2020	Annual water need
Settlement	**Population**		**Population**		**Population**	
Rural village	87364	0.80	99741	1.82	101415	3.70
Scattered rural	316989	2.89	323169	2.95	323169	2.95
Urban	249982	18.25	304727	22.25	352968	25.77
Peri-urban	60946	2.22	90208	4.94	103500	7.56
	715281	24.16	817845	31.95	881051	39.97

Table 4.3 reflects the probable demand pattern for those people living within the buffer zone and dependent upon run of river. It is not, however, necessarily a BHNR, as the amounts applied to some of the settlement types probably exceed the amounts that could be defined as making up a basic human need.

For those living outside the buffer zone, it is assumed that groundwater is probably of great importance. A groundwater report commissioned for this project (DWAF Report No PBV000-00-10304, DWAF 2003c) estimates that current groundwater abstraction for the BHNR is in the region of 18 MCM/a. According to this estimate, the population outside of the buffer zone uses approximately 57ℓ/c/d. The groundwater report indicates that the abstraction of groundwater for rural water supply is not expected to pose a threat to the resource as usage, as the percentage of the total amount available is very low. Assuming that this 60 litres of water per person per day should apply within the buffer zone, a BHNR scenario may look something like that summarised in Table 4.4.

Table 4.4 60ℓ per person per day BNHR allowance for population within 5km buffer zone (expressed in million cubic meters per annum)

Year	2001	Annual water need	2010	Annual water need	2020	Annual water need
Settlement	**Population**		**Population**		**Population**	
Rural village	87364	1.91	99741	2.18	101415	2.22
Scattered rural	316989	6.94	323169	7.08	323169	7.08
Urban	249982	5.47	304727	6.67	352968	7.73
Peri-urban	60946	2.22	90208	1.98	103500	2.27
	715281	16.55	817845	17.91	881051	19.30

4.4 CONCLUSION

For those living within the 5km buffer zone it should be assumed that 60ℓ water per capita per day constitutes the BHNR. This is close to that which is assumed to be abstracted from groundwater, for those not proximate to the river, and is probably sufficient to allow for all basic needs as defined by the NWA. It would also allow some water for uses such as minor subsistence irrigation of vegetables and other crops. At present this amounts to about 16.55 million cubic metres per annum to be provided from the river to those living in the buffer zone. The total amount required for all people within the catchment, including those supplied by groundwater, would be 34.32 million cubic metres per annum (at present population). For the year 2020 the 60ℓ per person allowance for people within the 5km buffer zone would be 19,30 million cubic metres per annum and for the entire catchment it would be 45.54 million cubic metres per annum.

5 GROUNDWATER

Note: This chapter is a summary of report DWAF Report No PBV000-00-10304 (DWAF 2003c).

5.1 OVERVIEW

None of the work undertaken in the lead-up to the TWP (see Chapter 1, Report PBV000-00-10304) has considered the role of groundwater in the functioning of the hydrological system, nor possible impacts should groundwater contributions be reduced.

Geohydrological investigations undertaken in the Thukela River catchment have focussed on developing groundwater supplies for rural communities (Hobbs, 1993; E. Martinelli and Associates, 1994, 1995; Davies Lynn and Partners, 1995; Groundwater Consulting Services, 1995; Steffen Robertson and Kirsten, 1995; VSA Earth Science Consultants, 1995; King, 1997). Issues such as borehole yield and groundwater quality in terms of fitness-for-use have been addressed, but little attempt has been made to quantify recharge, groundwater flow directions, and contribution to streamflow or environmental dependencies.

The study area addressed by this report includes the second largest river in South Africa and the largest river not subject to water demands and rights from other countries. Lack of previous investigations into surface – groundwater interaction, and the preliminary nature of this investigation, prevent a detailed assessment of the role of groundwater in the general catchment. Much of the assessment provided in this report was based on first principles and an understanding of prevailing geohydrological and hydrological conditions. Further, the sheer size of the catchment required a number of generalisations be made.

5.2 OBJECTIVES

A scoping study was required to assess the role of groundwater in sustaining the Reserve of the Thukela River and to consider the need for more detailed geohydrological assessment. The study aimed to describe prevailing geohydrological characteristics, to assess the role of groundwater in meeting basic human water needs, and to assess its contribution to baseflow. The findings of the scoping exercise were to be documented in a short report. Further work requirements were also to be documented in the report. The project outcome was to be based on available information.

The project was not required to quantify the groundwater component of the Reserve. As the purpose of the scoping exercise was to identify the role of groundwater in the Thukela River catchment, it was also not required to develop a comprehensive understanding of the hydrogeology of the catchment.

5.3 METHODS

The following tasks were undertaken during the groundwater scoping exercise:

- Collection of available maps of the study area.
- Collection of available geohydrological reports of the area.
- Visit to DWAF geohydrologists responsible for the study area.
- Discussion regarding baseflow characteristics with project hydrologist.
- Assessment of available information.
- Preparation of a short report documenting the findings of the scoping exercise.
- Discussion with project team regarding further work requirements.

5.3 RESULTS

Groundwater plays a number of important roles in the Thukela River catchment. In addition to providing water for the rural population (and thereby allowing basic human needs to be addressed), groundwater sustains river flow and aquatic ecosystems during dry winter months, particularly between June and September. As groundwater abstraction is widespread, generally takes place at low rates, and volumes abstracted are relatively small in comparison to estimates of recharge, the ability of groundwater to continue to support the Reserve on a catchment scale is generally not threatened (PBV000-00-10304).

Significant development of groundwater for rural water supplies has taken place in the study area since democratisation of South Africa in 1994. This has been supported by a number of drought relief programmes and foot and mouth eradication programmes. It was estimated some 6 000 boreholes are now operational in the study area. Current groundwater use amounts to about 35 MCM/a, of which about half is used to meet the basic water requirements of the rural population. The relatively small volume of groundwater abstracted (in relation to recharge) indicates that the prevailing aquifer systems are in pristine or near-pristine condition.

It was estimated that recharge in the Thukela River catchment is 620 MCM/a while the groundwater contribution to baseflow is 320 MCM/a. This equates to about 7.5% of MAR. Though this contribution may appear low, the timing of the contribution during dry months is crucial to the functioning of the river system.

Recharge is poorly quantified, and surface – groundwater interaction in the Thukela River catchment is poorly understood. This is not unique to this catchment, but applies to many catchments in the country. This inadequacy has emerged as a result of the implementation of the National Water Act (Act No. 36 of 1998), which requires an integrated approach to water resource management. Because recharge plays such an important role in quantifying the groundwater component of the Reserve, it is considered that a better assessment of recharge in the entire catchment should be required as part of the Reserve Determination.

Similarly, as the groundwater component of the Reserve is based on low maintenance baseflows, and these flows are likely to exceed total recharge in the catchment, the actual contribution of groundwater needs to be better quantified. Failure to do so will be likely to create conflict between maintaining the groundwater contribution during low flow periods, and the need to abstract groundwater for basic human needs.

As no tools are currently available to adequately assess the groundwater contribution to baseflow, support should be given to a national research programme which would result in tools being developed to quantify the groundwater contribution to rivers. Until the required tools are available, the project hydrologist and geohydrologist will have to consider all available baseflow data and, using expert judgement, make an assessment of the volume of groundwater discharged into rivers during periods of low flow. Because of this, any assessment of the groundwater component of the Reserve is unlikely to be at a confidence higher than a medium level.

It is at a local level that geohydrological expertise is most required. For example, groundwater abstraction directly adjacent to rivers or wetlands could impact the contribution of groundwater to river flow. Local-scale management measures need to be put into place to ensure that the supporting role played by groundwater is not impacted. Similarly, coal mining and the lack of sanitation potentially threaten the quality of groundwater discharged into streams. This is particularly true when assessing sites IFR 7, IFR 8, IFR 13 and IFR 14. The setting of Resource Quality Objectives (RQOs), which place limits or restrictions on groundwater abstraction near rivers, streams and wetlands, and will control potential contamination, will provide effective protection measures. However, these need to be implemented at a local level.

5.4 RECOMMENDATIONS

Given the findings of this scoping report and the need for additional work, the following recommendations are made with respect to further work requirements:

- At this stage, it is not recommended that a Comprehensive Reserve Determination of the groundwater component be done. Rather, Rapid Reserve Determinations should be undertaken for all quaternary catchments in the study area. The Rapid Reserve Determinations should be based on brief reconnaissance visits and inputs from local experts. This will provide an indication to DWAF officials of the allocatable groundwater resources in each quaternary catchment. (This could be the outcome of the groundwater component of the Reserve Determination).
- A catchment-wide recharge study of the Thukela River catchment should be commissioned. This would allow for better quantification of recharge (a key parameter for determining the groundwater component of the Reserve), promote a better understanding of surface – groundwater interaction, and allow for better quantification of groundwater resources in the catchment. To facilitate the Reserve Determination at a Rapid level, recharge to each quaternary catchment must be determined.
- In addition to supporting research to develop tools to quantify surface – groundwater interactions, research to better quantify the contribution of groundwater to baseflow is required, and should be commissioned. As traditional methods are clearly flawed, such a study needs to be based on available river flow data, groundwater level data and expert judgement. Both hydrological and geohydrological skills are required for this. Such a study would greatly contribute to assessing the role of groundwater in sustaining low maintenance baseflows, and to defining the level of groundwater dependence.
- Groundwater dependent ecosystems in the catchment need to be mapped and sensitive systems identified. This will allow for better protection of these systems. Input from the Reserve Determination team (hydrologists, water quality specialists, ecologists, wetland specialists etc.) is required for this. More detailed investigation may be required in some cases.
- Generic groundwater management guidelines are required to manage the groundwater resources and to guide allocations at a local scale. Such guidelines should address buffer zones adjacent to rivers and sensitive aquatic ecosystems, and allowable abstraction within the zone. The guidelines also need to consider groundwater monitoring requirements, particularly in sensitive areas or in instances of large-scale abstraction.

As a result of the National Water Act (Act No. 36 of 1998) recognising a unitary hydrological cycle, a number of deficiencies in knowledge regarding recharge estimation and surface – groundwater interaction have emerged. It is hence argued that geohydrological expertise is required in any Reserve Determination to facilitate a better understanding of the hydrological system and provide specific insights or inputs when required. Further, these deficiencies need to be made known to water resource and research managers so that actions can be implemented to improve current knowledge in this regard.

6 WATER QUALITY (RIVERS)

Note: This chapter is a summary of report DWAF Report No PBV000-00-10306 (DWAF 2004a).

6.1 OVERVIEW

This chapter of the report presents the approach followed for the water quality assessment, and presents the Reference Condition (RC) and Present Ecological State (PES) for each Quality Resource Unit (QRU) evaluated during the study. As water quality assessment methods were revised during the study, clarification of the approaches followed are briefly outlined. The data requirements for a comprehensive assessment, as defined by the Thukela Inception Report (DWAF Report no. PBV000-00-10301, DWAF 2001b) were provided in this study as far as possible.

6.2 OBJECTIVES

The objectives of the water quality assessment were to assess RC and PES per QRU (as defined in Chapter 3, DWAF Report no PBV000-00-10306 (DWAF, 2004a).

6.3 METHODS

The Thukela Reserve Determination (RD) water quality 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. 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.

6.3.1 Thukela water quality study: Approach 1

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

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

6.3.2 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. It should be noted that Version 2 specifically was used for the Thukela study.
- Additional tools not prescribed in DWAF (2002a), i.e. the use of toxicological data and flow-concentration modelling. Acute (96-hour) and short-term sub-lethal (10-day) toxicology experiments were performed in recirculating artificial streams using site-specific indigenous invertebrates, and following a standard protocol (DWAF, 2000b). Sodium chloride was used as stressor to evaluate responses to salinisation, with Total Dissolved Salts (TDS) serving as a surrogate for salinisation. This assessment was done during the first part of the study, with results used largely during the water quality modelling phase. TDS results generated using toxicity testing were not used

to set PES, as the method followed by Approach 2 uses disaggregated individual inorganic salts to evaluate salinity, rather than TDS.

Modelling integrates water quality and quantity, and predicts the water quality conditions likely to occur under proposed flow scenarios. The methodology followed during water quality modelling is outlined in Chapter 11 (Report no. PBV000-00-10306).

- Expert judgement and the 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.

Table 6.1 A description of the approaches followed during the Thukela RD water quality study

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 variables 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. Determination of benchmarks: Generate generic tables of water quality boundary values, determine the reference condition and present ecological state, water quality input into the ecological importance and sensitivity assessment.
4. Assess the present ecological status.	
5. Select a future management class.	
6. Assign the Reserve.	5. Describe ecological specifications for each class: qualitative and quantitative specifications.
7. Design a monitoring system	

The A – F classification system (Chapter 7 Report no. PBV000-00-10306) was used throughout the Thukela study, but as Approach 2 calls for a water resource classification of Natural, Good, Fair and Poor, results for the water quality assessment are presented using both classification systems.

A detailed comparison of the two approaches can be found in the main Water Quality specialist report (DWAF, 2004a). Main issues are as follows:

- Methods of data manipulation (e.g. Approach 1 used *medians*, whereas Approach 2 primarily uses *means* and has stringent data requirements).
- Weighting of seasonal data for selected variables - Approach 2 only.
- Approach 2 discounts water quality modelling and does not allow for the collection of additional data.
- Approach 2 incorporates response variables such as biotic community composition and chlorophyll-a.
- Approach 2 is still incomplete, and contains many inconsistencies, incomplete methods and discrepancies.
- Approach 2 does not provide a method to obtain an overall site classification, i.e. deriving an overall category based on the assessment of the individual water quality constituents.
- Approach 2 does not clearly state how to address the water quality assessment if data for all the water quality constituents are not available.

6.3.3 Methods for determining RC and PES: Determination of benchmarks, data collection, and definition of categories

This section outlines the procedure by which RC and PES 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 (DWAF, 1999).

Before benchmarks (i.e. the key quantitative values, and qualitative, narrative descriptions that comprise the water quality component of the Ecological Reserve), and the RC, PES categories and quality Ecospecs can be determined, the following data assessment and manipulation must be undertaken, as required by DWAF (2002a).

- Check length of data series.
- Check for seasonality and uneven frequency of sampling – if so, conduct weighting procedure. A simple weighting procedure was followed to adjust the median and percentile data. Data were evaluated according to flow season, i.e. a period of high (summer) flow (October – March), and a period of low (winter) flow (April – September), and these categories weighted where required by the method, e.g. nutrients.
- Manipulate data to produce means, 5^{th} and 95^{th} percentiles.

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 determination of RC or PES. Data from the monitoring points were analysed, and a decision made as to whether the benchmark boundary values provided in DWAF (2002a) should 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 is provided in DWAF (2002a). When suitable RC data were not available (e.g. no suitable water quality monitoring point was available for the QRU), the PES defaulted to the benchmark tables.

DWAF (2002a) provides methods for 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. Confidence in the PES assessment is also linked to the data record. DWAF (2002a) lists the requirements per variable being assessed. Data analysis and interpretation of each of the constituents are described separately. Where constituents were not included in the analysis and assessment, it was either because insufficient information was available in DWAF (2002a) documentation to facilitate the assessment; or because the DWAF monitoring network did not include that variable, e.g. turbidity was not measured routinely in most of the Thukela catchment.

Inorganic salts

The inorganic salts used as indicators of salinity are, in order of increasing toxicity, calcium sulphate ($CaSO_4$), sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), sodium sulphate (Na_2SO_4) and magnesium sulphate ($MgSO_4$). Methods in DWAF (2002b) describe how toxicity data from international databases were used to derive the upper boundary levels for the Natural, Good and Fair categories. Boundary values for the A, B, C and D categories provided in EWQRCalc Version 2.3 were used, rather than the values in the benchmark values in DWAF (2002a) as the values in EWQRCalc Version 2.3 were more up to date (Jooste, RQS, *pers. comm.*). This spreadsheet model (in MS Excel) was provided to the water quality team to undertake the water quality 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.

Nutrients

The nutrients considered for the water quality assessment were 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. Although a high confidence method for adjusting the benchmark table values is provided in DWAF (2002a), the correct adjustment is shown below (Jooste, RQS and Rossouw, Ninham Shand, *pers. comm.*):

New Natural boundary = average of the data record
New Good boundary = Old Good + ((New Natural – Old Natural)/2).
New Fair boundary = Old Fair + ((New Good – Old Good)/2).

The PES data were then compared to the adjusted benchmark table values and a category assigned accordingly.

Dissolved oxygen

The DWAF-HIS (Hydrological Information System) data do not contain 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 class boundaries for only the Good and Fair classes. Determining RC and PES for pH was problematic due to the change in methods in the late 1980s, resulting in an anomaly in monitoring data. Although PES assessments were not provided for pH, quality Ecospecs are provided.

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 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. Assessment of turbidity could therefore not be undertaken. Turbidity data were also not available from the DWAF monitoring network.

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, 2001a) although some of the dams were capable of bottom releases. However, along with the lack of a method specified to assess RC and PES, and the lack of values in the benchmark table, there were also insufficient data (or no data) to undertake an assessment 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 a poor water quality) (DWAF, 2002a) or an inventory of effluent discharges indicating that there may be water quality issues to consider. 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). 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 with which to undertake a PES assessment. For these reasons, toxic substances were omitted from the water quality assessment (but were included as quality Ecospecs), and qualitative information was provided where available.

Biotic community composition (response variable)
Invertebrate biomonitoring data provide 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 macroinvertebrate as indicators is that they are able to provide an integrated response to water quality (specifically water quality changes due to organic pollution) over time, and to respond to pulses of changing water quality (which may not be captured by intermittent chemical sampling) and constituents which are not monitored. The method describes how to derive the Reference Condition (RC) and use this to adjust the benchmark table values if necessary, and how to conduct the PES assessment using these tables. However, the high confidence assessment requires that three or more sites be surveyed per unimpacted unit (for RC) and per QRU (for PES) over three non-high-flow seasons. These data requirements could not be fulfilled during this project.

Invertebrate 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 (response variable)
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.

Chlorophyll-a assessments were not included in the RDM protocols (DWAF, 1999), 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. QRUs were selected on the basis of the outcome of discussions at a Thukela specialist meeting held in October 2001, and on the analysis of water quality data using the DWAF (1999) method, which 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).

In-stream toxicity

Toxicity testing is important 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. According to DWAF (2002a), in-stream toxicity tests should be undertaken for an intermediate or comprehensive ecological Reserve assessment (these are referred to as medium- or high-level confidence assessments in DWAF, 2002a), but 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 these were analysed for acute toxicity using *Daphnia pulex* (water flea), a fish (the guppy *Poecilia*) and an algal inhibition test using *Selenastrum*. Samples were also analysed for sub-lethal toxicity using the AMES *Salmonella* mutagenicity test. Sites sampled were as follows:

- Sundays River downstream of Wasbank confluence: S 28° 32' 54'', E 30° 07' 10''.
- Little Thukela River close to Winterton: S 28° 47' 40'', E 29° 32' 38''.
- Horn River: S 27° 53' 26'', E 29° 57' 40''.
- Buffalo River downstream of Ngagane confluence: S 27° 42' 29'', E 30° 06' 59''.
- Mandini Stream: S 29° 10' 20'', E 31° 25' 20''.
- Thukela River downstream of Mandini confluence: S 29° 10' 44'', E 31° 26' 11''.

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

Results

Present Ecological State assessments are presented in the following Tables. 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 to the most downstream tributary.

Table 6.2 PES for Resource Unit A: Thukela River Rugged Glen to Woodstock Dam

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**

Table 6.3 PES for 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), 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**

Table 6.4 PES for 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), n=152
IFR number	2	**PES**	V1H057 (1996 - 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**

Table 6.5 PES for 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), 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**

Table 6.6 PES for 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 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**

Table 6.7 PES for 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), 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**

Table 6.8 PES for 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, 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**

Table 6.9 PES for 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), 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**

Table 6.10 PES for 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), 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**

Table 6.11 PES for 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), 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**

Table 6.12 PES for 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), 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	Lower Fair
Overall site classification for WQ		**B/C**	**Lower Good**

Table 6.13 PES for 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), n=49
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**

Table 6.14 PES for 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), 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**

Table 6.15 PES for 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), 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**

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**

Table 6.16 PES for 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), 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**

Table 6.17 Resource Unit S-T: Mooi River, Segments 16 – 30

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.

Table 6.18 PES for 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), 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**

Table 6.19 PES for Resource Unit U: Buffalo River from Utrecht/Osizweni 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), 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**

Table 6.20 PES for Resource Unit V: Buffalo River from the start of the rejuvenated bedrock zone to the confluence with the Thukela River

<table>
<tr><td>River</td><td>Buffalo River</td><td colspan="2">DWAF Water Quality Monitoring points</td></tr>
<tr><td>QRU</td><td>26</td><td>RC</td><td>V3H011 (1975 – 1979), n=126</td></tr>
<tr><td>IFR number</td><td>14</td><td>PES</td><td>Collected water quality data, site 2, n=8</td></tr>
<tr><td colspan="2">Water Quality Constituents</td><td>A - F system</td><td>Descriptive system</td></tr>
<tr><td colspan="2">$MgSO_4$</td><td>E/F</td><td>Poor</td></tr>
<tr><td colspan="2">Na_2SO_4</td><td>C</td><td>Upper Fair</td></tr>
<tr><td colspan="2">$MgCl_2$</td><td>B</td><td>Good</td></tr>
<tr><td colspan="2">$CaCl_2$</td><td>B</td><td>Good</td></tr>
<tr><td colspan="2">NaCl</td><td>A</td><td>Natural</td></tr>
<tr><td colspan="2">$CaSO_4$</td><td>A</td><td>Natural</td></tr>
<tr><td colspan="2">SRP</td><td>E/F</td><td>Poor</td></tr>
<tr><td colspan="2">TIN</td><td>D</td><td>Lower Fair</td></tr>
<tr><td colspan="2">Chl-a: phytoplankton</td><td>A</td><td>Natural</td></tr>
<tr><td colspan="2">Chl-a: periphyton</td><td>E/F</td><td>Poor</td></tr>
<tr><td colspan="2">Biotic community composition (invertebrates)</td><td>B</td><td>Good</td></tr>
<tr><td colspan="2">Overall site classification for WQ</td><td>C/D</td><td>Fair</td></tr>
</table>

7 ECOLOGICAL CLASSIFICATION: RIVER

Note: This chapter is a summary of report DWAF Report No PBV000-00-10303 (DWAF 2003b). The report is supported by the following specialist appendices from this report:

Appendix A: Hydrology
Appendix B: Water quality
Appendix C: Fluvial geomorphology
Appendix D: Riparian vegetation
Appendix E: Fish
Appendix F: Aquatic invertebrates
Appendix G: Social importance

7.1 OVERVIEW AND OBJECTIVES

The objective of the ecological classification step is to create an understanding of the Present Ecological State (PES) and the ecological functioning of the river in each of the Resource Units (RUs) and, based on this, to set realistic ecological aims/objectives for the river. From the PES, Ecological Categories (EC) are generated (a Recommended Ecological Category (REC) and one category better and one worse from the REC). On the basis of these, Ecological Water Requirements (EWR) are calculated per RU. This information is used to determine a number of different flow scenarios. These scenarios are described in Chapter 10 and the ecological consequences are described in Chapter 11 of this report.

Ecological classification must not be confused with the Classification System to determine Management Classes. It forms a component of the Classification System that considers a much wider suite of components than just Ecological.

7.2 METHOD

The sequential steps followed in Ecological Classification are shown in Table 7.1.

Table 7.1 The sequence of actions required for providing technical information on the EC. The left hand column shows the question that the action in the right hand column answers

What was the river like before human impact?	1. DETERMINE REFERENCE CONDITIONS.
Compared to how the river used to look like, what does it look like now?	2. DETERMINE PES. (Category A - F).
Is the river changing, and if so, how severely? how fast?	3. DETERMINE TRAJECTORY OF CHANGE IF THE STATUS QUO IS MAINTAINED.
What is the main cause for the change?	4. DETERMINE CRITICAL CAUSE FOR THE PES and/or the TRAJECTORY OF CHANGE.
What is the source of the causes?	AND GIVE THE SOURCE OF THE CAUSE.
How ecologically and socially important is the river?	5. DETERMINE IMPORTANCE AND SENSITIVITY CATEGORIES (Low, Moderate, High, Very High) as well as Socio-Cultural Importance.
What would the ecological aims be for the river?	6. CONSIDERING THE IMPORTANCE AND THE PRESENT ECOLOGICAL STATE SHOULD THE PES BE IMPROVED (if so, by how much) OR MAINTAINED? (NOTE: Maintaining the PES could still require restoration management depending on the trajectory of change). (Category A - D).
Can the main cause realistically be addressed to achieve the ecological aims?	7. DETERMINE WHAT WOULD BE REQUIRED TO ADDRESS THE CAUSES. 8. DETERMINE HOW DIFFICULT IT WOULD BE TO ADDRESS THE SOURCE. (RESTORATION/REVERSIBILITY POTENTIAL). (Easy, reasonable, difficult, very difficult). PROVIDE REASONS.
What should the Ecological category be for the river?	9. CONSIDERING THE ECOLOGICAL AIMS, AND THE DIFFICULTY OF ACHIEVING THE AIMS, DETERMINE THE ATTAINABLE ECOLOGICAL CATEGORY FOR EACH COMPONENT.

7.2.1 Determination of Reference Conditions

Natural Reference Condition (RC) describes the condition prior to anthropogenic change. The RCs are described for each specialist component. Historical information and data, and/or data from reference sites (minimally impacted sites) are used to describe the RCs for the channel, hydrology, biota, and the water quality. Due to data limitations and/or the absence of any existing A category RU, the Reference Condition may not represent a natural river state, but rather the best estimate of a minimally impaired baseline state. If the river has not changed, then the PES can be described as being in an A category condition, and the resource is in a natural, near to pristine, or minimally impacted state. For such a resource, the present state equals the reference condition. If the river has changed, it leads to the next step.

7.2.2 Determination of PES

The PES is derived from, or described as, deterioration from a described reference condition (which ideally relates to an A category condition). The degree of change is indicated by assigning a PES category to the RU from the range of categories provided in DWAF's present classification system (i.e. A to F). The PES of the river is assessed for each of the following components: habitat (habitat integrity), biophysical (fish, riparian vegetation, aquatic invertebrates and geomorphology) and water quality (chemistry) integrity. Each component is assigned a category level (A - F), where categories A - D are judged to be ecologically sustainable, and categories E and F indicate a current state that is ecologically unsustainable. The PES is compared with the RCs using:

- Surveys during the project.
- Results of historical surveys/databases.
- Aerial photographs.
- Expert judgement.

The assignment of an overall 'Ecostatus' for the RU is based on a subjective integration of the categories assigned to individual components.

7.2.3 Determination of Trajectory of Change

The Trajectory of Change describes the direction and rate of change of conditions in the RU, assuming that all present conditions remain unchanged. This change is as a result of the causes and sources described hereinafter. The trajectory can be stable ('0' or equilibrium condition), negative ('-' or actively deteriorating) or positive ('+' or actively improving). The trajectory is described for each of the components for which a PES is determined, and from this information it is possible to deduce whether the PES evaluation on the whole reflects a stable state, or whether the RU is still changing under present conditions. The changes in ecological state can occur at different rates, and rate of change is recorded as either short-term (< 5 years) or long-term change (> 20 years). The short and long-term changes must be provided for each RU of the river for which an EC will be generated, and for each component for which a PES was determined. In developing a 'do nothing' scenario (in later steps), information on the expected category in which the river would be in the short term (less than 5 years) and the long term (more than 20 years) are used. This information is derived from the Trajectory of Change.

7.2.4 Determination of critical causes for the PES and sources of the causes

The impacts on the river are listed and separated into flow-related and non-flow related activities and are referred to as causes. Proximal causes observed in the system due to changes in water quality, flow and external factors are for example higher salinity, sedimentation, loss of indigenous riparian plants, flow reduction, low abundance of indigenous fish, etc.

Certain causes may be related to changes in flow, for example a decrease in fish population. Loss of indigenous riparian vegetation could however be caused by catchment related activities such as deforestation for purposes of firewood. The determination of whether the causes are flow or non-flow related is important, as this influences the decision of whether mitigation solely by flow manipulation is possible and appropriate, or whether source-directed measures are necessary. For example: Flow reduction due to abstraction for irrigation could be mitigated by flow measures; loss of indigenous riparian vegetation due to overgrazing could not be mitigated by flow manipulation; water quality problems due to sewage treatment works could be mitigated by increasing flows for dilution, but it would not be appropriate to recommend Reserve flows for this purpose. This could be a valid management option.

Best judgement of the activities which have been responsible for the changes from the reference state to the PES, such as: overgrazing, irrigation, mining effluent, sewage treatment works, etc is used.

7.2.5 Determine the Ecological Importance and Sensitivity (EIS) and Socio/cultural Importance (SI)

EIS: The ecological importance of a river is an expression of its importance to the maintenance of ecological diversity and functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance and its capability to recover from disturbance once it has occurred (resilience). Both abiotic and biotic components of the system are taken into consideration in the assessment of EIS (DWAF, 1999, Volume 3).

SI: A study consisting of workshops and meetings with stakeholders as well as making use of questionnaires are undertaken. The results are used to answer a simple set of questions to determine the dependency of people on a healthy functioning river and also to assess the cultural and tourism potential.

When considering SI within the context of EIS the underlying assumptions in the process are the following:

- If the EIS is High or Very High, the REC should be an improvement of the PES.
- If the EIS is Low or Moderate, the SI is also considered, and if also Moderate or Low, the REC should be a Category that equals the PES.
- If the EIS is Low or Moderate, but the SI is High or Very High, the REC should be an improvement of the PES.

7.2.6 Based on the EIS, SI and PES, determine the ecological aims for the river.

If the ecological or social importance is high or very high, the ecological aims should be to improve the river. However, the PES should also be considered to determine whether improvement is realistic. If the EIS and SI evaluation is moderate or low, the ecological aims should be to maintain the river in its PES.

7.2.7 Assuming the sources are addressed, determine what would be required to achieve the ecological aims

The recommended EC must be attainable and it must therefore be considered whether the problems in the catchment can be addressed to ensure that the ecological aims are achieved. The specialists decide to the best of their ability what would have to be done to address the causes of degradation, how effective such remedial actions might be, and how difficult they might be to achieve (e.g. if a major supply dam had to be demolished to improve the river, this would be classed as 'very difficult') (O'Keeffe & Louw, 1999). It is acknowledged that this process is subjective and that evaluations are undertaken on the basis of technical possibilities as determined by ecological specialists.

7.2.8 Consider the difficulty of addressing the source of critical causes, and thus achieving the ecological aims.

In general it can be accepted that if the PES is in a C or D category or lower, and the importance is High or Very High, more effort would be required to attain an EC that is an improvement on the PES. However, the kind of change(s) that resulted in a particular PES may vary in terms of the possibility of reducing their impact, in order to achieve rehabilitation of the system. It follows that each of the attributes will have to be assessed in terms of the perceived possibility of rehabilitating them to a condition where such an improvement would lead to an improvement of the PES (DWAF, 1999 - Volume 8). Some changes may not be practically reversible within the limits of time and effort (including financial resources) required to achieve this. While five years is a commonly used timeframe for many institutions, and is considered a realistic period for attempting to estimate future conditions (Gonzalez 1996) it is difficult to put limits on what could be regarded as realistic efforts.

7.2.9 Recommend the attainable Ecological Category.

The long-term EC recommended ***indicates the EC that should be the end target for the river***. This EC, even though considered attainable, might only be achieved in the long term, due to the present constraints on the system. Several causes of change are landscape-based, and even immediate improvements in management practice would not show immediate improvements in river condition. This will require a long-term catchment strategy, as one of the aims of the NWA is to protect the water resource for future generations.

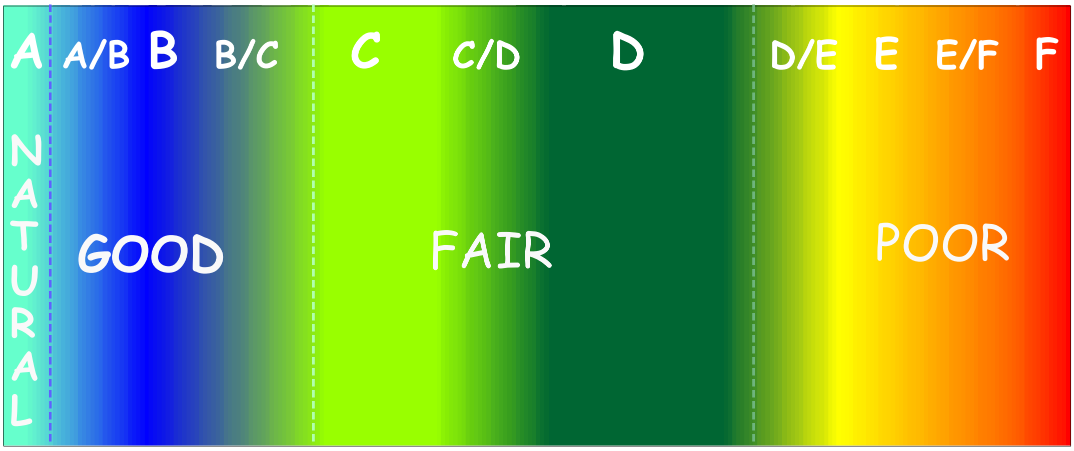
The PES and the difficulty of addressing the sources are assessed. As the EC must be realistic and attainable, even if only in the long term, an assessment must now be made of whether the aims (i.e. improvement or maintenance) can be met. For each component, an EC is set on this basis, and then the component ECs are integrated into one value, i.e. the Ecostatus EC and if necessary, a long-term EC.

7.2.10 Consider the link between Ecological Categories and Management Classes

The results of the process, i.e. the PES and EC determinations, are provided as different river categories, ranging from A (near natural) to F (completely modified). These will be converted to a descriptive terminology when applied to Management Classes, which are the output of the DWAF Classification System procedures (as referred to in the NWA and still in development). The interface between ECs and management Classes is provided in Figure 7.1.

The so-called ‘half categories’, e.g. B/C, are also used in cases where there are uncertainties regarding whether the category is, for example, a B or a C. Categories represent bands along a continuum, and the B/C therefore represents a condition between the B and C bands. An illustration of these concepts is provided in Figure 7.1.

Fig 7.1 **Illustration of the distribution of Ecological Categories on a continuum and the relationship with Management Classes. The Management classes are 'Natural, Good, Fair and Poor'.**



7.2.11 Define a range of ECs for which flow scenarios must be supplied

The range of Ecological Categories (ECs) for which flow scenarios must be supplied are guided by the rules as shown in Table 7.2. This must be seen as guidelines to determine a *realistic* range of ECs that can be addressed within the scenario-based approach.

Table 7.2 **Guidelines for the range of ECs to be addressed**

PES	Range of ECs
A	A
A/B	A/B, B/C
B	B, C
B/C	B, B/C, C/D
C	B, C, D
C/D	B/C, C/D, D
D	C, D
D/E, E, E/F, F	D

7.3 RESULTS OF THE ECOLOGICAL CLASSIFICATION PROCESS

The recommended ECs (from an ecological perspective) are provided spatially on maps (Figures 7.2 and 7.3) and tabulated (Table 7.3). A descriptive summary of the results follows.

Fig 7.2 Upper Thukela Ecological Classification results

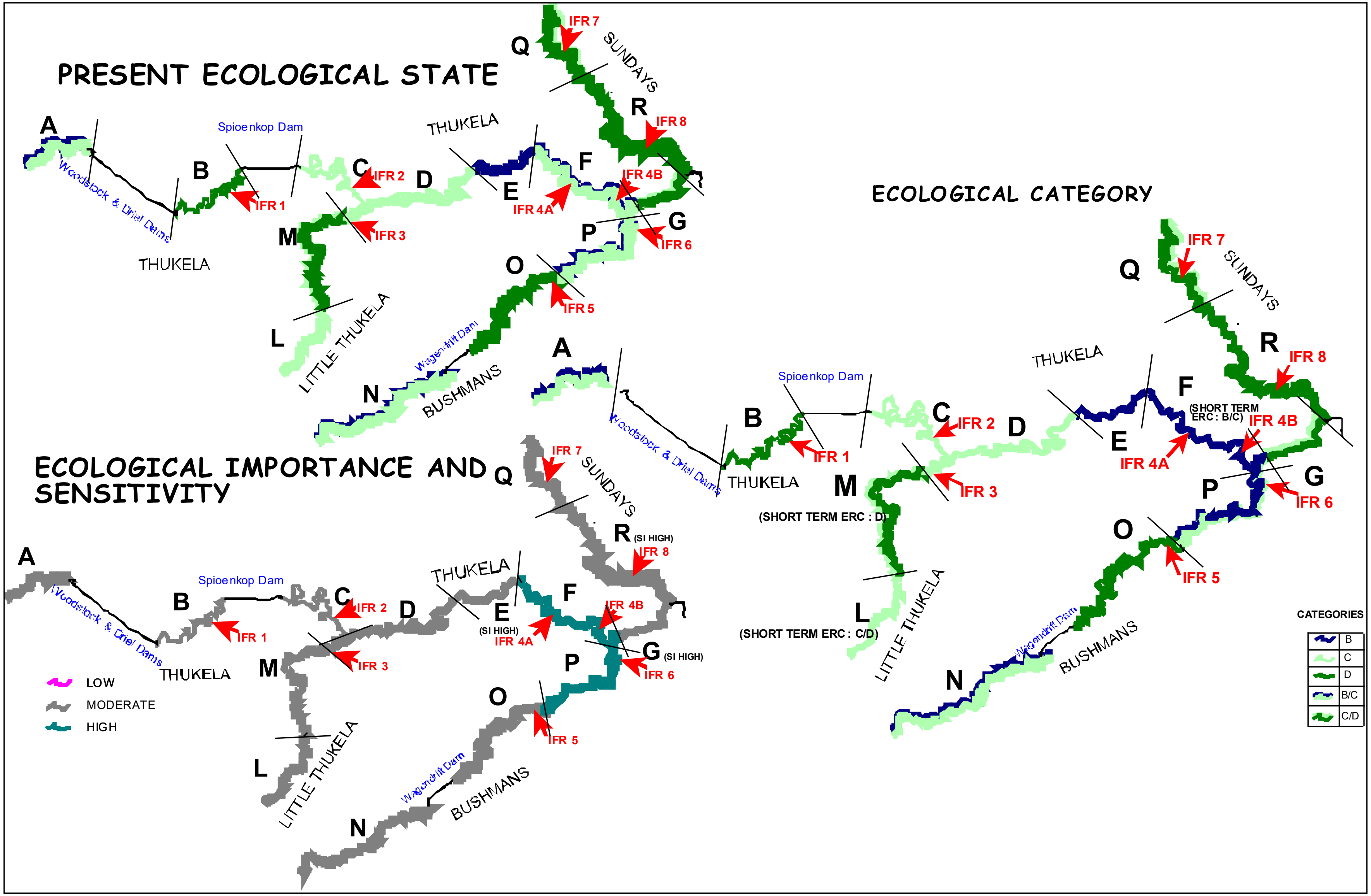
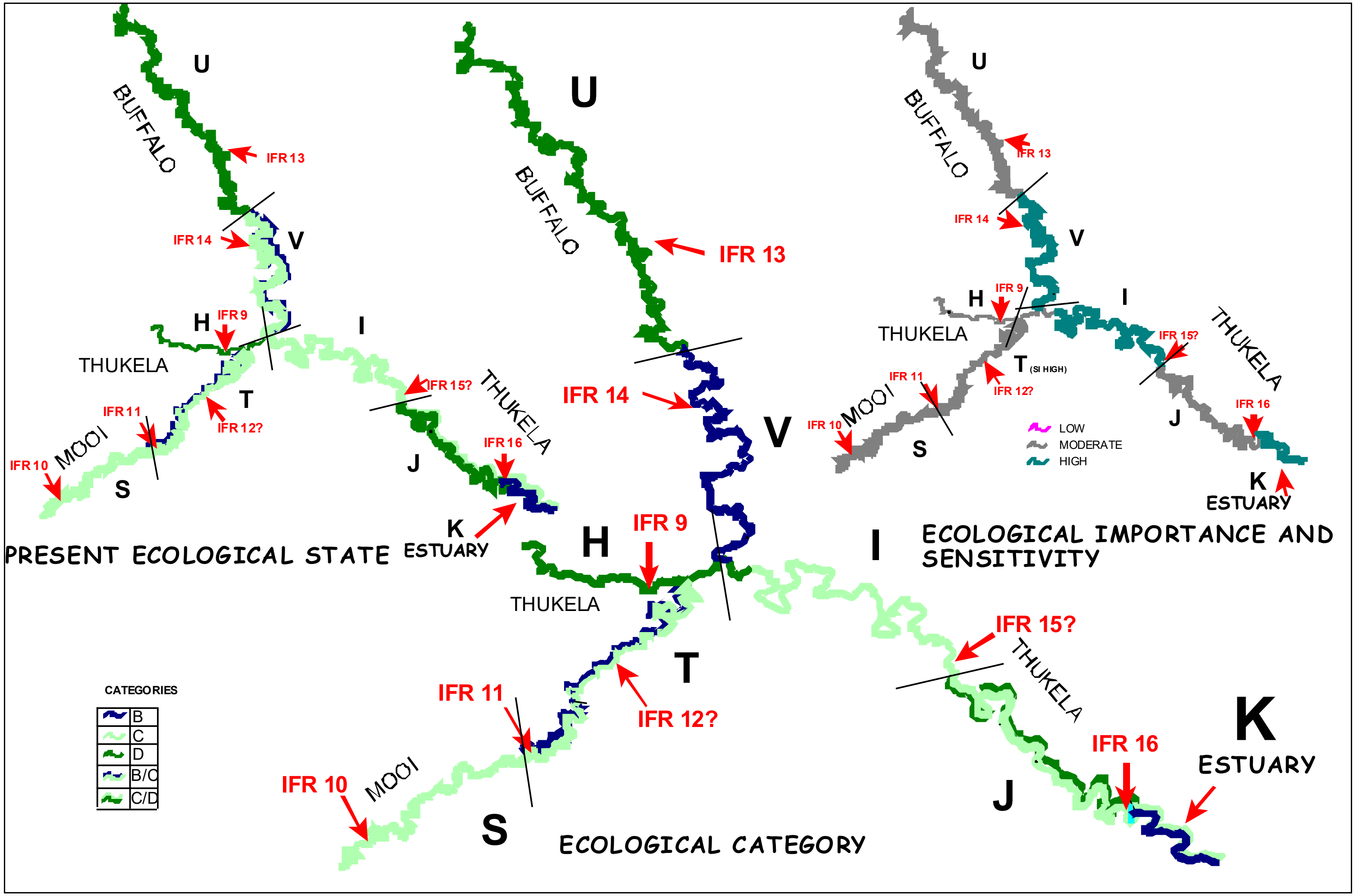


Fig 7.3 Lower Thukela Ecological Classification results



7.3.1 Thukela River

Ecologically, the section of the Thukela River that is considered closest to natural is the top most section of the study area (due to minimal disturbance) and the section in the gorge upstream of the Bloukrans River confluence (due to inaccessibility). The proposed Jana Dam site is situated in this gorge. The most ecologically modified sections in the Thukela River are those between Driel and Spioenkop Dams (due to the operation of the dams), and the downstream sections around Mandini (due to water quality and sedimentation problems).

The only sections assigned a high ecological importance are the gorge section in which Jana Dam site is situated, and the Buffalo River downstream of IFR 14. The aim for the gorge section is an improvement of the PES. The lower Buffalo River requires an improvement in water quality to achieve an improved EC.

The section downstream from the Klip River confluence has a higher SI than EIS. No improvement is however warranted, as the PES is a B and the recommended EC is already a B. The section of river downstream of the Bushmans River also has a high SI compared to the moderate EIS. However, an improvement of the PES will not improve the relevant socio-cultural components that are due to catchment (not flow) related problems.

7.3.2 Little Thukela River

The Little Thukela is in a moderately to largely modified state, mostly due to land-use practises. The EIS is moderate, and no improvements in categories are required.

7.3.3 Bushmans River

The Bushmans is presently in a largely natural to moderately modified ecological state above Wagendrift Dam, and in the gorge sections downstream of Wagendrift Dam. In the more accessible areas there are extensive irrigation activities that result in it being in a largely modified state. The EIS is high in the gorge section. Maintenance of the gorge will result in improvement of the downstream sections.

7.3.4 Sundays River

The Sundays River is largely modified due to land-use practises and specific water quality problems. The EIS is moderate, with a high SI in the lower section. This does not however warrant an improvement in the PES. Addressing the negative trajectory of change by recommending some improvements in the present management of the system will improve the social utilisation of the Goods and Services.

7.3.5 Mooi River

The section of the Mooi River included in the study area varies from largely natural in the gorge sections to largely modified areas in the downstream irrigation and rural areas. The EIS is moderate, and the SI is high in the downstream areas. Maintaining the gorge section in its present state will ensure an improvement of the downstream areas.

7.3.6 Buffalo River

The Buffalo River ranges from largely modified in the upper reaches or sections (largely due to formal agriculture and water quality problems) to largely natural in the gorge sections (mostly due to its inaccessibility). The high EIS in this section requires improvement in water quality to achieve an improved PES. The EC was therefore set half a category higher than the PES.

Table 7.3 Summary of the PES, EIS, SI and EC results

Dark blue = B; dark blue to light green = B/C; light green = C; light green to dark green = C/D; dark green = D

RU	PES	EIS	SI	EC
THUKELA				
A	B/C	Moderate	Moderate	B/C
B	D	Moderate	Low	D
C	C	Moderate	Moderate	C
D	C	Moderate	Moderate	C
E	B	Moderate	High	B
F	B/C	High	High	B (B/C)
G	C/D	Moderate/High	Moderate	C/D
H	D	Moderate	Moderate	D
I	C	High	High	C (C/D)
J	C/D	Moderate	Moderate	C/D (D)
Estuary	C	High	Moderate	C

RU	PES	EIS	SI	EC
LITTLE THUKELA				
L	C	Moderate	Moderate	C (C/D)
M	C/D	Moderate	Moderate	C/D (D)

RU	PES	EIS	SI	EC
BUSHMANS				
N	B/C	Moderate	Moderate	B/C
O	D	Moderate	Moderate	D
P	B/C	High	Moderate	B/C

RU	PES	EIS	SI	EC
SUNDAYS				
Q	C/D	High	High	C/D
R	D	Moderate	High	D

RU	PES	EIS	SI	EC
MOOI				
S	C	Moderate	Moderate	C
T	B/C	Moderate	High	B/C

RU	PES	EIS	SI	EC
BUFFALO				
U	D	Moderate	Moderate	D (D/E)
V	B/C	High	High	B (B/C)

7.4 CONCLUSION

In all cases apart from the following, the aim and EC were set to maintain the PES.

- IFR 4: Thukela River downstream of the proposed Jana Dam (RU F):
  Due to both the high EIS and SI, the B/C PES was improved to a B EC.
- IFR 14: Lower Buffalo River (RU V):
  Due to the both the high ecological and socio-cultural evaluation, the PES of a B/C was set to improve to a B EC. In this case however, the only improvement required to achieve this was in water quality. The flow regime for both a B/C and a B EC in this case would therefore be the same.

8 ECOLOGICAL CLASSIFICATION: ESTUARIES

Note: This chapter is a summary of report DWAF Report No PBV000-00-10308 (DWAF 2004c).

8.1 OVERVIEW

This chapter outlines the findings of an intermediate determination of the Ecological Reserve for the Thukela Estuary. In particular, it provides an outline and discussion of the following key components of the study:

- The Present Ecological State (PES).
- The Reference Condition (RC).
- The ecological importance of the Thukela Estuary (Note this is estuary-specific and is not equivalent to EIS).
- The Recommended Ecological Category (REC).

8.2 OBJECTIVE

The objective of the Intermediate Reserve Determination, as regards the estuary, was to examine various flow scenarios to establish their ecological consequences to this system.

8.3 METHOD

The standard RDM methodology for an Intermediate Estuarine Reserve Determination (DWAF (in press) Version 1) was following. The following sequential steps were taken to assess the Ecological Category of the estuary.

8.3.1 Initiation of the study

At the initiation of the RDM study, it was important to establish the level at which the study needed to be conducted (e.g. Rapid, Intermediate or Comprehensive). The Ecological Reserve Determination study on the Thukela was conducted at an Intermediate level, due to a lack of closed mouth condition survey information. Sediment dynamics, which is usually only included for the Comprehensive level study, was also included.

8.3.2 Determination of the Ecological Reserve

This step involved defining a REC for the estuary.

This exercise used simulated average monthly runoff scenarios that represented inflows at the head of the estuary, both for the *present state* and the *reference condition*.

In order to establish the present state of the estuary, the following components were evaluated and described:

Abiotic (or driving) components:
Physical dynamics (including hydrodynamics and sediment dynamics).
Water quality.

Biotic (or response) components:
Estuarine flora (microalgae and macrophytes).
Estuarine fauna (invertebrates, fish and birds).

Once the present state was established, the RC of the system was defined. The present state and RC of an estuary where then used to determine the PES using the Estuarine Health Index (EHI). The PES is a measure of the health of a resource, based on a comparison between the RC and the PES. The EHI score is made up of two key components: the habitat health score and the biotic health score. The habitat health score considers hydrology, hydrodynamics, water quality, and physical habitat. The biotic health score considers microalgae, macrophytes, invertebrates, fish and birds.

Once the PES was established, the ecological importance of the Thukela estuary was established. Ecological importance is an expression of the importance of an estuary to the maintenance of its ecological diversity and functioning on local and wider scales. Finally, the PES and ecological importance score were used to derive a Recommended Ecological Category for the estuary.

8.4 RESULTS

8.4.1 PES

The individual EHI scores, which were allocated to the PES of the Thukela Estuary, are presented in Table 8.1. The EHI score of 70 translated into a PES of a C (Table 8.2).

Table 8.1 Present State EHI scores

Variable	Weight	Score	Weighted score
Hydrology	25	87	22
Hydrodynamics and mouth condition	25	80	20
Water quality	25	54	14
Physical habitat alteration	25	80	20
Habitat health score			**75**
Microalgae	20	65	13
Macrophytes	20	60	12
Invertebrates	20	60	12
Fish	20	70	14
Birds	20	70	14
Biotic health score			**65**
ESTUARINE HEALTH SCORE			**70**

Table 8.2 EHI Score

EHI Score	Present Ecological State	General Description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	**C**	**Moderately modified**
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

8.4.2 Importance score

The estuarine importance scores allocated to the Thukela Estuary resulted in an overall importance score of 76 (Table 8.3) which translates into the estuary being ranked as 'Important' (Table 8.4).

Table 8.3 Estuarine Importance score

Criterion	Score	Weight	Weighted score
Estuary Size	80	15	12
Zonal Rarity Type	70	10	7
Habitat Diversity	50	25	13
Biodiversity Importance	76.5	25	19
Functional Importance	100	25	25
ESTUARINE IMPORTANCE SCORE			**76**

Table 8.4 Estuary Importance classification

Importance score	Description
80 – 100	Highly important
60 – 80	Important
0 – 60	Of low to average importance

The relationship between the EHI Score, PES and EC for estuaries is provided in table 8.5.

Table 8.5 EHI score, PES and EC for estuaries

EHI Score	PES	Description	REC
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

8.5 REC

Once the PES and the importance of the Thukela Estuary had been established, the REC was derived according to the rules outlined in Table 8.6.

In applying the rules it was established that because the Thukela Estuary is rated 'important' (reflected by the estuarine importance score of 76), the REC should be PES C+1 or 'Attainable State ', with Category C being the minimum class.

Results of the workshop indicated, however, that non-flow related anthropogenic activities (such as human disturbance of birds, over-fishing, and removal of wetlands for agriculture) had a significant influence on the PES of the estuary. As some of the changes caused by these activities would be difficult to reverse, the specialist team suggested that the PES corresponding to a C be selected as the REC, which would still remain within the REC allocation rules proposed for an 'Important' estuary.

Table 8.6 REC allocation rules

Current/desired protection status and estuary importance	REC	Policy basis	Corresponding Management Class
Protected area	A or BAS	Protected and desired protected areas should be restored to and maintained in the best possible state of health.	Natural
Desired Protected Area (based on correlation)	A or BAS		
Highly important	PES + 1, min B, or BAS	Highly important estuaries should be in an A or B category.	Good
Important	PES + 1, min C, or BAS	Important estuaries should be in an A, B or C category.	Fair
Of low to average importance	PES, min D	The remaining estuaries can be allowed to remain in a D category.	Fair

Thus, the REC for Thukela Estuary is a Category C (Confidence = Medium). However, it should be noted that the PES of the estuary corresponds to a high C (scored 70 in the range 61 – 75). This, together with the estuary being rated in the higher range of 'Important' estuaries (scored 76 in the range 60 – 80), is considered reasonable motivation to manage the estuary to be maintained in a **high C category**. This would be considered similar to a B/C in the riverine context.

9 INSTREAM FLOW REQUIREMENT SCENARIOS

Note: This chapter is a summary of report DWAF Report No PBV000-00-10307 (DWAF 2004b). and is supported by the following specialist appendices:

Appendix A: Hydrology
Appendix B: Hydraulics
Appendix C1: Bed material transport
Appendix C2: A review of the information relating to the geomorphology and sediment yield of the Thukela basin with a comment on its implications for the Instream Flow Requirements assessment
Appendix D: Habitat modelling
Appendix E: Fluvial geomorphology
Appendix F: Riparian vegetation
Appendix G: Low and high flow descriptions and requirements for all categories
Appendix H: Final results

9.1 OVERVIEW AND OBJECTIVES

The objective of this task was to provide flow regimes (IFR) for different sites in the rivers, to achieve a specific ecological state as described in Chapter 3 (Report no. PBV000-00-10307). These flow regimes are termed the flow scenarios, and should result in the achievement of the Ecological Categories recommended. The IFRs are provided as assurance rules that are used as input to the yield model. The flows are then modelled, the availability of the flows assessed, the impact on the yield evaluated, and the constraints in the system determined. The scenario development and ecological consequences assessment are described in Chapters 10 and 11.

9.2 METHODS

The Flow-Stress Response method (FS-R) was used to provide the low flows, and a method adjusted from the standard Building Block Methodology (BBM; King & Louw, 1998) and Downstream Response to Imposed Flow Transformation (DRIFT; Brown, C & King, J, 2002) approach was followed to set high flows.

The basis of the FS-R method is the application of a generic stress index describing the progressive consequences of flow reduction to the flow-dependent biota and river processes. Here, the **stressors** (e.g. flow), hydraulics and associated habitat changes are related to biotic **stress responses** in terms of abundance, life stages, and persistence. The generic stress index is adjusted for use to be specific both to sites and to components (fish, aquatic invertebrates, riparian vegetation). It is important that the values at both ends the stress index range (0 - 10) is well described. The zero stress index relates to optimum and abundant habitat conditions under low flows. Stress 8 relates to a trickle, stress 9 to no flow (i.e. still pools present) and stress 10 to no surface water available.

A FS-R approach is being developed for high flows but has not yet been used in a Reserve Determination study. The approach used for high flows in this study has elements of both the BBM and the DRIFT methodologies. The fish, invertebrate and riparian vegetation specialists provide the functions of floods (described as flood classes) and identify the size of the events using the hydraulic cross-sections, sediment transport modelling, photos and videos of known flows and interaction with the geomorphologists. The number of events of each flood class under natural conditions is determined. Depending on the objectives for each EC, the number of flood events is then recommended.

9.3 RESULTS

The results for the river, as linked to each IFR site, are provided in Figures 9.1 – 9.2. Results are presented as percentages of the natural MAR. All the results are summarised as percentages (see below) of the natural MAR in Table 9.1, with a confidence attached to the results.

- % Long (Long-term percentage): This refers to the % of the natural MAR required to match the IFR time series generated by the IFR rules, i.e. including periods of drought, maintenance, between drought and maintenance and above maintenance flows.
- % Tot: the total maintenance IFR a percentage of natural MAR.
- % Low: This refers to the maintenance low flow IFR as a percentage of the natural MAR.

The confidence column in Table 9.1 (last column) combines two sets of confidence evaluations, as well as the final evaluation, as follows:

- Requirements of the IFR components: These refer to the confidence in the biophysical data upon which specialists based their biophysical recommendations for required hydraulic parameters. Specialists provided these evaluations. Where applicable the column is split for low and high flows.
- Hydraulics: Confidence in the hydraulics varies for different ranges of discharges, depending on the discharges obtained in calibration of the hydraulic rating relationship. This confidence evaluation has been summarised for drought, low and high flows.
- Final confidence evaluation: Provided in capitals in the confidence column. The confidence is a combination of the confidence in the IFR components and the confidence in the conversion of ecological requirements to flow requirements by means of the hydraulics. A basic rule would be that even if one had reasonable confidence in the requirements of the individual IFR components, the overall confidence would be low if the hydraulic information to translate these requirements were of low confidence. Or, if one had low confidence in the requirements of the IFR components, but high confidence in the hydraulics; the overall confidence would be low as the conversion (of high confidence) to flow is irrelevant.

NOTE: IFR 6 and 12 was not evaluated further.

- IFR 6
  This was an old IFR site and had been irreversibly changed by the farmer. Access was limited and benchmarks destroyed. Due to the general lack of indicators present at the site additional (to the previous work) would not have any purpose.
- IFR 12
  This site could only be used if the benchmarks that had been vandalized would be reinstated by DWAF. These benchmarks were reinstated by DWAF after all site work was completed and could therefore not be used. However, this site could be used in future as a monitoring site.

Fig 9.1 IFR for the Upper Thukela, for a range of different Ecological Categories

(Note, where two pies are illustrated, the right pie is the REC. Where 3 pies are illustrated, the middle pie is the REC)

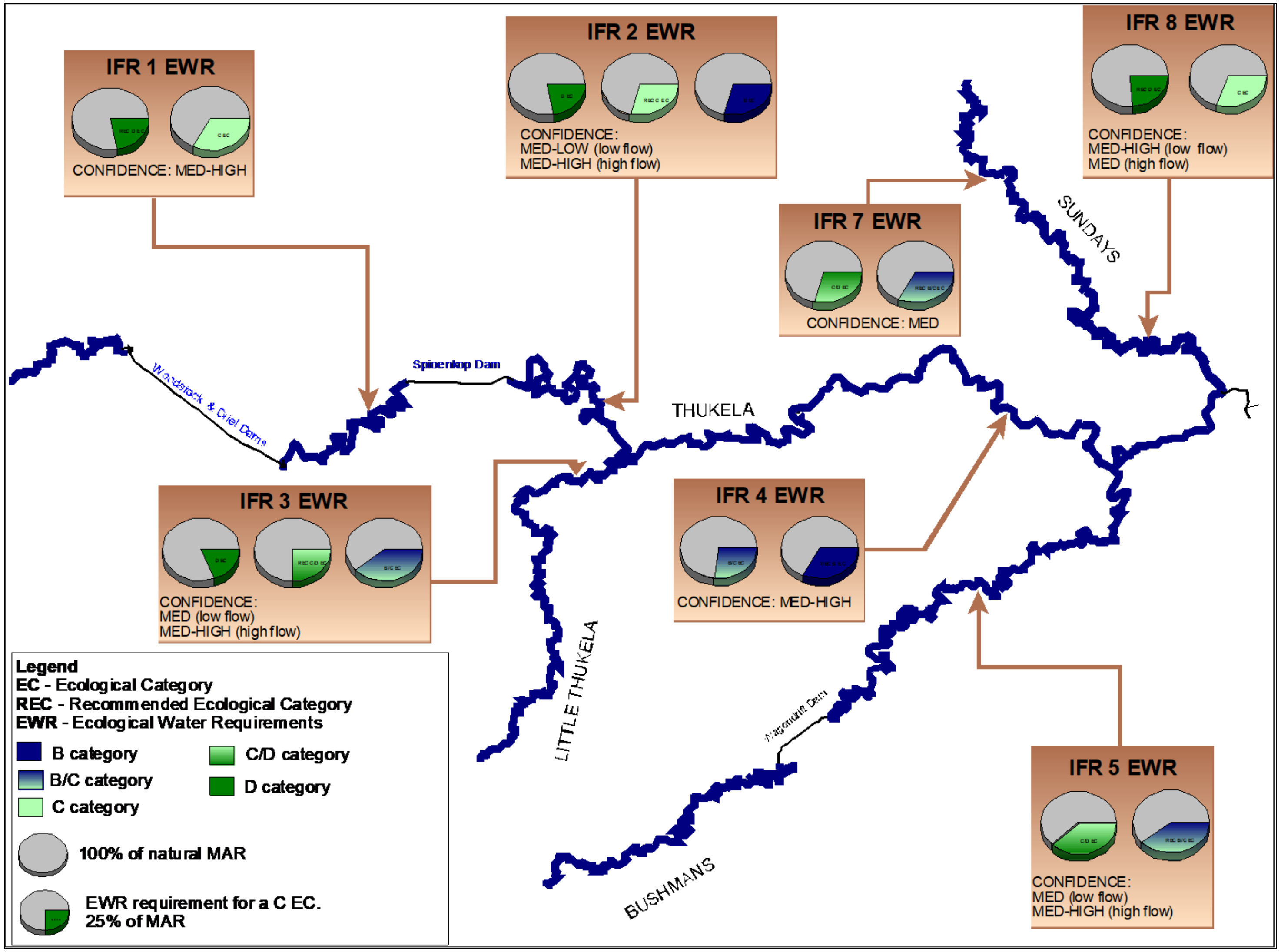


Fig 9.2 IFR for the Lower Thukela

(Note, where two pies are illustrated, the right pie is the REC. Where 3 pies are illustrated, the middle pie is the REC)

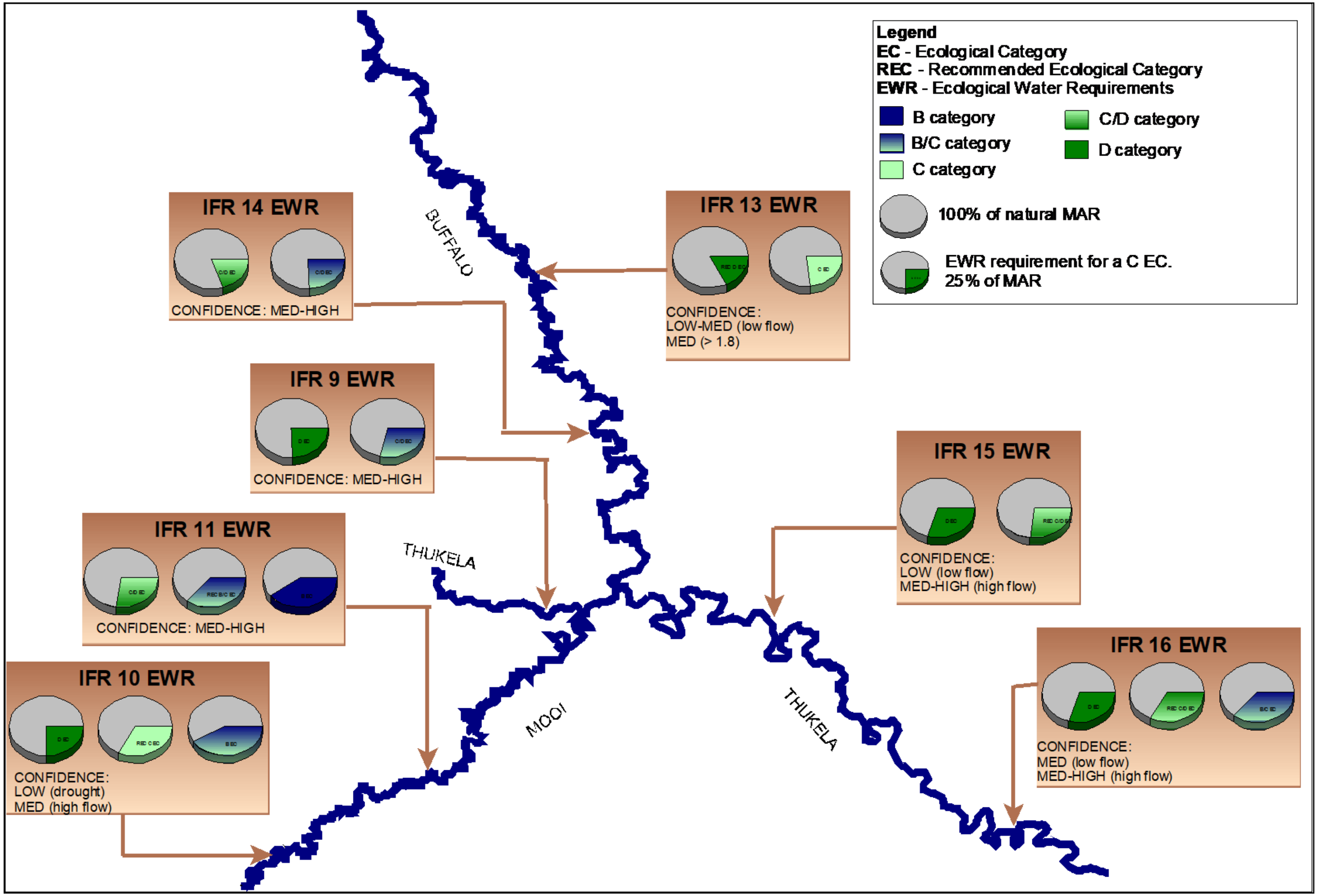


Table 9.1 IFR results

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
THUKELA RIVER														
A		C/D	-	22	9.2	B/C	-	35.5	19.1	B	-	40.84	24.4	Low, extrapolated
B	1	-	-	-	-	D	22.3	17.3	7	C	31.7	29.9	14.9	IFR components: Med-high to high Hydraulics: Med-high MED-HIGH
C	2	D	22	18.2	4.2	C	29	27.4	11.1	B	37.5	38.5	19.2	IFR components: Med-low (low flow), med-high (high flow). Hydraulics: High. MED-LOW (low flow), MED-High (high flow)
D		D	-	19.1	6.1	C	-	24.8	10.5	B	-	35.1	18	Low, extrapolated
E		C	-	25.4	10.1	B	-	35.3	18	-	-	-	-	Low, extrapolated
F	4 *1	B/C	29	28.4	12.4	B	31.8	31.8	14.7	-	-	-	-	IFR components: Med-high Hydraulics: Med-high MED-HIGH
G		D	-	18.94	-	C/D	-	22.1	9	B/C	-	30.8	14	Low, extrapolated
H	9	-	-	-	-	D	24.3	20.3	6.1	C	28.2	27.8	12	IFR components: Med-low Hydraulics: Med-high MED-HIGH*2
I	15	D	22.7	18.2	6.2	C	27	25.5	12.6	-	-	-	-	IFR components: Med-high Hydraulics: Low (low flow), med-high (high flow) LOW (low flow), MED-HIGH (high flow)
J	16	D	29.6	23.7	8.4	C/D	32.6	28.4	11.4	B/C	36	36.1	18	IFR components: Med (low flow), med- high (high flow) Hydraulics: Med (drought), med-high (rest) MED (low flow) MED-HIGH (high flow)

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
LITTLE THUKELA RIVER														
L		D				C				B				Low, extrapolated
M	3	D		18.6	6.1	C/D		24.7	11.1	B/C		42.8	21.4	IFR components: Med (low flow), med-high (high flow) Hydraulics: High MED (low flow), MED-HIGH (high flow)
BUSHMENS RIVER														
N		C/D	-	31.3	13.1	B/C	-	44.3	22	B	-	49.8	27.5	Low, extrapolated
O	5	C/D	37.5	32.7	13.3	B/C	47.4	45.4	22.4	-	-	-	-	IFR components: Med (low flow), med-high (high flow) Hydraulics: High MED (low flow), MED-HIGH (high flow)
P	6	C/D	-	32.1	13.1	B/C	-	44.7	22.2	-	-	-	-	Low, extrapolated
SUNDAYS RIVER														
Q	7	C/D	29.3	25.8	10.9	B/C	35.8	36.7	28.6	-	-	-	-	IFR components: Med Hydraulics: Med MED
R	8	-	-	-	-	D	24.1	19.6	6.8	C	29.5	28.7	13.1	IFR components: Med Hydraulics: High MED-HIGH (low flow), MED (high flow)
MOOI RIVER														
S	10	D	24.9	18.6	9	C	32.4	29.9	17.2	B	41.9	43.6	28.04	IFR components: Low-med to Med-high Hydraulics: Low (droughts), Med-high (low flow) LOW (droughts), MED (high flow)
T	11	C/D	27.2	23.5	12.4	B/C	35.4	36.3	22.1	B	39.5	42	27.7	IFR components: Med-high Hydraulics: Med-high MED-HIGH

RU	IFR	LOWER SCENARIO				RECOMMENDED SCENARIO				UPPER SCENARIO				CONFIDENCE
		ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	ERC	% Long	% tot	% low	
	BUFFALO RIVER													
U	13	-	-	-	-	D	18.1	16	3.9	C	23.1	22.2	9.2	IFR components: Med-high Hydraulics: Low-med (low), med-high (intermediate 0 LOW-MEDIUM (low flow), MEDIUM (>1.8)
V	14	C/D	20	18.1	5	B/C	24.1	24.8	10.2	-	-	-	-	IFR components: Med-high Hydraulics: High MED-HIGH

*1 Even though the IFR component evaluation is med-low, flows should be managed from Spioenkop to cater for IFR 4 which is a higher REC than IFR 9. IFR 9 should therefore get more flows than recommended and the confidence in achieving the REC is therefore linked to the hydraulics, i.e. med-high.

*2 IFR 4: 3 scenarios were supplied, B (recommended), B/C (alternative and PES), C/D (lower than PES). Only the B and B/C scenario fit into the table and C/D information needs to be used within the design of additional scenarios if necessary.

9.4 RECOMMENDATIONS

The confidence evaluation is discussed briefly in the second column of Table 9.2, the possible further work in the third column, and the opinion of the IFR coordinator regarding the necessity of the further work in the fourth column.

Table 9.2 Confidence evaluation approach

IFR site	Confidence Evaluation	Further work	Necessity
THUKELA RIVER			
1	Fish and invertebrates are primary motivators. Confidence for invertebrates is high and for fish medium to high. Hydraulics: Is low for the drought flow range. The lowest flow measured is $2.6m^3/s$ - the lowest droughts flows are $0.2m^3/s$.	Fish: Information can be obtained through monitoring. Hydraulics: Flows below $1m^3/s$ should be measured. Only necessary if the Reserve is challenged or if user requirements could impact the Reserve.	No immediate action required. Monitoring can address the issues.
2	Fish and invertebrates are primary motivators. Confidence at low flows is low to medium. This is related to lack of applicable habitat at the site. Hydraulics: Medium confidence for the drought flow range. The lowest flow measured is $1.5m^3/s$ - the lowest droughts flows are $0.5\ m^3/s$.	Fish and invertebrates: Information can be obtained through monitoring at more applicable sites. Requirements must then be translated for use at the IFR site. Hydraulics: Flows at $0.5m^3/s$ should be measured. As the confidence is medium, it is doubtful whether this is necessary.	No immediate action is required. Monitoring can address the issues.
4	Invertebrates and riparian vegetation are primary motivators. The confidence is medium-high. The lowest flow measured is $1.2m^3/s$. The lowest droughts flows are $1.7m^3/s$. The relevant confidence evaluation is medium-high.	No additional work is required. Standard monitoring should improve the confidence from medium-high to high. Hydraulics: No work is required unless any revision in the IFRs result in flows being recommended below $1.2m^3/s$.	None.
9	Aquatic invertebrates are the primary motivator. The confidence is low-medium. Hydraulics: Low – High confidence.	This site is a poor IFR site providing few cues for IFR determination. The REC of this site is a D compared to the B of the upstream site. If managing for the upstream B REC, this site will receive more water than required.	Standard monitoring could improve the confidence if required in future and if the upstream site is not managed for the B REC.
15	Invertebrates and fish are primary motivators. The confidence is medium-high to high. The lowest flow measured is $18m^3/s$ - the lowest droughts flows are approximately $2m^3/s$. The relevant confidence evaluation is low.	The site provides good instream cues. Riparian vegetation: Has low confidence, but this is due to the lack of vegetation on site and monitoring will probably be focused on the increase of exotics. Hydraulics: This is a very difficult site for modelling of hydraulics and photopoint monitoring and additional calibrations at all flows below approximate $183m^3/s$ are required.	As part of monitoring, the hydraulics and IFR should be updated.
16	Marginal vegetation dependent invertebrates are primary motivators (drivers?). The confidence is low-medium in the low flow range. The lowest flow measured is $17.3m^3/s$. The lowest droughts flows are approximately $4m^3/s$. The relevant confidence evaluation is medium.	Further work is required to confirm the primary driver's requirements on the cross-section, i.e. the marginal vegetation dependent invertebrates. Hydraulic: Further hydraulic calibrations under $10m^3/s$ are also required.	This work must be undertaken as part of the monitoring programme to confirm the invertebrate requirements. Hydraulics: Work to confirm the low flow conversions of the marginal vegetation invertebrate requirements is required as part of monitoring.

Table 9.2 Continued…

IFR site	Confidence Evaluation	Further work	Necessity
		LITTLE THUKELA	
3	Fish, marginal vegetation invertebrates and riparian vegetation are primary motivators. The confidence is medium for low flows. Fish: The confidence is based on the use of *Amphilius* as an indicator and the uncertainty regarding whether it occurs at the site. However, requirements set for *Amphilius* would be conservative for the other species, and it is therefore argued that the confidence in the IFRs from a fish perspective should be high. Invertebrates: The confidence is linked to a limited database. Hydraulics: The confidence is high.	Further work is required to refine the invertebrate requirements.	This work can be covered within the monitoring programme which should have specific emphasis on collating invertebrate baseline information.
		BUSHMANS RIVER	
5	Marginal vegetation invertebrates (wet season) and riparian vegetation are the drivers. Some fish points drive the line, but some are off the line. The confidence is medium. Hydraulics: The confidence is high apart from flows below 0.9 m^3/s and above $13m^3/s$.	Further work is required on the invertebrates and fish. This site formed part of the previous intermediate reserve assessment and no surveys on invertebrates have been undertaken. Hydraulics: Refinement at flows outside the range measured is required. Hydrology: The modelled hydrology was not representative of the hydrology at the site. The operation of the system in this river stretch is complex, especially the combination between abstractions and return flows. Further work is required to determine the applicability of the modelled hydrology (present day) to the IFR sites.	Invertebrates and fish: An extensive baseline study is required as part of monitoring. Hydraulics: Refinement at flows outside the range measured is required. Hydrology: A river reach specific hydrology study should be undertaken to determine the applicability of the RU hydrology to the site. All the above work must be included within the Reserve monitoring programme. This includes the refinement of the Reserve and the assumption on which the Reserve was based.
		SUNDAYS RIVER	
7	Invertebrates, fish and riparian vegetation (drought) are drivers. Vegetation: The confidence is low to medium (due to a lack of cues and understanding of the vegetation) and invertebrates (due to a lack of information of the link between marginal invertebrates and the marginal vegetation on the cross-section). The hydraulics confidence is medium above $0.25m^3/s$.	The IFR site is complex but provides a variety of cues for IFR sites. Fish and invertebrates: Further work is required on fish in general, and marginal invertebrates and the link to marginal vegetation and flow. Hydraulics: An improved rating table is required.	Fish and invertebrates baseline work is required as part of monitoring. This should also include the additional hydraulic refinement and the associated IFR refinement.

Table 9.2 Continued…

IFR site	Confidence Evaluation	Further work	Necessity
SUNDAYS RIVER			
8	Riparian vegetation (and one point of flow dependant invertebrates) is the driver. The confidence is medium. Hydraulics: The confidence is high due to the flows of 6.1 m^3/s. Higher flows are medium.	Further work is required for the riparian vegetation. However, as the vegetation is limited on site, further baseline collection surveys are not in the short-term going to supply any additional information. Monitoring on the vegetation and the status of alien vegetation would be more applicable. Hydraulics: Improved rating table is required.	Standard monitoring procedures are required as well as hydraulic refinement (and associated IFR refinement).
MOOI RIVER			
10	Fish and flow dependent invertebrates and riparian vegetation are drivers. Hydraulics: Confidence below 5.3m^3/s is low.	This site was a checking site during a previous Mooi River IFR refinement study and limited studies were undertaken on the site. Further work on the fish, vegetation and invertebrates is therefore required as well as hydraulics refinement at flows below 5.3m^3/s.	Intensive biological baseline required during monitoring. Hydraulics: Refinement is required - as well as the exact spacing of the cross-section.
11	The drivers are riparian vegetation and invertebrates. Confidence medium-high. Hydraulics: The confidence is medium below 1m^3/s and above 47m^3/s.	Limited additional information is required. Additional hydraulic refinement is only required if the Reserve flows fall outside the range.	Standard monitoring procedures.
12	This site was not evaluated as the benchmarks were removed. The results provided, were extrapolated and therefore of low confidence.	Once the benchmarks are re-established, a Reserve must be set after appropriate information has been collected.	As part of monitoring, the baseline information and hydraulic information must be collected. The Reserve must then be set.
BUFFALO RIVER			
13	The drivers are riparian vegetation, fish and flow dependent invertebrates. Confidence - Medium-High. Hydraulics: Medium below 1.8m^3/s	Although the confidence in the IFR components is reasonable, the requirements set for the different categories were not of much use to set the requirements. Some revision of the Reserve is required after monitoring. Hydraulics: Refinements are required if the IFR range is below 1.8m^3/s	Standard monitoring procedures as well as the refinement of hydraulics are required. A refinement of the IFR requirements for the different categories must be undertaken.
14	Drivers are flow invertebrates and riparian vegetation. Confidence: Medium-high. Hydraulics: Confidence is high to flows of 90 m^3/s. Above 90 m^3/s it is medium.	No further work is required.	Standard monitoring procedures is required.

9.5 CONCLUSIONS

The sites with the highest confidence results are IFR 1, 4, 9, 8, 11, and 14. Of these sites IFR 4, 9 and 11 are former IFR sites, i.e. more than the normal amount of information is available. Furthermore, for IFR sites 4, 11 and 14 sediment transport modelling as well as habitat modelling has been undertaken. This should result in higher confidence results.

Further work to increase the confidence in the results should be addressed as part of the monitoring programme.

10 DEVELOPMENT OF OPERATIONAL SCENARIOS

Note: This chapter is a summary of report DWAF Report No PBV000-00-10309 (DWAF 2004d).

10.1 OVERVIEW

IFR scenarios have now been developed by biophysical specialists as sets of possible flows which will achieve different river states (or Ecological Categories (EC)) for each IFR site. During this process, the specialists did not consider whether these flows could be supplied or managed. The impact on users was also not considered. To provide decision makers with more comprehensive information, it was necessary to examine each of the scenarios and their full range of implications. Thereafter, a process was followed to devise an optimised scenario that would have the least overall impact on the users and the ecology. All these scenarios were tested to determine the resulting state of the river and estuary, and the water quality consequences of each flow scenario were supplied.

10.2 METHODS

The decision-making process followed to determine a range of scenarios is described here:

- The Water Resources Yield Model (WRYM) was run using three different IFR scenarios: one that would achieve an EC higher than recommended (Scenario 1), one that would achieve the Recommended EC (REC) (Scenario 2), and one that would result in an EC lower than that recommended (Scenario 3).
- Water quality modelling was undertaken. The output of the yield model together with the water quality consequences form the Ecological Water Requirements (EWRs) or in this case, EWR scenarios.
- The results of the modelling process indicated that all three scenarios would result in a range of impacts on the yield and therefore on the users.
- An initial optimisation process that took account of operational constraints was completed and Scenarios 4, 5 and 6 were thus devised. These are called Operational Scenarios
- The WRYM model was run again, using the new scenarios as inputs.
- An initial evaluation of the ecological and yield impacts indicated that Scenario 5 had minimal ecological impacts, and Scenario 6 had minimal impacts on the yield.
- An additional scenario (Scenario 9) was devised using Scenario 6 input for areas where there were no ecological problems, and Scenario 5 where there were ecological problems (i.e. the EC was not being met) when Scenario 6 was applied. The flooding regime was also checked and optimised.

NOTE: All flow scenarios which are dealt with are, for the sake of simplicity, referred to as Flow Scenarios. Note, however, that Scenarios 1, 2 and 3 are EWR Scenarios and Scenarios 4, 5, 6, 7, 8 and 9 are Operational Scenarios.

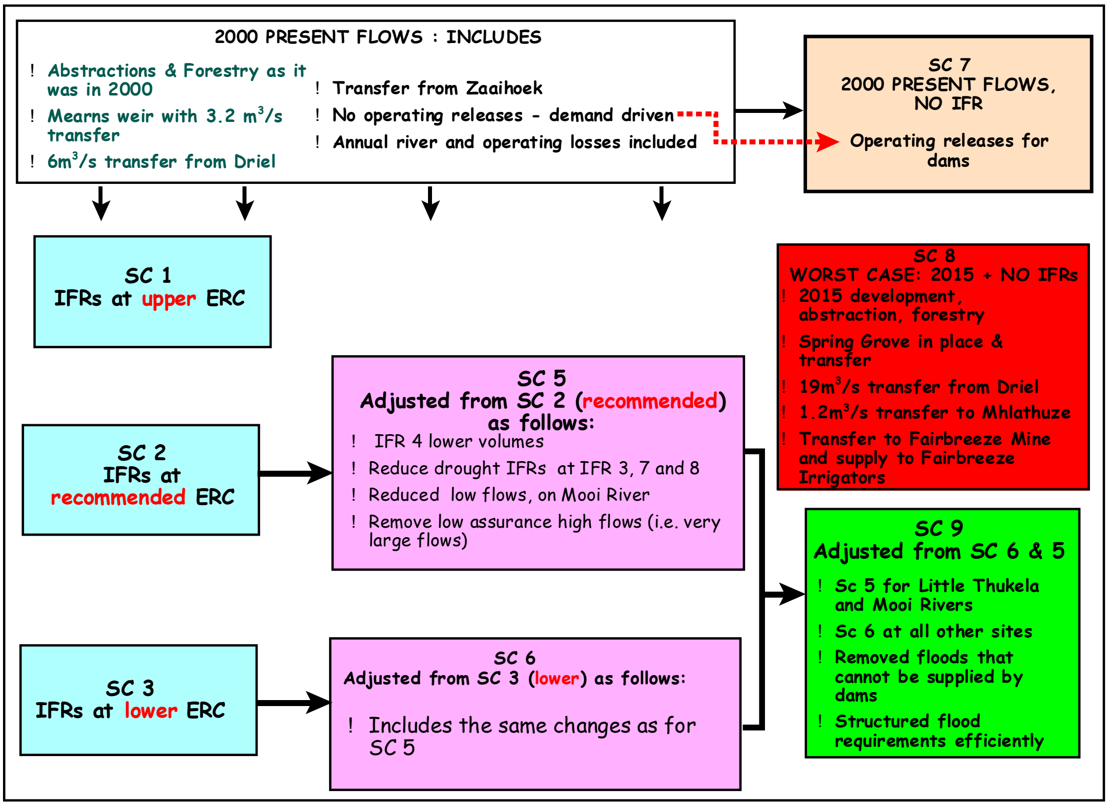
Note: Scenarios 1 and 4 were not evaluated further as they were considered unrealistic.

The Flow Scenarios are described in Table 10.1. The links between the scenarios are illustrated in Figure 10.1.

Table 10.1 Flow 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 Scenario 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 extended.
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 extended.
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.
9	This scenario was designed to achieve a better balance between ecological requirements and impact on water available to other users. Scenario 9 is a combination of Scenario 5 and 6, with changes in flood patterns.

Fig 10.1 Links between Flow Scenarios



11 ECOLOGICAL CONSEQUENCES OF THE FLOW SCENARIOS

Note: This chapter is a summary of report DWAF Report No PBV000-00-10309 (DWAF 2004d).

NOTE: All flow scenarios which are dealt with are, for the sake of simplicity, referred to as Flow Scenarios. Note, however, that Scenarios 1, 2 and 3 are EWR Scenarios and Scenarios 4, 5, 6, 7, 8 and 9 are Operational Scenarios.

11.1 OVERVIEW AND OBJECTIVES

In order for each of the Flow Scenarios to be thoroughly assessed, it was necessary to consider their ecological consequences. The ecological evaluation is based on an assessment of the impact of the scenario on the Ecological Categories (ECs) for each component. Information on the assessment of water quality as a key driver is provided here, followed by the overall ecological assessment.

11.2 WATER QUALITY CONSEQUENCES

Each of the Flow Scenarios was checked through simple flow-concentration modelling, to determine whether the water quality objectives would be met under various Operational Scenarios. Concentration exceedence curves were prepared, and the scenarios ranked according to the perceived impact on water quality. In addition, an examination was made of the percentage of time that the water quality variable would be in each water quality EC assessed. Where the water quality objectives could not be met, an assessment was made of whether the problems could be addressed at source. The methods followed during modelling are outlined below.

11.2.1 Methods

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 variables. 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. The flow scenarios were compared on the basis of the changes in the concentrations of key water quality constituents under changing flow conditions.

11.2.2 Assumptions and provisions

The most important assumptions and provisos in the Q-C method are as follows:

- Low confidence is expressed in the quantitative predictions obtained using flow-concentration and time-series water quality modelling, 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 at present.

- Concentration duration curves can be used to compare and rank some of the water quality consequences that will result from different flow scenarios. Caution should be used in using them to make exact quantitative predictions (e.g. to conclude that under a B category flow, TDS will be above (say) 300mg/ℓ *exactly* 50% of the time would be erroneous). Values given in this report are estimates.
- The water quality experienced by aquatic biota at a given site comprises many different variables. The effect of altered flow on many of these variables (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 that require further investigation, and 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..

The following information can be obtained using concentration-flow modelling, depending on the availability and reliability of data at each IFR site. The method is described in detail in Malan and Day (2002a, b) and Malan *et al*. (2003).

- Flow-concentration relationships for the key water quality variables that would be expected to occur in a river reach at a given flow.
- 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 (using the A-F classification system).
- In what month the worst water quality would be likely to occur and what concentrations could be expected.

11.2.3 Water quality modelling

Q-C modelling was used to estimate the concentration of a particular chemical constituent. RC water quality was inferred from either historical data or from an unimpacted tributary using the procedure described in the RDM manual of DWAF (1999). The data used for Q-C modelling were the same as those used in the water quality assessment, except for IFR 11 at Mooi River, where data from 1994 – 1998, V2H004Q01, was used for PES due to the proximity of the gauging weir to the IFR site, and IFR 13 on the Buffalo River where data from V3H011Q01, 1975-1979, was used for RC. 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 data set.

Mean monthly flow values were correlated with median monthly concentration values for each variable. 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 variables of concern were also modelled. Total dissolved solids (TDS) was the most common water quality variable that was modelled, as it is a conservative constituent that is usually highly correlated with flow. Modelling of individual salts was carried out only at sites where data were available, and where elevated salinity was considered to be an issue.

Graphs of concentration versus flow were plotted and a regression line drawn through the data points. Graphs can be seen in the main Water Quality specialist report, i.e. DWAF, 2004a - Report no PBV000-00-10306. The *best fit* was chosen by using the relationship that yielded the highest value of the coefficient r^2. Q-C relationships were 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 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 flows (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 represented 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 (2002).

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. Concentration exceedence curves were prepared and the scenarios ranked according to their 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. As is expected from the dilution effect at high flows, TDS, sulphate, and individual salts usually showed a slight to marked decrease with increasing flow at all sites. In general, the relationship between SRP and flow was poor, and this constituent was generally 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.

11.2.4 Results

Table 11.1 and Figure 11.2 present a summary of the results of the assessment of water quality consequences under different flow scenarios. Results indicate whether the recommended water quality EC will be met under each scenario per IFR site, and where Source Control Measures should be implemented (Figure 11.2). Conditions associated with the results are listed below the Table 11.1.

Table 11.1 Water quality consequences of the different flow scenarios

Y=Yes; N=No; EC=Ecological Category; SCM=Source Control Measures

IFR site	Sc2		Sc3		Sc 5		Sc6		Sc7		Sc8		Sc9	
	EC?[1]	SCM?[2]	EC?	SCM?	EC?	SCM?	EC?	SCM?	EC?	SCM?	EC?	SCM?	EC?	SCM?
THUKELA RIVER														
1	Y	N	Y	N	Y	N	Y	N	Y	N	N	Y	Y	N
2	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
4 *	Y	N	Y	N	Y	N	Y	N	Y	N	N	Y	Y	N
9	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
15 *	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
16	Y	N	Y	N	Y	N	Y	N	Y	N	N	Y	Y	N
LITTLE THUKELA RIVER														
3	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N

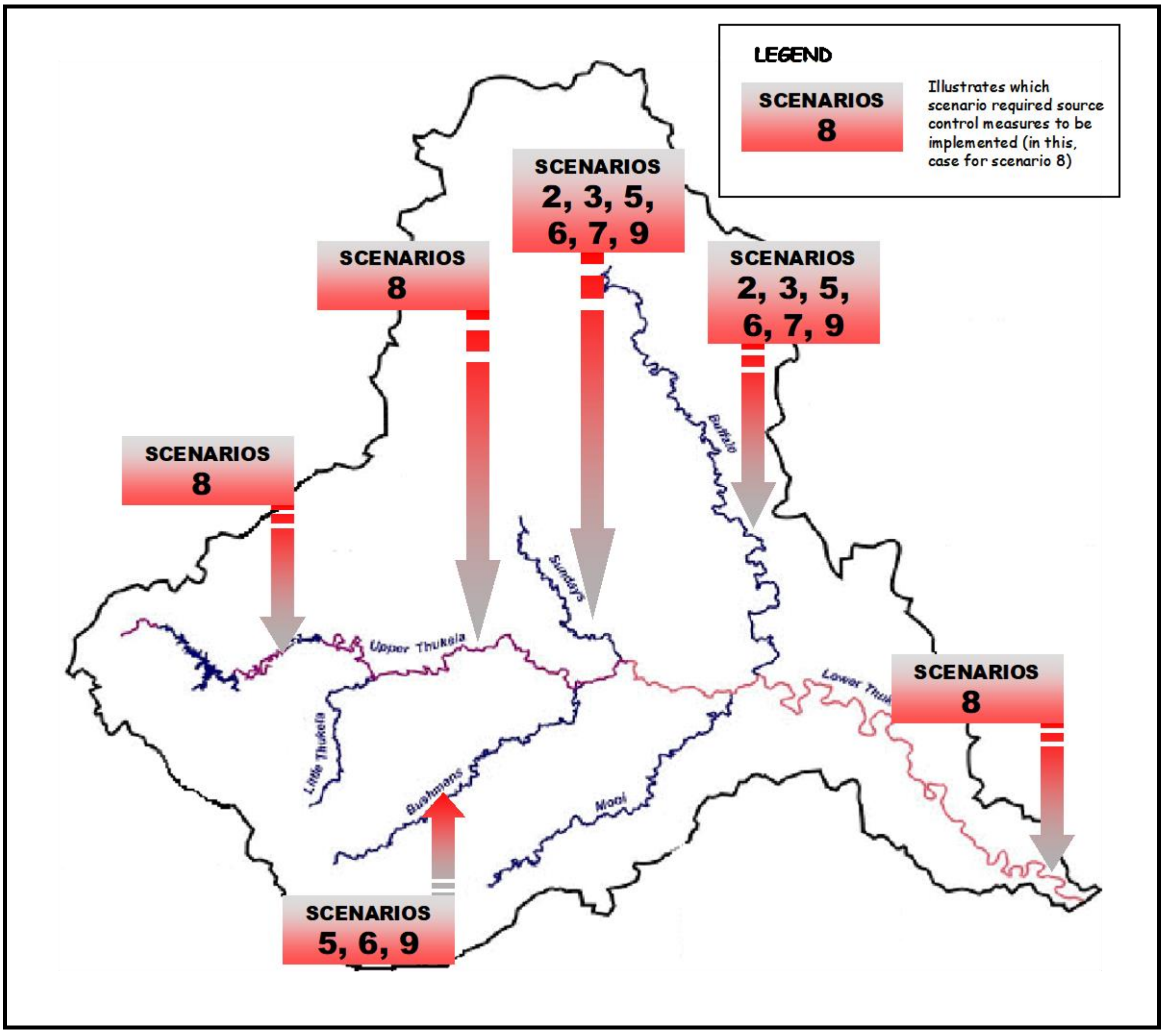
IFR site	Sc2		Sc3		Sc 5		Sc6		Sc7		Sc8		Sc9	
	EC?[1]	SCM?[2]	EC?	SCM?	EC?	SCM?	EC?	SCM?	EC?	SCM?	EC?	SCM?	EC?	SCM?
BUSHMANS RIVER														
5 *	Y	N	Y	N	N	Y	N	Y	Y	N	Y	N	N	Y
SUNDAYS RIVER														
7#	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
8 *#	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
MOOI RIVER														
10	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
11	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
BUFFALO RIVER														
13	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
14*	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y

1 REC (Recommended Ecological Category)?: If the flow scenario is implemented, will the recommended water quality EC be met?
2 SCM (Source Control Measures)?: If the EC cannot be met, is SCM required and realistic?
* Low confidence as no modelling was carried out and few data points for PES assessment (weekly data for two months – August and September 2001).
# Note that the criteria for evaluating magnesium sulphate have not been verified and there is therefore low confidence with the assessment of an E/F (see the notes for IFR 7 and 8 below).

Note that:

- Table 11.1 refers to the PES and EC as determined by the revised methods of DWAF (2002) for assessing the Ecological Reserve: Water Quality. To maintain continuity with previous reports based on DWAF (1999) water quality methods, a "y" or "yes" in the EC column means that the present state will be maintained
- **Sc 8, IFR 1:** Elevated phosphates, therefore agricultural practices to be managed and improved.
- **Sc 8, IFR 4:** Elevated sulphates and nutrients – Klip River input to be managed.
- **Sc 8, IFR 16:** Elevated phosphates and sulphates.
- **Sc 5, 6 and 8, IFR 5:** Concerns include Estcourt's sewage effluent and erosion in the area (professional judgement and catchment knowledge used, as water quality data does not reflect these concerns (e.g. no turbidity data)).
- **IFR 7:** Flow scenarios are similar to present, except during the dry season. Changes in flow would therefore not be sufficient to change the current status, but Source Control Measures (SCM) should be implemented under all scenarios due to high sulphates and phosphates. Management of acid-mine drainage from coal mines is therefore required.
- **IFR 8:** Flow scenarios are similar to present; changes in flow would therefore not be sufficient to change the current status, but SCM should be implemented under all scenarios due to high sulphates and periphyton. Management of acid-mine drainage from coal mines, particularly in the Wasbank catchment, is therefore required.
- **IFRs 10 + 11:** There are high periphyton levels at a site located between these IFR sites, so although conditions at the sites will be maintained under all flow scenarios, reductions in flow will exacerbate periphyton conditions downstream of IFR 10.
- **IFR 13:** Although all flow scenarios are similar and will maintain current conditions, the PES is not acceptable and SCM are needed to address high sulphates and nutrients. The upper Buffalo River is of particular concern.
- **IFR 14:** Although all flow scenarios are similar and will maintain current conditions, the PES is not acceptable and SCM are needed to address the high sulphates and the periphyton conditions.

Fig 11.1 Areas where Source Control Measures will be required under certain flow scenarios



11.3 CONCLUSION

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 possible using water quality modelling.

11.4 ECOLOGICAL CONSEQUENCES

11.4.1 Method

The ecological evaluation is based on an assessment of the impact on the ECs for each component, as well the overall Ecostatus.

The tools used to undertake the evaluation are the following:

- Flow duration graphs for the wettest and driest flow months, consisting of graphs for natural flow, present day, the IFRs and each flow scenario to be evaluated.

- Stress duration graphs (stress profiles) of the wet and dry season, illustrating the natural, present day and Flow Scenarios.
- Stress indices for each component, providing all the descriptions for stresses ranging from 0 - 10 as well as the motivations for the stress levels at specific durations that were selected to represent the requirements for each component in each category.

The process to provide the ecological consequences entailed the following:

- **Scenarios requiring evaluation:** As the scenarios were too numerous and in some cases too similar to evaluate individually, an initial evaluation based on the flow duration graphs was made to identify similarities at sites. Where necessary, these were checked using the FS-R profiles. Similar scenarios were combined and assessed as one.
- **Scenarios converted to stress profiles:** Each scenario to be evaluated at every IFR site was converted to a stress profile, and the wet and dry season stress profiles were provided in graph form.
- **Resulting states for each scenario:** The resulting categories for each component and for the Ecostatus were provided for each Flow Scenario.
- **Consideration of non-flow related issues:** A qualitative rationale for the changes in category which would result when non-flow related issues are considered is provided.
- **Geomorphological evaluation and assumptions:** As only monthly modelling is provided, it is problematic to evaluate the impact on required floods. For the purposes of these assessments, it is therefore assumed that if a higher volume than that required for low flows are provided for a flow scenario, this would be available for floods. The assessment is therefore undertaken based on available volume only.

2.3.2 RESULTS

The results depicted on Figures 11.3 – 11.4 are summarised in Table 11.2. A Traffic Light diagram comparing the ecological effects of the different scenarios is shown in Figure 11.2. The results per IFR site are summarised in Figures 11.3 and 11.4.

Table 11.2 Summary of ecological results

Note: For the purpose of this table the estuary is referred to as an IFR site, i.e. there are 14 IFR sites in the river which have been addressed, and the estuary – a total of 15 IFR sites.

Scenario	No. of IFR sites MEETING the recommended EC	No. of IFR sites NOT MEETING the recommended EC
2	14	1 (IFR 4[1])
3	11	4 (IFR 3, 4, 10 & 11)
5	14	1 (IFR 4)
6	11	4 (IFR 3, 4, 10 & 11)
7	6	9
8	2	13
9	14	1 (IFR 4)

1 None of the scenarios meet the recommended EC for IFR 4, which in this case was an improvement in the PES. The PES at IFR 4 would however be maintained.

11.4.2 Conclusions

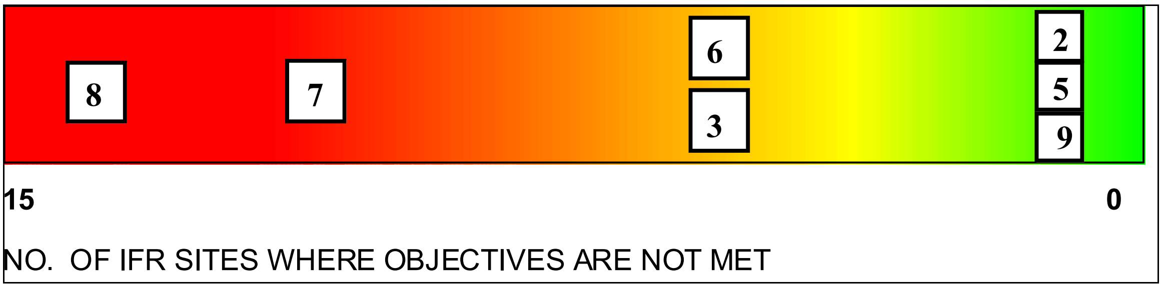
It is clear from Table 11.2 that Scenarios 2, 5 and 9 would provide adequate flows to attain the recommended Ecological Category at most sites (although IFR 4 below Spioenkop Dam is problematic as it does not meet the ecological objectives). Scenarios 3 and 6 would be problematic at IFR Sites 3 (Little Thukela), 10 and 11 (Mooi), as well as at IFR 4. Scenario 7 shows that the current situation, even with releases from the main dams, does not meet the recommended EC at 9 sites. Scenario 8 shows that the river, if not better managed, would continue to degrade at 13 sites as the system was further developed.

It should be noted that Scenarios 2 and 3 were initial attempts to see what flows meeting the EC would do in terms of the amount of water available. Scenarios 2 and 3 should be seen as one end of a continuum and, in fact, some of the floods that were included in the scenarios could not be supplied. As such, Scenarios 5, 6 and 9 were developed to give a more realistic picture of how the river could be managed.

The Traffic Light diagram in Figure 11.2 summarises Table 11.2 and shows the approximate difference between scenarios, from an ecological point of view, along a continuum of the scenarios.

Fig 11.2 Ecological comparison of scenarios.

Note that red illustrates an unacceptable situation for ecology and green an acceptable condition. The numbers in the traffic diagram in the white blocks refer to scenarios. The scale refers to the number of IFR sites.



The continuum illustrates how successfully the Flow Scenarios meet the IFR objectives at the 15 IFR sites. Scenario 8 fails to meet the ecological objectives at 12 IFR sites, whereas Flow Scenarios 2, 5 and 9 fail to meet the objectives only at IFR 4. IFR 4 is one of the sites where improvement is required. Although the improvement cannot be met, the PES is maintained. These scenarios will therefore not degrade the river at IFR 4.

Fig 11.3 Ecological consequences of Operational Scenarios at each IFR site: Upper Thukela

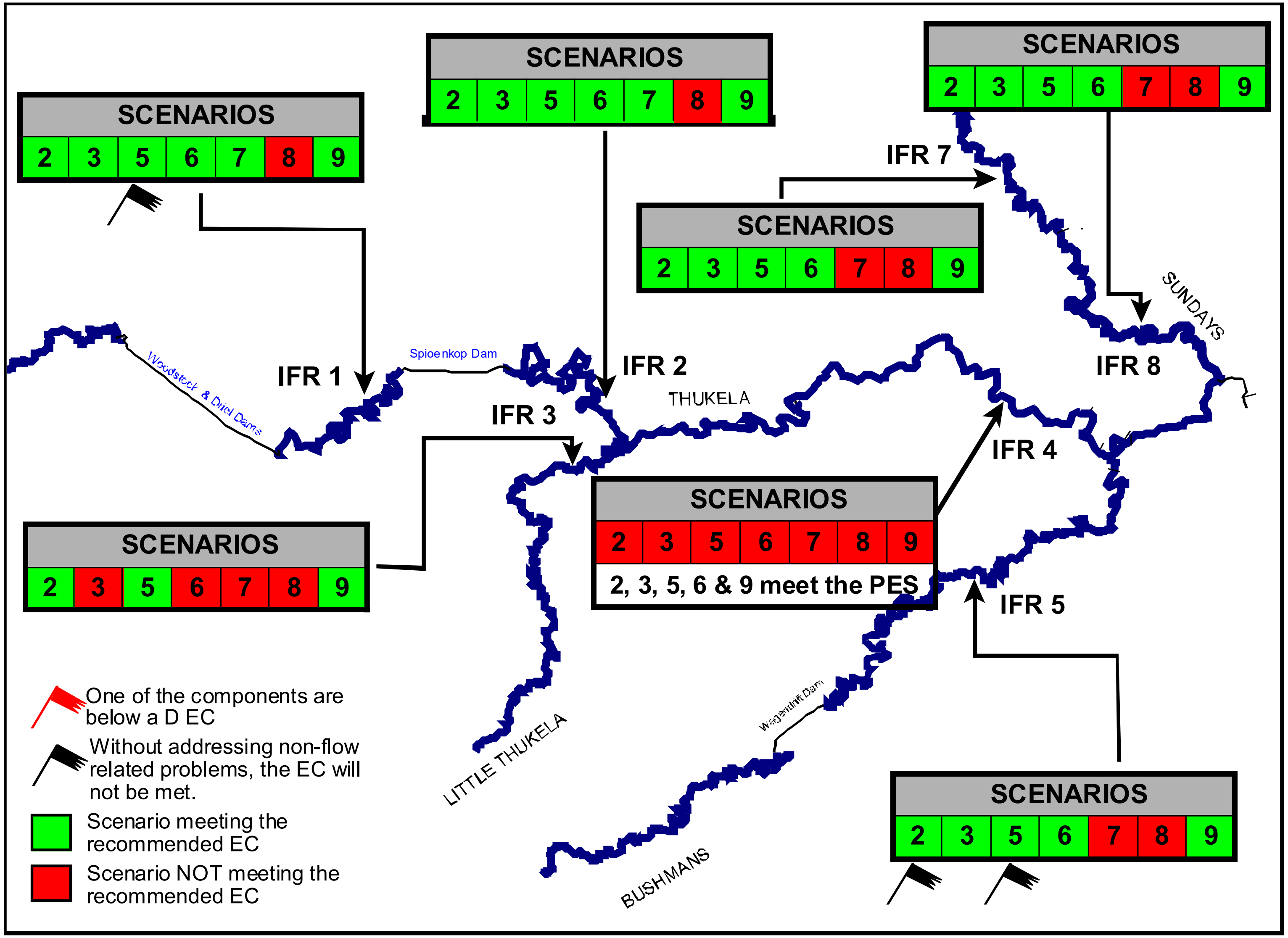
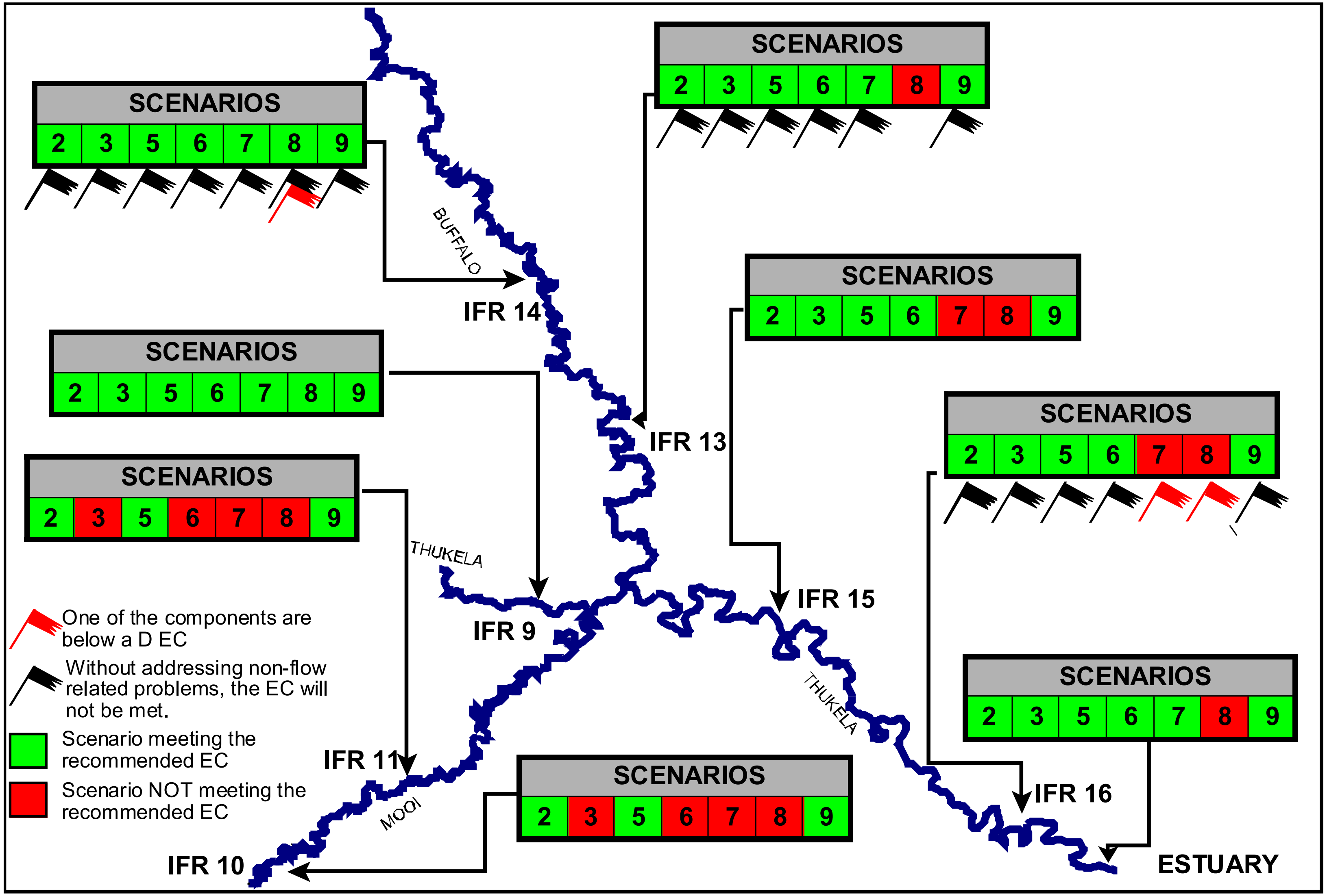


Fig 11.4 Ecological consequences of Operational Scenarios at each IFR site: Lower Thukela



12 ECOLOGICAL CONSEQUENCES OF THE FLOW SCENARIOS: ESTUARIES

Note: This chapter is a summary of report DWAF Report No PBV000-00-10309 (DWAF 2004d).

NOTE: All flow scenarios which are dealt with are, for the sake of simplicity, referred to as Flow Scenarios. Note, however, that Scenarios 1, 2 and 3 are EWR Scenarios and Scenarios 4, 5, 6, 7, 8 and 9 are Operational Scenarios. For the estuaries additional scenarios were also evaluated. These were estimated IFR scenarios and are referred to as River Desktop Estimates.

12.1 OVERVIEW

This chapter outlines the findings of an Intermediate Reserve Determination of the Ecological Reserve for the Thukela Estuary. In particular, this chapter outlines and discusses the following key components of the study:

- The ecological consequences of the River Desktop Estimates.
- The ecological consequences of the IFR and Operational scenarios, i.e. the Flow Scenarios.

12.2 OBJECTIVE

The objective of the Intermediate Estuarine Reserve Determination was to examine various flow scenarios to establish their ecological consequences to the Estuary.

12.3 METHODS

The standard RDM methodology for an Intermediate Estuarine Reserve Determination was followed, a number of sequential steps being completed to establish the consequences of the various flow scenarios

12.3.1 Quantification of the River Desktop Estimates

To ensure that the riverine and estuarine results were integrated, an initial set of flow scenarios (Table 12.1) were examined by the estuary specialists in June 2002. These scenarios were generated using the Desktop Model prior to the IFR scenarios becoming available. The evaluation of these scenarios involved examining the Desktop Estimates for different Ecological Categories (ECs) (i.e. A to D) provided for the river reach immediately upstream of the estuary (RU J). In addition, to ensure that a good spread of scenarios had been examined, two worst-case flow scenarios were included.

Table 12.1 River Desktop Estimates

Scenario	MAR ($m^3 \times 10^6$)	% MAR
Reference Condition	3753.6	100
Present Day (1995)	2756.4	73.4
Category A River	2494.8	66.5
Category B River	2258.4	60.2
Category C River	2056.8	54.8
Category D River	1915.2	51.0
Worst Case 1	1788.0	47.6
Worst Case 2	1669.2	44.5

To determine the EC of the estuary for each scenario, the anticipated changes in abiotic characteristics were assessed in terms of their biological implications, using the same Estuarine Health Index used to derive the Present Ecological State (PES). Results from these evaluations were then used to select the 'recommended reserve scenario', defined as the run-off scenario (or a slight modification thereof) that represented the largest reduction in river inflow that would still protect the aquatic ecosystem of the estuary and maintain it in the Recommended Ecological Category.

12.3.2 Ecological consequences of Flow Scenarios

The second set of Flow Scenarios examined by the specialist team (during January 2003) are illustrated in Table 12.2. The rationale and characteristics of the operational scenarios are outlined in Figure 10.1. As with the initial scenarios, the changes in typical abiotic states within the estuary for each of the operational scenarios was established. The changes in abiotic characteristics were then assessed in terms of their biological implications, using the same Estuarine Health Index that was used to derive the PES.

Table 12.2 Operational Flow Scenarios

Scenario	MAR (m^3 x 10^6)	% MAR
1	3053.6	81.7
2	3039.2	81.4
3	3027.3	81.0
4	3034.8	81.2
5	3031.3	81.1
6	3023.8	81.0
7	2996.8	80.2
8	2501.0	67.0

12.4 RESULTS

12.4.1 River Desktop Estimates

According to the general rule in the methods for estuaries, the Scenario for a category D river (Table 12.1) should have been the recommended 'Reserve' in terms of all the scenarios examined, i.e. this was the scenario which represented the largest modification in flow but would still maintain the estuary in the recommended EC, in this case a high C (Table 12.3). However, the April/May flow reduction in this scenario could be problematic, particularly in light of recent research (Coastal Research Unit of Zululand, University of Zululand indicating that there is a narrow window period for larval recruitment of the crab *Varuna litterata* during late autumn each year. This freshwater species has an obligate marine phase during its lifecycle. This flow scenario would exclude the required freshwater flows into the marine environment which would facilitate recruitment.

Also, the PES of the estuary corresponds to a high C (scored 70 in the range 61 – 75) or a B/C in river terminology. This, together with the estuary being rated in the higher range of 'Important' estuaries (scored 76 in the range 60 - 80), is considered reasonable motivation to manage the estuary to maintain a high C category. Therefore, the scenario for a category B River (Table 12.1) was selected as the recommended scenario for the Thukela Estuary. This is the flow scenario which would be required to maintain an EC of a high C.

In terms of the initial scenarios, only the scenarios for Category A and B rivers are acceptable (i.e. they would result in a C+ or higher EC in the estuary). The specific impact that the initial scenarios had on the different components of the EHI are outlined in Tables 12.3 and 12.4.

Table 12.3 Acceptability of the initial scenarios

Type	Scenario	Ecological State	Acceptability
Initial scenario	Present State	C+	
	River A	C+	YES
	River B	C+	YES
	River C	C-	NO
	River D	C-	NO
	Worst Case 1	D-	NO
	Worst Case 2	D-	NO

12.4.2 Flow Scenarios

In terms of the Flow scenarios examined, only Scenario 8 was regarded as being unacceptable in that this would result in an estuarine EC of C-, following the rationale established in the Ecological Scenarios workshop (June 2002) the recommended minimum state should be a C+ (Table 12.4). The specific impact that the Flow Scenarios had on the different components of the EHI are outlined in Tables 12.5 and Table 12.6.

After consideration of the operational scenarios it became apparent that it was possible to develop a scenario that optimised flow requirements. As such, Scenario 9 was developed. This is basically a combination of Scenarios 5 and 6. Scenario 9 was reviewed by the estuarine abiotic team, and was found to lie between Scenarios 6 and 7 in terms of flow characteristics. As Scenarios 6 and 7 were both acceptable, the scenario was not fully evaluated using the EHI, and it is assumed that the EC under Scenario 9 would be a C+.

Table 12.4 Acceptability of Flow Scenarios

Flow Scenario	State	Acceptability
1	B-	YES
2	C+	YES
3	C+	YES
4	C+	YES
5	C+	YES
6	C+	YES
7 (Present Day)	C+	
8	C-	NO
9	C+	YES

Table 12.5 EHI scoring for different flow scenarios

COMPONENT	EHI SCORING FOR DIFFERENT INITIAL AND OPERATIONAL SCENARIOS														
	INITIAL SCENARIO							OPERATIONAL SCENARIOS							
	Present State	River Category A	River Category B	River Category C	River Category D	Worst Case 1	Worst Case 2	1	2	3	4	5	6	7	8
Hydrology	87	89	79	74	69	69	69	87	87	87	87	87	87	87	87
Hydrodynamics	80	100	100	95	95	20	20	100	100	100	95	95	95	90	85
Water quality	54	70	62	58	50	46	46	62	60	58	56	56	56	54	50
Physical habitat	80	68	68	68	68	68	68	80	80	80	80	80	80	80	80
HABITAT HEALTH SCORE	**75**	**82**	**77**	**74**	**70**	**51**	**51**	**82**	**82**	**81**	**80**	**80**	**80**	**78**	**76**
Microalgae	65	65	65	65	65	35	35	70	70	70	70	70	70	65	60
Macrophytes	60	62	64	67	67	60	60	60	60	60	60	60	60	60	60
Invertebrates	60	65	65	25	25	17	17	65	65	65	65	65	65	60	42
Fish	70	70	70	60	60	40	40	80	80	80	70	70	70	70	60
Birds	70	70	70	70	70	25	25	70	70	70	70	70	70	70	50
BIOTICA HEALTH SCORE	**65**	**66**	**67**	**57**	**57**	**35**	**35**	**69**	**69**	**69**	**67**	**67**	**67**	**65**	**54**
EHI SCORE	**70**	**74**	**72**	**66**	**64**	**43**	**43**	**76**	**75**	**75**	**73**	**73**	**73**	**71**	**65**
CORRESPONDING EC	**C+**	**C+**	**C+**	**C-**	**C-**	**D-**	**D-**	**B-**	**C+**	**C+**	**C+**	**C+**	**C+**	**C+**	**C-**

Table 12.6 Flow scenarios in relation to the Recommended EC (C+)

Scenario	State		Better than Recommended EC									Worse than Recommended EC									Same as for recommended EC								
			H	HD	WQ	PH	MI	MA	IV	F	B	H	HD	WQ	PH	MI	MA	IV	F	B	H	HD	WQ	PH	MI	MA	IV	F	B
INITIAL																													
River A	C+	↔	●		●												●					●		●	●		●	●	●
River B	C+	↔																			●	●	●	●	●	●	●	●	●
River C	C-	↓						●				●	●	●				●	●					●	●				●
River D	C-	↓						●				●	●	●				●	●					●	●				●
Worst 1	D-	↓										●	●	●			●	●	●	●				●	●				
Worst 2	D-	↓										●	●	●			●	●	●	●				●	●				
OPERATIONAL																													
1	B-	↑	●			●				●						●	●					●	●				●		●
2	C+	↔	●			●				●				●		●	●					●					●		●
3	C+	↔	●			●	●			●				●			●					●					●		●
4	C+	↔	●			●	●						●	●			●										●	●	●
5	C+	↔	●			●	●						●	●			●										●	●	●
6	C+	↔	●			●	●						●	●			●										●	●	●
7	C+	↔	●			●							●	●			●	●							●			●	●
8	C-	↓	●			●	●						●	●			●	●	●	●									
				BETTER THAN EC									**WORSE THAN EC**									**SAME AS EC**							

H = Hydrology
PH = Physical habitat alteration
IV = Invertebrates

HD = Hydrodynamics/Mouth Conditions
MI = Microalgae
F = Fish

WQ = Water quality
MA = Macrophytes;
B = Birds

13 RIVERINE GOODS AND SERVICES: CONSEQUENCES OF THE OPERATIONAL SCENARIOS

Note: This chapter is a summary of report DWAF Report No PBV000-00-10311 (DWAF 2004f.

13.1 OVERVIEW

As set out in Chapter 10, a number of Flow Scenarios have been developed for the Thukela River. To assist decision-makers in their selection of options, the economic implications of the various scenarios are identified to highlight the trade-offs between the formal economy and the Goods and Services (i.e. the more water required for the formal economy, the greater the implications to the Goods and Services). The economic implications can be analysed from two perspectives: the implications of changes to the volumes of water available for abstraction from the river (largely the formal economic or 'out-of-river' implications), and the implications of changes to the level of Goods and Services supplied by the water remaining in the river (the 'in-river' services). This chapter analyses the economic implications of changes to ecosystem Goods and Services, which result from changes to the volume of water volume remaining in the Thukela River. A separate chapter discusses the economic implications of the changes in the formal economy that arise from changes to the volume of water abstracted from the river.

13.2 OBJECTIVES

The objective of the Goods and Services study was to undertake an economic assessment that would highlight the trade-offs needed in the selection of IFR options, including:

- The trade-offs between different Goods and Services supplied in each scenario;
- the trade-offs in terms of the benefits and costs to different river users in each scenario; and
- the trade-offs between the tributaries for each scenario.

This chapter quantifies the status quo regarding Goods and Services in the river, as this forms the basis for making comment on proposed changes in flow. The chapter then also focuses on the economic implications of service changes that are likely to result from the various scenarios. The evaluation is not complete and is based on information that is readily available. Importantly, the specific values figures are not important in themselves, but provide an indication of the direction of change and the orders of magnitude of the potential change in the supply of Goods and Services to user groups.

During the analysis, several assumptions were made. Some of these are based on previous research done in the Crocodile River catchment by the study team, where similar methods were used to estimate the values of selected Goods and Services supplied by a catchment. These assumptions are reflected in the discussion that follows.

13.3 METHODS

A number of the scenarios developed as potential options for implementation within the Thukela catchment have been clustered into three groups with similar impacts, and include:

- Scenarios 2 to 5;
- Scenario 8; and
- Scenario 9.

These three scenarios have been identified as those likely to be implemented, and consequently an understanding of their economic implications is required, to inform the trade-offs that will need to be made.

Assessment of the economic impacts of the various scenarios essentially identifies the direction of change (either positive or negative), and estimates the magnitude of the change in benefits and costs that may be experienced within the Thukela catchment. The process adopted was as follows:

- The analysis of potential economic changes is based on a valuation of the status quo, that is, the value of the Goods and Services currently provided by the water in the Thukela and its tributaries. The economics team made estimates of the current value of key Goods and Services that the Thukela River tributaries currently supply. For example, the value of subsistence fishing in the Upper Thukela River was estimated to be R2.7 million per annum.
- The biophysical specialists then identified the potential change that each of the key Goods and Services may undergo in the each of the three scenario clusters. The potential change was noted as a factor and used in later calculations. For example, no change = 1, a 50% increase = 1.5, and a 20% decrease = 0.8. (PBV000-00-103011).
- The current value of Goods and Services was then multiplied by these factors for each tributary in each scenario, to provide an indication of the potential future value of the Goods and Services. The change in value was thus measured. For example, in the Upper Thukela, Scenario 8 was estimated to result in a 10% decrease in subsistence fishing. The following calculation was then used:

  Future value (FV) of fishing = change factor x the current value of fishing
  FV = 0.9 x R2.7million
  FV = R2.44 million per annum
  This equates to a reduction of R272 000 per annum[2]
- The number of people or households impacted by the potential changes was also noted. For example, in the Upper Thukela, some 4 800 households may be impacted by the change in subsistence fishing.

The direction and magnitude of change, together with the number of people impacted, could then be used to inform decision-making regarding the choice of one scenario.

13.4 RESULTS

Table 13.1 and Fig 13.1 presents the key results of the study. The results of the impacts can be considered from a number of perspectives:

- The status quo value (or the benefits) of Goods and Services in each tributary, and the potential positive and negative changes in value associated with the three possible scenarios (2 to 5, 8 and 9). The tables presented later in this section show the detailed trade-offs that may occur between the scenarios for each of the Goods and Service and for each tributary. These tables will be most useful for local interest groups in identifying the potential impacts of each scenario on their river use activities. The numbers of households or individuals impacted are also listed in these tables and this serves to provide an indication of the numbers of people that may be affected. This information will be useful to local and strategic decision-making.
- It should be noted that while rivers supply benefits with positive values to the Thukela community, they might also represent disservices to the community. Rivers may host water-borne diseases, and changes (increases or decreases) to these

2 Figures are in 2000 Rands and based on market associated costs obtained from research into prices in the area.

disservices can be measured by assessing the changes in the costs (rather than the benefits) that they generate for communities. The status quo value of disservices (or the costs) in each tributary, and the potential positive and negative changes in value associated with the three possible scenarios (2 to 5, 8 and 9) was calculated. The tables show the trade-offs between the scenarios for each disservice and each tributary. These tables will be most useful for local interest groups in identifying the potential impacts of each scenario on their activities. The numbers of households or individuals impacted are also listed in these tables and this provides an indication of the number of people that may be affected. This information will be useful in both local and strategic decision-making.

- Overall changes in value for the Thukela tributaries under the three scenarios. This information can be used to evaluate the trade-offs between the rivers under each scenario. This information is useful to strategic decision-making at the catchment level.
- Overall changes in value to Thukela catchment households for the three scenarios. This information helps in identification of the trade-offs for households under the three scenarios. This information is useful to strategic decision-making at all levels.
- Overall changes in value to the Goods and Services and disservices supplied by the Thukela catchment. This analysis outlines the trade-offs between the Goods and Services / disservices associated with each scenario. This analysis will be useful for strategic decision-making at all levels.

Under Scenarios 2, 5 and 9 the main changes were that subsistence fishing (Upper Thukela and Little Thukela) would be negatively affected. Overall, these scenarios had a positive impact on the Goods and Services available. In Scenario 8, with the exception of trout fishing and estuary fishing, all the Goods and Services would be either seriously impacted or partially negatively impacted.

Under Scenarios 2-5, all the disservices would be reduced, with a subsequent reduction of costs to user communities. In Scenario 9, the impacts would be similar to Scenario 2-5, except that there would be an increase in costs associated with bilharzia in the lower Mooi River. In Scenario 8, all the disservices would be aggravated, with serious increases in costs being borne by Thukela river communities.

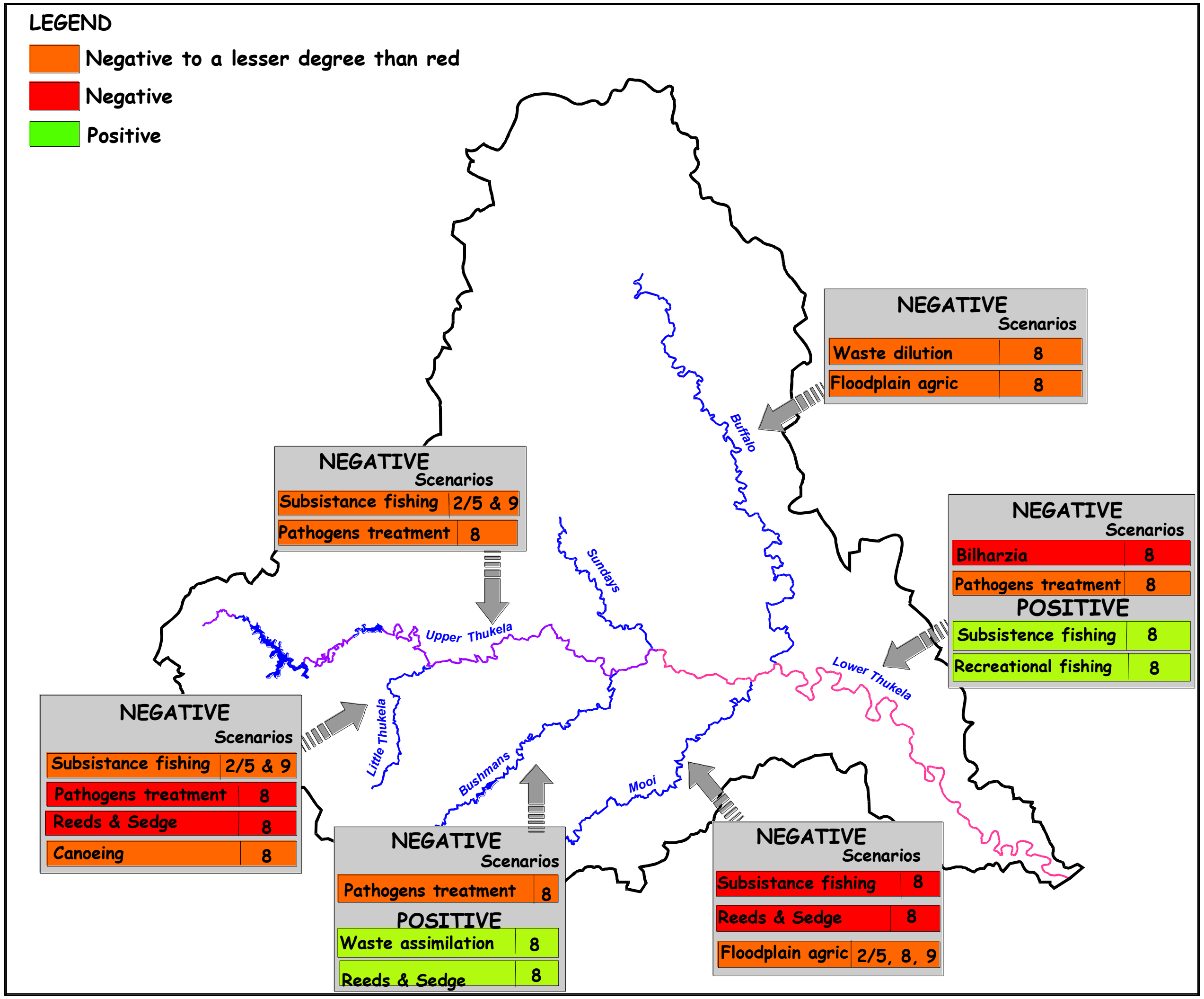
Table 13.1 Summary of changes to service benefits and costs

Thukela River: Summary of service benefits and costs								
Services and disservices	Households or individuals impacted	Status quo	Scenario 2/5		Scenario 8		Scenario 9	
		Total value (R millions)	Total value (R millions)	Total change in value (R Millions)	Total value (R millions)	Total change in value (R Millions)	Total value (R millions)	Total change in value (R Millions)
Services as benefits								
Fish*	17,000	9.00	7.60	-1.40	8.10	-0.90	7.60	-1.40
Reeds*	7,000	0.50	0.50	0.00	0.50	0.00	0.50	0.00
Sedges*	16,000	1.00	1.10	0.10	1.00	0.00	1.10	0.10
Waste assimilation*	64,000	4.40	4.50	0.10	3.60	-0.80	4.50	0.10
Waste dilution*	64,000	29.00	29.10	0.10	14.50	-14.50	29.10	0.10
Cultivated floodplains*	16,000	3.00	3.10	0.10	2.60	-0.40	3.10	0.10
Cynodon lawns*	16,000	17.00	17.40	0.40	14.00	-3.00	17.30	0.30
Rafting	3,000	1.30	1.30	0.00	1.00	-0.30	1.30	0.00
Canoeing	2,000	0.90	1.00	0.10	0.90	0.00	1.00	0.10
Trout fishing	300	4.20	4.20	0.00	4.20	0.00	4.20	0.00
Estuary fishing	5,000	1.00	1.10	0.10	1.50	0.50	1.10	0.10
Disservices as costs								
Bilharzia treatment	105,000	15.60	15.00	0.60	33.30	-17.70	15.60	0.00
Bilharzia productivity loss	105,000	12.00	11.60	0.40	25.70	-13.70	12.00	0.00
Pathogens treatments	36,000	0.80	0.70	0.10	1.00	-0.20	0.70	0.10
Pathogens productivity loss	36,000	7.20	6.50	0.70	9.40	-2.20	6.60	0.60
Cholera treatment	5,000	0.30	0.30	0.00	0.40	-0.10	0.30	0.00
Cholera productivity loss	5,000	1.40	1.30	0.10	1.80	-0.40	1.30	0.10

* These services benefit households while the rest (including costs) are for individuals.

[red box] Significant negative change.

Fig 13.1 Goods and Services impact summary map



The major reasons for the significant changes in the values of the Goods and Services are outlined in Table 13.2

Table 13.2 Reasons for significant changes in Goods and Services

Change in Goods and Services	Sub-catchments	Scenario	Extent of change	Reason for change
Subsistence fishing	Upper and Little Thukela	2/5, 9	0.5	Reduction in water volume, with habitat loss.
Subsistence fishing	Mooi	8	0.05	No flows in winter with major habitat loss.
Subsistence fishing	Thukela estuary	8	1.5	Low flows result in salt water intrusion with entry of marine fish.
Reed and sedge harvesting	Bushmans	8	1.5	Increased flows increase habitat available for reeds.
Reed and sedge harvesting	Mooi and Little Thukela	8	0.6	Low flows result in habitat reduction for reeds and sedges
Waste assimilation	Bushmans	8	1.5	Increased flows result in greater assimilation capacity.
Waste dilution	Buffalo	8	0.5	Lower flows reduces dilution capacity.
Floodplain agriculture	Mooi	2/5, 8, 9	0.5	Lowering of water table in surrounding floodplain.
Floodplain agriculture	Buffalo	8	0.5	Lowering of water table in surrounding floodplain.
Cynodon lawns	Mooi,	2/5, 8, 9	0.5	Lowering of water table in surrounding floodplain.
Canoeing	Little Thukela	8	0.5	Lower water levels with insufficient water depth.
Recreation fishing	Thukela estuary	8	1.5	Low flows result in salt water intrusion with entry of marine fish.
Bilharzia treatment costs and productivity loss	Lower Thukela and Mooi	8, 9	3	Increasing vector habitat, reduced dilution and many people potentially infected.
Bilharzia treatment costs and productivity loss	Mooi	9	1.15	Increasing vector habitat, reduced dilution and many people potentially infected.
Pathogens treatment and productivity loss	Bushmans, Upper and Lower Thukela	8	1.5 – 1.3	Decreasing flow in lower regions, with lower dilution and many people potentially infected.
Pathogens treatment and productivity loss	Little Thukela	8	2	Decreasing flow in lower regions, with lower dilution and many people potentially infected.

13.5 CONCLUSION

Overall, the change in value between the status quo and Scenarios 2-5 is insignificant. There is also an insignificant overall reduction in value of Scenario 9. In summary Scenario 8 has serious negative impacts on the Thukela community, despite there being an improvement in the Bushmans River and Thukela estuary. This scenario has serious implications for community well being in the Thukela catchment. It should be borne in mind that although the values that are estimated are relatively low, in the greater scheme of things, they represent changes to communities that can least afford it, and as such, impacts are significant. Of note are the changes to the bilharzia and pathogen regimes. These were deemed to have changed significantly as the amount of water under Scenario 8 was greatly reduced at certain points of the river thereby exposing some communities to greater health risks.

To illustrate the level of impacts of the three scenarios of communities in the Thukela, impacts on individual households was estimated for the catchment as a whole. In Scenario 2-5 and 9, the overall impact on households in the Thukela catchment is negligible. Scenario 8 shows substantial losses for communities, close to R900 loss per household per annum. This is very significant for rural households who can least afford this type of loss.

14 ECONOMIC CONSEQUENCES OF THE OPERATIONAL SCENARIOS

Note: This chapter is a summary of report DWAF Report No PBV000-00-10311 (DWAF 2004f).

14.1 OVERVIEW

In addition to the Goods and Services investigations, a formal market economic study was commissioned. A regional overview of the Thukela catchment was required together with a set of water accounts and a Social Accounting Matrix (a format for socio-economic evaluation), as the basis for this study. This information served to underpin the economic evaluation of selected scenarios (as generated by other task teams), and provided a base scenario from which other economic scenarios could be evaluated.

Water is an important aspect of production in most economic activities. Changes in the water availability can have extensive impacts on the economy as a whole. This market economic study provides an overview of the economy of the Thukela catchment as it exists at present, and highlights the links between the economy and water usage. The study generated an overview of the water dependant sectors of the catchment economy.

The size of the Thukela catchment economy, measured in Gross Geographic Product (GGP) terms, was R13.9 billion in 1998 (See Table 14.1). Approximately 46 percent of this value-added quantity was paid as remuneration to labour, and 49 percent was allocated to gross operating surplus.

Table 14.1 Composition of the GGP of the Thukela catchment at market prices (1998 R millions) (source - Conningarth Consultants, Social Accounting Matrix, unpublished, (1998))

	Values	Percentage Distribution
Labour remuneration	6430.1	46.23
Gross operating surplus	6808.2	48.94
Net indirect tax	670.95	4.83
TOTAL	**13909.25**	**100**

Table 14.2 indicates the contribution of the Thukela catchment to the KwaZulu-Natal and South African economies, given in billions of Rand at market prices during 1998.

Table 14.2 Contribution by Thukela Catchment to the KZN and South African economies (1998 R Billion) (source - Conningarth Consultants, Social Accounting Matrix, unpublished, (1998))

	Thukela Catchment	KZN	Rest of RSA
Value	13.91	110.437	737.813
Thukela as percentage of KZN	N.A	12,6 %	1,9 %
KZN as percentage of SA	N.A	N.A	15 %

Source: Conningarth Consultants, Social Accounting Matrix, unpublished, (1998)

The economy of the Thukela catchment accounted for more than 12,6 % of the provincial economy and 1,9% of the national economy in 1998. Considering that the population of this region represents more than 22% of the provincial population, it follows that the mean per capita contribution to economic activity in the region is well below the provincial average. This indicates that there is likely to be a move to encourage development to improve this situation.

The overview pointed to some issues relating to the state of the economy in the region at present, and its likely future direction. These include the following:

- Overall, the economy of the area that depends on the Thukela River for its water supply is showing slow growth and even stagnating in some areas.
- Some growth in irrigation agriculture can be expected. A growth rate of 5 % per year is estimated.
- Coal mining in the relevant areas is not expanding.
- At this stage, only the Ladysmith-Ezakheni area is experiencing industrial growth while areas such as Newcastle-Madadeni, Mandini-Isithebe are not showing growth.
- The Government Services sector is not an important consumer of water.
- As a result of the incidence of HIV, population growth in the area is expected to slow down. It should also be noted that many young people in the rural areas are moving into metropolitan areas outside the Thukela catchment.
- Although there is a definite need for a regular water supply in certain rural areas, affordability is a constraining if not prohibitive consideration.

14.2 METHODS

On the basis of the overview of the Thukela economy, the value of each of the following sectors in the regional economy was calculated:

- Irrigated Agriculture
- Livestock
- Forestry
- Sugar Cane
- Mining and Heavy Industries
- Urban Requirements (incl. light industries, commerce and tourism ventures)

The study further disaggregated the Thukela River system into the following sections:

- Upper Thukela (from source to confluence with the Sundays River)
- Lower Thukela (from confluence with the Sundays River to the mouth)
- Little Thukela
- Bushmans
- Sundays
- Mooi
- Buffalo

It should be noted that all minor catchments e.g. the Klip River, fall within one or other of the above sections. After the value of each of the sectors was determined for each of the river sections, the economic impacts of the following scenarios were measured:

- Baseline (Scenario 8) with development projected to the year 2015. Projected economic development was based on historic trends as well as likely growth.
- Scenario 2 with development projected to the year 2015.
- Scenario 6 with development projected to the year 2015.
- Scenario 9 with development projected to the year 2015.

14.3 RESULTS

The results are summarised per sector and per river section in the following tables as well as in the figures. Where the sector would grow from the present day to 2015, an up-arrow is shown. Where projected growth is likely to be affected, a red down-arrow is shown, meaning that this sector will not grow at the projected rate, but not inferring necessarily that existing development will be negatively affected. It should be noted that for Scenarios 6 and 9, no existing development would need to be curtailed.

Table 14.3 Impact per scenario and river section on the irrigation sector

Scenario	Upper Thukela	Lower Thukela	Little Thukela	Bushmans	Sundays	Mooi	Buffalo
8	↑	↑	↑	↑	↑	↑	↑
2	↓	↓	↓M	↑	↓M	↑*	↑
6	↑	↑	↓M	↑	↓M	↑*	↑
9	↑	↑	↓M	↑	↓M	↑*	↑

M Marginal loss of value
* If Spring Grove Dam were not built, the arrows would be down and red.

Scenarios 6 and 9 both have negative economic impacts on projected irrigation growth in the Little Thukela and Sundays Rivers. The potential for the irrigation sector to expand, particularly in the Little Thukela and Sundays River, is very limited under any scenario as it is already over-subscribed.

Table 14.4 Impact per scenario and river section on the Forestry sector

Scenario	Upper Thukela	Lower Thukela	Little Thukela	Bushmans	Sundays	Mooi	Buffalo
8	↑	↑	NA	↑	NA	↑	↑
2	↓	↓	NA	↑	NA	↑*	↑
6	↑	↑	NA	↑	NA	↑*	↑
9	↑	↑	NA	↑	NA	↑*	↑

* If Spring Grove Dam were not built, these arrows would be downward and red.

Only Scenario 2 has a negative impact on projected (marginal) afforestation growth in the main Thukela River.

Table 14.5 Impact per scenario and river section on the mining and heavy industry sector

Scenario	Upper Thukela	Lower Thukela	Little Thukela	Bushmans	Sundays	Mooi	Buffalo
8	↑	↑	NA	NA	↑	NA	↑
2	↓	↓	NA	NA	↓	NA	↑
6	↑	↑	NA	NA	↓	NA	↑
9	↑	↑	NA	NA	↓	NA	↑

* If Spring Grove Dam were not built, these arrows would be downward and red.

Scenarios 6 and 9 have negative economic impacts on the projected growth in this sector in the Sundays River. Scenario 2 has a negative impact on projected growth in the main Thukela River.

Table 14.6 Impact per scenario and river section on the commercial and light industrial sector

Scenario	Upper Thukela	Lower Thukela	Little Thukela	Bushmans	Sundays	Mooi	Buffalo
8	↑	↑	↑	↑	↑	↑	↑
2	↓	↓	↑	↑	↓	↑*	↑
6	↑	↑	↑	↑	↓	↑*	↑
9	↑	↑	↑	↑	↓	↑*	↑

* If Spring Grove Dam were not built, these arrows would be downward and red.

Scenarios 2, 6 and 9 have negative economic impacts on projected growth in the Sundays River only. Scenario 2 has negative economic impacts on the main Thukela River.

In the livestock and sugar cane sectors, the scenarios have negligible impact on projected growth.

14.4 CONCLUSION

From an economic perspective, Scenario 2 would have the greatest negative impact (see Table 14.7).

Table 14.7 Impact of Scenarios expressed in terms of loss of value to the relevant sector (in millions of Rand)

	Scenario 2	Scenario 9	Scenario 6
	R million	R million	R million
Irrigated Agriculture	57.6	17.7	9.7
Livestock	0.0	0.0	0.0
Afforrestation	0.6	0.0	0.0
Sugar cane	0.0	0.0	0.0
Mining & Heavy Industries	284.0	68.0	51.0
Urban Requirements (incl. light industries)	547.7	86.0	49.4
Total value lost if scenario is implemented	889.9	171.6	110.1
Estimated value added in 2015(constant 2000 prices)	8424.5	8424.5	8424.5
Estimated value added in 2015 for scenario (constant 2000 prices)	7534.6	8252.8	8314.4
Percentage impact of scenario	10.6%	2.0%	1.3%

The negative impacts of Scenario 6 and 9 are only relevant for the Little Thukela and Sundays River for the irrigation sector, and only for the Sundays River for the other sectors. A comparison is provided in Table 14.8. It should, however, be noted that without Spring Grove Dam in place, there would be a potentially negative impact on projected growth in the Mooi River under all the scenarios.

Table 14.8 Summary of negative impacts of Scenario 6 and 9 on projected economic growth in various sectors

Scenario	Little Thukela	Sundays
Irrigation		
6	↓M	↓M
9	↓M	↓M
Mining and heavy industry; urban, commercial and light industrial		
6		↓
9		↓

Fig 14.1 Impact on economic growth to 2015 – Upper Thukela

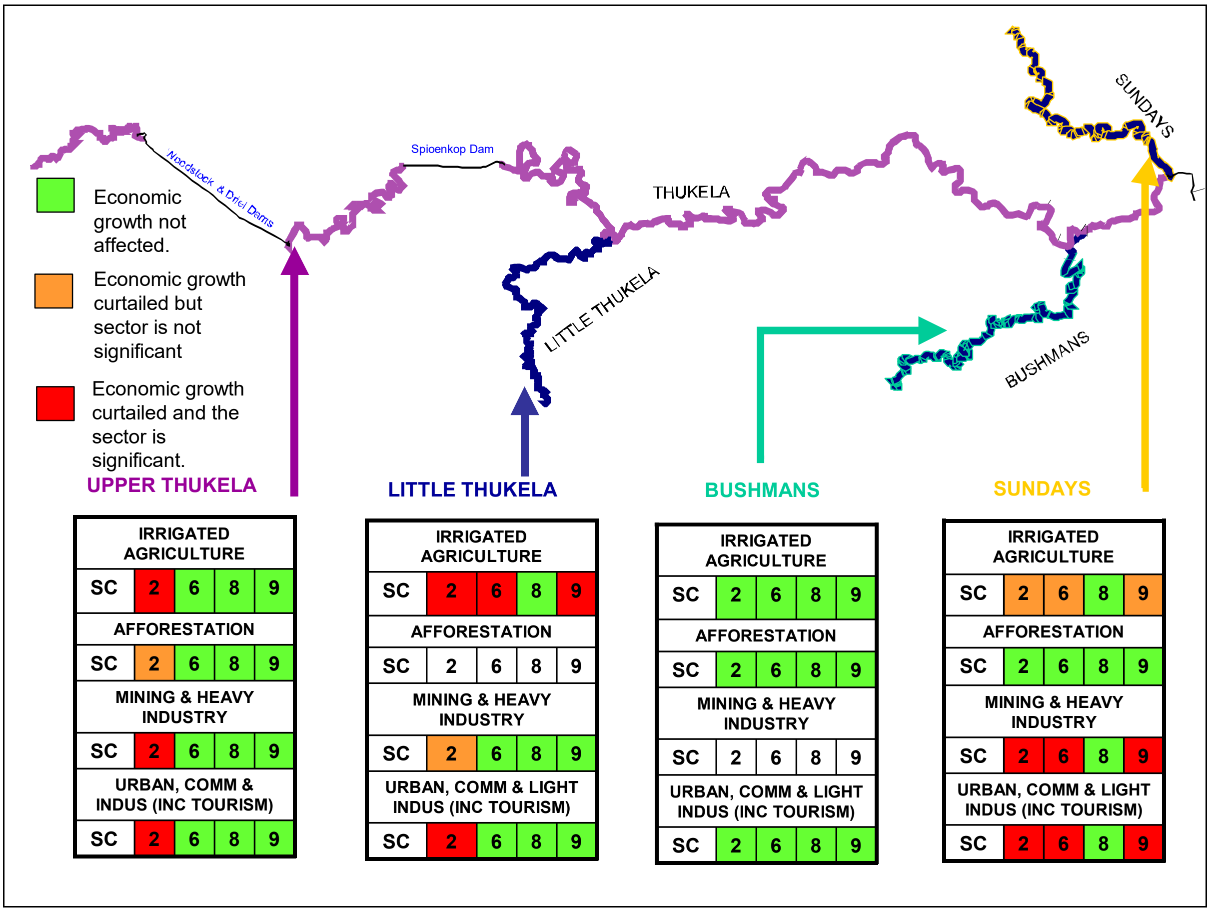
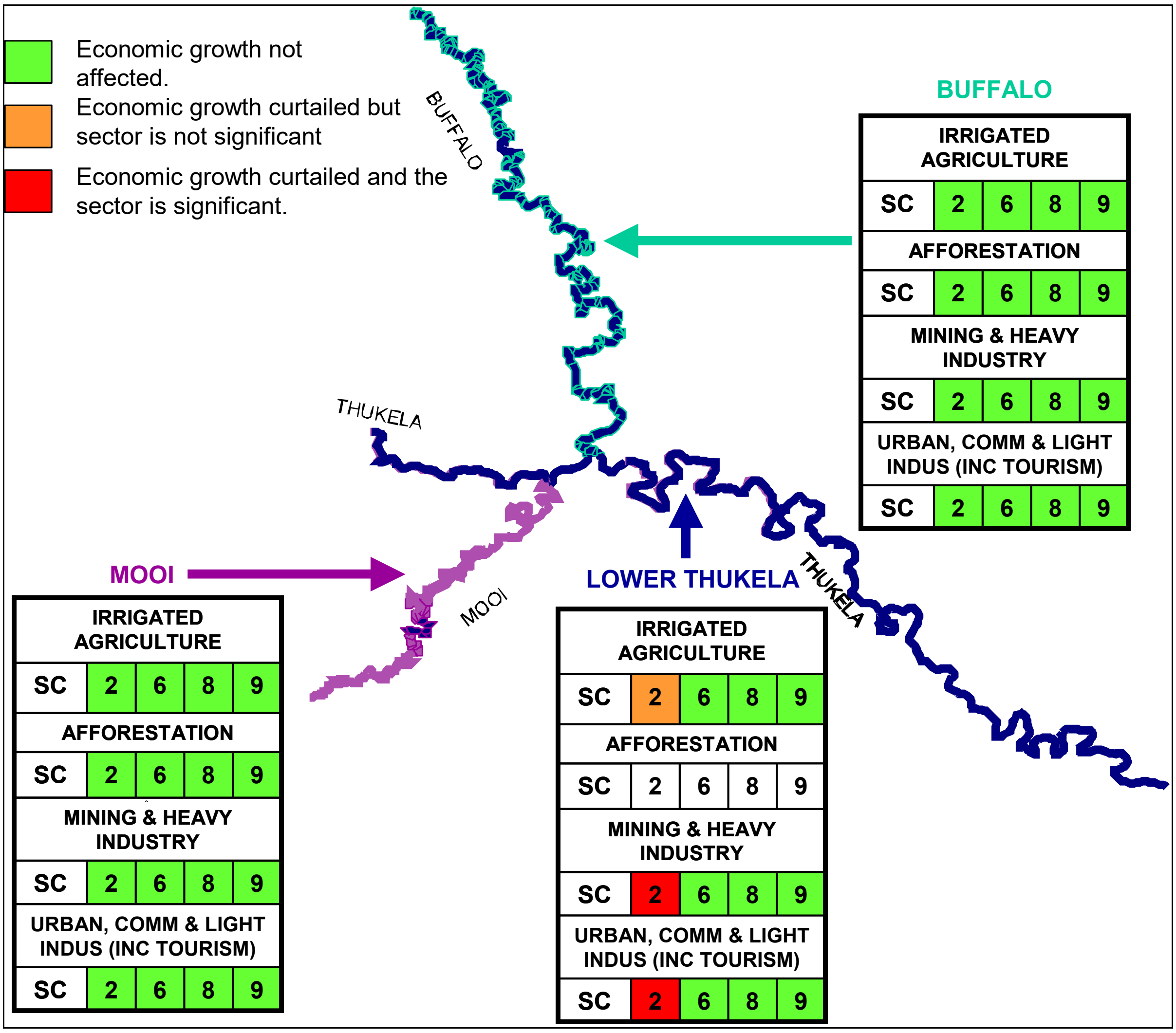


Fig 14.2 Impact on economic growth to 2015 – Lower Thukela



15 ECONOMIC IMPACT ON THE THUKELA BANK

15.1 OVERVIEW AND OBJECTIVE

Note: This chapter is a summary of report DWAF Report No PBV000-00-10310 (DWAF 2004e).

Worldwide, it is generally accepted that there are links between freshwater input from the land and rivers, and ecosystem functioning in the marine environment (Gillanders & Kingsford 2002). Much of this acceptance is derived from examples in which altered freshwater inflows have led to the loss or erosion of a near-shore habitat or the collapse of a marine fishery. The most famous example of this was the construction of the Aswan High Dam on the Nile River, which trapped much of the river's silt load, leading to erosion of the delta, a drastic decline in nutrient input and primary production, and ultimately the collapse of the fisheries in the sea. Elsewhere, fisheries collapse in the marine environment, and the near extinction of some cetaceans (dolphins and porpoises), has followed freshwater regulation and abstraction of the Colorado, Yellow and Ganges Rivers (Gillanders & Kingsford 2002).

River flows influence marine fish, invertebrates and fisheries directly and indirectly through the export of nutrients, sediment and detritus. Nutrient supply stimulates production of phytoplankton and zooplankton, and ultimately, the larval, juvenile and adult fish that depend on them as a food source. Detritus may either be broken down into useful nutrients, serve as a substrate for micro-flora and fauna, or be consumed directly by detritivorous fish and invertebrates. Sediment export replenishes the near-shore habitats that are continuously eroded by oceanic currents, and also increases turbidity, thereby providing a refuge for many fish. Turbidity also tends to increase the catchability of many species, especially the larger individuals that move into the turbid environment in search of concentrated prey. Freshwater flows also provide cues for the migration of estuarine-dependent juvenile and adult fish into and out of the estuarine environment. The strength (and timing) of these cues will ultimately dictate how many individuals of these species recruit into the marine fisheries. From a fisheries perspective, altered freshwater flows and consequent alteration in any of the aforementioned variables can cause changes in catch composition, resource base (e.g. demersal vs pelagic fish abundance), fleet structure, the spatial and temporal distribution of effort, and ultimately the economic value of the fishery concerned.

A catchment-derived nutrient supply is especially important in oligotrophic nearshore waters such as the Thukela Banks, where nutrient supply from upwelling events is limited. In turn, nutrient export from the Thukela is likely to be greater than elsewhere in KwaZulu-Natal because, besides providing approximately 40% of the annual volume, it has a small estuarine area (classified as a river mouth), whereas in other true estuarine systems such as St Lucia, the bulk of the nutrients are incorporated into phytoplankton production before being exported into the marine environment. The Thukela also supplies the bulk of the terrigenous sediment on the adjacent marine banks, estimated at approximately 10 million metric tons per year (Fleming & Hay 1988). Reductions in flow and change in land-use practices in the catchment may see an increase or decrease in the sediment load reaching the sea, as well as a change in the proportions of fine and coarse sediments. In the long term, an increase in fine sediments would favour penaeid prawns and flatfish species, but be detrimental to invertebrate filter-feeders and ultimately to the reef-dwelling fish species that prey on them. In the short term, increased turbidity would provide refuge and foraging area for many fish species. The Thukela Estuary is a river mouth, relatively unimportant as a nursery area, and altered freshwater flows are unlikely to be of consequence to the eventual recruitment of estuarine-dependent species into the marine fisheries. However, the opposite is the case for the Thukela Banks, where freshwater flows are likely to provide cues for spawning and for the recruitment of juveniles that utilise the banks as a nursery area.

As part of the Thukela Study, it was identified that the various freshwater flow scenarios could potentially have an economic impact on the fisheries associated with the Thukela Banks. The objectives of the study were to:

- Assess the economic consequences of various flow scenarios.
- Determine whether a link between flow and catch exists (assuming that nutrient and sediment function is being provided by flow).
- Define the link if it does exist.
- Isolate the contribution of the Thukela flows.

15.2 METHODS

Studies assessing the impacts of altered freshwater flows on the marine environment may be broadly categorized into two approaches (Van Niekerk & Van Ballegooyen 2003).

- A correlation approach whereby changes in faunal abundance, biomass or diversity are analysed statistically in relation to flow or rainfall without any attempt at an in-depth analysis of the processes involved.
- A process-orientated approach whereby the basic drivers and processes involved are identified and measured in order to understand the functional role of freshwater input into the sea and to provide a more robust predictive capability.

Most studies assessing the impacts of altered freshwater flows on the marine environment have only been initiated once the said impacts have become noticeable. Few have begun prior to developments being completed, and therefore few have been aimed at either predicting or mitigating the consequences of altered freshwater flows for the marine environment or fisheries. Consequently, and hindcasting aside, the lack of any baseline data precludes a process-orientated approach, with the result that most studies have taken the correlative approach. The latter is also usually the cheaper option.

The Thukela Bank study took the correlative approach by linking commercial prawn and linefish catch data with monthly flow over a 20-year period. The first step was to ascertain if there was a link between flow and catches, whilst assuming that drivers such as nutrient and sediment input were inextricably linked with flow. It was also recognised that the Thukela was not the only river feeding the Thukela Banks, and that other catchments (14 in all) would have to be taken into consideration. These catchments were also separated in terms of whether their main function was to provide a nursery area for prawns and fish (e.g. St Lucia) or to provide flow (nutrient and sediment input, e.g. Thukela) to the Thukela Banks. Once this was done the contribution of the Thukela was isolated, enabling the economic implications of various flow scenarios for the commercial prawn and line-fisheries to be assessed.

15.2.1 Hydrology

Monthly historical flow records for all catchments within the study area covering the period from 1980 to 2000 were required. Gauging stations are the only source of historical flow data, but not all the rivers have gauging stations, and not all the stations cover the required record period. Other data sourced were ACRU, WR90, WRYM data, and WRS90.

The different flow scenarios which were evaluated were:

- **Natural:** This scenario provides the upper boundary for the results and is based on the naturalised flows for the Thukela.
- **Scenario 1:** Development as at the year 2000 in the Thukela with **Reserve Scenario 1:** (high category Reserve) in place. Of the 6 Reserve scenarios, this scenario will result in the highest inflow to the Bank from the Thukela River.

- **Scenario 8:** This scenario represents a realistic 2015 development worst-case scenario, with no releases for the environment and full transfer allocation and development allowed. No TWP dams are in place.
- **Worst Case:** This scenario was included to provide a lower boundary for the results. This is a highly unlikely future scenario, with development at the 2025 level and with the TWP dams in place. The full transfer capacity of the Thukela system to the Vaal of $35m^3/s$ was utilised, and no releases were made for the Reserve.

15.2.2 Prawns

Commercial catch statistics for the period 1988 – 2000 for the prawn fishery on the Thukela Bank were provided by the Directorate of Marine and Coastal Management (MCM) of the Department of Environmental Affairs and Tourism (DEAT). Unfortunately, the time value data were found to be entered incorrectly for a large proportion of the records. This meant that the data had to be compared and verified using the additional dataset held by Marine and Estuarine Research. This dataset, obtained from the fishing companies records for the period 1984 – 1995 and from the actual drag and landing records from 1996 – 2000, overlaps the dataset provided by MCM (1988 – 2000).

15.2.3 Prawn catch-flow relationship

The predictive prawn catch equations' independent variables had to be developed. The purpose of the predictive equation was to determine a link between historical river flows and historical prawn catch from the Thukela Bank. This equation would then be used to quantitatively estimate the impact of altered Thukela flows on the prawn catch.

The rivers and estuaries provide a habitat and nursery area and also provide nutrients and/or detritus to the Bank. These two main functions are summarised below:

- **Nursery Function:** River estuaries provide a crucial habitat for the post-larvae and juvenile stage of the prawn life cycle. Only two catchments have been identified as nursery grounds and were treated separately as Nursery Rivers. These nursery rivers are provided below:
  - Lake St Lucia (Mkuze, Mezene, Hluhluwe and Nyalazi Rivers)
  - Mhlathuze River
- **Nutrient Function:** All the rivers in the study area contribute to the nutrient and organic input available to the Thukela Bank.

Nursery function:
The prawns in the **post-larval** stage generally enter the estuaries (**recruitment**) during July, August and September and remain there for about 8 months. The **juvenile** prawns start leaving the estuaries (**emigration**) during February, March and April. The prawn catch season was limited to the period between March and September. The flows from the Nursery Rivers were converted to an equivalent **Nursery Index**, based on the following relationship:

Nursery Index (NI) = Recruitment Index (RI) + Emigration Index (EI)

The RI indicates the period (July, August and September) where the prawns in the **post-larval** stage enter the estuaries, where they will mature to the **juvenile** stage, and from where they return to the Bank. This is an indicator of the likely *catch in the following year* from March to September.

The EI indicates the period where the juvenile prawns leave the estuary area and return to the Bank (February to April).

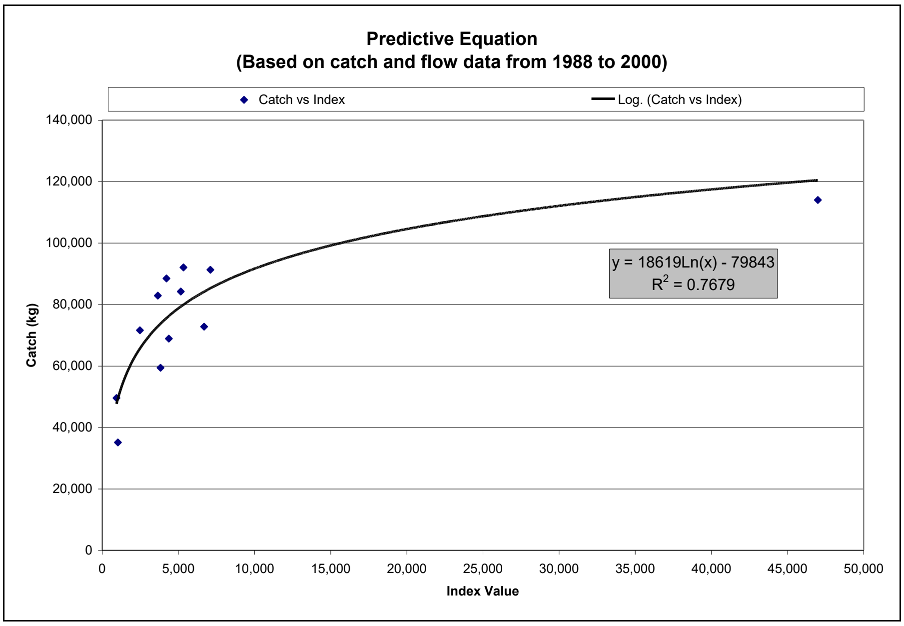
Nutrient Function:
All the rivers in the catchment contribute to the nutrient load available on the Bank, and the nutrient index values will therefore be based on the sum of all the rivers' inputs. Both the larval and adult stages of the prawn life cycle are spent in the inshore marine environment. These two life stages have been treated separately in the equation, as they are dependent on different periods of flow. The Nutrient Index for the Larval stage (NUTIL) is the sum of the flows from the Thukela and other rivers from **July to October**. The Nutrient Index for the Adult stage (NUTIA) is the sum of the flows from the Thukela and other rivers from **November to February**.

Different flow regimes in the Thukela River can now be included and the NI will remain unchanged but the NUTIL and NUTIA indices will be affected.

The three independent variables will be combined based on a weighting system, in order to provide a single independent variable called the **Index Value**.

Regression analysis was undertaken in order to determine the final predictive equation. The **NUTIL** and **NUTIA** variables were determined based on the historical flows in the Thukela. The regression equation was based on the weighted annual totals of the three monthly independent variables and the total catch during the main season. The most appropriate regression analysis was a log function where X represented the independent variable (Index Value) and Y the dependent variable (prawn catch in kg). The results of the analysis are provided in Figure 15.1.

Fig 15.1 Regression Analysis



This equation has a Coefficient of Determination = 0.77 (R^2). Effectively this means that the predictive equation explains 77% of the variance in the observed catch data.

The predictive equation was used to predict catch for the period from 1988 to 1995 for the four scenarios. The scenarios were simulated, and the results were compared to the predicted historical catch.

15.2.4 Fish

The commercial and recreational boat-based linefishery is the most important marine fishery in KwaZulu-Natal, accounting for 40% of the total landed mass there. Effort is distributed fairly evenly to the north and south of Durban, with 40-50 boats and 200-300 crew operating in the vicinity of the Thukela Bank.

In all, 140 species, 60 of which are regarded as important, are caught by the KZN linefishery, and approximately 1 200 tons are landed annually. The commercial and recreational sectors are responsible for 62% and 38% of this catch respectively.

15.2.5 Link between fish catch and flow

Exploratory analyses of the relationships between monthly flows and catches were performed using Spectral Analysis and General Linear Models (GLMs). The information available comprised 17 years (1985-2001) of monthly commercial catch and effort data for 140 species from the National Marine Linefish System (NMLS, MCM, DEAT), and monthly flow data from seventeen catchments to the north of Durban compiled by WRP (Water Resources Planning). Spectral Analysis examines the relationships between two time-series (flow and catch) in terms of their similarity in frequency and intensity of recurring events. Cross-spectral density provides a measure of the intensity of the relationships. The GLMs were run using the direct monthly flow *vs* cpue (catch per unit effort) data, as well as with the lag-times associated with the highest cross-spectral densities from the spectral analysis.

15.3 RESULTS

Modelling results indicated that under natural conditions prawn catches were 8% higher than average, whereas under the worst-case scenario they would be 4% lower than average. The response of fish to flow varied between species, but an overall 20% decline in line-fish catches was predicted under the worst-case scenario. From an economic perspective, the viability of the prawn fishery (1% decline in value) was unlikely to be noticeably impacted, whereas the line-fishery would suffer a 17% decline in value under the worst-case scenario. It must be noted, however, that the fish data were of much lower confidence than the prawn data.

15.4 CONCLUSIONS

Although the decline in prawn catches may be negligible in response to a reduction in discharge from the Thukela, it is still necessary to take heed of the cumulative impacts of flow reduction in other KZN catchments. It is also necessary to take cognisance of the fact that the analysis addressed changes over a short time period (a prawn's life-span), and that long-term changes such as gradual loss of a particular sediment habitat type are unlikely to be detected. The loss of a nursery habitat (e.g. 2003-2004 closure of St Lucia) is more immediately evident in catches than the long-term loss of habitat on the Thukela Banks. In turn, the loss of nursery habitat is likely to be temporary, whereas the loss of adult bank habitat is likely to last for long enough to be considered permanent.

In comparison to the changes in prawn catches, the decline in fish catches in response to a reduction in flow would be substantial. This would be even more severe if the impacts of flow reductions in other KZN catchments were taken into account. In turn, depending on their stock-recruitment relationships, the cumulative effects of successive year-classes getting smaller and smaller may see the reduction in catches being greater than predicted in the long-term.

16 RECOMMENDED RESERVE

16.1 OVERVIEW

At this stage of the Reserve Determination study, various flow scenarios have been produced and the consequences of each determined. To finalise the study according to the project plan, one of these scenarios had to be selected as the potential Reserve. The outstanding tasks, i.e. the identification of the final Ecospecs and the monitoring programme will be undertaken for the recommended Reserve.

16.2 METHODS

This part of the decision-making process would form part of the Classification Process. In the absence of the Classification Process, a process was designed for the Thukela RD. All the information collated as well as the results of the stakeholder process was used so that the Thukela Project Management could provide a motivated recommendation. The results of the studies and the rationale for the recommendation were documented in a briefing document (DWAF Report no PBV000-00-10313, DWAF 2004h). Senior Management from DWAF was presented with this documented and invited to a meeting during which the study and recommendation was presented.

16.3 RESULTS

After consideration of the original scenarios it became apparent that it was possible to develop a scenario that optimised flow requirements and had the least potential impact on all sectors. As such, Scenario 9 was developed. The specific impacts of Scenario 9, as compared to the other relevant scenarios, are specified in Chapters 5, 6, 7 and 8.

Figure 16.1 below indicates the degree to which Scenario 9 achieves a compromise in satisfying the range of all user components.

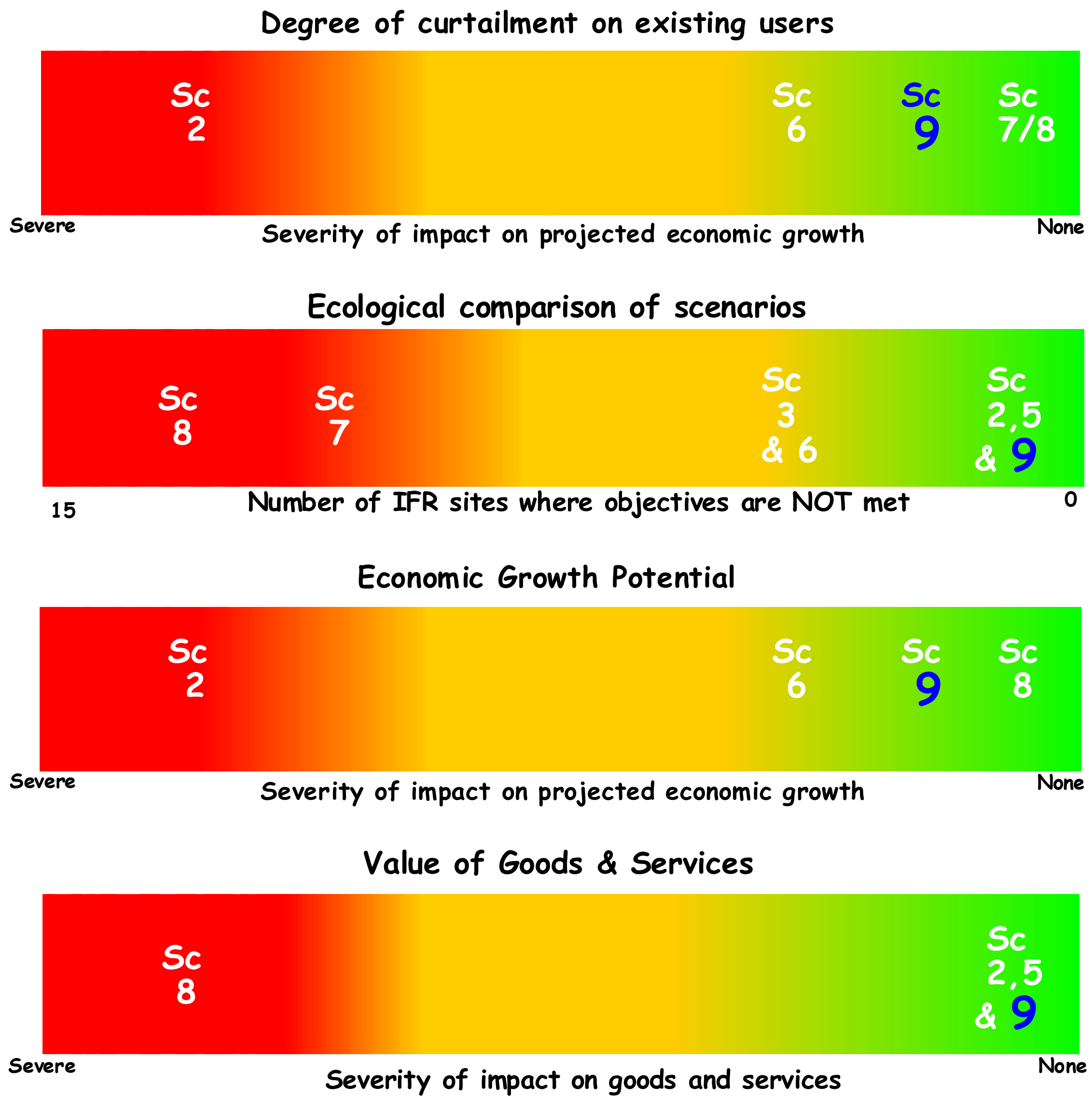
- Yield analysis: Results indicate that water users in the Bushmans and Buffalo River catchments are the only ones that will not be impacted upon under all the Ecological Reserve Water Requirement scenarios from 2 to 9. Under Scenario 2 there will be some level of curtailment (or reduction in the level of supply) in all of the remaining sub-catchments in the Thukela River System. Scenario 6 has a slightly diminished impact on the water resource yield availability, with Scenario 9 having only a relatively small impact on the Tugela-Vaal transfer as well as on the Little Thukela and Sundays River systems.
- Ecology: Scenario 9 (as well as 2 and 5) meets the ecological objectives at all the IFR sites (apart from IFR 4) and the estuary. The ecological objectives at IFR 4 represent an improvement and even though these objectives are not met, the Present Ecological State will be maintained. It must be noted that in order to achieve the ecological objectives under Scenario 9, Source Control Measures will have to be implemented in the Sundays, Buffalo and Bushmans Rivers. Some catchment management activities will also be required in the Buffalo River and the Lower Thukela at IFR 16.
- Goods and Services: Overall, There is an insignificant reduction in value of scenario 9. The change in value between the status quo and scenario 2/5 is also insignificant. Scenario 8 has serious negative impacts on the Thukela community and has serious implications for well being in the Thukela catchment.
- Market Economics: Scenario 2 would, from an economic perspective, have the greatest negative impact and is not further considered. The negative impacts of Scenario 6 and 9 are only relevant for the Little Thukela and Sundays River (irrigation) and only on the Sundays River for the other sectors.

As such, Scenario 9 meets most ecological objectives and has among the least negative impact on the economy of the area and on the delivery of riverine Goods and Services.

During the last stakeholder meeting the overall results of the Thukela Reserve Determination study as well as the implications of the scenarios were presented. The general feeling form the stakeholder grouping was that there was no reason why Scenario 9 should not be favoured.

The recommendation was that Scenario 9 and the resulting Ecological Categories at each IFR site and the estuary be accepted as a Preliminary Reserve and for future planning purposes. Water quality objectives that cannot be met due to Source Directed problems have been identified.

Fig 16.1 Comparison of scenario impacts across major study components



16.4 CONCLUSION

During the meeting held on 28 August 2003, no major objections were given for Scenario 9 to be presented as the Reserve. This information can now be used to complete the standard formats for signing-off purposes.

17 ECOSPECS AND MONITORING

Note: This chapter is a summary of report DWAF Report No PBV000-00-10314 (DWAF 2004i).

17.1 OVERVIEW AND OBJECTIVES

According to the National Water Act as well as the TOR and project plan for the (RD) Study, monitoring is required to ensure that the RQOs are achieved. As part of the TOR of the study, a monitoring programme must be provided that sets out all the actions required to measure whether the Ecospecs (the ecological component of the RQOs) are met. It must be noted that within this RD study, only Ecospecs, not RQOs, were generated.

The monitoring programme would allow the DWAF to plan and budget for implementation of monitoring.

17.2 METHOD

The time scale and the scale of intensity that will be used for monitoring specific components will vary depending on the rate at which a component reacts to disturbance. However, wherever possible, monitoring should be directed towards direct measurement of biological end-points. Drivers/primary determinants of the EC should be monitored and interpreted with reference to the biological/ecological end-points.

Detail monitoring programmes have been provided for various IFR studies as well as for the Mhlathuze Reserve (IWR Environmental, 2003. Mhlathuze Monitoring Report). The Mhlathuze process was used as the basis for the Thukela monitoring programme.

The monitoring programme is based on Adaptive Environmental Assessment and Management (AEAM) principles. This means that:

- There is a realisation that insufficient knowledge exist to accurately predict the outcome of particular management actions.
- There may be an under- or overprotection of the accepted Ecological Category (EC), i.e. the desired state.
- The monitoring programme is designed according to an iterative and feedback system (learning-by-doing-by-learning-by-doing) with specified. Thresholds of Potential Concern (TPCs)and built in contingency procedures.
- Ecological specifications (referred to as Ecospecs) will be formulated according to the available information, and will be used as hypothesis as to their applicability and relevancy. The first stage in defining ecological specifications will be broad and generic and will be improved and refined by providing more detail and insight that emanates from baseline surveys and repeated biomonitoring surveys.

Ecospecs are derived from RQOs and are clear and measurable specifications of ecological attributes (e.g. water quality, flow, biological integrity) that define the Class and serve as an input to Resource Quality Objectives. Ecospecs refer explicitly and only to ecological information whereas RQOs include economic and social objectives.

TPCs provide a set of end-points which describe the desired state in scientific detail and also provide the basis of a parsimonious programme of monitoring for a wide range of biodiversity indicators. TPCs are upper and lower levels along a continuum of change in selected environmental indicators. When this level is reached (or when modelling predicts it will be reached), it prompts an assessment of the causes of the extent of the change. The assessment provides the basis for deciding whether management action is needed or recalibrates the TPC. TPCs provide management with strategic goals or end-points within which to manage the system. They form the basis of an inductive approach to adaptive management, as they are invariably hypotheses of limits of acceptable change in ecosystem structure, function and composition. As such their validity and appropriateness are always open to challenge and they must be adaptively modified as understanding and experience of the system being managed increases.

The requirements for a monitoring programme, and the steps taken to meet these in the development of the programme, were as follows:

- A Baseline Monitoring Decision Support System (DSS) must be formulated to determine the additional information required to set a Baseline. The Baseline Monitoring DSS (BMDSS) which was devised during the Mhlathuze study was refined and used during this study to set the baseline. The method was refined during a one-day specialist meeting with key specialists present during October 2003.
- A Compliance Biomonitoring DSS (BIODSS) was required to provide structure to the monitoring programme and to provide some indication of how the monitoring results will be used during the overall management of the system. The BIODSS formulated for the Mhlathuze Study was again adapted and refined for use within this study at the above one-day meeting.
- Ecospecs for the relevant ECs must be defined. The Ecospecs associated with Scenario 9 had to be identified for flow, quality, biota and habitat. Flow and quality information have already been identified and was available. Preliminary information identified during the course of the study was collated and provided to specialists so that the final Ecospecs per IFR site for the relevant EC could be stipulated. For each of the Ecospecs, a TPC had to be identified. This information was generated during a two-day specialist meeting where specialists had to complete tables within a format provided to them.
- Actions required to establish a baseline for monitoring purposes had to be identified. Each action is linked to the Ecospec and TPC identified earlier. During the RD study, information is collated that could serve as the baseline. Constraints within the study do however not allow for all the information to be compiled in the format required for monitoring. The specialists used the BMDSS during the specialist meeting to identify the outstanding information. Set templates were completed per IFR site and for the estuary, to indicate the time and human resources required. The Baseline is usually collated over a period of one-year.
- Actions required during long-term monitoring were then also identified for key IFR sites in the same manner as above.

17.3 RESULTS

The following assumptions are made prior to the DSS being implemented as described below:

- Both the Present Ecological State (PES) and Ecological Category (EC) derived from the Management Class have been specified in qualitative and quantitative terms. This is a product of the Ecological RD process.
- Water quantity and quality specifications for the EC are available.
- A particular Decision Support System has been followed to determine whether Compliance Reserve Monitoring is required.

17.3.1 River Baseline

The baseline monitoring requirements for 1 year were provided during the 2-day monitoring specialist workshop (October 2003). The results were produced on Excel spreadsheet. A summary of the results is provided below.

Table 17.1 River baseline monitoring (Time provided in 8 hour days)

Component	Sampling		Analysis		Reporting	
	Sp	Tech	Sp	Tech	Sp	Tech
IFR 1 total	5.7	12.2	5.85	13.5	4.3	0.5
IFR 2 total	5.7	12.2	5.85	13.5	4.3	0.5
IFR 4 total	5.7	16.2	5.85	11.5	4.3	0.5
IFR 9 total	5.7	2.2	3.35	1	1.3	
IFR 15 total	5.7	6.2	5.85	1.5	3.3	0.5
IFR 16 total	5.7	8.2	3.35	13	2.3	
IFR 3 total	5.7	12.7	5.85	16.5	4.8	0.5
IFR 5 total	5.7	16.2	5.85	13.5	4.3	0.5
IFR 7 total	5.7	16.2	5.85	11.5	4.3	0.5
IFR 8 total	5.7	2.2	3.35	1	1.3	
IFR 10 total	5.7	12.2	5.85	7.5	4.3	0.5
IFR 11 total	5.7	2.2	3.35	1	1.3	
IFR 13 total	5.7	12.2	5.85	11.5	4.3	0.5
IFR 14 total	5.7	2.2	3.35	1	1.3	
GRAND TOTAL	**79.8**	**137.3**	**66.4**	**97.5**	**45.7**	**5.5**

17.3.2 River Long-term monitoring

The monitoring requirements for 5 years were provided during the 2-day monitoring specialist workshop (October 2003). The results were produced on Excel spreadsheet. A summary of the results is provided below.

Table 17.2 River long-term monitoring (Time provided in 8 hour days)

Component	Sampling		Analysis		Reporting	
	Sp	Tech	Sp	Tech	Sp	Tech
IFR 1 total	8.5	45	5.6	43	7	0.5
IFR 2 total	8.5	45	6.1	41.5	8.5	0.5
IFR 4 total	8.5	45	6.1	41.5	8.5	0.5
IFR 15 total	4	5	3.5	0.5	4	0.5
IFR 16 total	4.5	40	2.6	41	4.5	
IFR 3 total	8.5	45	6.1	41.5	8.5	0.5
IFR 5 total	8.5	45	6.1	41.5	8.5	0.5
IFR 7 total	8.5	45	6.1	41.5	8.5	0.5
IFR 10 total	4	42	3	40.5	6.5	0.5
IFR 11 total	4.5	5	3.6	1	2.5	0
IFR 13 total	4	40	2.5	40.5	6	0.5
IFR 14 total	4.5	5	3.6	1	2.5	0
GRAND TOTAL	**76.5**	**399**	**54.9**	**385**	**78.5**	**37.7**

17.3.3 Estuary Baseline

Table 17.3 Estimated budget (in days) for baseline surveys for high priority components

Component	Sampling				Analysis				Reporting			
	Specialist		Tech		Specialist		Tech		Specialist		Tech	
	Closed	Other	Closed	Other	Closed	Other	Closed	Other	Closed	Other	Closed	Other
Birds	1	-	-	-	-	-	-	-	1	1	-	-
Fish	2	1	2	10	1	-	2	5	3	3	-	-
Invertebrates	-	3	4	21	10	-	3	17	5	9	-	-
Macrophytes	-	-	-	-	-	-	-	-	-	-	-	-
Microalgae	4	-	4	-	8	-	12	-	8	-	-	-
Water quality	2	-	2	-	Accredited laboratories				2	1	-	-
Hydrodynamics	-	-		14	-	-	-	4	-	1	-	1
Sediment	-	1	-	20	-	1	-	1 plus R 37 000	-	4	-	-
TOTAL	**9**	**5**	**12**	**65**	**19**	**1**	**17**	**27 plus R 37 000**	**19**	**19**	**-**	**1**

17.3.4 Estuary Long-term monitoring

Table 17.4 Estimated budget (in days) for long term monitoring programme per sampling year for high priority components

	Sampling		Analysis		Reporting	
	Specialist	Tech	Specialist	Tech	Specialist	Tech
Birds	-	-	-	-	2	-
Fish	3	5	-	2	1	-
Invertebrates*	-	4 (+6)	10	3 (+6)	5 (+2)	-
Macrophytes	1	1	2	3	1	1
Microalgae**	2 (+3)	2 (+3)	4 (+6)	6(+6)	8 (+ 4)	-
Water quality	1	3	Accredited laboratories		3	-
Hydrodynamics	-	14	-	4	1	1
Sediment	2	12	1	R 5000	2	-
TOTAL	**9 (+3)**	**41 (+9)**	**17 (+6)**	**18 (+12) R 5000**	**23 (+6)**	**2**

* Resources in brackets only required if *Varuna* are absent from IFR sites where these were identified under the baseline study

** Resources in brackets only required if an algal bloom occurs in the estuary

17.4 CONCLUSION

The above results should allow DWAF to make an estimate of costs associated with the monitoring and to allow for planning and budgeting. The above costs exclude management costs, VAT, disbursements and escalation. If an average cost of an hourly rate of R370 for a specialist and R150 for a technician is used, the estimated costs are provided in Table 17.5. Also note that the costs exclude the hydraulic costs to provide rated sections, as well as any hydrological monitoring.

Table 17.5 Illustration of potential costs

Monitoring	River	Estuary	Total
Baseline (1 year)	R856 864	R359 520	R1 216 384
Long term average over 1 year (based on 5 year total)	R321 469	R218 240	R539 709

17.5 IMPLEMENTATION OF THE RESERVE: HYDROLOGY MONITORING REQUIRED

There is a need to provide the natural triggers/cues, which are used to determine the Reserve requirements on a day-to-day (or month-to-month) basis. The natural trigger is used to determine the exceedence % point of the expected natural flow at any moment in time.

Three possible methods have been identified, i.e. using gauged records, real time monthly simulation and real time daily simulation. Each of these has a range of advantages and disadvantages.

Either of the modelling approaches have distinct long-term advantages, which will be applicable not only to the Thukela system, but to every other catchment in the country. The main advantages being, the approach is flexible, has value beyond the immediate objectives of implementing the Reserve, and can be established as a generic methodology for any catchment.

18 CAPACITY BUILDING AND TRAINING REPORT

Note: This chapter is a summary of report DWAF Report No PBV000-00-10312 (DWAF 2004g).

18.1 OVERVIEW

One of the components of the Thukela RD module was a capacity building exercise to extend the current specialist skills base. Trainee and mentor teams were identified at the outset of the study, and training was primarily conducted through workshops, field trips and a final 'wrap-up' training session in the last quarter of the study. The training in each component, e.g. hydrology vs. water quality vs. estuaries, was conducted following the most relevant format to that component. Common objectives, assessment criteria and reporting structures were distributed to all mentors at the beginning of the study, so as to work toward a common goal.

This report therefore presents training reports from each mentor, and includes contributions and reports from trainees. An important component of training evaluation was the preparation and assessment of trainee questionnaires distributed at the final training workshop in October 2003, and submitted for evaluation to an independent assessor. Results, and conclusions and recommendations drawn from the trainee questionnaires, mentor reports and trainee sessions at workshops, are included in the final section of the report.

The following mentor and trainee teams were identified at the outset of the project.

- **Hydrology:** Prof Denis Hughes (Institute for Water Research (IWR), Rhodes University) and Ms Sihle Bukhosini (previously Ms Shange) (trainee) of Umgeni Water.
- **Geomorphology**: Dr Roy Wadeson (private consultant) and Mr Malixole Soviti (trainee) of the Geography Department of Rhodes University. Mr Soviti completed his M Sc and moved on to a lecturing post at the University of the Transkei in 2002/2003.
- **Water quality:** Dr Patsy Scherman (Coastal and Environmental Services, previously of the IWR, Rhodes University) and Ms Ntomboxolo Valisa (trainee), a technician at the IWR, Rhodes University. Ms Valisa registered as a B Sc student in 2003.
- **Macroinvertebrates:** Dr Chris Dickens and Mr Tobile Bokwe (trainee), both of Umgeni Water.
- **Estuaries – macrophytes:** Dr Janine Adams and Mr Phumelele Gama (trainee), both of the University of Port Elizabeth's Botany Department.
- **Estuaries – zooplankton and macrocrustacea:** Ms Fiona Mackay and Mr Mdu Mzimela (trainee - zooplankton) and Mr Phinda Buthulezi (trainee - macrocrustacea), all of the Coastal Research Unit of Zululand, based at the University of Zululand.
- **Estuaries and the Reserve process:** Dr Jane Turpie – undergraduate student course at the University of Cape Town.

18.2 OBJECTIVES

The following information was distributed to the mentors at the outset of the project as the aims and objectives of capacity building and training.

- A theoretical understanding of the Reserve concept and process.
- An understanding of the concepts related to their specific discipline.
- The ability to utilize the tools or software required by their discipline within the Reserve process, or understands the use of these tools, e.g. time-series analysis, water quality modelling of field techniques.

- The ability to interpret information related to their discipline, particularly within the broader scope of the Reserve process.
- An understanding of the requirements of other specialists within the process.
- The ability to communicate this information to other specialists - both verbally and in a report format. It was recognised that this aim may be difficult to report on. Mentors were therefore requested to include their assessment of the trainee's input to the process, and understanding thereof.
- The ability to work in a team of specialists from different disciplines, but with a common goal.

Guidelines for training and evaluating trainee progress were also distributed to mentors at the outset of the Thukela study.

18.3 MENTOR AND TRAINEE REPORTS

Reports were received from each mentor in the programme, according to the most suitable format for their particular component. Trainee contributions were in the form of assessments attached to mentors reports, trainee reports e.g. contributions to specialist reports or reports written as a record of a workshop or field trip, and trainee questionnaires. Questionnaires were sent to an independent evaluator, and a summary of results submitted for inclusion in the training report.

These inputs are not included in this summary, but can be seen in the main capacity building and training report.

18.4 CONCLUSIONS AND RECOMMENDATIONS

The main training tools used in this programme were the attendance of trainees at workshops and meetings, field surveys, and mentor-trainee one-on-one training sessions. One of the most successful training tools appears to have been the final 'wrap-up' training session in October 2003 – providing a useful overview of the study to trainees and mentors alike.

A capacity building and training budget was set up for the study, with budget allocations for each mentor and trainee team. In some instances organisations made extra provision for trainees to receive additional training; other organisations allowed trainees extra time to spend on Thukela training activities. This contribution is seen as a positive indication of commitment to training, both to building capacity of trainees and increasing the specialist skills base of organizations.

The following recommendations were drawn from the contributions of mentors and trainees to the training process:

- Specific budgets must be allocated to training, either as a sum of money to be allocated or a percentage of the overall Reserve budget. A training budget allowed for successful training in the Thukela Reserve study, but a similar process has not been followed for the Reserve studies initiated in 2003.
- Trainees and the client must have realistic expectations of the training process. The expectations must therefore meet the budget and skills level of the trainees.
- A combined rivers and estuaries training session should also be conducted at the outset of the study, so as to allow trainees time to understand the process they will be conducting.
- All river trainees should attend an IFR site visit, including the hydrological trainee. The water quality trainee may choose to rather accompany the water quality team on the survey of the study area.
- All trainees should be involved from the beginning of the study, so as to be exposed to all the preparatory work before workshops and field surveys are initiated.

- The training programme must address the long pauses between workshops, meetings and field surveys, which leads to fragmentation of the training process. Mentors must be encouraged to remain in close contact with their trainees during these times, and update them regarding progress. A suggestion may be that progress reports be distributed to trainees, so as to keep them updated. The final main report of the Thukela study should also be distributed to all trainees.
- The training programme should be more structured – possibly with general feedback on the progress of the study through one person.
- If Reserve training is to be successful, follow-up training e.g. inclusion in subsequent Reserve studies should be offered to trainees. It must be understood by the trainee that training in the Reserve process will require commitment and hard work, particularly as mentors carry additional demands of meeting deadlines and fulfilling the tasks required of them. Trainees working on subsequent studies should be carefully selected; particularly in terms of specialist field and time they will be able to commit to the project while still fulfilling their other work commitments. Additional exposure and training is critical to expanding the specialist skills base in South Africa.
- More time and budget must be allocated to practice and proper learning. Due to deadline constraints and the pressures of a workshop environment, there is not enough time for trainees to practice on associated case studies, so as to develop their skills. It is possible that this type of training should be conducted outside of a specific Reserve study, but should be seen as a development tool for trainees specifically wanting to train as Reserve specialists.
- Trainees must be carefully selected. If a trainee is selected for a particular discipline on the basis of some previous or associated exposure to the subject, it cannot be expected that they develop as independent Reserve specialists. These trainees often feel abandoned by the process, partly because they do not have the specific background in the field. There is a vast amount of background knowledge and experience that is required to be a successful specialist, and this cannot be taught in workshops and field surveys. This is perceived to be an important shortcoming, primarily due to the lack of trainees available to specialists. One recommendation is that DWAF: RDM Directorate develop a database of available trainees for Reserve studies – the inclusion of trainees on this database should be according to a set of coherent guidelines.
- It is acknowledged that changes do take place in mentors and trainees' careers over a 3 year study, and that this contributes to the fragmentation of the training process.
- Trainees must be encouraged to be proactive in their inclusion in future studies. A suggestion was that the Thukela trainees (either individually or as a group) approach the RDM Directorate with the request to be included on future Reserve studies.
- It must be acknowledged that there are two levels of training.
    - Specialist training, so that the trainee is proficient and has some experience in their particular field, and
    - application and further development of this specialist training and knowledge to the Reserve process.

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