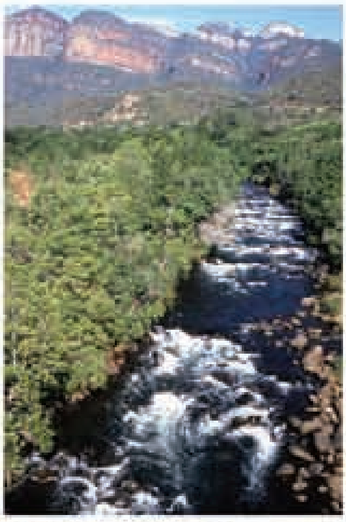
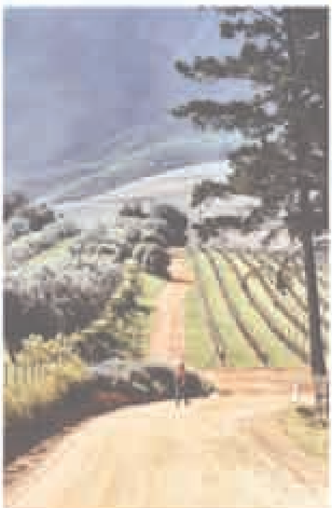
DEVELOPMENT OF THE WATER RESOURCE CLASSIFICATION SYSTEM (WRCS)

Ecological, hydrological and water quality guidelines for the 7-step classification procedure · February 2007






1st Edition

Chief Directorate
Resource Directed Measures

Volume 2

water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

THE DEVELOPMENT OF THE WATER RESOURCE CLASSIFICATION SYSTEM (WRCS)

First Edition: February 2007
Volume 2

Ecological, Hydrological and Water Quality Guidelines for the 7 – Step Classification Procedure

Chief Directorate: Resource Directed Measures

Technical Guidelines for
DEVELOPMENT OF THE WATER RESOURCE CLASSIFICATION SYSTEM (WRCS)

First Edition

Department: Water Affairs and Forestry

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Preface

The Water Resource Classification System (WRCS) was established in response to the South African National Water Act of 1998. The WRCS is a set of guidelines and procedures that, when applied to a specific catchment, will ultimately assist in the process of maintaining a balance between protecting our national water resources and using them to meet economic and social goals. The procedures are to be applied as part of a consultative ‘Classification Process’, the final outcome of which is a decision about the set of desired characteristics for each of the water resources in a given catchment.

The Classification Process sets a ‘Class’, which defines objectives for every significant water resource—watercourse, surface water, estuary, or aquifer. There are three classes, ranging from the minimally used to the heavily used. These objectives describe the desired condition of these resources and the extent to which they can be utilised.

The Classification Process is not carried out in isolation, but is integrated within the overall planning for water resource protection, development and use. A key component of classification is therefore the ongoing process of evaluating options with stakeholders in which the economic, social and ecological trade-offs will be clarified and decided upon.

Volumes 1 to 5 of these reports build on an earlier version of the classification system and meet the terms of reference as set out in the inception report (DWAF, 2005). The development of the new system was completed in twelve months using the Olifants/Doring catchment as a ‘proof of concept’ catchment. The Olifants/Doring system was chosen for two reasons: 1) A recent Reserve determination study had provided much of the required information. 2) Most of the WRCS project team had been involved in the determination study.

It was initially planned that once the draft WRCS had been developed, it would be tested, refined and possibly streamlined using two other, more complex catchments (such as Thukela and Incomati). This turned out not to be possible. The description of the classification procedure has therefore been left as generic as possible so that future applications of the WRCS can build on and improve the procedures and guidelines presented in these volumes.

The classification system regulations will be developed from these volumes.

Acknowledgements

The following persons and organisations are thanked for their contributions to this project:

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ACRONYMS AND GLOSSARY

ADE	Aquifer Dependent Ecosystems
AEC	Alternative Ecological Category
BBM	Building Block Methodology
BHN	Basic Human Needs
CD: RDM	Chief Directorate: Resource Directed Measures
CMS	Catchment Management Strategy
Cons.	Freshwater Conservation Targets
CSIR	Council for Scientific and Industrial Research
D: RQS	Directorate: Resource Quality Services
DRIFT	Downstream Response to Imposed Flow Transformations
DSLF	Dry Season Low Flow
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EGSA	Ecosystem Goods, Services and Attributes
EIS	Ecological Importance and Sensitivity
EISC	Ecological Importance and Sensitivity Category
ELU	Existing Lawful Use
ESBC	Ecological Sustainability Base Configuration
EWR	Ecological Water Requirements
FHSR	Flow Habitat Stressor Response
GIS	Geographic Information System
GRU	Groundwater Response Unit
GW	Groundwater
HI	Habitat Integrity
HIA	Habitat Integrity Assessment
HydI	Hydrological Index
I&AP	Interested and Affected Parties
IBT	Interbasin Transfer
ISP	Internal Strategic Perspective
IUA	Integrated Units of Analysis
IWA	International Water Agreement
IWRM	Integrated Water Resource Management
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbgl	metres below ground level
MC	Management Class
MSL	Mean Sea Level
MTIFR	Maintenance Total Instream Flow Requirement
NDSD	National Department of Social Development
NGDB	National Groundwater Database
nMAR	Naturalised Mean Annual Runoff
NWA	National Water Act
PBML	Potential Bed Material Load
PES	Present Ecological Status
PESC	Present Ecological Status Category
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RHP	River Health Programme
RQOs	Resource Quality Objectives
RU	Resource Unit

RWQO	Resource Water Quality Objective
SAM	Social Accounting Matrix
SANBI	South African National Biodiversity Institute
SAWQG	South African Water Quality Guidelines
SW	Surface Water
TC1	Test Catchment 1 (Olifants/Doring catchment)
TDGE	Terrestrial Dependent Groundwater Ecosystems
TDS	Total Dissolved Solids
TWQR	Target Water Quality Range
WMA	Water Management Area
WMS	Water Management System
WQT	Water Quality TDS
WR2005	Water Resource 2005
WRCS	Water Resource Classification System[1]
WRSA	Water Resource Situation Assessment
WSAM	Water Resource Situation Assessment Model
WWTW	Waste Water Treatment Works
WWTW	Waste Water Treatment Works

Catchment configuration: A set of ecological categories (ECs) within a catchment for each nodal reach representing a significant water resource.

Ecostatus: The totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna and it capacity to provide a variety of goods and services (Kleynhans *et al.* 2005).

Habitat Integrity: A measure of the extent or degree to which the integrated composition of physico-chemical and habitat characteristics is maintained on scale that is comparable with the characteristics under natural conditions. Habitat integrity can be used as a surrogate for Ecostatus (Kleynhans *et al.* 2005).

IUA class: The desired condition or characteristics of a resource and concomitantly, the degree to which it can be utilised. It may range from minimally to heavily used, depending on societal requirements. The IUA Class is a summary condition recommended for a configuration of water resources within an IUA and between IUAs in a catchment.

Nodes: These are modelling point's representative of an upstream reach or area of an aquatic ecosystem (rivers, wetlands, estuaries and groundwater) for which a suite of relationships apply.

Nodal reaches: the upstream reach or area of an aquatic ecosystem as represented by nodes.

Present Ecological State: the current state or condition of a resource in terms of its various biophysical components, i.e. drivers (physico-chemical, geomorphology, and hydrology and biological responses (i.e. fish, riparian vegetation and aquatic invertebrates).

Significant Water Resources: Water resources that are deemed to be significant from a water resource use perspective, and/or for which sufficient data exist to enable an evaluation of changes in their ecological condition in response to changes in their quality and quantity of water.

[1] Note: This was previously referred to as the National Water Resource Classification System (NWRCS).

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1 INTRODUCTION

The WRCS is required by the National Water Act (NWA) (No. 36 of 1998), and consists of a set of guidelines and procedures for determining the different classes of water resources (Chapter 3, Part 1, Section 12). Desired characteristics of the resource are represented by a Management Class (MC) which outlines the attributes required of different water resources by the resource custodian (Department: Water Affairs and Forestry (DWAF)) and by society.

The WRCS will be used in a consultative process (i.e. the Classification Process) to classify the water resources within a geographic region in order to facilitate finding a balance between protection and use of the water resources. The actual process of *applying* the WRCS procedures described in this volume to a catchment is called the Classification Process i.e. establishing the MC. The economic, social and ecological implications of choosing a MC need to be established and communicated to all Interested and Affected Parties (I&AP) during the Classification Process.

The outcome of the Classification Process will be the setting of the MC, Reserve and Resource Quality Objectives (RQOs) by the Minister or delegated authority for every significant water resource (watercourse, surface water, estuary, or aquifer) under consideration. This will be binding on all authorities or institutions when exercising any power, or performing any duty under the NWA. This MC, which will range from Minimally to Heavily used (**Error! Reference source not found.**), essentially describes the desired condition of the resource, and concomitantly, the degree to which it can be utilised. In other words, the MC of a resource sets the boundaries for the volume, distribution and quality of the Reserve and RQOs, and therefore informs the determination of the allocatable portion of a water resource for use. This has considerable economic, social and ecological implications.

Table 1.1 Proposed water resource classes

Class I: Minimally used
The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is minimally altered from its pre-development condition.
Class II: Moderately used
The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is moderately altered from its pre-development condition.
Class III: Heavily used
The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is significantly altered from its pre-development condition.

1.1 Objectives of this report

This report presents the ecological, hydrological and water quality guidelines and procedures for undertaking Steps 1 to 5 of the classification procedure (see Section 0) through a ‘proof of concept’ application to the Olifants/Doring catchment (Test Catchment 1 (TC 1)). The context of the WRCS, the definition of the classes and description of the overall classification procedure are presented in Volume 1 of this series (Dollar *et al*., 2007). The guidelines and procedures for the socio-economic and decision analysis components of the classification procedure and their application to the Olifants/Doring catchment are presented in Volumes 3 (Turpie *et al*., 2007) and 4 (Joubert *et al*., 2007), respectively.

1.2 7-Step classification procedure

A seven-step procedure to recommending the Class of a resource (the outcome of the Classification Process) is proposed (Figure 1.1). The seven steps, which may be embedded in other DWAF processes, are:

Step 1: Delineate the units of analysis and describe the status quo of the water resources:-

a. Describe the present-day socio-economic status of the catchment;
b. Divide the catchment into socio-economic zones;
c. Identify a network of significant resources, describe the water resource infrastructure and identify the water user allocations;
d. Define a network of significant resources and establish the biophysical and allocation nodes.
e. Describe communities and their wellbeing;
f. Describe and value the use of water;
g. Describe and value the use of aquatic ecosystems;
h. Define the Integrated Units of Analysis (IUA);
i. Develop and/or adjust the socio-economic framework and the decision-analysis framework; and
j. Describe the present-day community wellbeing within each Integrated Unit of Analysis.

Step 2: Link the value and condition of the water resource:-

a. Select the ecosystem values to be considered based on ecological and economic data;
b. Describe the relationships that determine how economic value and social wellbeing are influenced by the ecosystem characteristics and the sectoral use of water; and
c. Define the scoring system for evaluating scenarios.

Step 3: Quantify the Ecological Water Requirements and changes in non-water quality Ecosystem Goods, Services and Attributes:-

a. Identify the nodes to which Resource Directed Measures data can be extrapolated and make the extrapolation;
b. Develop rule curves, summary tables and modified time series for all nodes for all ecological categories; and
c. Quantify the changes in relevant ecosystem components, functions and attributes for each ecological category for each node.

Step 4: Determine an Ecologically Sustainable Base Configuration scenario and establish the starter configuration scenarios:-

a. Determine an Ecologically Sustainable Base Configuration (ESBC) scenario that meets feasibility criteria for water quantity, water quality and ecological needs;
b. Incorporate the planning scenarios (future use, equity considerations and existing lawful use); and
c. Establish the Resource Directed Measures configuration scenarios.

Step 5: Evaluate scenarios within the Integrated Water Resource Management (IWRM) process:-

Steps 5 and 6 form part of the 'Larger Process' where the economic, social and ecological trade-offs will be made. Trade-offs will also need to be made between Existing Lawful Use (ELU) and equity considerations. Emerging from this 'Larger Process' will be the recommended MC, Reserve and RQOs, CMS, allocation schedule, modelling system and the monitoring, auditing and compliance strategy. A number of key questions will need to be addressed in this 'Larger Process'. These include:

- at what level will the trade-offs be negotiated?
- in what institutional setting will they be negotiated?
- what types of scenarios will inform the process of negotiation?; and
- since the recommended MC, Reserve, RQOs, CMS and allocation schedule will impact on specific groups of people in different ways, what processes will guide decisions about who benefits and who pays the social and economic cost?

These key questions should be framed (and assessed) in the context of equity, efficiency and sustainability as required by the NWA, and by the core objectives of the present government which are, amongst others, to halve poverty and unemployment by 2014, to reduce the regulatory burden on small and medium businesses, and to eliminate the second economy[2]. Step 5 should therefore contribute to meeting government's objective of '…reduce(ing) inequality and virtually eliminating poverty'.[3] To address these objectives and to fit within the larger DWAF institutional context, Classification Procedure Step 5 needs to include the following sub-steps:

a. Run a yield model for the Ecologically Sustainable Base Configuration scenario and other scenarios and adjust the scenarios if necessary;
b. Assess the water quality implications (fitness for use) for all users;
c. Report on the IUA-scale ecological condition and aggregate impacts for each preliminary scenario;
d. Value the changes in aquatic ecosystems and water yield;
e. Describe the macro-economic and social implications of different catchment configuration scenarios;
f. Evaluate the overall implications at an Integrated Unit of Analysis-level and a regional-level; and
g. Select a subset of scenarios for stakeholder evaluation.

Step 6: Evaluate the scenarios with stakeholders:-

a. Stakeholders evaluate scenarios and agree on a short-list; and
b. Recommend classes for the Integrated Units of Analysis.

Step 7: Gazette the class configuration:-

a. Populate the Integrated Water Resource Management summary template and present to the Minister or his/her delegated authority;
b. Decision by the Minister or his/her delegated authority on the Integrated Unit of Analysis classes, nested ecological category configurations, Reserve(s), allocation schedule(s) and the Catchment Management Strategy;
c. Set the resource quality objectives;
d. Gazette Integrated Unit of Analysis classes, nested ecological category configurations, Reserve(s) and resource quality objectives; and
e. Develop a plan of action for implementation of the recommended scenario which must include a monitoring programme.

[2] www.info.gov.za/issues/asgisa/.
[3] www.info.gov.za/issues/asgisa/.

1.3 Structure of this report

The report is structured and aligned with the classification procedure presented in Figure 1.1. The guidelines and procedures for the ecological, hydrological and water quality components of each of the 7-Steps are presented, together with an example of application of the guidelines and procedures to the ‘proof of concept’ catchment, the Olifants/Doring.

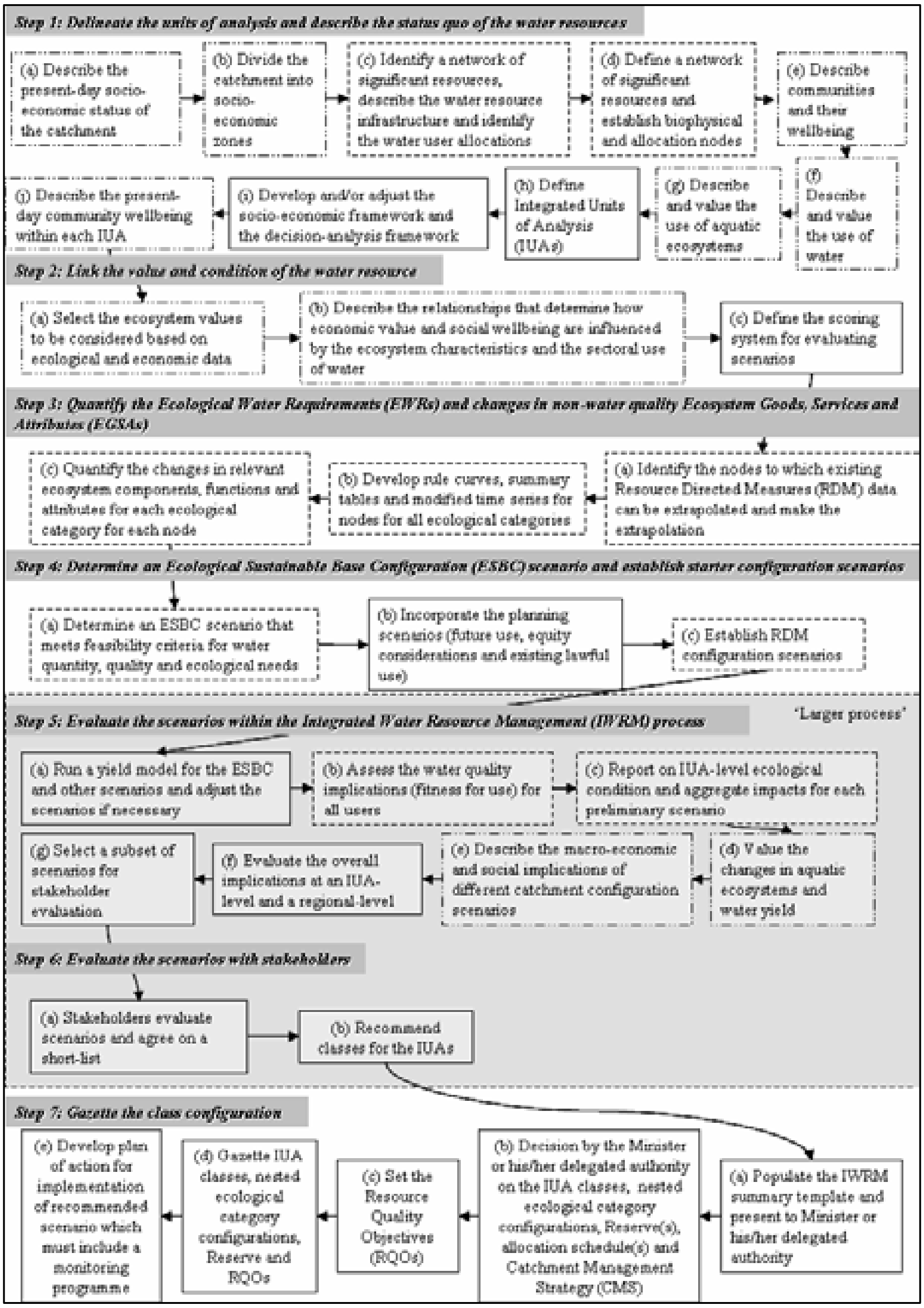

Figure 1.1 Proposed 7-Step classification procedure (note that Steps 5 and 6 form part of the ‘Larger Process’)

1.4 Using the Olifants/Doring catchment (TC 1) as a 'proof of concept' catchment

The Olifants/Doring catchment has been used as a 'proof of concept' catchment in developing the WRCS. The catchment is situated in the south-west of South Africa (Figure 1.2 and Figure 1.3). Significant portions of the catchment fall within the relatively dry Northern Cape Province. The remaining portion of the catchment falls within the wetter Western Cape Province (Brown *et al*., 2004). Additional detailed descriptions of the catchment are available in King and Tharme (1994), Dallas (1997) and DWAF (2004b).

A topographic divide and the ocean delineate the river basin or catchment (Brown *et al*., 2006). It is important to note, however, that for purposes of this project the Olifants/Doring catchment does not share the same boundaries as the Olifants/Doorn Water Management Area (WMA), which incorporates the catchments of the Swartland rivers to the west of the Olifants River mainstem, *viz*. the G secondary catchments (Midgley *et al*., 1994).

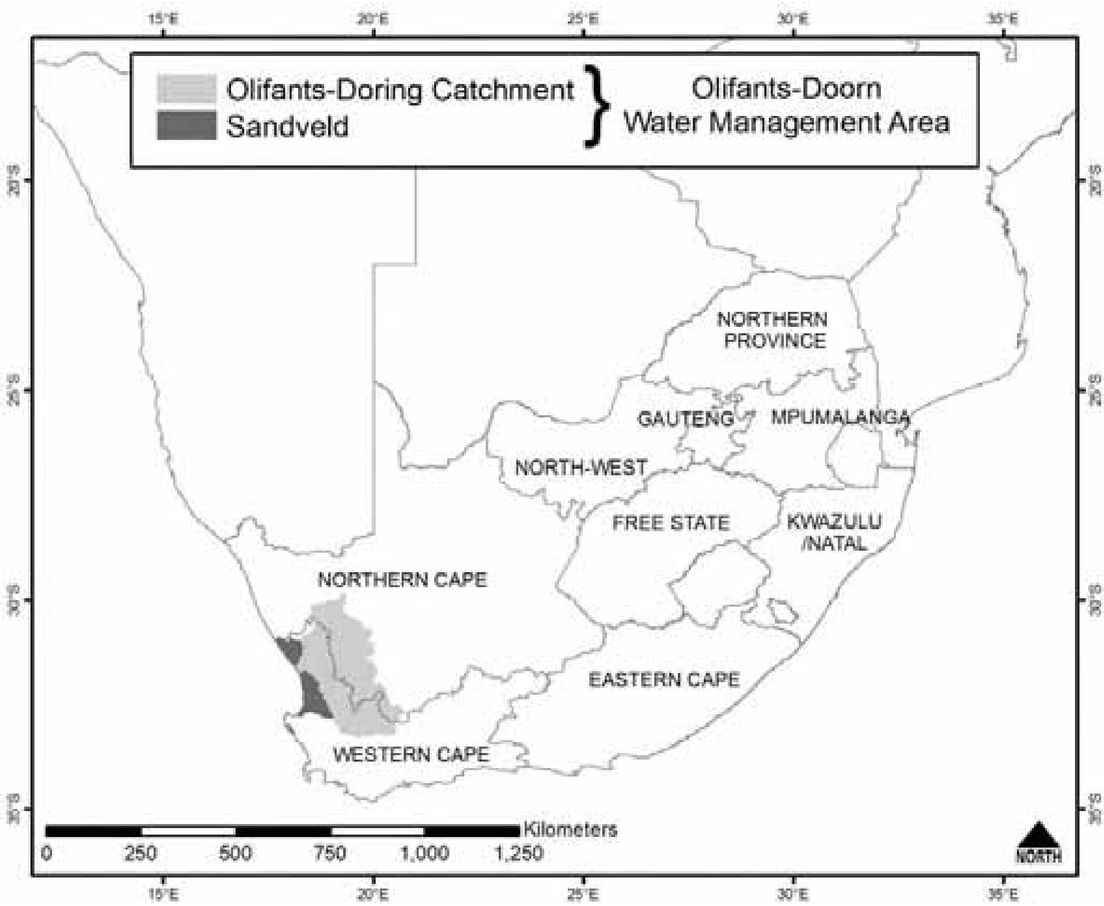

Figure 1.2 Map of South Africa showing the locality of the Olifants/Doring catchment

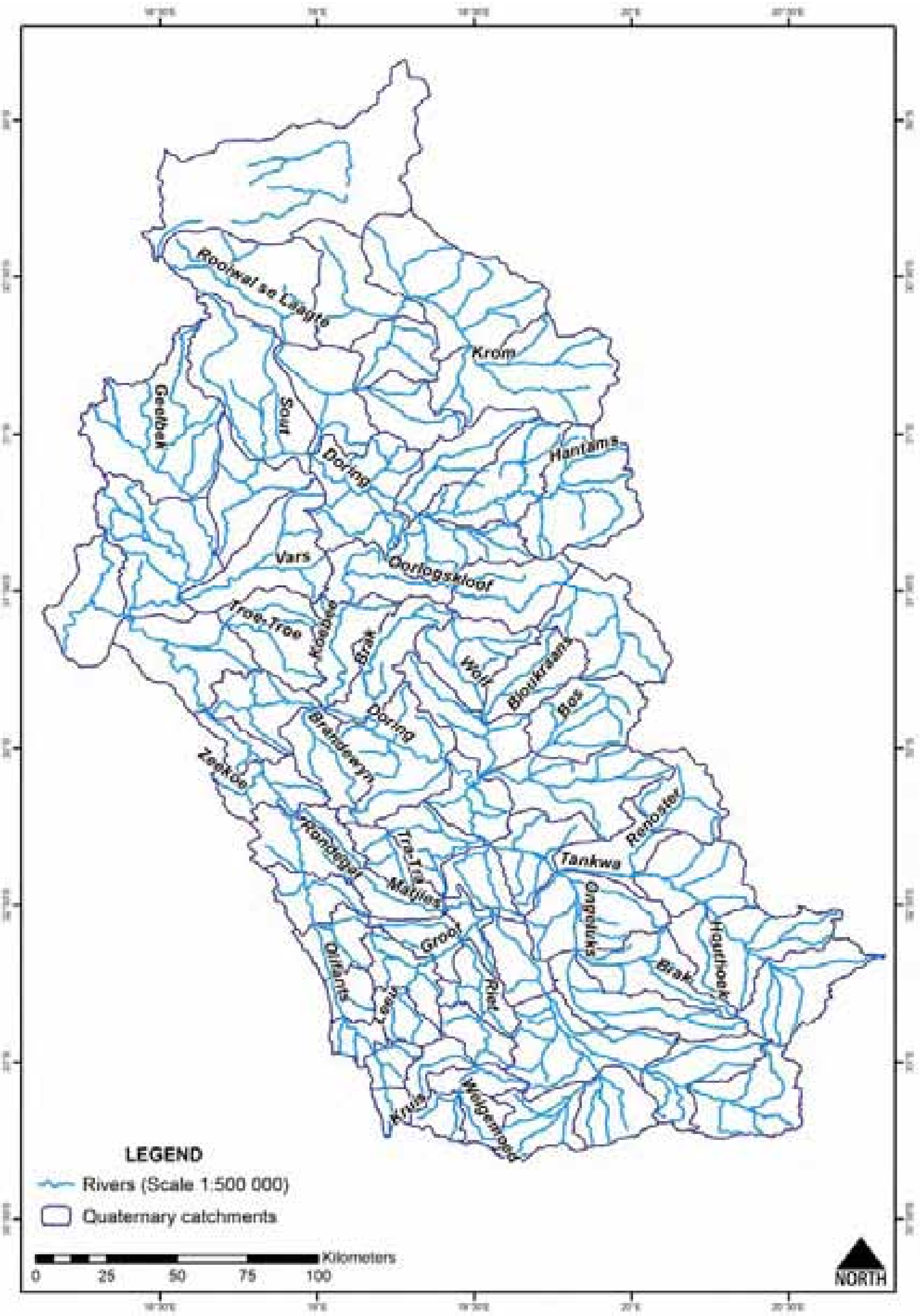

Figure 1.3 The Olifants-Doring Catchment

2 SUMMARY OF THE PROCEDURE FOR DELIVERY OF ECOLOGICAL, HYDROLOGICAL AND WATER QUALITY INFORMATION FOR THE CLASSIFICATION PROCESS

The process of delivery of ecological, hydrological and water quality information in each of the steps in the classification procedure is summarised in Figure 1.1 and detailed in later Sections in the report. The ecological, hydrological and water quality steps of the classification procedure is summarised in Table 2.1. Steps that require input from the ecological component, but are not the exclusive domain of the ecological component are highlighted in *italics*.

Table 2.1 Summary of the ecological, hydrological and water quality information in each of the steps in the classification procedure

Step	Description	Section
1c	Identify a network of significant resources, describe water resource infrastructure and identify water user allocations[4]	3
1d	Define a network of significant resources and establish biophysical and allocation nodes	4
1h	*Define the Integrated Units of Analysis (IUAs)*	*5*
1i	*Develop and/or adjust the socio-economic framework and the decision-analysis framework*	*6*
3a	Identify the nodes to which existing Resource Directed Measures (RDM) data can be extrapolated and make the extrapolation	7
3b	Develop rule curves, summary tables and modified time series for nodes for all ecological categories	8
3c	Quantify the changes in relevant ecosystem components, functions and attributes for each ecological category for each node	9
4a	Determine an ESBC scenario that meets feasibility criteria for water quantity, quality and ecological needs	11
4b	*Incorporate the planning scenarios (future use, equity considerations and existing lawful use)*	*12*
4c	Establish the RDM configuration scenarios	13
5a	*Run a yield model for ESBC scenario and other scenarios and adjust the scenarios if necessary*	*14*
5b	Assess the water quality implications (fitness for use) for all users[5]	15
5c	Report on the IUA-scale ecological condition and aggregate impacts for each preliminary scenario	16

Note: The procedures and tools provided in this report are intended only as guidelines for implementation of the WRCS, and the examples provided for the Olifants/Doring catchment are used only as a 'proof of concept'. It is expected that these will be adjusted depending on the characteristics of, and data available for, different catchments around the country, as well as further research and development of the tools themselves.

[4] Ensure inputs received from all areas, e.g., water quality, agriculture, water resource planning.
[5] All users refers to any users of the catchment water be it in or outside of the catchment.

3 IDENTIFY A NETWORK OF SIGNIFICANT RESOURCES, DESCRIBE WATER RESOURCE INFRASTRUCTURE AND IDENTIFY WATER USER ALLOCATIONS (STEP 1C)

3.1 Introduction

This Section provides an overview of the procedure recommended for the designation of ecologically-relevant biophysical nodes for all significant resources (aquatic ecosystems) at which responses of the **upstream** ecosystem to changes in water quality, quantity and timing will be determined. Nodes are modelling points representing an upstream reach or area of an aquatic ecosystem (rivers, wetlands, estuaries and groundwater) for which a suite of relationships apply. The detail of node establishment for individual ecosystems is provided in Section 4. While procedures and data requirements recommended for use herein (and in subsequent chapters) draw heavily on those developed for, *inter alia*, RDM (e.g. DWAF, 1999), the River Health Programme (RHP; DWAF, 2004a) and the Freshwater Conservation Planning Initiative (Nel *et al.,* 2006; Roux *et al.,* 2006), the goal of this process differs from those of the programmes from which methodological inspiration has been drawn.

The primary aim in defining biophysical nodes is to delineate a **network of significant resources that will form the basis of a classification process in a catchment**. In the case of surface water resources, nodes are located at the end-points of ecosystem reaches that will allow for meaningful trade-offs between different parts of the catchment in terms of the quantity (volume and distribution) and quality of water that remains in the aquatic ecosystem(s) – and thus the quantity (volume and distribution) and quality of water available for off-stream use.

To this end, a few simple rules were developed to guide the number and distribution of nodes. These are outlined in detail in the ecosystem-specific sections that follow. At the level of the whole catchment, however, the basic guidelines adopted at the outset were:

- too few nodes distributed through-out a catchment would provide insufficient scope for the trade-offs that may be required. The minimum number of nodes was thus set at 10;
- conversely, because each node needs to be incorporated into a system model and linked with hydrological, ecological, social and other data, too many nodes are not operationally feasible. The maximum number of nodes was thus set at 100; and
- the 'ideal' number of biophysical nodes was deemed to be between 40 and 60[6].

Negotiations may still be required within a reach (i.e. between nodes), but this scale was deemed to be too small a scale for provision of Classification information at the catchment level.

3.2 Identification of significant water resources

For the purposes of the WRCS significant water resources are defined as:

Water resources that are deemed to be significant from a water resource use perspective, and/or for which sufficient data exist to enable an evaluation of changes in their ecological condition in response to changes in water quality and quantity.

[6] This may however differ depending on catchment characteristics and uses.

As a first cut, these are[7]:

- mainstem river courses in each quaternary catchment, which has been created for the whole country using the DWAF 1:500 000 GIS rivers coverage (http://www.dwaf.gov.za/IWQS/gis_data/river/ rivs500k.html);
- wetlands, as identified by the national wetlands inventory (http://wetlands.csir.co.za/website/wetlands_inventory/intro.htm). This coverage is currently under development but will become available in the near future;
- estuaries as identified by Turpie (2004); and
- aquifers as defined by the DWAF hydrogeological map series within areas with yields of > 0.1 l/sec.

3.2.1 Rivers

For any classification process it will be necessary to reduce and/or augment the number of river systems under consideration on a case-by-case basis. Thus, as a first step, the following mainstem quaternary rivers can be augmented with:

- rivers for which Comprehensive or Intermediate Reserve Determinations have been undertaken;
- rivers for which sub-quaternary level hydrological data are available; and
- other rivers considered important from a water resource use perspective.

For the Olifants/Doring catchment, there are 39 mainstem rivers (Figure 3.1). These were augmented with the following rivers:

- Rondegat River, for which a Comprehensive Reserve Determination has been completed (Brown *et al*., 2005); and
- Zeekoei River, as a representative of the tributaries of the Olifants River that flow in from the west.

The base map for significant rivers in the Olifants/Doring catchment is provided in Figure 3.1.

3.2.2 Estuary

Turpie (2004) lists the Olifants Estuary as a permanently open estuary. Permanently open estuaries are described as estuaries where vertical and horizontal salinity gradients are present and are modified by the river flow, tidal range and mouth condition (Whitfield, 1992). Wetlands (salt marshes), as well as submerged macrophyte beds are common and the fauna are predominantly marine and estuarine. Hypersaline conditions in the upper reaches can occur during times of severe drought. The sea controls water temperatures in this estuary type during low flow conditions, with the rivers influence only felt during flood conditions (Whitfield, 1992).

[7] Wetlands are not included in this study, and will not be considered further here. However, as and when a RDM wetlands methodology becomes available, it should be included.

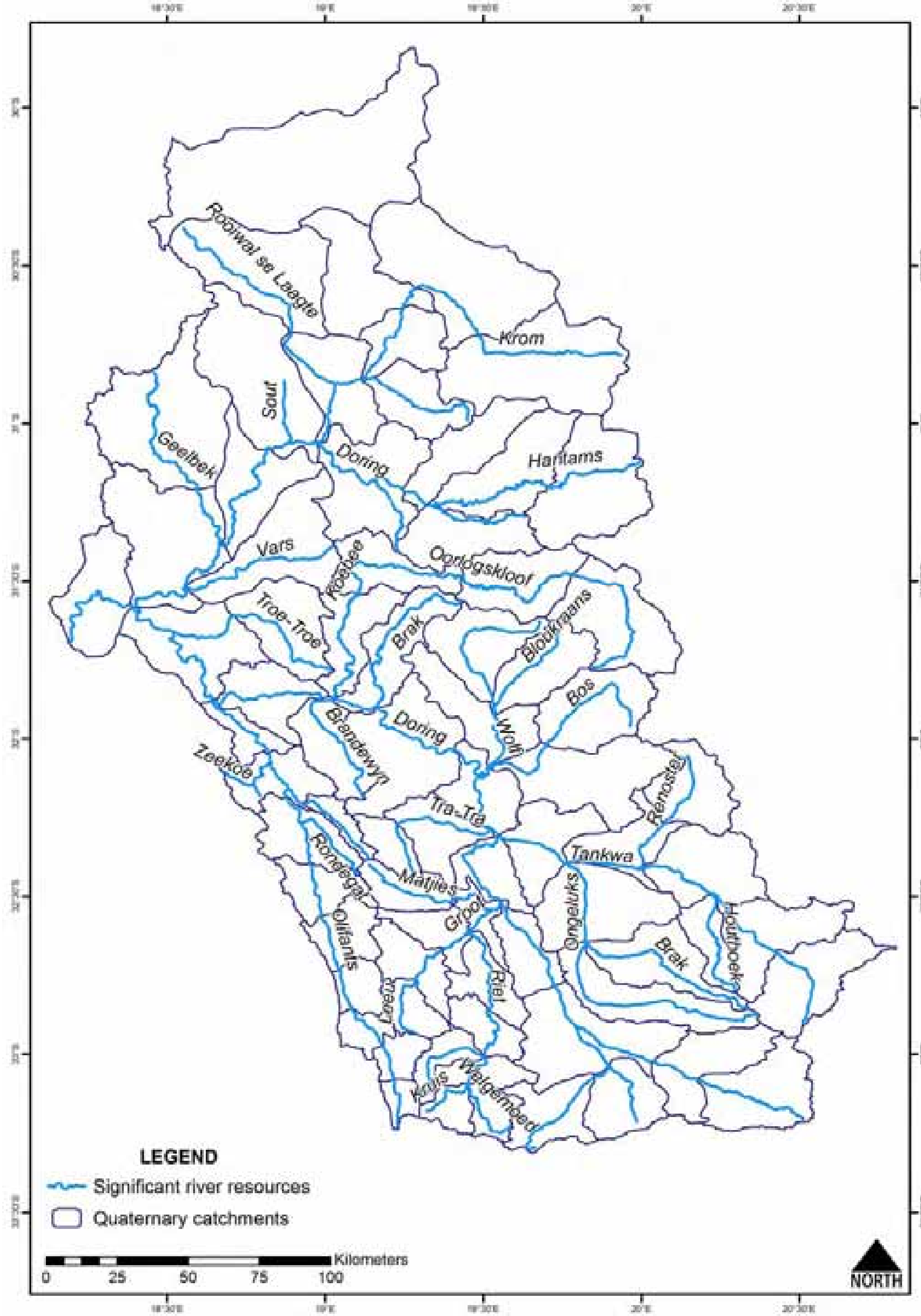

Figure 3.1 Base map for significant rivers in the Olifants/Doring catchment

Table 3.1 Significant river resources preliminarily identified in the Olifants/Doring catchment

	Beukesfontein
	Bloukraans
	Bos
	Brak
	Brandewyn
	Doring
	Geelbek
	Gemsbok
	Groot
	Hantams
	Houdenbek
	Houthoek
	Jakkals
	Jan Dissel
	Kamdanie
	Klein-Goerap
	Koebee
	Krom
	Kruis
	Kruismans

	Langvlei
	Leeu
	Matjies
	Olifants
	Ongeluks
	Oorlogskloof
	Papkuil
	Renoster
	Riet
	Rooiwal se Laagte
	Sout
	Tankwa
	Tra-Tra
	Troe-Troe
	Vars
	Verlorevlei
	Welgemoed
	Winkelhaak
	Wolf
	Rondegat
	Zeekoei

The geographical boundaries of the Olifants River estuary are provided in Figure 3.2. The geographical boundaries are as follows:

Downstream boundary: Estuary mouth (31^{o} 42.00'S; 18^{o}11.34'E).
Upstream boundary: Extent of tidal influence, i.e. the causeway at Lutzville - about 36 km from the mouth (31^{o}33.80'S; 18^{o}19.78'E).
Lateral boundaries: 5 m contour above Mean Sea Level (MSL) along each bank.

The 5 m contour above MSL is indicated on the provided on 1:10 000 orthophotos[8]. Although the 1:10 000 orthophotos are electronically available, the 5 m contour above MSL is not available on the electronic versions.

3.2.3 Groundwater

Groundwater resource units (GRUs) are defined on aquifer flow systems (based on geology and climate) within a catchment. They may include multiple recharge and discharge areas, but should only encompass a single macro-scale flow system within a lithostratigraphic unit such as a formation (e.g. the dolomitic Monte Christo formation), a group (e.g. Table Mountain Group aquifer), or a set of structurally controlled features (e.g. Karoo system dykes; see Section 4.6).

[8] Olifants River Estuary spans about 10 1:10 000 orthophotographs.

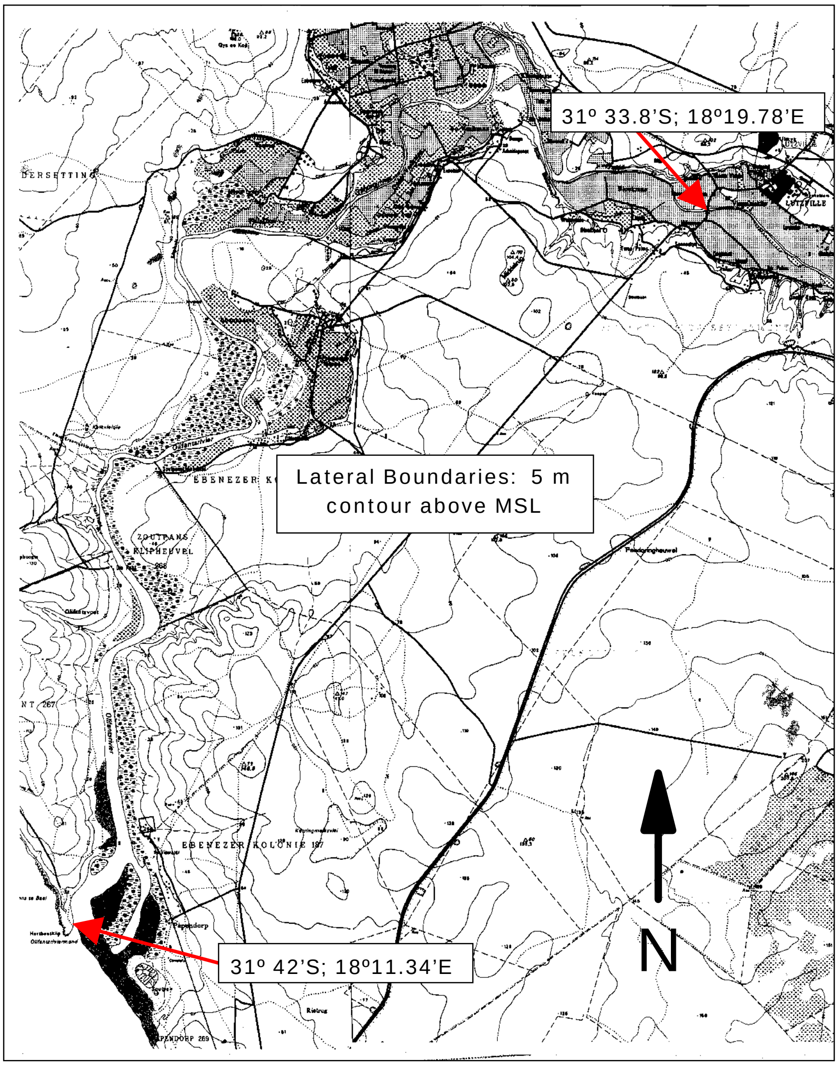

Figure 3.2 Map showing the boundaries of the Olifants River estuary

4 DEFINE A NETWORK OF SIGNIFICANT RESOURCES AND ESTABLISH BIOPHYSICAL AND ALLOCATION NODES (STEP 1D)

The objective of this procedure is to define the network of significant resources and to establish the network of biophysical and allocation nodes that will be used as the basis of the Classification Process. The proposed procedure for the definition of the network of significant resources and establishment of biophysical and allocation nodes comprises four steps, which commence after the significant resources have been identified, the water resource infrastructure described, and the water user allocations identified (see Section 3).

The four steps are:

1. Establishment of ecosystem-specific units (details in Sections 4.2, 0 and 4.6).
2. Identification of areas of interaction between ecosystems (details in Section 4.6).
3. Identification of nodes that will account for the interactions between ecosystems.
4. Establishment of allocation nodes.

These steps allow for discipline specific determination of sub-units, defined by nodes, before inter-disciplinary discussion on areas of interaction.

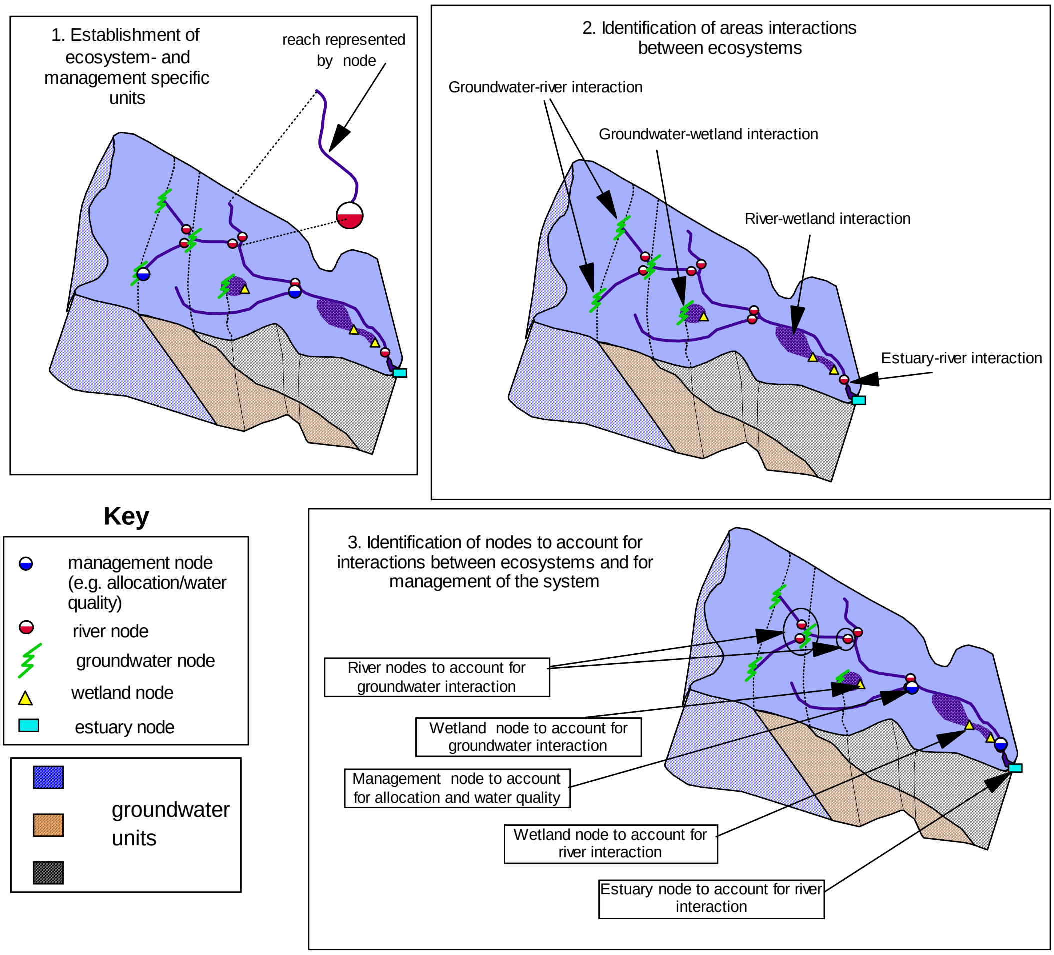

Figure 4.1 Procedure for the definition of the network of significant resources and establishment of biophysical and allocation nodes

Interpretation of the information pertaining to the hypothetical catchment in Figure 4.1 is aided by the following:

- river, estuary, groundwater and wetland nodes are depicted using different symbols (see Section 4.1);
- nodes are situated at the downstream end of the sub-unit they represent (see inset in Figure 4.1). For example, assuming a wetland is supplied by groundwater, a wetland node situated at the interface of the wetland and groundwater will describe implications for the wetland, and not for the groundwater; and
- nodes between groundwater units may not apply and have not been illustrated.

4.1 Coding nodes

The node designation procedure will result in many nodes added (or deleted) for different reasons. It is essential that some form of symbol/coding be adopted so that the reasons for the presence of a node and its intended function(s) can be clearly and quickly identified. A suggested coding key is provided in Appendix B.

4.2 Establishment of river nodes (Step 1d)

This sub-section deals specifically with the establishment of river nodes, i.e. the river ecosystem component of Step 1d in the procedure for the definition of the network of significant resources.

4.2.1 The difference between WRCS river nodes and RDM Resource Units (RUs)

WRCS river nodes are intended as modeling points, and as such, no data will be collected at the points, as they represent the downstream end of a reach or area for which a suite of relationships apply. In some instances, the reach demarcated by a WRCS river node may encompass one or more RDM RUs. However, it is as likely that these nodes will sub-divide RUs. The river node should also not be confused with EWR sites or RDM/RHP monitoring sites. It is envisaged that these sites will be nested within a reach represented by a river node. In other words, river nodes are situated at the downstream edge of a reach of interest, as required for modelling, but EWR sites and monitoring sites should be situated in the middle of a reach of interest so as to avoid confusing 'edge effects' in the data collected at those sites.

4.2.2 Procedure for the establishment of river nodes

A multi-tiered approach for establishing the location and number of river nodes within a catchment is recommended (Figure 4.2), as it allows for consideration of a suite of characteristics that dictate the ecological nature of rivers at different scales. Once the ecological criteria have been fulfilled, and the relevant nodes selected, the procedure makes provision for additional node selection on the basis of other criteria relevant to Classification, such as nodes required for licensing and or hydrological modelling. The node establishment procedure for rivers is outlined in Table 4.1. This comprises the sequential analysis

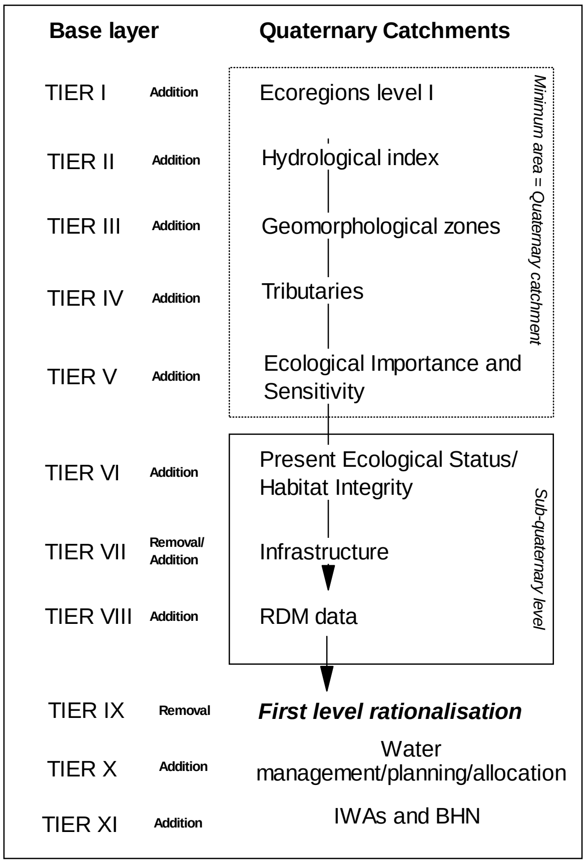

Figure 4.2 Summary of the procedure of river node establishment

Table 4.1 Procedure for the establishment of river nodes

BASE LAYER	
DWAF 1:500 000 rivers. Quaternary catchments. Main stem river courses in each quaternary catchment.	Significant river resources for the WRCS are defined as mainstem river courses in each DWAF quaternary catchment augmented with: • rivers for which Comprehensive or Intermediate Reserve Determinations have been undertaken; • rivers for which sub-quaternary level hydrological data are available; and • other rivers considered important from a water resource use perspective.

Procedure for river node selection					
TIER	**Data/GIS layers**	**Filtering process/additional explanation**	**Explanation**	**Minimum unit**	**Aim**
I	Ecoregions Level I (Kleynhans *et al*., 2005)	Exclude Ecoregions that comprise < 5% of the total area of the primary catchment AND where >75% is represented elsewhere.	Place node at each Ecoregion/quaternary catchment intersection where >75% of the upstream quaternary is comprised of a different Ecoregion from the downstream quaternary.	Quaternary catchments	Insert nodes where required
II	Hydrological index Classes (HydI) (Dollar *et al*., 2006) derived from the hydrololgical index (Hughes and Hannart, 2003)	HydI Class 1: HydI = 1 to 4 (perennial). HydI Class 2: HydI = 5 (seasonal). HydI Class 3: HydI = 6 to 9 (ephemeral).	Place node at each Quaternary intersection where there is a change in HydI Class.		
III	Geomorphic zones (Rowntree and Wadeson, 1999[9]).	Group 1: Mountain Headwater, Mountain Stream, Transitional and Upper Foothills. Group 2: Lower Foothills. Group 3: Lowland Rivers. Group 4: Rejuvenated Floodplains.	Place node at each quaternary intersection, where >75% of the upstream quaternary is comprised of a different geomorphic zone from the downstream quaternary. Place node at the head of the estuary.		
IV	Tributaries	Two nodes: one for each river upstream of the confluence.	Place node at the nearest quaternary intersection on each river.		
V	Ecological Importance and Sensitivity Category (EISC)	Use EISC information (Kleynhans, 2000) and augment with local data where applicable.	Place node at each quaternary intersection downstream of high or very high EISC.		

[9] These zones have been determined by DWAF's Directorate: Resource Quality Services (D: RQS) for the 1:500 000 rivers coverage for the whole of South Africa, and are available on request from the CD: RQS.

Procedure for river node selection

TIER	Data/GIS layers	Filtering process/additional explanation	Explanation	Minimum unit	Aim
VI	Present Ecological Status (PES)/Habitat Integrity (HI)	Use PES information (Kleynhans, 2000) and augment with local data where applicable.	Place node at each quaternary intersection, where > 75% of the upstream quaternary is comprised of a different PES/HI from the downstream quaternary. If sub-quaternary data are available, then adjust the information accordingly.		
		Group 1: A and B.			
		Group 2: C.			
		Group 3: D.			
		Group 4: E and F.			
VII	Infrastructure	This Tier comprises both establishment of river nodes and some rationalisation of previously established nodes.			
		Insertions.	Place a node at each DWAF gauging weir for which there is a hydrological record.	Sub-quaternary level	
			Place a node at the upstream limit of the inundation of any major dam.		
			Place a node upstream of mines, towns or other localities likely to influence water quality.		
			Place a node at each quaternary intersection where the area covered by farm dams in the upstream quaternary is > 5 times that of the downstream quaternary.	Quaternary catchments	
			Place a node on a river immediately upstream of the confluence with an Inter Basin Transfer (IBT).	Sub-quaternary level	
		Deletions.	Remove any nodes that are inundated by impoundments.		Delete nodes
			Remove any nodes that describe upstream sections for which no description is required, e.g. impoundments.		
VIII	RDM data	Comprehensive or Intermediate Reserve determinations.	Place a node at the nearest quaternary boundary downstream of each Ecological Water Requirement (EWR) site.		Insert nodes
IX	First level rationalisation	Minimum distance between nodes = 10 km.	Delete nodes that are less than 10 km (river length) apart. Retain the node that is closest to a quaternary intersection.	n/a	Delete nodes
		Minimum contribution to natural Mean Annual Runoff (nMAR) = 1%.	Delete nodes where the cumulative contribution to nMAR <1%.		

Procedure for river node selection					
TIER	**Data/GIS layers**	**Filtering process/additional explanation**	**Explanation**	**Minimum unit**	**Aim**
X	Water resource management/planning/ allocation	Where applicable for hydrology/water resource management/planning/ allocation.	It is essential that ecological information can be provided at a scale (and locations) relevant to other procedures linked to the Classification Process. Thus, if these are not already captured in the node delineation process described above, insert nodes at relevant positions as dictated to by other procedures linked to the Classification Process.	Sub-quaternary	Insert nodes
XI	International Water Agreements (IWA)	Based on IWAs signed between South Africa and neighbouring countries.	Place node at each quaternary intersection where required for an IWA.	Sub-quaternary	

of relevant GIS-covers and the insertion of nodes at key points to account for habitat, and water quality and quantity variations. The addition of nodes (TIERs I to VIII) according to the recommended guidelines is then followed by a rationalisation process (TIER IX) to arrive at the preliminary set of river nodes that will be used as the input to the integration process with the significant groundwater units, estuary and wetlands in the catchment. An additional Tier (TIER X) has been added to account for the possibility that in some catchments hydrological information may be required at quinternary level in which case, additional nodes will need to be delineated wherever ecologists are required to provide input on the EWRs of the systems. This does not apply to the Olifants/Doring catchment.

A worked example of the procedure using the Olifants/Doring catchment is provided in Section 4.3.

4.3 Example: Olifants/Doring catchment

The following is a worked example of the procedure provided in Table 4.1 using the Olifants/Doring catchment.

4.3.1 Base layer

The significant river resources identified for the Olifants/Doring catchment are listed in Table 3.1 and depicted in Figure 3.1.

4.3.2 Tier I - Ecoregions Level I

The data used for the Level I Ecoregions[10,11] were obtained from www.dwaf.gov.za/IWQS/gis_data/ecoregions/get-ecoregions.htm (Kleynhans *et al.*, 2005).

There are seven Level I Ecoregions that fall, either wholly or partly, within the Olifants/Doring catchment (Figure 4.3). Of these, three (Southern Folded Mountains, Namaqua Highlands and South Western Coastal Belt) represent less than 5% of their area of the catchment, and have greater than 75% of their area represented outside

Table 4.2 Level 1 Ecoregions falling within the Olifants/Doring catchment

Ecoregion	Ecoregion level 1 code	% of catchment area	% represented outside catchment
Nama Karoo	26	22	95
Western Coastal Belt	25	17	60
Great Karoo	21	37	71
Western Folded Mountains	23	19	38
Namaqua Highlands	27	3.5	92
South Western Coastal Belt	24	0.1	99.9
Southern Folded Mountains	19	0.8	99.9

the catchment. These three were thus excluded from further analysis. Descriptions for the remaining four Ecoregions are provided in Appendix A. The areas represented by the three Ecoregions that were excluded were 'absorbed' into the nearest similar Ecoregion, e.g. Namaqua Highlands was absorbed into Nama Karoo (rather than the Western Coastal Belt).

[10] Ecoregions Level II was not used because they proved too detailed given that it was necessary to consider other catchment specific data, e.g. hydrology. Further, this would have resulted in double accounting. In addition, no detailed descriptions are available for Ecoregions II.

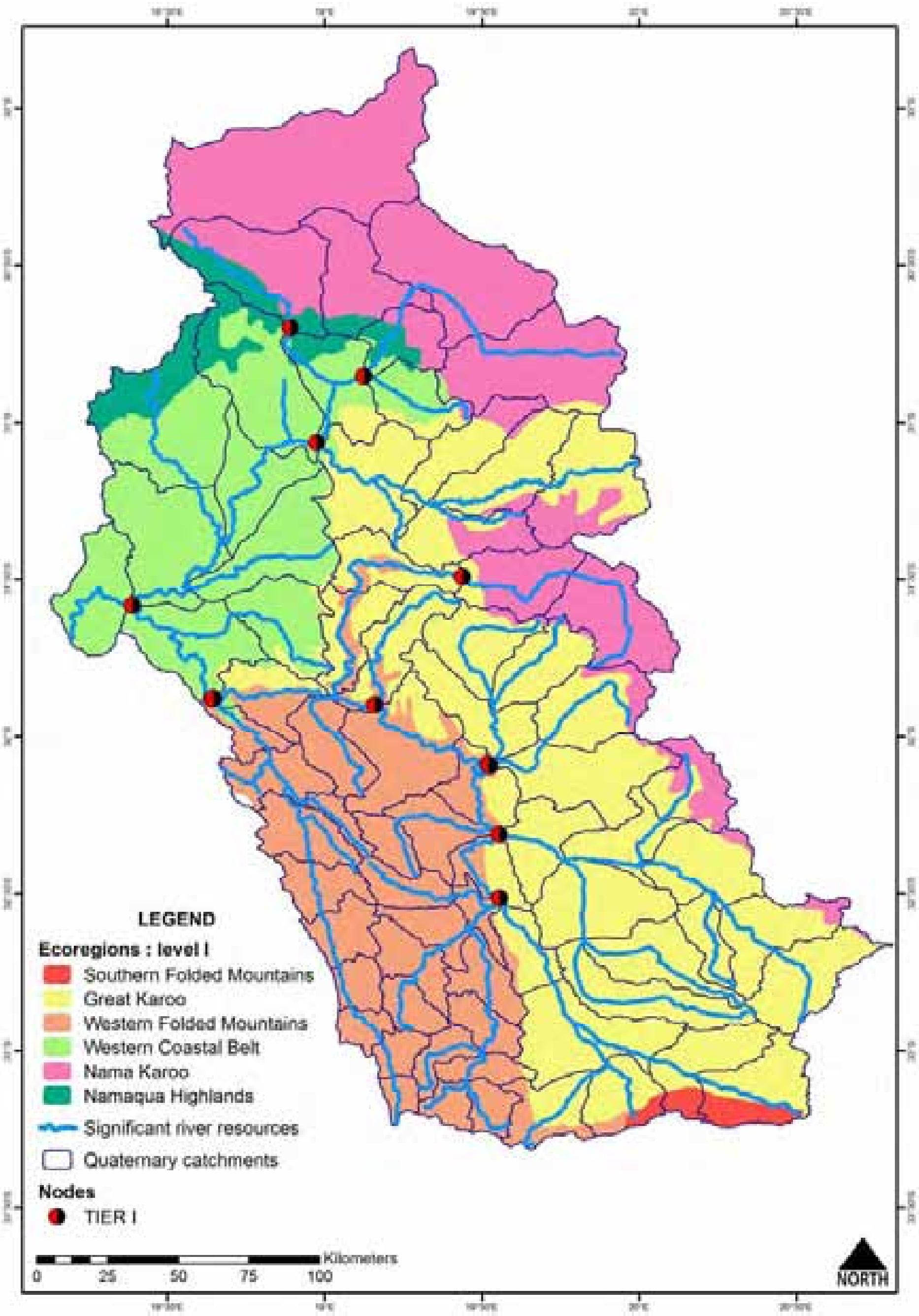

Figure 4.3 Level 1 Ecoregions in the Olifants/Doring catchment, with Tier I node designations depicted

Tier I nodes were allocated at quaternary boundaries where >75% of the upstream quaternary was comprised of a different Ecoregion from the downstream quaternary (Table 4.2). This resulted in the allocation of 12 nodes for the catchment (Figure 4.3).

4.3.3 Tier II – Hydrological Index

Hydrological Index (HydI.) values determined by Hughes and Hannart (2003) to characterise hydrological variability at a quaternary catchment level throughout South Africa have been grouped into nine statistical classes using an automated version of the Worsley Likelihood Ratio test (Worsley, 1979; Dollar *et al.,* 2006). The values for the hydrological index classes (Dollar *et al*., 2006) in the Olifants/Doring catchment varied between 2 and 7. These were further divided into three classes, *viz*. Perennial = 1 to 4; Seasonal = 5; Ephemeral = 6 to 9

(Table 4.1). Nodes were allocated at quaternary boundaries where there was a change in HydI Class (Figure 4.4). In some cases, the required Tier II establishment had already been fulfilled in Tier I, in which case no additional allocation was made.

Allocation of Tier II nodes in accordance with the rules in Table 4.1 yielded nine additional nodes[12] for the catchment (Figure 4.4). Total nodes after Tier II = 21.

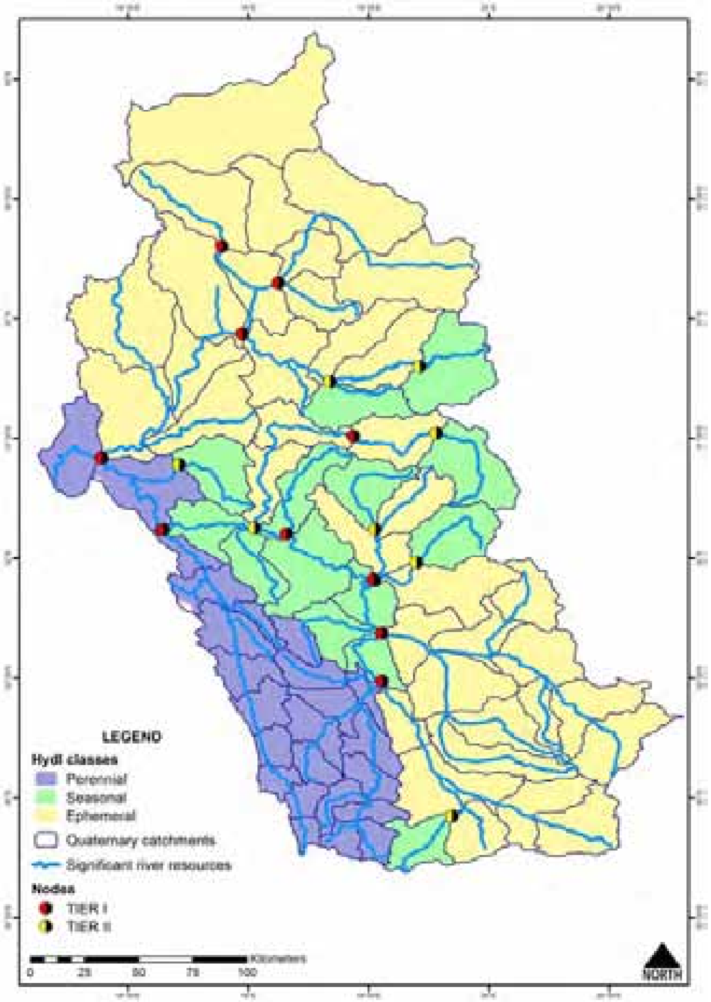

Figure 4.4 Distribution of Hydrological Index classes in the Olifants/Doring catchment, with Tier I and II node designations depicted

4.3.4 Tier III – Geomorphic zones

The information used for the geomorphic reaches was obtained from Ms J. Moolman from the D: RQS, and is available for most rivers in South Africa. Four grouped zones were utilised:

- Zone 1: Mountain Headwaters, Mountain Streams and Upper Foothill Rivers;
- Zone 2: Lower Foothill Rivers;
- Zone 3: Lowland Rivers; and
- Zone 4: Rejuvenated Floodplain Rivers.

[12] Over and above those allocated for Tier I.

The GIS layer of the significant river resources identified in Section 3.2.1 was overlain directly on the 1:500 000 coverage provided by D: RQS (Figure 4.5).

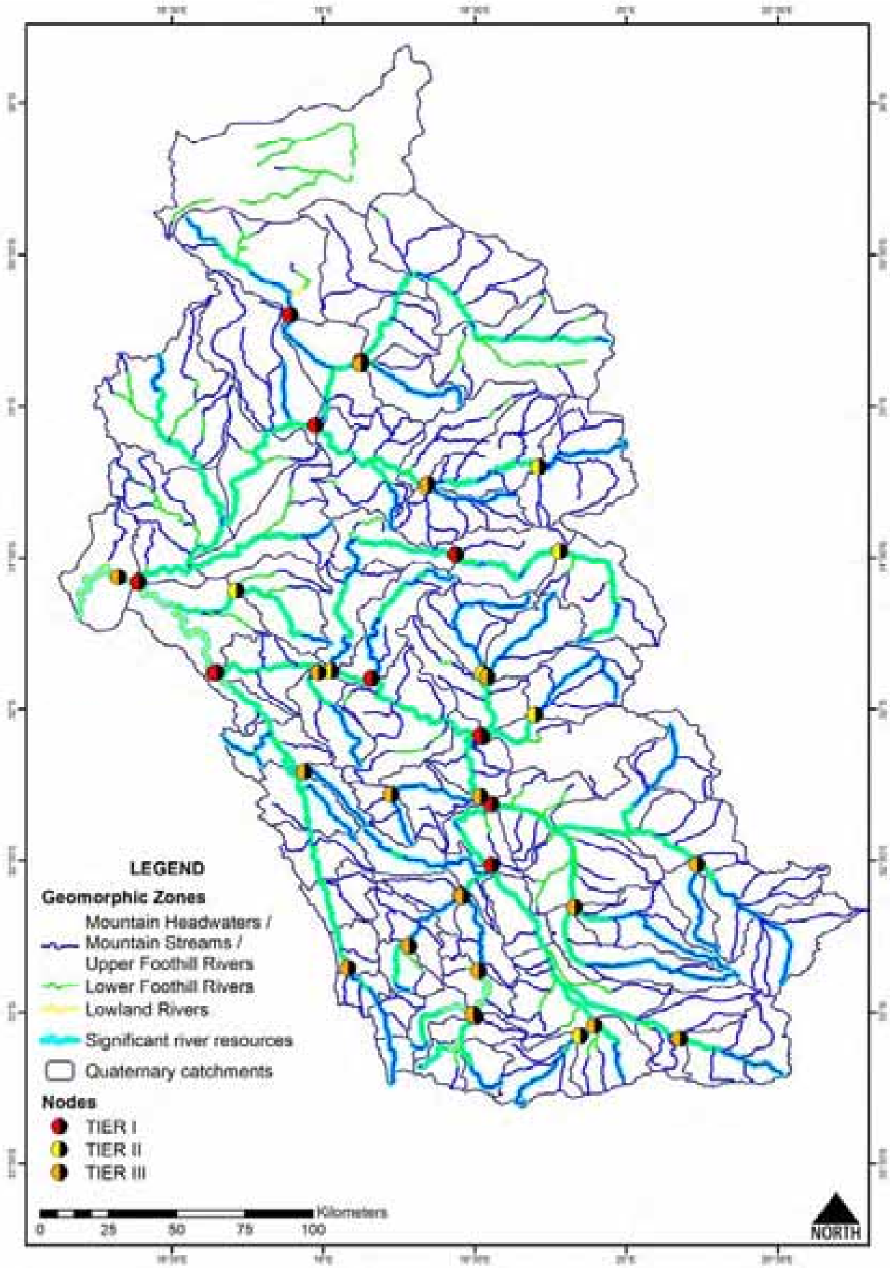

Figure 4.5 Geomorphic zones within the Olifants/Doring catchment, with Tier I, II and III node designations depicted

Tier III nodes were inserted:

- at quaternary boundaries where >75% of the upstream quaternary was comprised of a different geomorphic zone from the downstream quaternary (Figure 4.5). Where Tier III nodes coincided with Tier I or II nodes, no further nodes were inserted; and
- upstream of a change in ecosystem type, e.g. at the head of the estuary as defined in Section 3.2.2.

Allocation of Tier III nodes in accordance with the rules in Table 4.1 yielded 19 additional nodes[13] for the catchment (Figure 4.5). Total nodes after Tier III = 40.

4.3.5 Tier IV – Tributaries

The number of nodes designated in the catchment increased markedly with this tier, mainly because each tributary requires the establishment of two nodes, i.e. one on each river upstream of the confluence (Figure 4.6).

Allocation of Tier IV nodes in accordance with the rules in Table 4.1 yielded 19 additional nodes[14] for the catchment (Figure 4.7). Total nodes after Tier IV = 59.

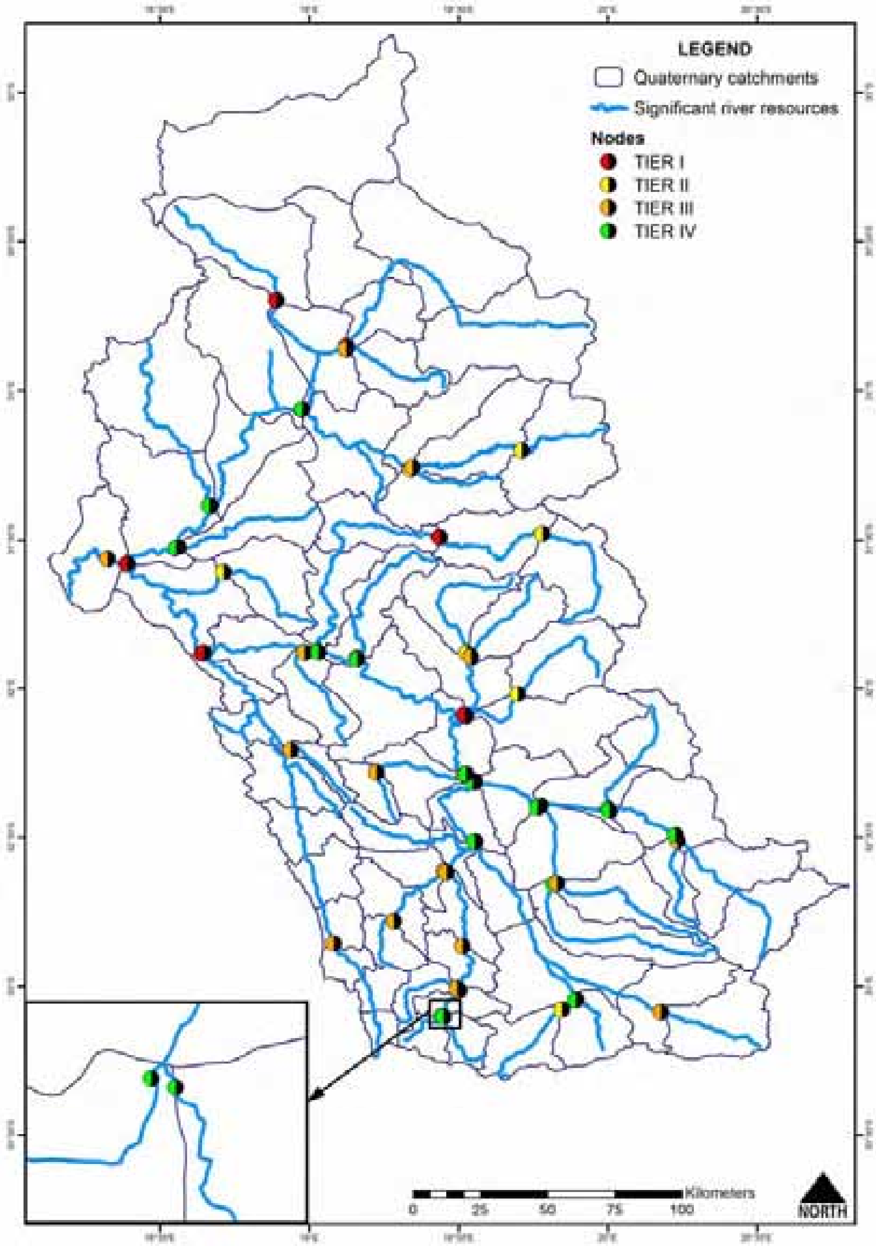

Figure 4.6 The Olifants/Doring catchment, with Tier I to IV node designations depicted[15]

[13] Over and above those allocated for Tiers I and II.
[14] Over and above those allocated for Tiers I, II and III.
[15] The insert indicates that in places, e.g. at a confluence between two rivers, there are two nodes.

4.3.6 Tier V – Ecological Importance and Sensitivity Category (EISC)

The information used for the EISC was obtained from the desktop estimate of ecological importance and sensitivity developed for the national Water Situation Assessment Model (WSAM) to depict river integrity in South Africa (Kleynhans, 2000). Nodes were allocated at each quaternary/river intersection downstream of high or very high EISC reach.

Allocation of Tier V nodes in accordance with the rules in Table 4.1 yielded four additional nodes[16] for the catchment. Total nodes after Tier V = 63.

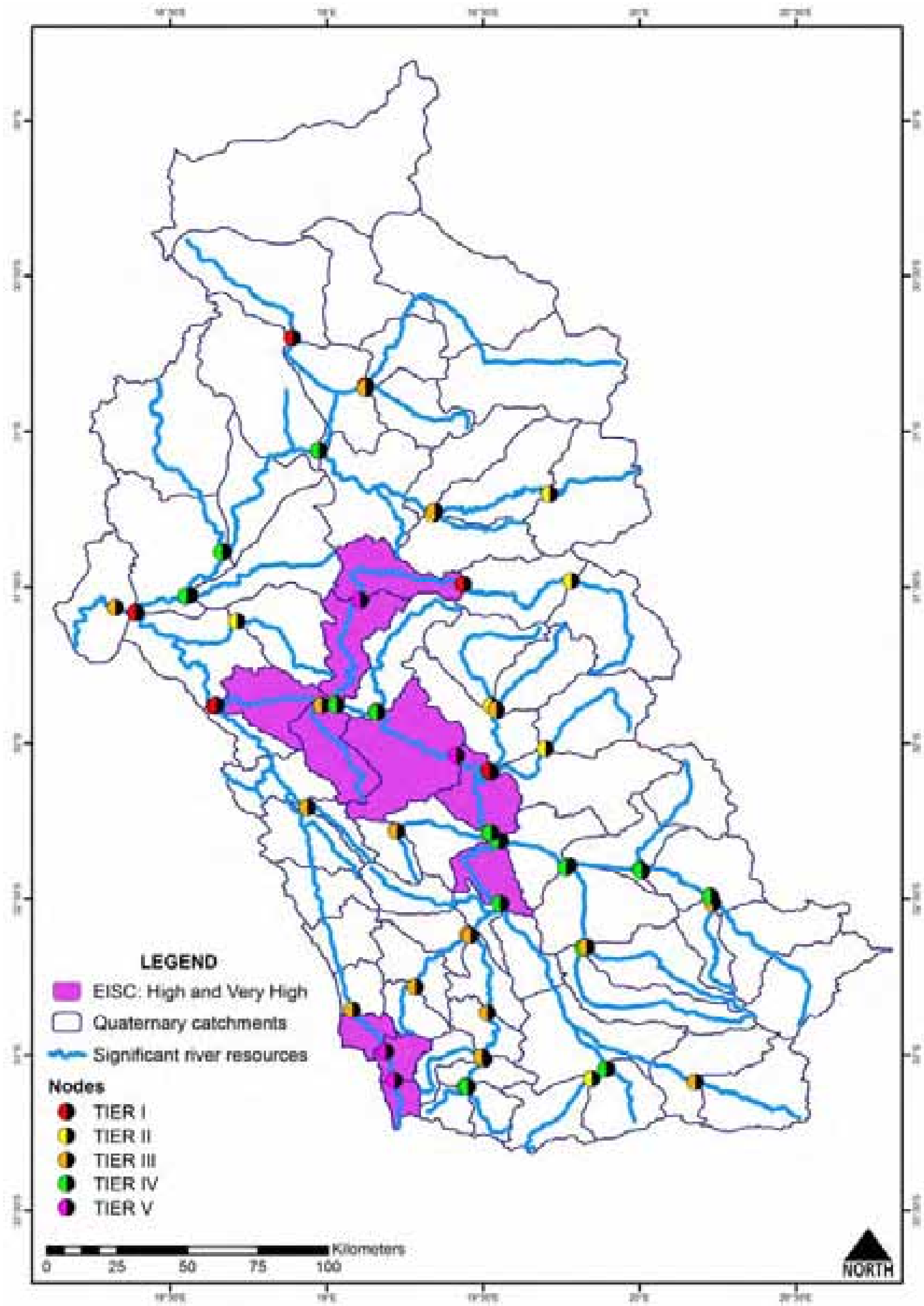

Figure 4.7 High and Very high EISC reaches the Olifants/Doring catchment, with Tier I to V node designations depicted

[16] Over and above those allocated for Tiers I to IV.

4.3.7 Tier VI – Present Ecological Status (PES)/Habitat Integrity (HI)

The information used for the PES/HI was obtained from the desktop estimate of PES developed for the national WSAM to depict river integrity in South Africa (Kleynhans, 2000). National-level data were updated, where appropriate, with data from local studies, including Kleynhans (1997); Brown (2003); Day *et al*. (1998); Brown *et al*. (2004).

To avoid the over-allocation of nodes, the following PES/HI categories were combined:

- categories A and B; and
- categories E and F.

Thereafter, Tier VI nodes were allocated at quaternary boundaries where >75% of the upstream quaternary is comprised of a different PES/HI from the downstream quaternary (Figure 4.8). In some cases, the required Tier VI designation had already been fulfilled in Tier I to V, in which case no additional allocation was made.

Allocation of Tier VI nodes in accordance with the rules in Table 4.1 yielded five additional nodes for the catchment (Figure 4.8). Total nodes after Tier VI = 68.

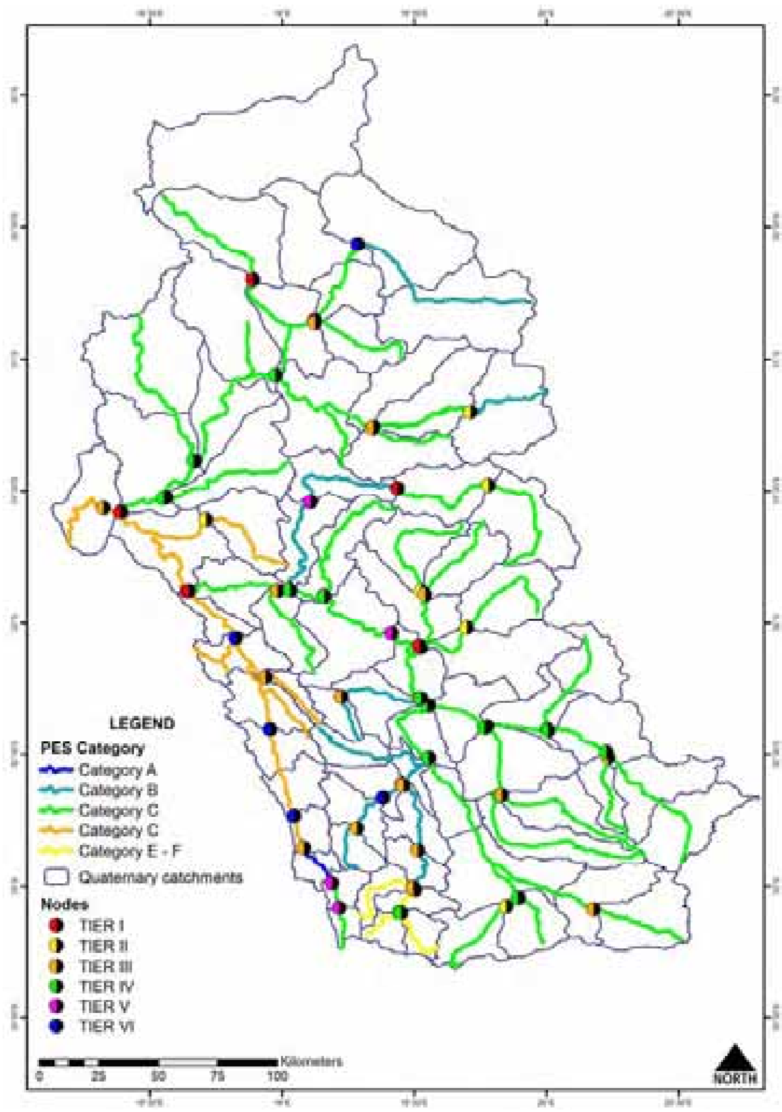

Figure 4.8 PES/HI for the Olifants/Doring catchment, with Tier I to VI node designations depicted

4.3.8 Tier VII – Water resource infrastructure

A description of the water resource infrastructure for the Olifants/Doring catchment is provided in Mallory *et al*. (2006).

This tier comprises both a nodes augmentation and a node rationalisation exercise. Nodes should be added to the existing suite of nodes:

- at DWAF gauging weirs;
- at the upstream end of major impoundments, e.g. Clanwilliam Dam and Bulshoek Barrage;
- on a river immediately upstream of the confluence with an IBT;
- on a river immediately upstream of the influence of a town, mine or other locale likely to have a major impact on water quality; and
- at the quaternary intersection where the area covered by farm dams in the upstream quaternary is >5 times that of the downstream quaternary[17].

Nodes should be removed from the existing suite of nodes if:

- they are inundated by an impoundment; and
- they are located such that they will describe an upstream section of river for which no description is required, e.g. a dam.

Allocation and/or removal of Tier VII nodes in accordance with the rules in Table 4.1 yielded one additional node[18] for the catchment (Figure 4.9). Total nodes after Tier VII = 69.

4.3.9 Tier VIII – RDM data

A Comprehensive Reserve determination was undertaken for six river sites in the Olifants/Doring catchment in 2003 to 2006 (Brown *et al.,* 2004). A node was placed at the quaternary intersection downstream of each of the six EWR sites (Figure 4.10). A node was also placed at the exact location of the EWR Site on sub-quaternary tributaries, in this case, the Rondegat River. This resulted in one additional node.

Total nodes after Tier VIII = 70.

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[17] The reason for the last condition is that in some cases the PES data used in Tier VI are at a relatively coarse scale and the different concentrations of farms dams point to a possible change in PES that was perhaps not recognized at the scale used.

[18] Over and above those allocated for Tiers I to IV.

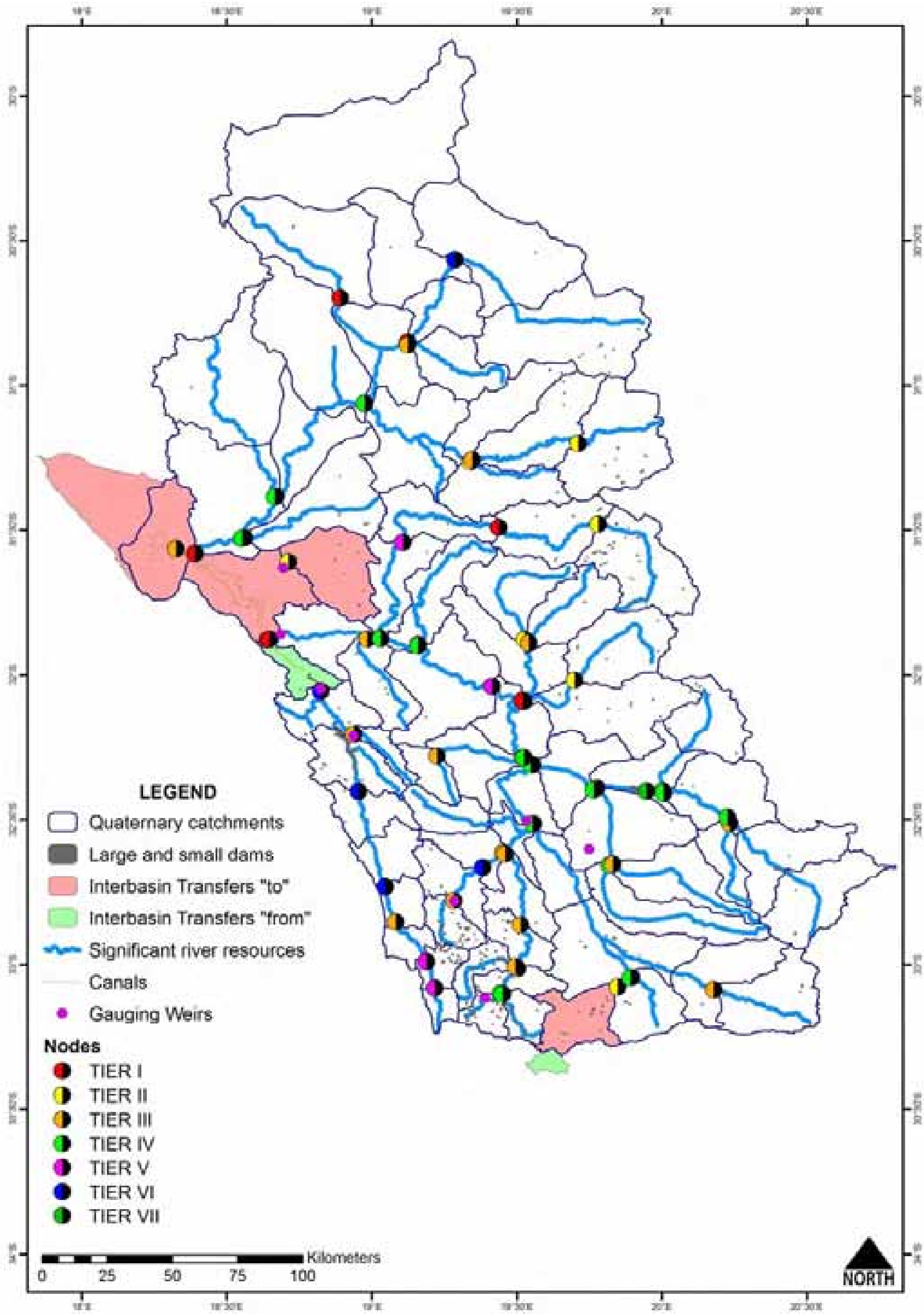

Figure 4.9 Water resource infrastructure in the Olifants/Doring catchment, with Tier I to VII node designations depicted[19]

[19] The purple node in the inset should be on the quaternary intersection. When placing the nodes in GIS, the different scale will result in this sort of discrepancy. For Tier I to IV and Tier VI nodes, it should be assumed that the nodes should be on the quaternary intersection, unless otherwise stated.

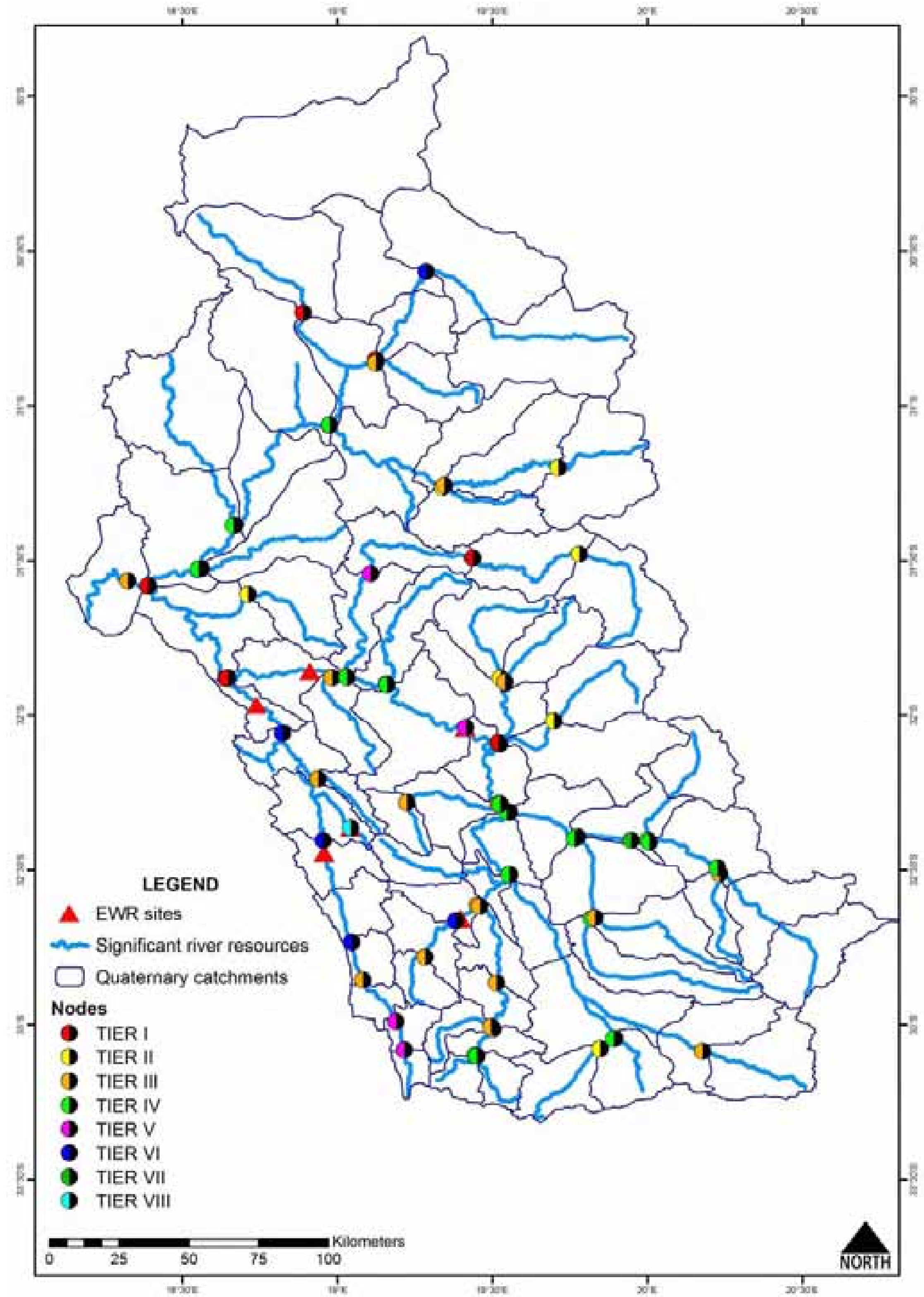

Figure 4.10 Localities of the six EWR sites of the Comprehensive Reserve determination for the Olifants/Doring catchment, with Tier I to VIII node designations depicted

4.3.10 Tier IX – First level rationalisation[20]

The objective of Tier IX is to begin to reduce the number of nodes to a manageable level.

Nodes that should not be deleted include Tier I nodes and nodes that demarcate an Integrated Unit of Analysis (IUA) outlet. For the remaining nodes, three criteria were applied in an effort to reduce the number of nodes taken into the next stage of the process:

- Minimum river length between nodes = 10 km.
- Minimum contribution to nMAR = 1%[21].
- Nodes nested within a quaternary catchment with no independent hydrological data[22].

Twenty-four nodes were deleted in Tier IX (Figure 4.11).

The deletions on the basis of criterion 1 (i.e. nodes <10 km apart) were:

- Node P at EWR Site 6. Originally selected because of a change in PES (Tier V) and because it represented an EWR site (Tier VII). The downstream node was retained in favour of this node because:
  - it is on at the quaternary boundary (which offers WR90 hydrological data); and
  - the results from the Reserve study can be transferred to the downstream node as they are only 6 km apart in a similar geomorphic zone.

- Node K on the Doring River at the confluence with the Tra-Tra River. Originally selected because it is a tributary confluence (Tier IV). The upstream node (on the Doring River upstream of the confluence with the Tankwa River) was retained in favour of this node because:
  - it is at the quaternary boundary (which offers WR90 hydrological data); and
  - the Tankwa River has a major influence on the Doring River (Brown and Day, 1996).

- Node R in the middle of quaternary catchment E22D. Originally selected because it is at a confluence (Tier IV). The upstream node was retained in favour of this node because:
  - it is on at the quaternary boundary (which offers WR90 hydrological data).

- Node L at the head of Ouboskraal Dam on the Tankwa River. Originally selected because it is upstream of a water resource development (Tier VII). The upstream node was retained in favour of this node because:
  - it is on at the quaternary boundary (which offers WR90 hydrological data); and
  - it is at a confluence.

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[20] This step should not be done until after the delineation of the IUAs (see Section 5).

[21] The percentage used for the cut-off will depend on the catchment under consideration. In the Olifants/Doring 0.5% and 1% were tested. It was decided to use the 1% cut-off because it reduced the number of nodes in the area of the catchment where there were very few data, and where the rivers were largely episodic.

[22] This criterion was added later in the development of the WRCS and so the deletions are not illustrated in Figure 4.11.

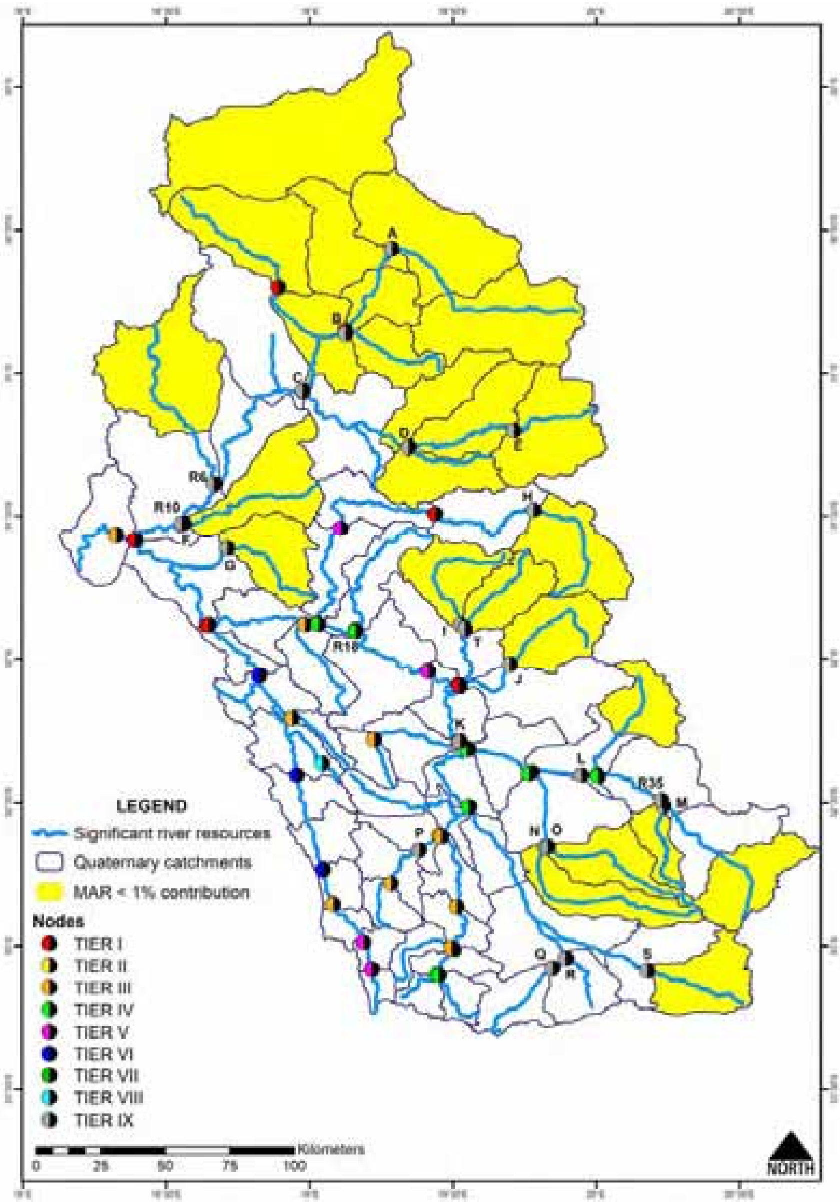

Figure 4.11 Nodes deleted in Tier IX - First level rationalization

The deletions on the basis of criterion 2 (i.e. cumulative contribution of <1% of nMAR) were any nodes designated at the quaternary intersections of the following sub-catchments (shown in yellow in Figure 4.11): E23E, E23C, E24C, E24F, E24E, E23H, E33F, E23A, E40A, E23G, E32C, E33C, E32A, E32B, E32D, E31F, E31H, E33D, E22A, E31E, E31B, E31G, E31D, E31C, E31A. Nodes A to J, M to O, Q, S and T were deleted using criterion 2.

For criterion 3, each quaternary should be checked and nodes should be removed if they are nested within a quaternary catchment and have no independent hydrological data, i.e. if the node will be reliant on WR90 (or WR2005) data, then nested nodes should be removed unless the apportionment of the catchment is relatively clear. Based on this process, R6, R10, R18 and R35 were removed from the node cover.

Total river nodes after Tier IX = 46.

4.3.11 Tier X – Water resource management/planning/allocation

No additional nodes were added to account for water resource management/ planning/allocation for the Olifants/Doring catchment as accessing these data was not possible within the scope of the project. However, for the purposes of the Classification Process, a procedure for achieving this will need to be developed in liaison with the relevant DWAF departments.

4.3.12 Tier XI – International Water Agreements (IWAs)

No additional nodes were required to account for IWAs in the Olifants/Doring catchment. However, where applicable, these need to be added.

4.3.13 Summary

A total of 46 river nodes (R1 to R50)[23] were selected for the Olifants/Doring catchment (Figure 4.12). The code, location, reasons for selection and typology of each node is listed in Table 4.3.

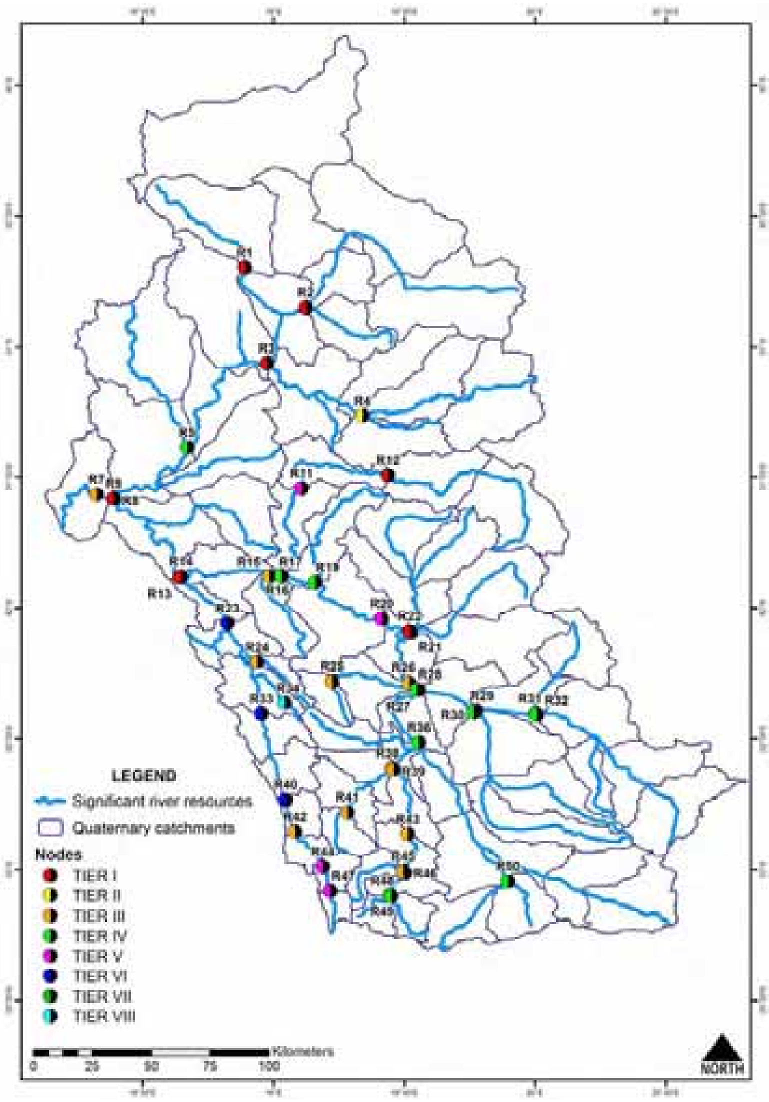

Figure 4.12 River nodes selected for the Olifants/Doring catchment (remaining 46 nodes after the Tier IX rationalisation process)

[23] These were later reduced to 46 as a result of rationalizations on the basis of Criterion 3 (Nodes R6, R10, R18 and R35 were deleted: Tier IX – Section 4.3.10)

Table 4.3 Selection details for river nodes established in the Olifants/Doring catchment

Node code	Node order	X co-ordinate	X co-ordinate	Tier	Quaternary catchment	River	Ecoregion number	Ecoregion	Reserve Assurance Region	Geomorphic zone	Altitude range	PES	EISC
R1	Rooi_1	18.89143	-30.69902	TIER I	E31G	Rooiwalse Laagte	26	NAMA KAROO	W. Karoo	Mnt Stream/Upper Foothill	600-800	C: MODERATELY MODIFIED	MODERATE
R2	Krom_1	19.12508	-30.85182	TIER I	E31E	Krom	26	NAMA KAROO	W. Karoo	Lower Foothill	400-600	C: MODERATELY MODIFIED	MODERATE
R3	Dor(2)_1	18.97574	-31.06371	TIER I	E32E	Doring	25	WESTERN COASTAL BELT	W. Karoo	Lower Foothill	0-200	C: MODERATELY MODIFIED	MODERATE
R4	Hant_1	19.34046	-31.26471	TIER II	E32C	Hantams	21	GREAT KAROO	W. Karoo	Mnt Stream/Upper Foothill	200-400	C: MODERATELY MODIFIED	MODERATE
R5	Sout_3	18.67074	-31.38564	TIER IV	E33B	Sout	25	WESTERN COASTAL BELT	W. Karoo	Lower Foothill	0-200	C: MODERATELY MODIFIED	MODERATE
R7	Oli_1	18.32512	-31.56546	TIER III	E33H	Olifants	25	WESTERN COASTAL BELT	W. Cape (w)	Lower River	0-200	D: LARGELY MODIFIED	MODERATE
R8	Sout_1	18.39163	-31.58091	TIER II	E33E	Sout	25	WESTERN COASTAL BELT	W. Karoo	Lower Foothill	0-200	C: MODERATELY MODIFIED	MODERATE
R9	Oli_2	18.38963	-31.58207	TIER I	E33G	Olifants	25	WESTERN COASTAL BELT	W. Cape (w)	Lower Foothill	0-200	D: LARGELY MODIFIED	MODERATE
R11	Oor_2	19.10808	-31.54260	TIER V	E40C	Oorlogskloof	23	WESTERN FOLDED MOUNTAINS	W. Karoo	Lower Foothill	0-200	B: LARGELY NATURAL	HIGH
R12	Oor_3	19.43821	-31.49104	TIER I	E40B	Oorlogskloof	21	GREAT KAROO	W. Karoo	Lower Foothill	600-800	C: MODERATELY MODIFIED	MODERATE
R13	Oli_3	18.64194	-31.88070	TIER I	E10K	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Lower Foothill	0-200	E - F: not AN ACCEPTABLE	MODERATE
R14	Dor_1	18.64701	-31.87786	TIER I	E24M	Doring	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	0-200	B: LARGELY NATURAL	HIGH
R15	Bran_1	18.98443	-31.87757	TIER III	E24L	Brandewyn	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	0-200	C: MODERATELY MODIFIED	HIGH
R16	Dor_2	19.03132	-31.87705	TIER IV	E24K	Doring	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	0-200	C: MODERATELY MODIFIED	HIGH
R17	Oor_1	19.02700	-31.87300	TIER II	E40D	Koebee	23	WESTERN FOLDED MOUNTAINS	W. Karoo	Lower Foothill	0-200	B: LARGELY NATURAL	HIGH
R19	Dor_3	19.16085	-31.90069	TIER IV	E24J	Doring	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	0-200	B: LARGELY NATURAL	HIGH
R20	Dor_4	19.41483	-32.04035	TIER V	E24H	Doring	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	0-200	B: LARGELY NATURAL	HIGH
R21	Bos_1	19.52545	-32.09369	TIER I	E24D	Bos	21	GREAT KAROO	W. Karoo	Mnt Stream/Upper Foothill	0-200	C: MODERATELY MODIFIED	LOW
R22	Wolf_1	19.52062	-32.08817	TIER I	E24G	Wolf	21	GREAT KAROO	W. Karoo	Mnt Stream/Upper Foothill	200-400	C: MODERATELY MODIFIED	LOW
R23	Oli_4	18.82468	-32.05797	TIER VI	E10J	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Lower Foothill	0-200	D: LARGELY MODIFIED	MODERATE
R24	Jan_1	18.93836	-32.20683	TIER III	E10H	Jan Dissel	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	200-400	D: LARGELY MODIFIED	MODERATE
R25	Tra_2	19.22515	-32.28100	TIER III	E24A	Tra-Tra	23	WESTERN FOLDED MOUNTAINS	W. Karoo	Mnt Stream/Upper Foothill	400-600	B: LARGELY NATURAL	LOW
R26	Tra_1	19.52012	-32.28647	TIER III	E24B	Tra-Tra	23	WESTERN FOLDED MOUNTAINS	W. Karoo	Mnt Stream/Upper Foothill	0-200	B: LARGELY NATURAL	LOW
R27	Tank_1	19.55555	-32.31224	TIER I	E23K	Tanskwa	21	GREAT KAROO	W. Karoo	Lower Foothill	0-200	C: MODERATELY MODIFIED	LOW
R28	Dor_5	19.54824	-32.31143	TIER IV	E22G	Doring	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	200-400	B: LARGELY NATURAL	VERY HIGH
R29	Tank_2	19.77559	-32.39186	TIER IV	E23F	Tankwa	21	GREAT KAROO	W. Karoo	Lower Foothill	200-400	C: MODERATELY MODIFIED	LOW
R30	Ong_1	19.76575	-32.39893	TIER IV	E23J	Ongeluks	21	GREAT KAROO	W. Karoo	Lower Foothill	200-400	C: MODERATELY MODIFIED	LOW
R31	Reno_1	20.00310	-32.40301	TIER IV	E23F	Renoster	21	GREAT KAROO	W. Karoo	Mnt Stream/Upper Foothill	200-400	C: MODERATELY MODIFIED	LOW
R32	Tank_3	20.00689	-32.41017	TIER IV	E23D	Tankwa	21	GREAT KAROO	W. Karoo	Lower Foothill	200-400	C: MODERATELY MODIFIED	LOW
R33	Oli_5	18.95540	-32.40409	TIER VI	E10F	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Lower Foothill	0-200	D: LARGELY MODIFIED	MODERATE
R34	Ron_1	19.04361	-32.36223	TIER VIII	E10G	Rondegat	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Mnt Stream/Upper Foothill	0-200	B: LARGELY NATURAL	MODERATE
R36	Dor_6	19.55708	-32.51453	TIER I	E22F	Doring	21	GREAT KAROO	W. Karoo	Lower Foothill	200-400	B: LARGELY NATURAL	LOW
R37	Gro_1	19.55507	-32.51413	TIER IV	E21L	Groot	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	200-400	B: LARGELY NATURAL	LOW
R38	Gro_2	19.45249	-32.61348	TIER III	E21J	Groot	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	400-600	B: LARGELY NATURAL	LOW
R39	Riet_1	19.46011	-32.61806	TIER III	E21F	Riet	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	400-600	B: LARGELY NATURAL	LOW
R40	Oli_6	19.04739	-32.73275	TIER VI	E10D	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Lower Foothill	0-200	C: MODERATELY MODIFIED	MODERATE
R41	Gro_3	19.28380	-32.78066	TIER III	E21G	Leeu	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	600-800	B: LARGELY NATURAL	LOW
R42	Oli_7	19.08281	-32.85409	TIER III	E10C	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Mnt Stream/Upper Foothill	0-200	B: LARGELY NATURAL	VERY HIGH
R43	Riet_2	19.51372	-32.86375	TIER III	E21E	Riet	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Rejuventated Floodplain	800-1000	B: LARGELY NATURAL	LOW
R44	Oli_7	19.18898	-32.98912	TIER V	E10B	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Lower Foothill	400-600	C: MODERATELY MODIFIED	HIGH
R45	Hou_1	19.49603	-33.00630	TIER III	E21D	Houdenbeks	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Rejuventated Floodplain	800-1000	E - F: not AN ACCEPTABLE	LOW
R46	Win_1	19.50316	-33.01429	TIER III	E21C	Winkelhaak	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	800-1000	E - F: not AN ACCEPTABLE	LOW
R47	Oli_9	19.21721	-33.08207	TIER V	E10A	Olifants	23	WESTERN FOLDED MOUNTAINS	W. Cape (w)	Mnt Stream/Upper Foothill	600-800	C: MODERATELY MODIFIED	HIGH
R48	Krui_1	19.44471	-33.09976	TIER IV	E21A	Kruis	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Lower Foothill	800-1000	E - F: not AN ACCEPTABLE	LOW
R49	Wel_1	19.45107	-33.10210	TIER IV	E21B	Welgemoed	23	WESTERN FOLDED MOUNTAINS	W. Cape (d)	Mnt Stream/Upper Foothill	800-1000	E - F: not AN ACCEPTABLE	LOW
R50	Dor_7	19.89674	-33.04445	TIER III	E22D	no name	21	GREAT KAROO	W. Karoo	Mnt Stream/Upper Foothill	400-600	C: MODERATELY MODIFIED	LOW

4.4 Information required for the node table

At the end of node establishment, the node table should comprise the following information:

- node code – prefaced by R (for river);
- X- and Y-co-ordinates;
- TIER at which the node was selected;
- quaternary catchment;
- Ecoregion Level I number and name;
- Hydrological Index;
- Geomorphic zone;
- PES; and
- EISC.

Various procedures in later stages of the classification procedure will require the information incorporated into the node table (see Olifants/Doring example in Table 4.3), as well as additional information. It makes sense to augment the table with some of this additional information at this stage, particularly since much of it comes from the GIS covers used in node establishment.

The additional information recommended is:

- Node order. This is essentially a renumbering of the nodes for each river from the downstream end upstream. The Node order code comprises a three- to four-letter abbreviation of the river name and the sequential numbering (upstream) of the node. This Node order code helps with orientation;
- Reserve Assurance Region. This is required for the Desktop Model in Section 8.3.2; and
- altitude range. This is the range of elevation above MSL into which the reach represented by the river node predominately falls. It is required for the Extrapolation Decision Support System (DSS) in Section7.1.

Note:	The information in the node table should be entered into a spreadsheet, as many of the procedures that follow require some form of re-ordering of the information.

4.5 Establishment of estuary nodes

This sub-section deals with the establishment of ecosystem-specific nodes for the estuary, i.e. the estuary ecosystem component of Step 1d in the procedure for the definition of the network of significant resources.

4.5.1 Procedure for the establishment of estuary nodes

Zonation of the estuary forms part of the procedure for the determination of the Reserve, as water quality characteristics along the length of the estuary are dependent on the extent of marine or freshwater influence at that point (Dr Barry Clark, Anchor Environmental Consultants, pers. comm.). For all practical purposes, however, the Reserve and the response of the estuary to fluctuations in water quality and quantity is reported for the estuary as a whole (Lara van Niekerk, CSIR, pers. comm.).

Thus, in accordance with the philosophy adopted for the WRCS, an estuary node should be placed at the downstream end of the estuary, i.e. at the interface with the sea (Figure 4.13).

This node would then provide the relationships that will be used to predict the responses of the **upstream** estuarine ecosystem to changes in water quality, quantity and timing.

4.5.2 Example: Olifants/Doring catchment

The result of the procedure applied to the Olifants/Doring catchment is given in Figure 4.13

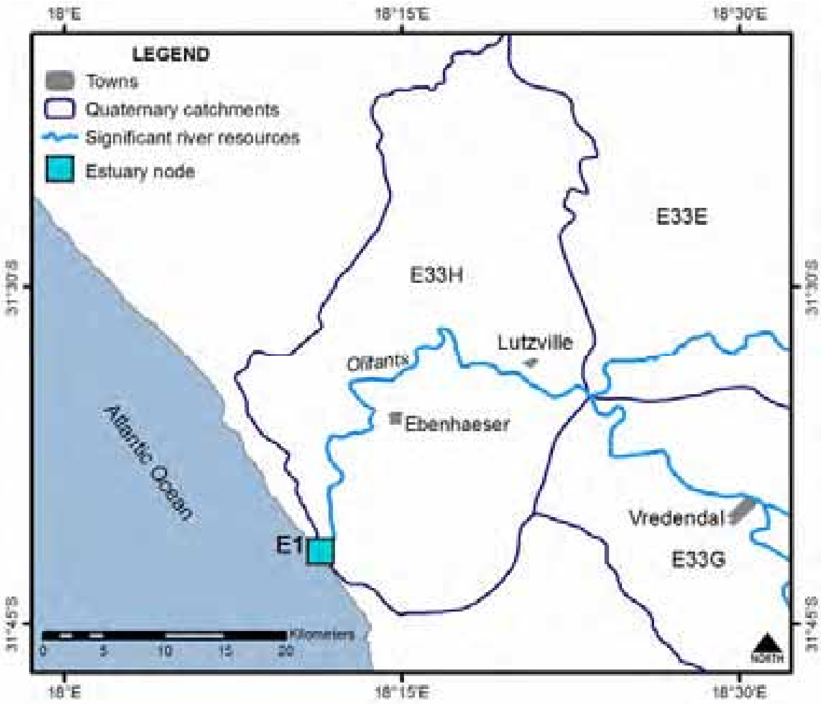

Figure 4.13 Estuary node selected for the Olifants/Doring catchment

4.6 Procedure for the establishment of groundwater/surface water areas of interaction

The procedure outlined in this section comprises a set of criteria chosen to predict *probable* groundwater/surface water (GW/SW) areas of interaction, specifically groundwater supplying water to rivers. The criteria used as indicators of groundwater discharging to rivers, are:

- groundwater contribution to base flow;
- lithological boundaries at aquifers and aquitards;
- geological faults;
- groundwater levels;
- springs; and
- aquifer dependent ecosystems.

The data are processed sequentially in a GIS to identify areas where groundwater may interact with the surface environment, and where groundwater may input to surface water. This processing corresponds with different 'tiers' of data sets used in other parts of the WRCS. Groundwater nodes are selected either at a GRU boundary where there is a medium to high probability upstream, or where there is a change to a lower level of probability of interaction, e.g. from medium to low probablility. Ratings are allocated on a five-point scale, where 1= low and 5 = very high.

Table 4.4 Criteria selected to indicate probability of groundwater feeding rivers, and controls on the level of confidence in the data used

GW Tier	Description	Level of confidence in GW/SW interaction based on
I	Groundwater Response Units	Spatial scale
II	Groundwater contribution to base flow	Spatial scale of calculated inflow and field verification
III	Groundwater levels	Data density and time span of record
IV	Springs	Spatial scale
V	Geological faulting	Spatial scale
VI	Aquifer Dependent Ecosystems (ADEs)	Spatial scale and ground truthing

4.6.1 Example: Olifants/Doring catchment[24]

The definition of probable areas of aquifer-fed rivers was carried out using existing data sets (desktop) for the Olifants/Doring catchment. Table 4.5 shows the data sets used and weightings given for these based on the relative level of confidence in the available data. The weightings should therefore change with each application of the procedure, based on the confidence in the data. Recommended ratings for the different criteria should remain constant for different areas.

4.6.1.1 GWTier I: Delineate GRUs

GRUs were delineated to identify areas which are hydrogeologically similar (for monitoring and reporting purposes) and where there is a boundary between an aquifer and an aquitards or aquiclude.

This delineation was carried out at a course, desktop level, based on the 1:1 000 000 scale geological data provided by the Council for Geoscience. The lithostratigraphic subdivisions for the area are presented in Table 4.6. GRUs were then assigned to hydrogeologically similar geological formations in chronological sequence. The determination of whether an entire Group or a Formation within a Group acts as a GRU is a subjective process informed by existing knowledge of the hydrogeological characteristics of the formations and their boundary conditions. The formations or groups are characterised as aquifers, aquitards or aquicludes, e.g. the Bokkeveld Group.

Nine GRUs were identified for the Olifants/Doring catchment, only three of which are significant aquifers. The other units may have local groundwater-bearing structures of strata, but have limited groundwater potential. At this scale and level of confidence, the dolerite intrusions were not identified separately, but are included on the GRU map in Figure 4.14 in the intruded Beaufort to Witteberg Groups, which comprise an aquitard GRU.

[24] Surface topography was not taken into account when defining GW/SW interaction areas.

Table 4.5 Rates and weights for attributes indicating the probability of groundwater feeding rivers in the Olifants-Doring Catchment

Attribute	Values	Rates	Weights[25] for region	Data based on
GRUs	Aquifer			Scale (1:1 000 000)
	Aquitard			
	Aquiclude			
Groundwater levels	<2.5 mbgl	3	1	Data density Verification Time series
	2.5 - 5	2	1	
	5 - 10	1	1	
	>10	0	1	
Springs	Point location	3	3	Scale (Point data)
Aquifer/aquitard	Linear contact	2	3	
Faults	Lineament	1	3	Scale of faults identified on map aerial photograph
ADEs	High probability	3	2	Desktop or ground truthed
	Medium	2	2	
	Low	1	2	
GW fed baseflow	>20%	4	1	Desktop or ground truthed
	10-20%	3	1	
	5-10%	2	1	
	1-5%	1	1	
	0	0	1	

Table 4.6 Lithostratigraphic subdivisions and associated hydrogeologically defined groundwater response units (GRUs) for the Olifants/Doring catchment

Age	Formations"	Group	Aqui-type	GRU
Phanerozoic	Alluvium		Aquifer	1
	Dolerite		Intrusion	2
		Beaufort	Aquitard	3
		Ecca	Aquitard	
		Dwyka Tillite	Aquitard	3
		Witteberg	Aquifer	3
		Bokkeveld	Aquitard	4
	Nardouw	Table Mountain Group	Aquifer	5
	Peninsula		Aquifer	6
	Piekienerskloof		Aquifer	6
Namibian Erathem		VanRhynsdorp	Aquitard	7
		Nama: (Knersvlakte and Gifberg)	Aquitard	7
		Klipheuwel	Aquitard	7
		Cape Granite	Aquitard	8
		Malmesbury	Aquifer/ Aquitard	7
		Gariep	Aquitard	7
Mokolian Erathem	Spektakel	Namaqualand Metamorphic Complex	Aquitard	9
	Hoogoor		Aquitard	9
	Little Namaqualand		Aquitard	9
	Garies		Aquitard	9
	Okiep		Aquitard	9

[25] Based on the relative confidence in the data available

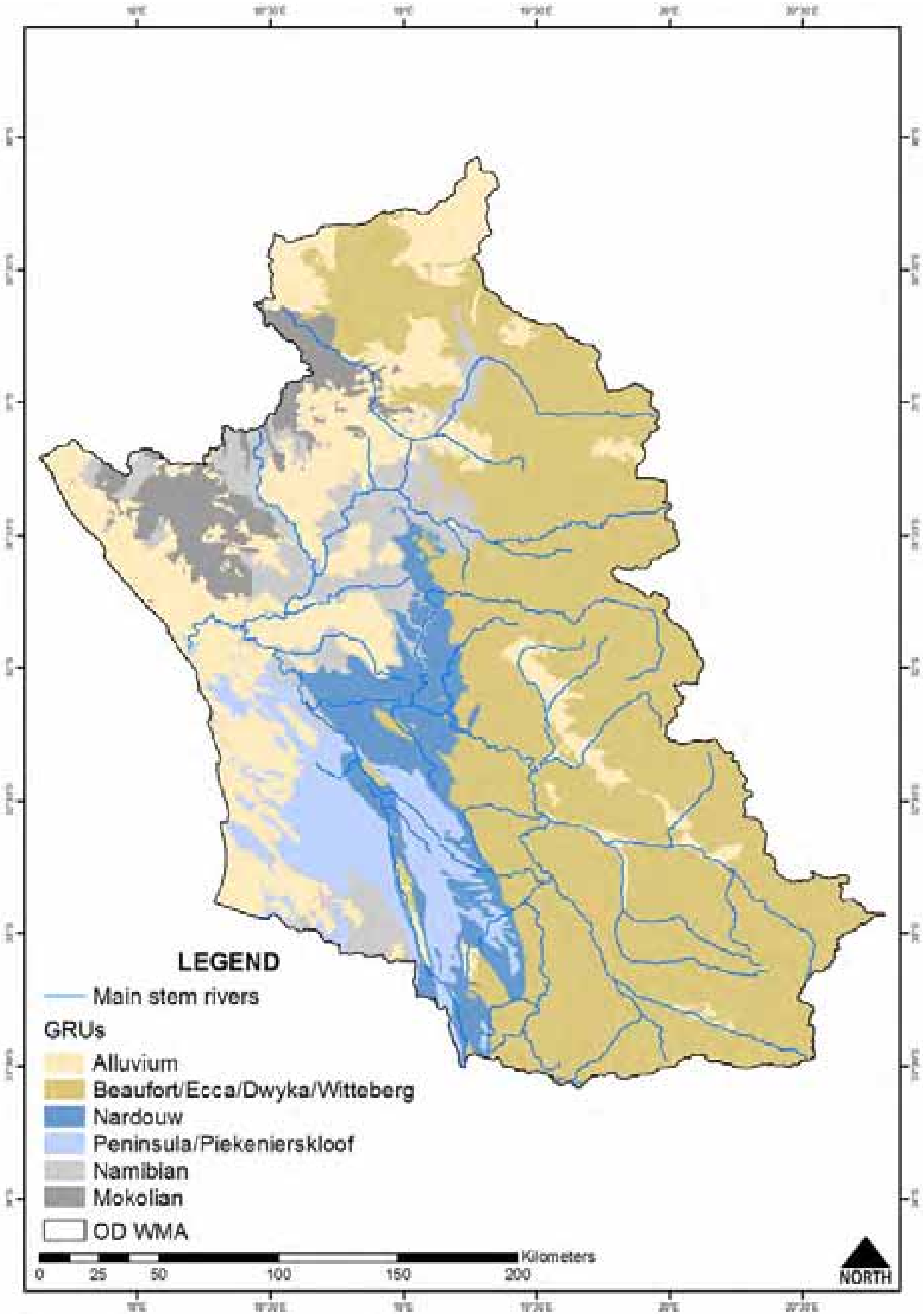

Figure 4.14 The Olifants/Doring catchment, with GW Tier I showing the delineation of GRUs

Probable GW/SW areas of interaction were defined according to where a change in GRU may have resulted in groundwater flowing to the surface, or daylighting, due to a significant change in permeability. For example, where the Nardouw Formation (GRU 5) contacts the Bokkeveld (GRU 4), a GW/SW interaction area was allocated. The alluvium (GRU 1) is considered an important feature. However it often overlays other secondary aquifers and structural features, thus no GW/SW interaction area allocation was attributed to the presence of GRU 1.

Where dolerite dykes crossed the selected river systems a GW/SW area of interaction was allocated. However, there is high degree of uncertainty as to whether groundwater flow occurs within dolerite dykes. GW/SW interaction areas were assigned to the up-gradient contact of the dolerite, the assumption being that the dolerite presence may influence surface water conditions, by contributing groundwater to the river flow.

4.6.1.2 GW Tier II: Groundwater fed base flow

Groundwater fed base flow data as a percentage of total flow was used as GW Tier II. This is a calculated value available nationally at a quaternary catchment scale and has not been verified for the Olifants-Doorn WMA. Thus there is low confidence in this value and it is given a weighting of 1. In this area, this value is useful only in the perennial systems, as there is no baseflow in the seasonal and ephemeral systems. However, in the latter systems groundwater is ecologically important in terms of maintaining water levels in permanent pools and supporting riparian habitats. Figure 4.15 shows where the groundwater fed base flow, as a percentage of total mean annual runoff, is high (>10%), medium (5-9.99%) or low (0-4.99%).

4.6.1.3 GW Tier III: Groundwater levels

Groundwater levels were included as an indicator as there is a high probability of aquifers discharging to rivers where shallow groundwater levels maintain hydraulic continuity between the river and aquifer.

All borehole water levels were obtained from the National Groundwater Database (NGDB), which is managed by DWAF. No additional water level data were obtained. The data obtained from the NGDB was not filtered, i.e. borehole positions were not verified with field work[26]; nor were the water levels differentiated as to the time of year the measurement was taken. Also, boreholes were not differentiated into 'primary aquifer boreholes' or deeper 'fractured rock (secondary aquifer) boreholes'; and there was no indication of whether the water levels measured were of a 'resting' borehole or measured in a production borehole whilst the pump was running.

All water level point data were interpolated to produce a depth to groundwater layer for use within the GIS. The presence of springs was also taken into account when interpolating groundwater levels, with the spring position being allocated a value of 0 mbgl. However, interpolation was not co-krigged with topography data.

Interrogation of the borehole water level data revealed inconsistencies. For example, in places where the majority of reported water levels in boreholes were very shallow (<5 mbgl), there were a few boreholes with very deep water levels (>50 mbgl). The consequence of interpolating water level data is that in a shallow groundwater area, one deep groundwater value skews interpolated water levels to the lower end. For the example above, the water level would be *c.*10 mbgl, rather than *c*. 3 mbgl, which would be the case if the deep data are erroneous. In using the groundwater level grid, a value of 2.5 m was considered to represent shallow groundwater. The depth to groundwater was rated as follows:

1. < 2.5 m Rating = 3
2. 2.5 – 5 m Rating = 2
3. 5 – 10 m Rating = 1
4. > 10 m Rating = 0.

[26] This is a costly exercise.

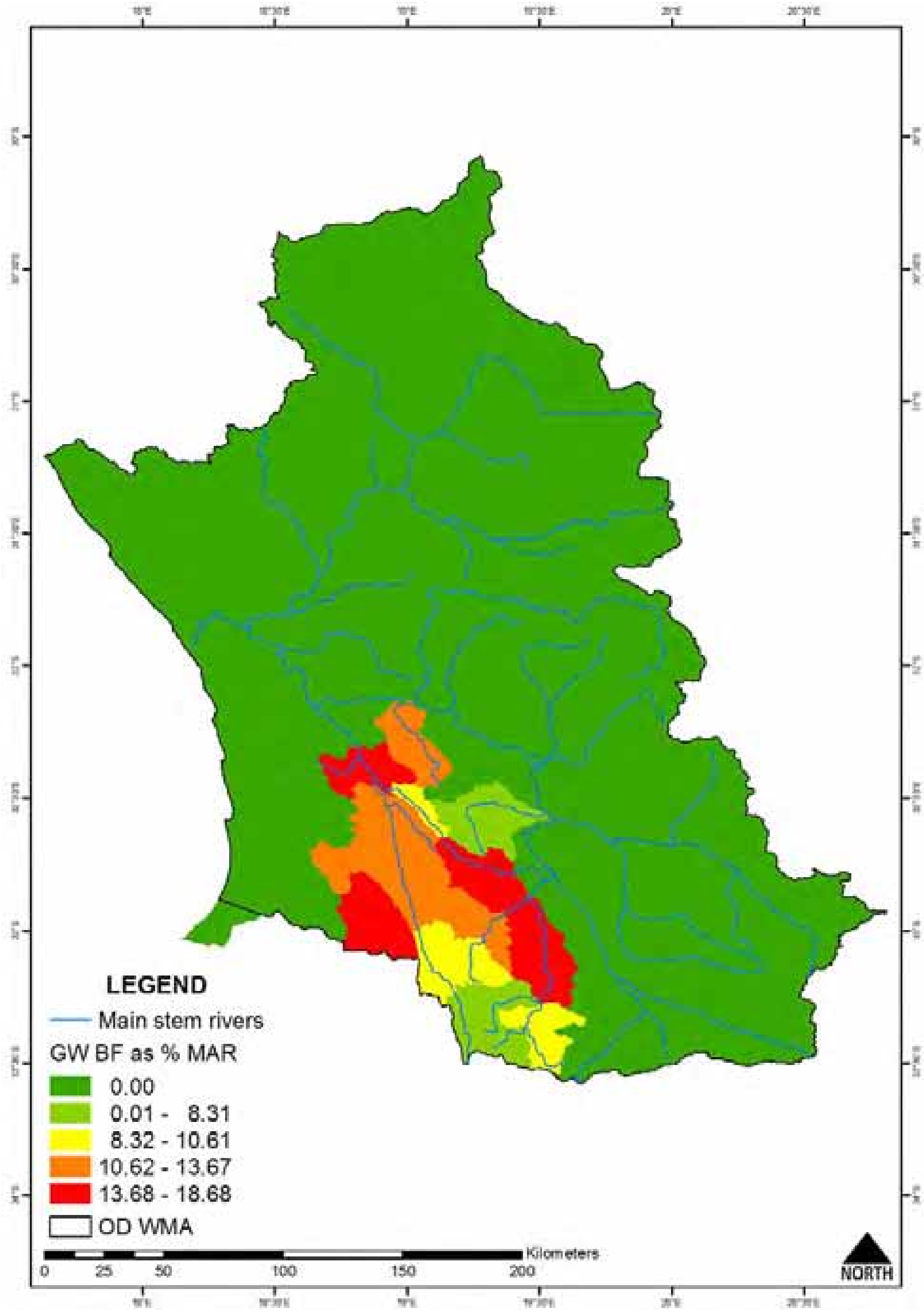

Figure 4.15 Groundwater Tier II, indicating probable groundwater contribution to base flow in the Olifants/Doring catchment based on calculated, national scale data (low confidence)

The weight applied to this Tier for this particular study area was 1.

For the groundwater level data, no time series data (i.e. groundwater levels measured with time) were analysed. The value of analyzing time series water level data is that it can indicate if a shallow groundwater area remains all year or whether the water table fluctuates through the area and if, in close proximity to a river, may indicate intermittent, as opposed to permanent, interaction between surface water flows and groundwater.

GW/SW interaction areas of GW Tier III were allocated to the selected rivers sections where the interpolated groundwater table was less than 2.5 mbgl (Figure 4.16). The individual borehole values were not taken into account. The GW/SW interaction areas indicate the general area where groundwater may be contributing to surface water flow, however there is much uncertainty (at the current project scale) in delineating if and exactly where GW/SW interaction may be occurring.

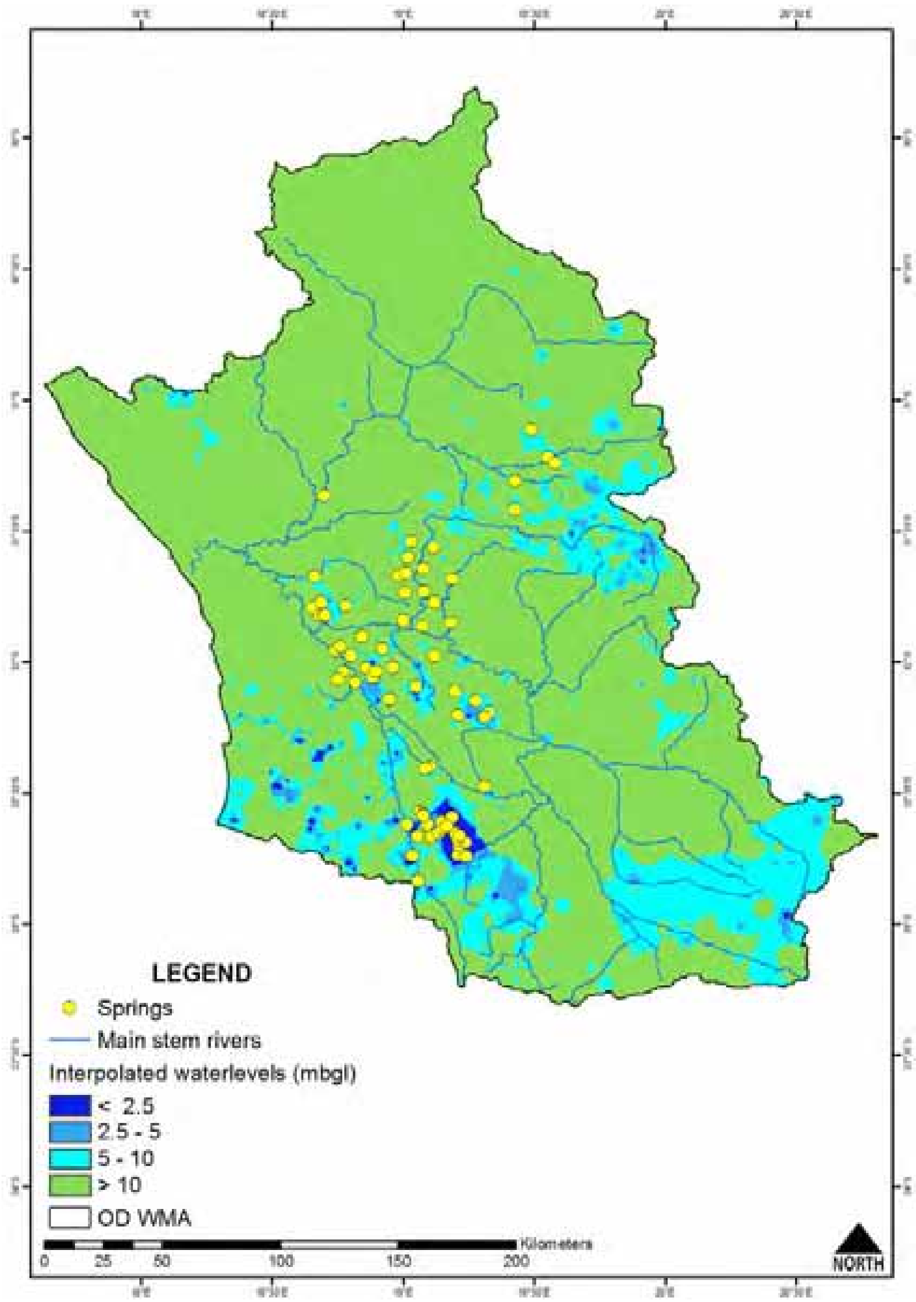

Figure 4.16 The Olifants/Doring catchment showing GW Tier III, groundwater levels categorised based on the probability of interaction with rivers (<2.5mbgl – very high; 2.5-5.0mbgl high; 5 -10mbgl medium; >10mbgl low)

4.6.1.4 GW Tier IV: Springs

Spring positions were obtained from the NGDB.[27] Unfortunately only the spring position was available and not spring flow. It could well be that some of the springs no longer flow, or have very low flow, however this detail is not known. The assumption was made that all springs were significant if they occurred within 200 m of the selected rivers. An added concern was that the NGDB does not indicate springs in some of the (usually more remote) places where springs are known to occur. The dataset was thus augmented to include known springs in the Doring River valley near EWR Site 5 (Figure 4.16). All springs (as they are not differentiated) were assigned a rating of two and, because of their perceived importance in the study area, assigned a weight of 3.

A GW Tier IV GW/SW interaction area was allocated to the river sections if a spring was within 200 m of the selected river channel.

4.6.1.5 GW Tier V: Geological faulting

Groundwater Tier V takes into account geological faulting (1:500 000 hydrogeological map series). The presence of geological faulting does not imply that groundwater flow definitely occurs along these features. There are many faults that are weathered and essentially sealed, with no associated groundwater presence or movement. Faults can, however, be favourable flow paths. Because there are no data on the hydrogeological characteristics of the faults available at the desktop level, it was assumed that all faults are water bearing. The faults were assigned a rating of 1 and an overall weight of 3. A GW/SW interaction area is allocated where a fault intersects the selected river section (Figure 4.17). The attribute table of the GW Tier V GW/SW interaction areas indicates whether the area occurs on the selected river sections or on a river that is not a selected river section. It may still be important to consider tributaries that feed into the selected river sections if they are groundwater fed via fault structures. At a more comprehensive level, more fault structures should be identified from remotely sensed data and/or other available datasets or geohydrological reports.

4.6.1.6 Aquifer dependent ecosystems

Groundwater Tier VI used the classification of SANBI vegetation classes, which have been ranked at a desktop level according to the probability that at least some of species within these communities are dependent on access to the water table (Colvin *et al*., 2006). These areas have been given a weighting of 2 for this catchment (Figure 4.18). More supporting information and ground truthing of groundwater use by phreatophytes would increase the confidence in this tier. Importantly, this tier captures links to groundwater in seasonal and ephemeral surface water drainage systems where there is no baseflow, but where the riparian vegetation and permanent pools are dependent on groundwater.

4.6.2 Results

The Olifants/Doring catchment with river and estuary reaches, as delimited by their nodes, assigned a 'high', 'medium' or 'low' probability of groundwater/surface water interaction on the basis of procedure outlined here is shown in Figure 4.19.

The denotations do not necessarily mean that the volume of water contributed to the system by groundwater is high. While this may be the case, particularly in some perennial streams, in many cases the denotation of 'high', 'medium' or 'low' probability of GW/SW interaction is intended to highlight the importance of the groundwater in maintaining ecological function in those systems, and may not be related to volume. For instance, at R14 and R16, the

[27] Anecdotal information suggests that the spring information available in the NGDB is incomplete for parts of the catchment.

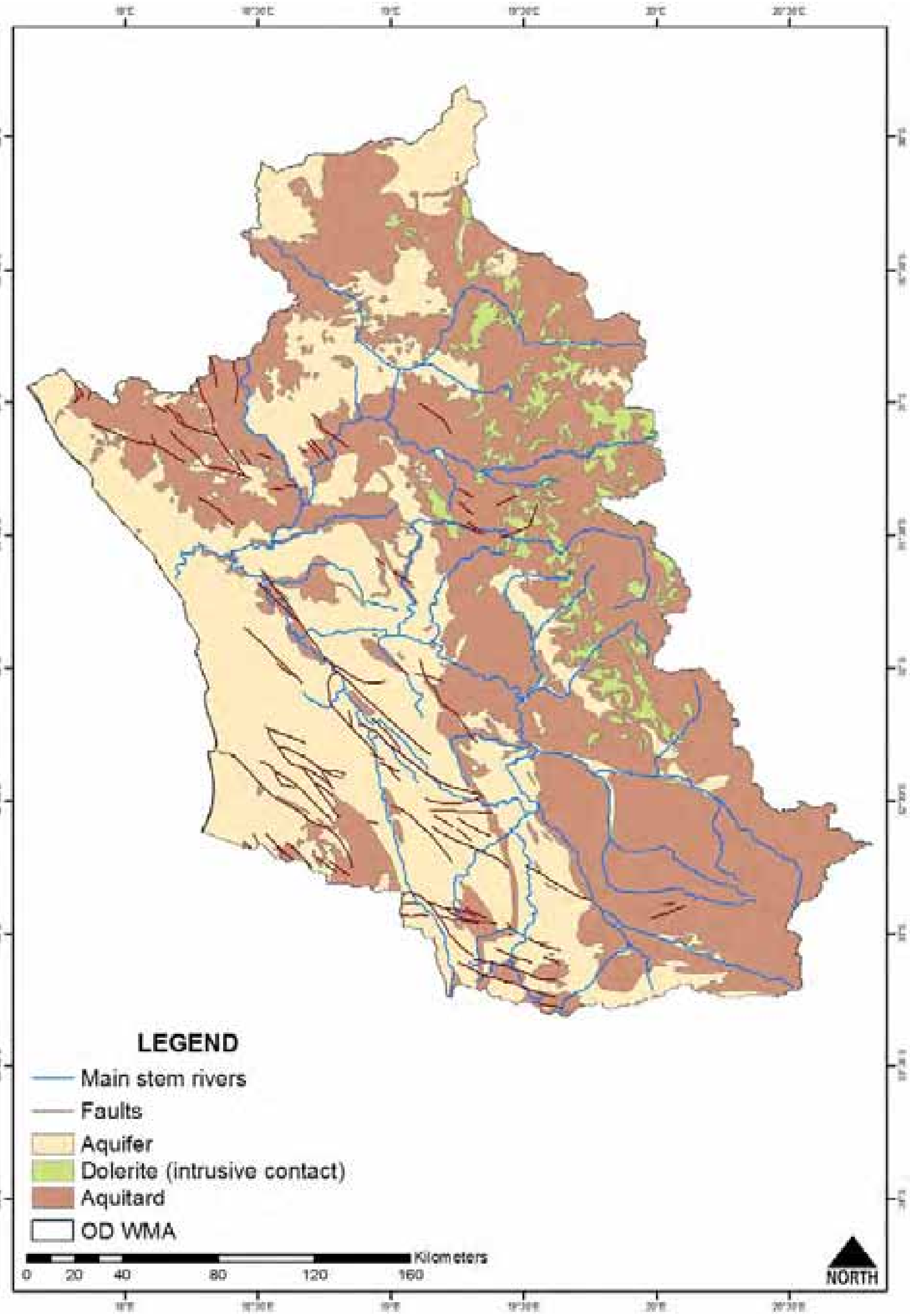

Figure 4.17 The Olifants/Doring catchment, with GW Tier V with faults identified as possible groundwater discharge points where they intersect rivers

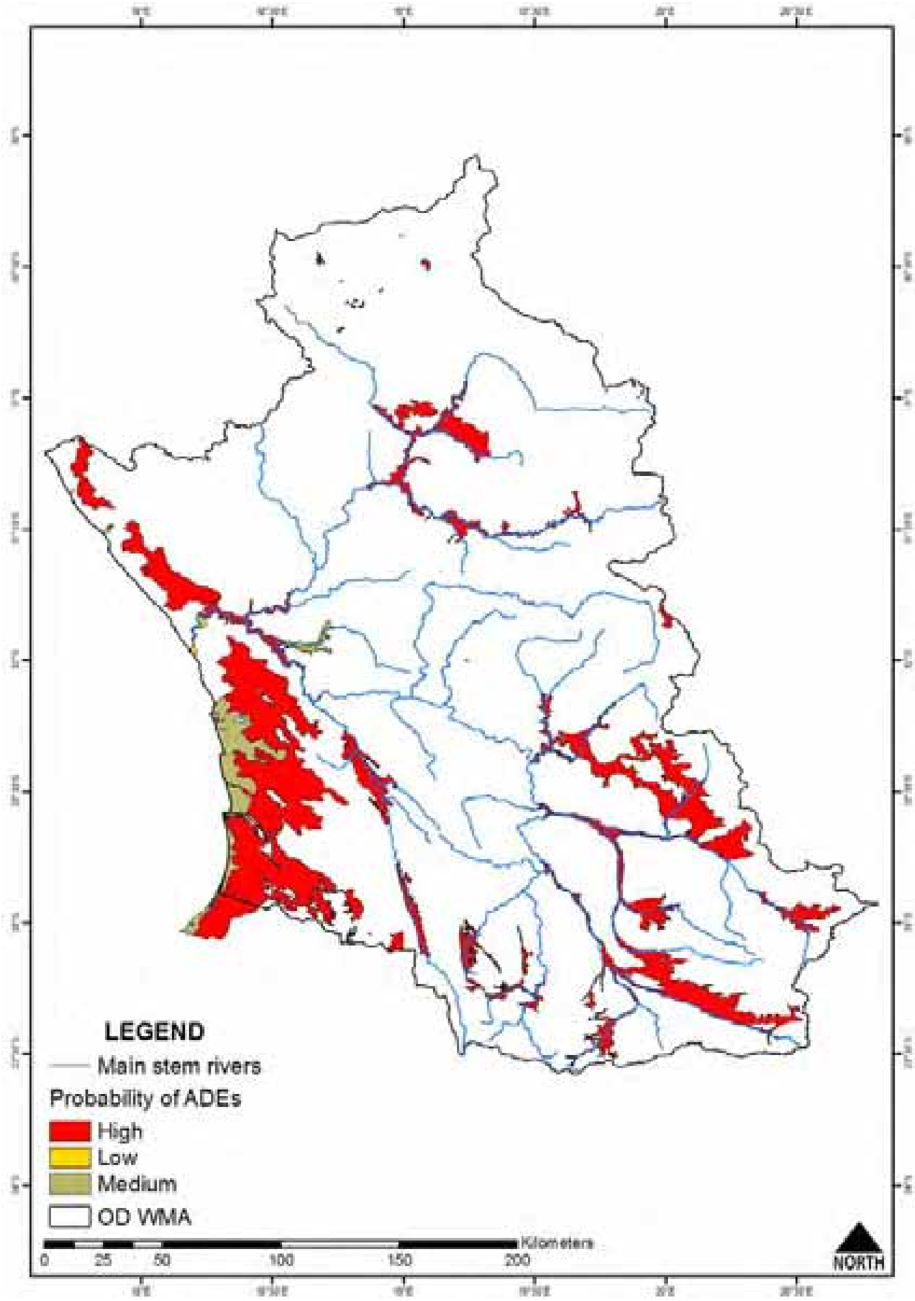

Figure 4.18 The Olifants/Doring catchment, with GW Tier VI, areas where aquifer dependent ecosystems are probable

groundwater contributions are extremely important (from an ecological perspective) in the summer months when they off-set evaporation from isolated pools in the river, albeit that the contributions are at very low volumes.

The groundwater tiers were processed sequentially for the full area of the catchment and categorised into areas of high, medium and low probability of GW-SW interaction (Figure 4.19). This probability is based on the cumulative presence of one or more of the following indicators: shallow groundwater levels; the presence spring; the presence of a fault or aquitard flow barrier which may cause groundwater to daylight; phreatophyte vegetation; calculated (or measured in other examples) groundwater contribution to baseflow.

Figure 4.19 shows how these probability categories intersect the main stems of the rivers in the catchment and these main stems are categorised. Nodes have been assigned to the main stem for GW-SW interaction monitoring based on the following rules:

- where there is greater than 5 km length of high or medium probability main stem;
- where the length of the high or medium category extends for >30 km there should be a new node;
- where the probability decreases downstream a node is place approx. 1 km upstream of the decrease; and
- where a high or medium category main stem passes into a new GRU, a node is placed approx. 1 km upstream of the boundary.

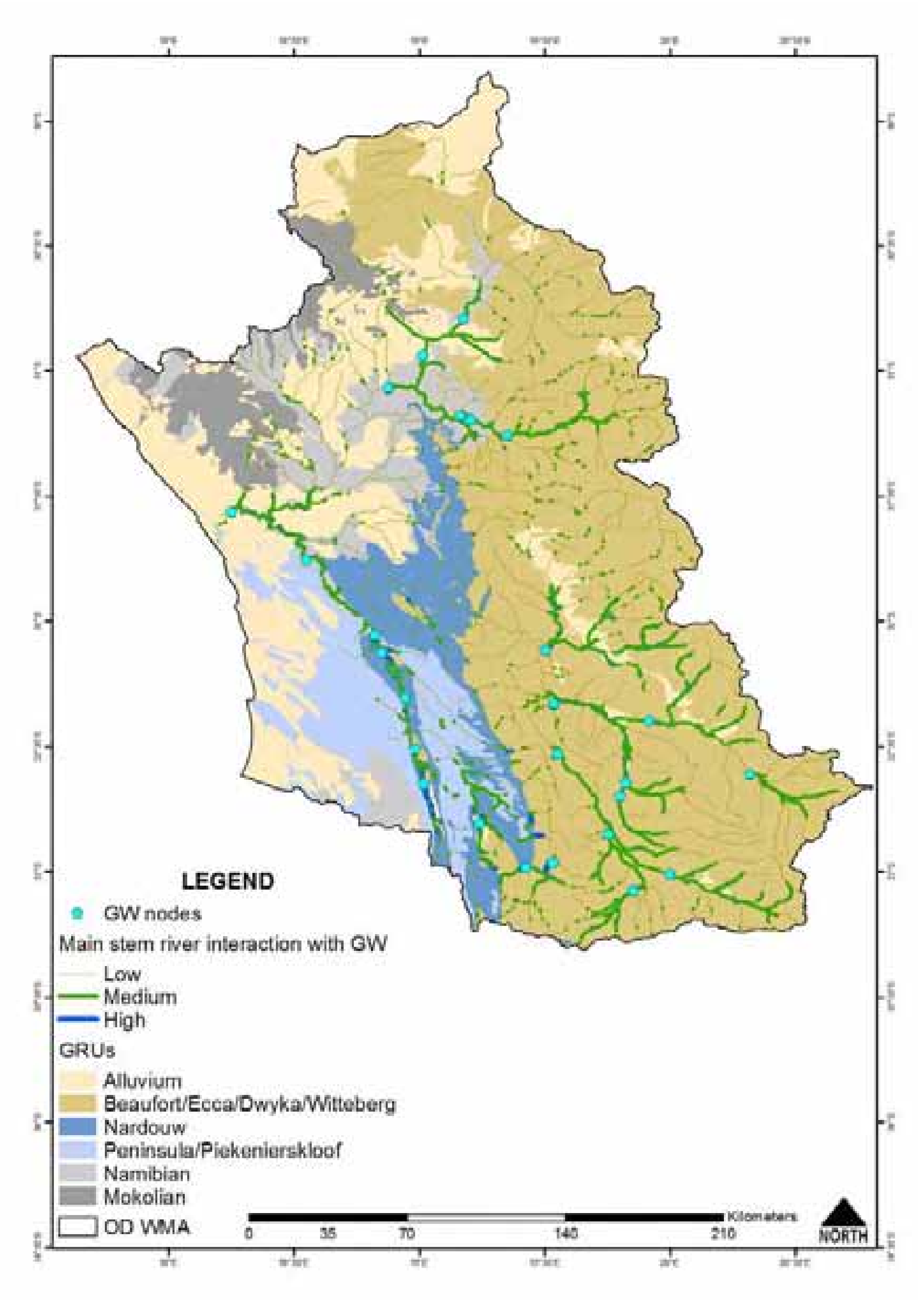

Figure 4.19 The Olifants/Doring catchment with areas assigned a 'high', 'medium' or 'low' probability of GW/SW interaction based on combination of groundwater tiers

4.6.3 Limitations

This test application highlighted the following limitations:

- the scale of lineament mapping on the 1: 1 000 000 geology under-represents these important features significantly;
- interpolated groundwater levels have a high degree of uncertainty;
- there are multiple scales of spatial data input and this appears to result in offsets and create intersections which are simply an artefact of the different scales (e.g. alluvium crossing a main stem river appearing to create a GRU boundary); and
- the calculated groundwater contribution of base flow is based on quaternary catchment scale data with very low confidence.

5 DEFINE THE INTEGRATED UNITS OF ANALYSIS (IUAS) (STEP 1H)

Integrated Units of Analysis (IUAs) are a combination of the socio-economic zones defined in Step 1b (see Turpie *et al*., 2007) and watershed boundaries, within which ecological information is provided at a finer scale of resolution (Figure 5.1). IUAs are defined according to a number of socio-economic criteria detailed in Turpie *et al*. (2007), and adjusted so that the boundaries follow sub-catchment boundaries. Biophysical nodes within each IUA are identified so that socio-economically-relevant ecological data can be provided for later steps in the classification procedure (Figure 5.1).

Note: The process of identifying the biophysical nodes at which socio-economically-relevant ecological data are required does not necessarily mean that the required data can be provided for those nodes. Provision of the data at a node is contingent on the pre-existence of relevant Reserve related data and is dealt with in detail in Section 4.3.9.

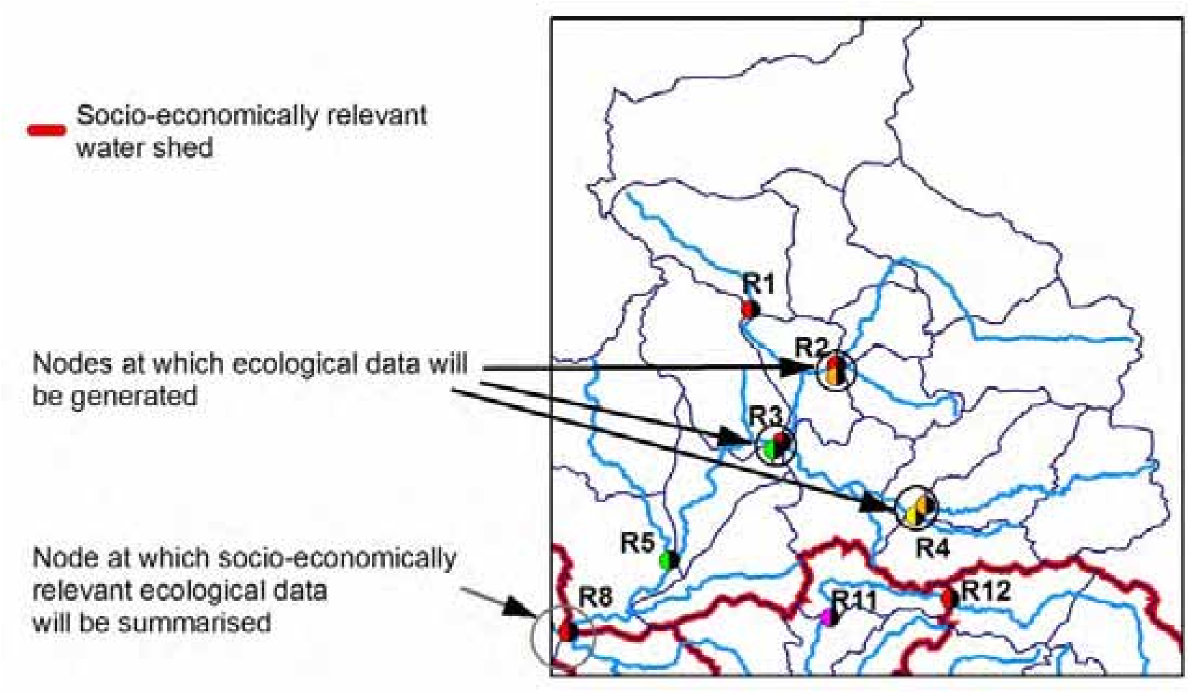

Figure 5.1 IUAs are the adjusted socio-economic zones, within which ecological information will be provided at a finer scale of resolution

5.1 Example: Olifants/Doring catchment

The socio-economic zones for the Olifants/Doring catchment overlaid with the biophysical nodes are provided in Figure 5.2.

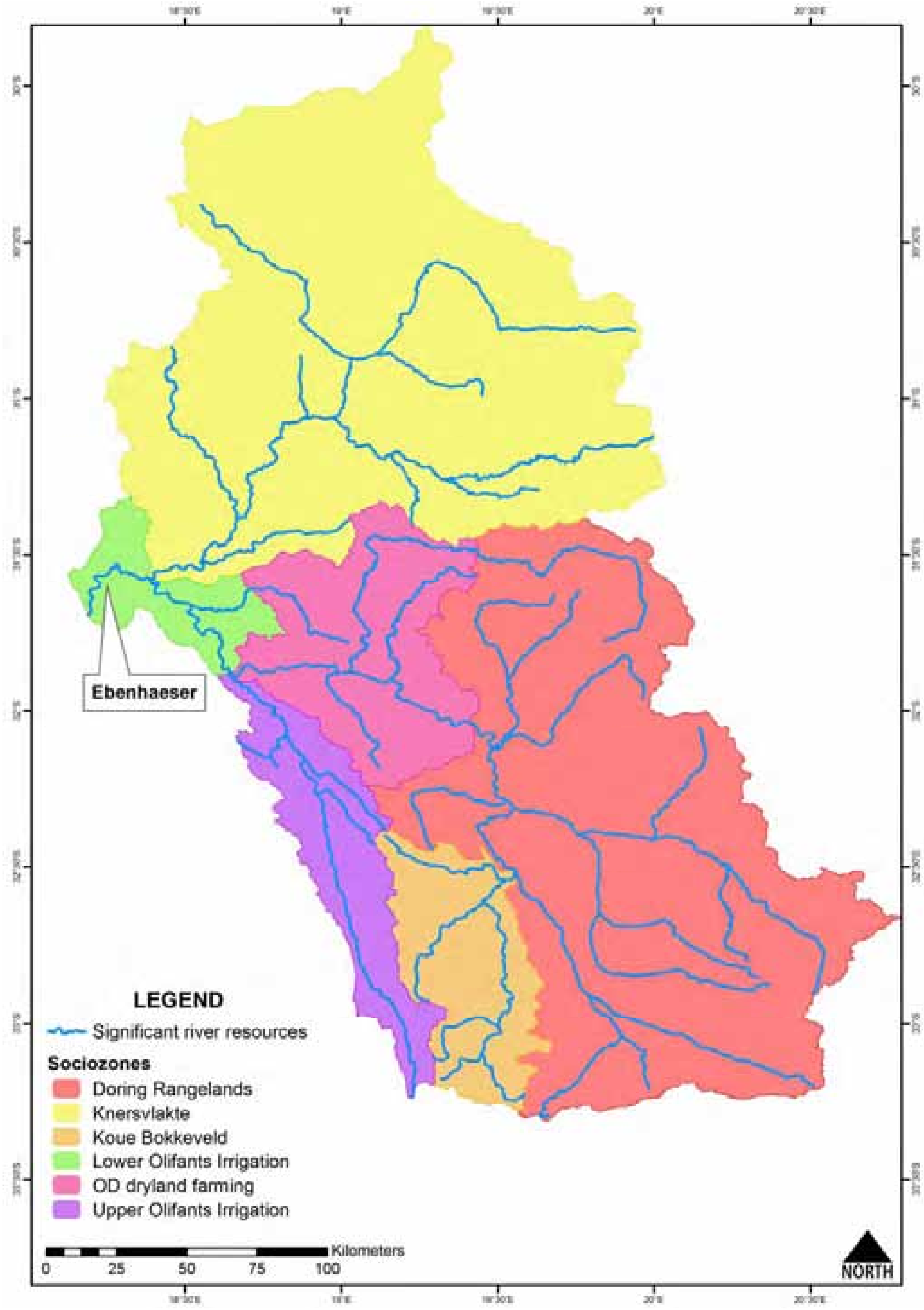

Figure 5.2 Socio-economic catchment division

The IUAs for the catchment, with their nested biophysical nodes are listed in Table 5.1. The so-called integration point at the IUA outlet, which represents the point(s) at which socio-economically-relevant ecological data will be summarised, is also identified for each IUA. The IUAs for the catchment, with their nested quaternary catchments are listed in Table 5.2.

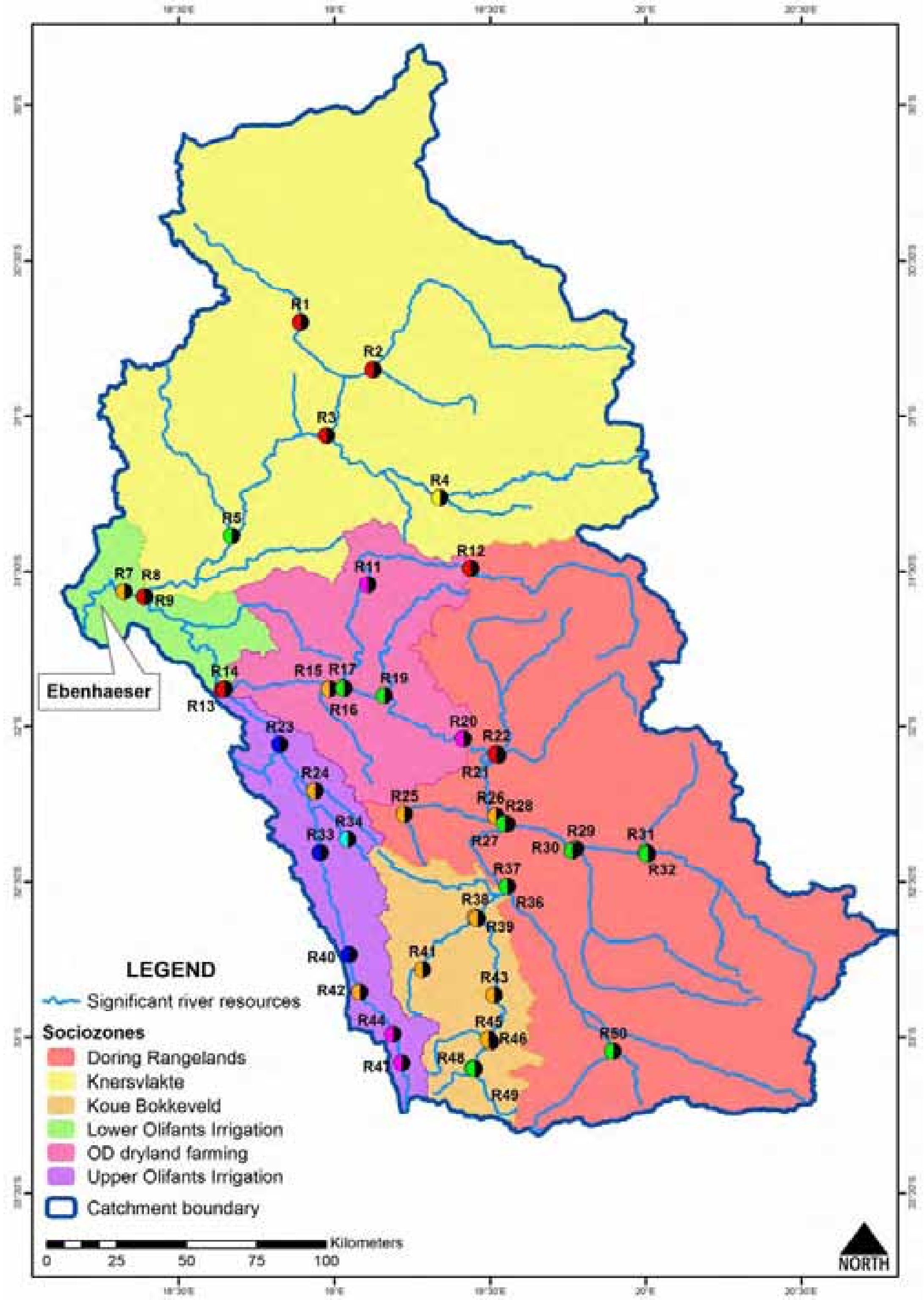

Figure 5.3 IUAs for the Olifants/Doring catchment (note the adjustment of watershed)

Table 5.1 IUAs for the Olifants/Doring catchment, with their nested biophysical nodes

IUA	Biophysical nodes	IUA outlet
Doring Rangelands	**R12, R20,** R21, R22, R25, R27, R28, R29, R30, R31, R32, R35, R36, R50	R12, R20
Knersvlakte	R1, R3, R2, R4, R5, **R8**	R8
Koue Bokkeveld	**R37**, R38, R39, R41, R43, R45, R46, R48, R49	R37
Lower Olifants Irrigation	**R7**, R9	R7
Olifants/Doring Dryland Farming	R11, **R14**, R15, R16, R17, R18, R19, R26	R14, R26
Upper Olifants Irrigation	**R13**, R23, R24, R33, R34, R40, R42, R44, R47	R23
Ebenezer	**E1**	E1

Table 5.2 IUAs for the Olifants/Doring catchment, with their nested quaternary catchments

IUA	Quaternary catchments
Doring Rangelands	E40B, E40A, E24E, E24F,E24G, E24C, E24D, E23E, E24H, E23F, E23K, E23D, E22G, E23J, E23C, E23B, E22F, E23H, E23A, E23G, E22E, E22B, E22A, E22D, E22C, E24B, E24A
Knersvlakte	E31A, E31C, E31D, E31G, E33A, E31B, E31E, E33D, E31H, E31F, E32D, E33B, E32B, E32A, E32E, E33E, E33C, E32C
Koue Bokkeveld	E21K, E21L, E21J, E21H, E21F, E21G, E21E, E21D, E21C, E21B, E21A
Lower Olifants Irrigation	E33H, E33G
Olifants/Doring Dryland Farming	E40C, E33F, E40D, E24K, E24M, E24J, E24L
Upper Olifants Irrigation	E10K, E10J, E10G, E10H, E10F, E10E, E10D, E10C, E10B, E10A
Ebenezer	E1

6 DEVELOP AND/OR ADJUST THE SOCIO-ECONOMIC FRAMEWORK AND DECISION-ANALYSIS FRAMEWORK (STEP 1I)

The socio-economic framework (see Turpie *et al*., 2007) established to relate changes in yield and ecosystem characteristics to socio-economic values, together with the decision-analysis framework (Joubert *et al*., 2007) that have been recommended to assess the implications of different scenarios will need to be adjusted given the characteristics of individual catchments, new information, methods, models and technology. The ecological component will need to provide information in this regard as and when required.

7 IDENTIFY NODES TO WHICH EXISTING RESOURCE DIRECTED MEASURES (RDM) CAN BE EXTRAPOLATED, AND MAKE THE EXTRAPOLATION (STEP 3A)

The Reserve determination process is an integral component of the classification procedure. However, two situations may arise during a Classification Process in a catchment. First, a Classification Process may occur in a catchment with an existing signed-off preliminary Reserve. Second, a Classification Process may occur where there is no existing preliminary Reserve. In the case of the second scenario, a Reserve determination process would need to be incorporated into the Classification Process, in which case, standard Reserve procedures should be followed (DWAF, 1999). However, in the case of an existing preliminary Reserve (first scenario), an extrapolation process would be required, and if necessary, high confidence RDM data collected. This sub-section deals with the first scenario[28].

The testing of the biophysical nodes to assess whether high-confidence Reserve determination data at established EWR sites can be extrapolated to any of the biophysical nodes established in Section 7.1 (Step 3a) is important for two future steps:

1. Develop rule curves, summary tables and modified time series for nodes for all categories (Step 3b).
2. Quantify the changes in relevant ecosystem components, function and attributes for each category for each node (Step 3c).

In terms of Step 3a, a distinction needs to be made between:

a. nodes that are suitable for extrapolation (see Section 7.1) from sites with high-confidence Reserve data; the EWR quantification for those nodes should be based on those data rather than the Desktop Model (Hughes and Hannart, 2003); and
b. nodes that are not suitable for extrapolation from sites with high-confidence Reserve data, the EWR quantification for those nodes will be based on the Desktop Model[29].

Clearly, the greater the number and distribution of Comprehensive EWR sites in a catchment, the greater the proportion of the catchment that will be covered by such assessment, and the greater the overall confidence in the EWR assessments (and EGSA changes) for the catchment.

In terms of Step 3c, changes in some EGSAs, in particular biophysical EGSAs, can only be provided:

a. at nodes that are suitable for extrapolation from sites with high-confidence Reserve data; and
b. for EGSAs that were considered during the Reserve determinations.

7.1 Procedure for determining whether existing Reserve data can be extrapolated to river nodes (Step 3a)

The procedure for testing river nodes to determine whether existing Reserve data can be extrapolated to them follows the draft Extrapolation Decision-Support System (DSS) proposed by Louw *et al*. (2006). The procedural components to be incorporated into the DSS are under development and may well change in their final form. Updates should be incorporated into the WRCS. The component of the procedure that is applicable to the WRCS is outlined in Table 7.1.

The first three steps of the procedure closely approximate the Tiers used in the river node selection (Section 4.2.2). The data in Section 4 can therefore be used to follow these steps.

[28] Where no preliminary Reserve exists (i.e. Scenario 1), follow the DWAF (1999) methods to determine EWRs.
[29] There are no extant Desktop Models for Reserve determinations for estuaries and wetlands.

Table 7.1 Procedure for extrapolation testing of river nodes (adapted from Louw *et al*. (2006))

STEP	Data	Action	Explanation	Outcome
I	Existing high-confidence EWR sites	Use data from TIER VII in river node establishment (Section 4.3.8).	Determine: • location; • EWR method used; • confidence level; and • EGSAs considered.	List of EWR sites and corresponding biophysical nodes.
II	Hydrological Index Class	Use data from TIER II in river node establishment (Section 4.3.3).	Sort nodes according to HydI Class.	List of similar nodes.
III	Ecoregion Level I	Use data from TIER I in river node establishment (Section 4.3.2).	Sort nodes according to HydI Class and then Ecostatus.	
IV	Ecoregion Level II	NOT USED IN THIS VERSION OF WRCS.		
V	Geomorphic zone	Use data from Tier III.	Sort nodes according to HydI Class, then EcoStatus and then Geomorphic zone.	List of similar nodes.
VI	Altitude	Use Digital Terrain Model (DTM). Group elevations as follows: A1. 0-200 m MSL A2. 201-400 m MSL A3. 401-600 m MSL A4. 601-800 m MSL A5. 801-1000 m MSL A6. >1001 m MSL.	Altitude Class the same: Score 1.	List of similar nodes.
VII	Stream width	NOT YET DEVELOPED.		
VIII	Channel type	NOT YET DEVELOPED.		
IX	Riparian vegetation assemblage	NOT YET DEVELOPED.		
X	Fish assemblage	Derive: Expected reference fish assemblage and present fish assemblage. Use FISHBASE (expected) and knowledge of the catchment/recent records (present).	Indicator species the same: Score 1. All species the same and the same indicator species: Score 2.	List of similar nodes.
XI	Invertebrate assemblage	NOT YET DEVELOPED.		
XII	Assess extent of extrapolation	For each EWR site and each river node considered for extrapolation. Interim rules[30]:	Extrapolation allowed if there is: • agreement TIERs I to IV; and • sum of score for altitude and fish ≥ 2.	List of nodes to which EWR data can be extrapolated.

[30] The rules will be established as part of the development of the Extrapolation DSS, these rules are only used to facilitate the testing process in the development of the WRCS.

7.2 Example: Olifants/Doring catchment

The location of existing EWR sites in the Olifants/Doring catchment and their corresponding downstream biophysical nodes are given in or the Olifants/Doring catchment, only those components of the Extrapolation DSS that have been developed were applied. The only developed component not applied was the Ecoregion Level II data, which were not incorporated because the data were almost identical to the Geomorphic zones, which had already been done as Tier III of the nodal establishment (Section 4.3.4).

Table 7.2 The location of existing EWR Sites in the Olifants/Doring catchment and their corresponding downstream nodes

EWR site no.	Corresponding River node code	River	Site name	Latitude	Longitude
1a 1b	R33	Olifants	Olifants at Hex River	32°26.764' 32°26.680'	18°57.601' 18°57.504'
2	R13	Olifants	Olifants at Alwynskop	31°57.974'	18°44.463'
3a 3b	R34	Rondegat	Rondegat at Algeria	32°21.760' 32°21.739'	19°02.618' 19°02.593'
4a 4b	R19	Doring	Doring at Biedou	32°02.410' 32°02.416'	19°24.896' 19°24.783'
5	R15	Doring	Doring at Ou Drif	31°51.446'	18°54.754'
6a 6b	R38	Groot	Groot at Mount Cedar	32°39.552' 32°39.377'	19°23.786' 19°23.982'

River nodes R33 (EWR Site 1), R13 (EWR Site 2), R34 (EWR Site 3), R19 (EWR Site 4), R15 (EWR Site 5) and R38 (EWR Site 6) all had Comprehensive Reserve data (Table 1.1). The EWR Sites were then compared with the other river nodes to determine whether the data from those sites could be extrapolated to them. The results of Tiers I to V of the extrapolation testing are given in Table 7.3. Approximately 14% of all significant river resources, based on river length, can be represented by data derived from the extrapolation process (Table 7.4).

The nodes that share the same HydI Class, Ecoregion Level I and Geomorphic zone (but not necessarily an altitude Class) with one of the EWR sites were taken forward to a comparison of their fish communities (Figure 7.1).

Table 7.3 provides a summary of the procedure undertaken to extrapolate information from high confidence EWR sites to river nodes selected for the WRCS in the Olifants/Doring Catchment. As indicated, this procedure is an adaptation of that currently under development by Louw *et al*. (2006). Firstly, all river nodes are 'filtered' based on three biophysical characteristics, i.e. Ecoregion, Hydrological Index and Geomorphic zone. For example, river nodes R13, R23, R33, R40, R41 and R48 all share the same Ecoregion, Hydrological Index and Geomorphic zone with EWR 1 and 2, i.e. they all occur within the Western Folded Mountains Ecoregion, they are all perennial and they all occur in Lower Foothill Geomorphic zone.

Second, river nodes selected in the first process are 'filtered' for a second time in terms of their altitude Class and fish assemblage characteristics. If they fall within the same altitude Class as the EWR sites, they are assigned a score of 1. In this example, R13, R23, R33 and R40 all fall within altitude Class A1 (i.e. 0-200 m MSL), which is the same group as EWR Sites 1 and 2, and are therefore assigned a score of 1; while R41 and R48 each score 0 because they are in different altitude Classes to EWR Sites 1 and 2. If they share the same fish assemblage characteristics or indicator species, they are assigned a score of 1. If

Table 7.3 Results of the TIER I to V extrapolation testing for the Olifants/Doring catchment

Node code	Node order	Hydrological Index Class	Ecoregion number	Ecoregion	Geomorphic zone	Altitude Class
R37	Gro_1	1	21	GREAT KAROO	Mnt. Stream/Upper Foothill	A2
R13	Oli_3		23	WESTERN FOLDED MOUNTAINS	Lower Foothill	A1
R23	Oli_4					
R33	Oli_5					
R40	Oli_6					
R44	Oli_7					A3
R41	Gro_3					A4
R48	Krui_1					A5
R34	Ron_1				Mnt. Stream/Upper Foothill	A1
R42	Oli_7					
R24	Jan_1					A2
R25	Tra_2					A3
R38	Gro_2					
R39	Riet_1					
R47	Oli_9					A4
R46	Win_1					A5
R49	Wel_1					
R43	Riet_2				Rejuvenated Floodplain	A5
R45	Hou_1					
R9	Oli_2		25	WESTERN COASTAL BELT	Lower Foothill	A1
R7	Oli_1				Lower River	A1
R18	Brak_1	2	21	GREAT KAROO	Mnt. Stream/Upper Foothill	A1
R4	Hant_1				Mnt. Stream/Upper Foothill	A2
R14	Dor_1		23	WESTERN FOLDED MOUNTAINS	Lower Foothill.	A1
R16	Dor_2					
R19	Dor_3					
R20	Dor_4					
R28	Dor_5					A2
R15	Bran_1				Mnt. Stream/Upper Foothill	A1
R26	Tra_1					
R27	Tank_1	3	21	GREAT KAROO	Lower Foothill	A1
R29	Tank_2					
R30	Ong_1					
R32	Tank_3					

Node code	Node order	Hydrological Index Class	Ecoregion number	Ecoregion	Geomorphic zone	Altitude Class
R36	Dor_6					
R12	Oor_3					A4
R21	Bos_1				Mnt.Stream/Upper Foothill	A1
R31	Reno_1					A2
R35	Tank_4					
R50	Dor_7					A3
R17	Oor_1		23	WESTERN FOLDED MOUNTAINS	Lower Foothill	A1
R11	Oor_2					A4
R22	Wolf_1				Mnt. Stream/Upper Foothill	A2
R3	Dor(2)_1		25	WESTERN COASTAL BELT	Lower Foothill	A1
R5	Sout_3					
R6	Geel_1					
R8	Sout_1					
R10	Sout_2					
R2	Krom_1		26	NAMA KAROO	Lower Foothill	A3
R1	Rooi_1				Mnt. Stream/Upper Foothill	A4

Filter nodes on:

- Ecoregion
- HydI
- Geomorphi

Filter and score nodes on:

- Altitude
- Fish assemblage
- Indicator spp

EWR 1 + 2 → Western Folded Mountains; Perennial; Lower Foothill 0-200 masl (A1)

Selected nodes
R13
R23
R33
R40
R41
R48

→

Altitude	Fish Assemblage	Indicator fish species	Score
A1	Same	Same	3
	Same	Same	3
	Same	Same	3
	Same	Same	3
A3	No data	No data	0
A5	No data	No data	0

→

Selected Nodes for extrapolation
R13
R23
R33
R40

EWR 3 + 6 → Western Folded Mountains; Perennial; Mountain stream/ Upper Foothill 400-600 masl (A3)

Selected nodes
R34
R42
R24
R44
R25
R38
R39
R47
R46
R49

→

Altitude	Fish Assemblage	Indicator fish species	Score
A1	Same	Same	2
	Different	Same	1
A2	Same	Same	2
A3	Different	Same	2
	Different	Different	1
	Same	Same	3
	Same	Same	3
A4	Different	Different	0
A5	No data	No data	0
	No data	No data	0

→

Selected Nodes for extrapolation
R 34
R42
R24
R44
R38
R39

EWR 4 + 5 → Western Folded Mountains; Seasonal; Lower Foothill 0-200 masl (A1)

Selected nodes
R14
R16
R19
R20
R28

→

Altitude	Fish Assemblage	Indicator fish species	Score
A1	Same	Same	3
	Same	Same	3
	Same	Same	3
	Same	Same	3
A2	Same	Same	2

→

Selected Nodes for extrapolation
R14
R16
R19
R20
R28

Figure 7.1 Fish community comparison for nodes that passed Tier I to IV testing in the Olifants/Doring catchment

Table 7.4 River length represented by each node and EWR site from which data can be extrapolated

Extrapolation from node	Extrapolation to node	River length in kilometres
EWR 1 and 2	R13, R23, R33, R40.	92.95
EWR 3 and 6	R24, R34, R38, R39, R42, R44.	119.54
EWR 4 and 5	R14, R16, R19, R20, R28.	175.47
Total river length represented by extrapolatable sites		387.96
Total length in Olifants/Doring catchment		2944.00
% of total river length for which data can be extrapolated		**13.18**

both the fish assemblage characteristics and indicator species are the same as that for the EWR site, they are assigned a score of 2. For example R13, R23, R33 and R40 all have the same fish assemblage characteristics and indicator species as EWR Sites 1 and 2 and thus are assigned a score of 2. Together, their altitude score and fish community characteristic scores give a total score of 3, while river nodes R41 and R48 both score 0 for their fish assemblage characteristics because no data exists and thus the overall score for these two sites is 0. If a score of 2 or more is given for any River node, then extrapolation from the EWR sites in question is allowed (Table 7.3). In this example, information from EWR Sites 1 and 2 can be extrapolated to river nodes R13, R33, R23 and R40. The same procedure was followed for EWR Sites 3 and 6 (R24, R34, R38, R39, R42 and R44) and EWR Sites 4 and 5 (R14, R16, R19, R20 and R28).

7.3 Procedure for testing estuarine nodes to determine whether existing Reserve data can be extrapolated to them

There are currently no Desktop methods for the determination of an estuarine Reserve. Thus, unless a Reserve determination has been done for the estuary in the catchment, the WRCS cannot include estuarine requirements.

8 DEVELOP RULE CURVES, SUMMARY TABLES AND MODIFIED TIME SERIES FOR ALL NODES FOR ALL CATEGORIES (STEP 3B)

This sub-section deals with the provision of the flow-ecological condition information at biophysical nodes using the tools available at present. As is the case with all the procedures recommended for the WRCS, updated and improved data and models should be incorporated into this part of the classification procedure as and when they become available.

8.1 Procedures for developing rule curves, summary tables and modified time series for all nodes for all categories (Step 3b)

Following on from Section 7, the biophysical nodes are divided into two groups:

1. Extrapolation nodes.
2. Non-extrapolation nodes.

For nodes that are not suitable for extrapolation (i.e. low EISC and low calibration confidence) of data from sites with high-confidence Reserve data, the EWR quantifications should be done using the Desktop Model (Section 8.3.2). For nodes that are suitable for extrapolation (i.e. node can be extrapolated from high-confidence Reserve data), the EWR quantifications should be done using the model compiled during the Reserve determination study, in the case of the Olifants/Doring catchment this is the Downstream Response to Imposed Flow Transformation (DRIFT) Model (Brown *et al.,* 2006).

8.2 Ecological categories for which EWRs are generated

Ideally, EWRs at each node (for all ecosystems types, e.g. rivers, wetlands and estuary) should be generated for the maintenance of a full-suite of ecological conditions, *viz*.:

- category A/B;
- category B;
- category C;
- category D; and where applicable,
- Intermediate categories, e.g. C/D, C/B.

This is required because, in theory, the Classification Process should allow consideration of any ecological category from A to D for all ecosystems or portions thereof. In addition, many of the procedures that follow, e.g. the Ecological Sustainability Base Configuration (ESBC) scenario establishment (Section 11), are greatly facilitated by readily available EWR data for different categories.

8.3 Levels of ecological Reserve assessment

Four basic levels of ecological Reserve assessment (DWAF, 1999) can be applied in the classification procedure:

1. Comprehensive.
2. Intermediate.
3. Rapid (consisting of Rapid I, II and III).
4. Desktop.

The levels, as the names indicate, are associated with different degrees of effort (time and cost), mostly with different levels of confidence, and apply tools with different levels of complexity.

In this sub-section the Comprehensive and Desktop methodologies, as they apply to the WRCS, are listed. The Intermediate and Rapid procedures are variations on the other two levels, with activities and data being added or subtracted as appropriate. Details on the methodologies are provided elsewhere, e.g. DWAF (1999).

Although there are several models/tools available for providing EWRs for various categories throughout a catchment, some expert judgment is required when extrapolating data and/or making EWR recommendations outside the range covered by the models, such as providing a configuration scenario that 'allows' a resource (e.g. river reach) to remain in an E/F category (e.g. R13, R45, R46, R48, R49 in Section 8.6.1), or maintaining a D category in the face of overwhelming non-flow related impacts (e.g. R33 and R40). It is neither practical nor desirable to prescribe rules for these situations as they are best dealt with on a catchment-by-catchment basis. It is however suggested that the decisions made, and their attendant assumptions, are documented as clearly as possible (see example in Section 8.6.1).

8.3.1 Comprehensive methodologies

There is a suite of methods accepted by the Chief Directorate: RDM for use in Comprehensive Reserve determinations. The three most frequently applied methods are listed below.

1. *Downstream Response to Instream Flow Transformations (DRIFT):* DRIFT is explained in detail in King *et al*. (2003) and Brown *et al*. (2005). DRIFT was the method of choice in the Olifants/Doring Reserve determination.

2. *Flow Stressor Response (FHSR):* FHSR is explained in detail in IWR Source-to-Sea (2004).
3. *Building Block Methodology* (BBM): BBM is explained in detail in King *et al*. (2000).

Table 8.1 Procedure for the provision of flow-ecological condition information at biophysical nodes

STEP	Task	Tool	Explanation
I	Check nodes for extrapolation potential	Extrapolation DSS	See Section 7.
II	EWRs for non-extrapolatable river nodes.	Desktop	Provide the cumulative EWRs for A/B-D category: • summary tables; • rule curves; and • modified time series
III	EWRs for extrapolatable river nodes.	Calibrate the Desktop using results from appropriate Comprehensive EWR site	
IV	Estuary.	Use results from appropriate Comprehensive Reserve Study	Provide for the EWR for A/B to D categories: 1. rule curves
V	Package data and provide to Hydrologist.	Windows Explorer	See Section 8.4

8.3.2 Desktop Model

The Desktop Model[31] is a rule-based model calibrated using trends emerging from the existing Comprehensive Reserve determinations (Hughes and Hannart, 2003). Hughes and Münster (1999) provide an indication of the relationship between recommended EWRs in South Africa (as a percentage of nMAR) relative to the condition in which the resource is expected to be maintained, *viz*. category A, B, C or D.

It is important to note, however, that in some cases the Desktop Model provides markedly different estimates of the Reserve requirements from determinations done using more Comprehensive methods. One reason for this is that while the Desktop Model is based on the results of past Comprehensive Reserve studies, it provides EWR information for rivers with Hydrological Index values up to 9.0, while most of those actually studied are in the region of 1.8 to 6.0. Thus the estimates for rivers with higher index values, i.e. > 6, have a low confidence. One of the areas where calibration data have been lacking until now is in the Olifants/Doring catchment. Thus, in the examples provided there may be cases where the EWR for the same category ‘jumps’ between one node and the next.

8.4 Output of Step 3b

Three major outputs emerge from Step 3b:

1. EWR rules curves for each category for each node.
2. EWR summary tables for each category for each node.
3. Modified time series for each category for each node.

[31] Refer to Hughes and Hannart (2003) for the details of the model and its use.

8.4.1 EWR rule curves

An example of the EWR rule curves provided to the hydrologist for the pre-yield screening model in Step 4 (Section 11.2) is provided in Table 8.2. The rule curves detail the EWR requirements as a flow duration curve, which represents the EWR portion of the natural flow regime.

Table 8.2 Example of the rule curve output from the Desktop Model

Summary of EWR rule curves for R41:
Total Runoff: Quaternaries E21G
Regional Type: W.Cape(dry)
EMC = B

Data are given in m^3 * 10^6 monthly flow volume

Month	% Points									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	1.598	1.583	1.547	1.472	1.336	1.127	0.862	0.600	0.407	0.324
Nov	0.710	0.703	0.688	0.655	0.595	0.503	0.387	0.272	0.188	0.151
Dec	0.151	0.149	0.146	0.139	0.126	0.107	0.083	0.058	0.040	0.033
Jan	0.018	0.018	0.018	0.017	0.015	0.013	0.010	0.008	0.005	0.005
Feb	0.013	0.013	0.013	0.012	0.011	0.010	0.008	0.006	0.004	0.004
Mar	0.011	0.011	0.011	0.011	0.010	0.008	0.007	0.005	0.004	0.000
Apr	0.033	0.033	0.032	0.031	0.028	0.024	0.018	0.013	0.009	0.008
May	0.292	0.289	0.282	0.267	0.241	0.200	0.149	0.098	0.061	0.020
Jun	0.898	0.889	0.868	0.824	0.744	0.620	0.464	0.309	0.196	0.147
Jul	1.462	1.348	1.244	1.133	0.945	0.794	0.604	0.414	0.275	0.215
Aug	3.398	3.046	2.742	2.446	1.955	1.637	1.235	0.835	0.543	0.416
Sep	2.106	1.986	1.868	1.726	1.485	1.251	0.955	0.660	0.445	0.352
Natural Duration curves										
Oct	5.500	4.630	4.100	3.440	3.180	2.870	2.630	2.210	1.880	1.120
Nov	3.010	2.300	1.950	1.680	1.510	1.340	1.280	1.110	0.840	0.680
Dec	1.250	0.850	0.670	0.570	0.470	0.430	0.410	0.370	0.260	0.180
Jan	0.420	0.270	0.190	0.150	0.130	0.110	0.090	0.080	0.070	0.030
Feb	0.420	0.150	0.100	0.070	0.050	0.040	0.020	0.020	0.010	0.010
Mar	0.330	0.240	0.130	0.110	0.050	0.030	0.030	0.020	0.010	0.000
Apr	0.970	0.490	0.370	0.210	0.150	0.120	0.100	0.060	0.030	0.010
May	5.640	1.750	1.370	0.930	0.730	0.520	0.310	0.260	0.140	0.020
Jun	11.320	5.150	3.990	3.390	2.760	2.110	1.530	0.880	0.530	0.240
Jul	13.350	7.290	5.820	4.980	4.490	4.040	2.720	1.870	1.090	0.430
Aug	13.780	8.800	8.220	6.600	5.470	4.640	3.860	3.040	2.050	0.870
Sep	10.970	7.520	6.570	5.320	4.960	4.310	3.570	3.180	2.300	1.390

8.4.2 Modified time series

A time-series representing the actual flows that would result in the river if the rule file were applied to the natural hydrology is required.

8.5 Naming provision and folder structure for provision of flow-ecological condition information at biophysical nodes

The data generated in this Step 3b needs to be provided to the hydrologist responsible for the pre-yield screening modelling that forms part of Step 4 (see Section 11.2.1). The suggested naming conventions and folder structure for presentation of the flow-ecological data are presented below.

8.5.1 Naming convention

The files generated in this procedure need to be clearly named, as they will be used in several later procedures. The suggested naming convention is:

For cumulative EWRs at each node:

CA_B_D.x, where:

C = cumulative
A = node number, e.g. R13
B = relevant quaternary catchment, e.g. E10G
D = ecological category for which the EWR was determined
x = suffix denoting file type, *viz*. .tab = summary table, .rul = rule curve and .mrv = modified time series

Thus for Node R13, for a C category EWR, the files generated would be:

CR13_E10G_C.tab;
CR13_E10G_C.rul; and
CR13_E10G_C.mrv.

For incremental EWRs at each quaternary:

IncB_D.x, where:

Inc = incremental
B = relevant quaternary catchment, e.g. E10G.
D = ecological category for which the EWR was determined
x = suffix denoting file type, *viz*. .tab = summary table, .rul = rule curve and .mrv = modified time series.

Thus for E10G, for a B category EWR, the files generated would be:

IncE10G_B.tab;
IncE10G_B.rul; and
IncE10G_B.mrv.

8.5.2 Folders

Individual folders should be constructed for the cumulative and incremental information, but thereafter all the relevant files for each node/quaternary should be stored in one folder, i.e. all the cumulative files in one folder and all the incremental files in another.

8.6 Example: Olifants/Doring catchment

8.6.1 Rivers

EWRs were determined using either the Desktop Model or DRIFT for each of the nodes selected in the Olifants/Doring catchment. EWRs were provided for the range of ecological conditions required for the catchment configuration scenarios. The list of nodes and comments relevant to their EWR determinations, are provided in Table 8.3.

Table 8.3 Nodes for which EWRs were provided and comments relevant to their EWR determinations

Node	Quaternary	Method used	Comments[32]
E		COMPREHEN.	
R1	E31G	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.
R2	E31E	Desktop	
R3	E32E	Desktop	
R4	E32C	Desktop	
R5	E33B	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.
R7	E33H	Desktop	
R8	E33E	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.
R9	E33G	Desktop	
R11	E40C	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.
R12	E40B	Desktop	
R13	E10K	DRIFT	A >D category at this node cannot be attained without major rehabilitation and possibly removal of Bulshoek Barrage (Brown *et al*., 2005). A D category EWR was set for the site using data extrapolated from EWR Site 1 (i.e. R33). For the EWR category (PES), no EWR was set, and the river reach will receive whatever is left over after abstractions, or whatever needs to pass through the reach to supply a downstream site.
R14	E24M	DRIFT	Extrapolated from EWR Site 4.
R15	E24L	Desktop	
R16	E24K	DRIFT	Extrapolated from EWR Site 4.
R17	E40D	Desktop	
R19	E24J	DRIFT	Extrapolated from EWR Site 4.
R20	E24H	DRIFT	Extrapolated from EWR Site 4.
R21	E24D	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.
R22	E24G	Desktop	
R23	E10J	DRIFT	A D category EWR was set for the site using data extrapolated from EWR Site 1 (i.e. R33).
R24	E10H	DRIFT	Extrapolated from EWR Site 3.
R25	E24A	Desktop	
R26	E24B	Desktop	
R27	E23K	Desktop	
R28	E22G	DRIFT	Extrapolated from EWR Site 4.
R29	E23F	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.
R30	E23J	Desktop	
R31	E23F	Desktop	
R32	E23D	Desktop	
R33	E10F	DRIFT	EWRs were set for the site using data extrapolated from EWR Site 1 (situated in the reach represented by R33). The same volume was used for a C and D category as non-flow related impacts are driving the category down (see Brown *et al.,* 2006)
R34	E10G	DRIFT	Extrapolated from EWR Site 3.
R36	E22F	Desktop	Hydrological Index ≥ 6. Very low confidence Desktop assessment.

[32] Assumptions, exceptions, cautions.

Node	Quaternary	Method used	Comments[32]
R37	E21L	Desktop	
R38	E21J	DRIFT	Extrapolated from EWR Site 3.
R39	E21F	DRIFT	Extrapolated from EWR Site 3.
R40	E10D	DRIFT	EWRs were set for the site using data extrapolated from EWR Site 1 (i.e. R33). D category was calculated from EWR Site 1 data, assuming non-flow related impacts lower at R40 than at R33. This is probably a slight overestimate of the requirements for a D, but is sufficient for this test exercise.
R41	E21G	Desktop	
R42	E10C	DRIFT	Extrapolated from EWR Site 3.
R43	E21E	Desktop	
R44	E10B	DRIFT	Extrapolated from EWR Site 3.
R45	E21D	Desktop	For the EWR category (PES), no EWRs were set, and the river reaches will receive whatever is left over after abstractions, or whatever needs to pass through the reach to supply a downstream site.
R46	E21C	Desktop	
R47	E10A	Desktop	
R48	E21A	Desktop	For the EWR category (PES), no EWRs were set, and the river reaches will receive whatever is left over after abstractions, or whatever needs to pass through the reach to supply a downstream site.
R49	E21B	Desktop	
R50	E22D	Desktop	

8.6.2 Estuary

In the case of the Olifants Estuary Reserve determination study, the estuarine team considered seven flow scenarios, *viz*. natural, present-day and five possible future scenarios (Taljaard *et al.,* 2006). Three of these were selected to provide for a future B, C and D category for the estuary. These three categories were used to provide the rule-curves for the estuary requirements for different catchment configurations in the hydrological model (see Table 8.4 for the B category).

Table 8.4 Rule-curve for the requirements for a B category in the Olifants estuary (Values in 10^6 m^3)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	48.13	32.08	21.5	37.21	24.46	7.77	96.73	194.2	550.92	472.06	230.02	153.7
90%ile	28.9	9.6	7.24	3.64	3.76	3.85	9.62	80.9	151.71	159.08	126.25	65.58
80%ile	16.05	4.3	2.06	1.75	1.68	2.21	4.85	22.01	93.83	104.19	79.44	48.08
70%ile	12.84	2.93	1.68	1.55	1.38	1.81	3.07	11.18	57.99	78.1	66.22	34.22
60%ile	11.49	2.93	1.51	1.51	1.37	1.46	2.88	8.24	42.45	58.26	50.45	25.66
50%ile	10.11	2.93	1.5	1.51	1.34	1.42	2.84	6.19	37.99	51.82	47.54	22.18
40%ile	9.01	2.49	1.5	1.51	1.34	1.42	2.49	3.57	36.22	39.92	44.77	16.34
30%ile	8.32	1.51	1.5	1.51	1.34	1.42	1.76	3.42	24.2	30.79	33.23	14.73
20%ile	6.36	1.43	1.18	1.51	0.91	1.11	1.41	2.05	15.78	21.17	28.07	11.21
10%ile	4.02	0.83	0.58	0.99	0.85	1	1.28	1.15	7.44	9.49	17.41	9.66
1%ile	1.01	0.15	0	0.99	0.34	0	0.04	0.29	0.82	2.07	5.35	4.04

9 QUANTIFY THE CHANGES IN RELEVANT ECOSYSTEM COMPONENTS, FUNCTIONS AND ATTRIBUTES FOR EACH ECOLOGICAL CATEGORY FOR EACH NODE (STEP 3C)

9.1 Types of Ecosystem Goods, Services and Attributes (EGSA) information required for the socio-economic component of the classification procedure

The types of EGSA information required for the socio-economic evaluations are indicated in Table 9.1.

9.1.1 Provision of required data

The required information can be divided into five broad groups, *viz*.:

1. Hydrological characteristics, which can be further divided into three groups:
    a. those for which system yield is required, and which will be determined using the Yield Model;
    b. those for which a percentage change in volume can be provided from the hydrological models/EWR results, e.g. water use; and
    c. those for which a combination of hydrology and hydraulics is required and which are unlikely to be provided for the WRCS in the near future.

2. Biological components and processes, which can be further divided into two groups:
    a. those for which an index of change in abundance (or a surrogate for abundance) from pre-development conditions can be derived from RDM studies, provided the information pertains to one of the sub-components of the ecosystems that was considered in the study; and
    b. those that require more detailed studies than are normally undertaken as part of a RDM study.

3. Physical components and processes, excluding water quality, that usually require more detailed studies than are normally undertaken as part of a RDM study.

4. Water quality characteristics for which a change in ‘fitness for use’ for a particular activity can be provided.

5. Structure and organisation of aquatic ecosystems, which can be further divided into two groups:
    a. those that are assumed to be related to ecological condition; and
    b. those for which the required information is not available.

Table 9.1 provides a summary for each of the ‘Output from RDM studies’, which indicates whether the required information can be provided.

9.1.2 Hydrological characteristics

This forms part of Yield Modelling, which falls outside of this project.

Table 9.1 Types of EGSA information required for the socio-economic component of the classification procedure

System	EGSA		Description of value	Aspects considered	Output from RDM studies
Whole system/IUA	Yield		Value derived from off-channel uses	MAR	EFR (Yield model calculated consequence of nMAR-EWRs).
River	Water use		Subsistence use of water	Water quality	Change in ‘fitness for use’.
				Dry season volumes	Dry season discharge for EWR.
	Food, medicines	Riparian vegetation	Subsistence or commercial use	Vegetables	Index of change in abundance (or a surrogate for abundance) from pre-development conditions.
				Medicinal plants	
				Grazing grasses	
				Browsing shrubs	
		Instream vegetation		Vegetables	
		Invertebrates		e.g. Crabs	
				Bait?	
		Fish		Indigenous	
				Alien	
	Raw materials (building/crafts)	Riparian vegetation	Subsistence or commercial use	Woody vegetation (firewood)	
				Large trees (building)	
				Reeds and sedges (building)	
				Reeds and sedges (crafts)	
		Sediments		Clay	
				Sand	
				Pebbles and cobbles	
	Gas regulation	Carbon sequestration	Riparian growth form	Percentage change in biomass	Not provided.
	Flow regulation	Flood attenuation	Costs of flood damage	Peak, duration and frequency of floods	
		Temporal variability	Temporal availability of water - implications for yield/assurance of supply	Temporal distribution of flows	
	Erosion control/sediment retention	Bank collapse	Loss agriculture land/hazard (livestock)	Likelihood of bank collapse	Not provided (Might be derived in some cases).
			Implication for real estate/vineyards		
			Loss of buffering/habitat/building material		
	Waste absorption	Assimilation	Treatment cost (savings); reduction in water use value (production costs; i.e. water use externality)	None	Not provided.
		Dilution		Waste Water Treatment Works	
				Other point-source effluents	Change in ‘fitness for use’.
				Non-point source	Not provided.
	Biological hazards	Macro floral	Economic costs incurred by plant invasions	Riparian	Index of change in abundance (or a surrogate for abundance)
				Aquatic	

System	EGSA		Description of value	Aspects considered	Output from RDM studies
				Algal blooms	from pre-development conditions/present-day.
		Macro faunal	Costs associated with human and livestock health affected by river related diseases	Disease hosts and vectors	
			Economic costs incurred by pest species	Pest species	
		Micro faunal	Costs associated with human and livestock health affected by river related diseases	Pathogens	Not provided.
	Importance for other systems	Sediment availability	Affects storage capacity (see dams)	Sediment transport capacity	Changes in potential sediment transport capacity from pre-development conditions /present day state.
			Sediment supply to marine ecosystem		
		Habitat for migratory species	Knock-on effects to EGSAs in linked ecosystems	Habitat availability and quality for migratory animals	Not provided.
		Export of nutrients		Nutrients transported to other ecosystems	
		Refugia		e.g. use of riparian corridor by terrestrial species	
	Direct attributes associated with structure and composition of biological communities	Tourism and recreation	Benefits accrued fishing	Fly-fishing	Index of change in abundance (or a surrogate for abundance) from natural/present day.
				Coarse fishing	
			Benefits accrued by river rafting/canoeing (including large sporting events)	Depth over typical riffles and rapids	Depth over typical riffle and rapids.
			Benefits accrued by other river use	Nature trails	Linked to ecological condition.
				Swimming	Pool depth and algal growth.
			Benefits accrued by scenic attractions	Geomorphic features	Discharge.
				Flora and fauna	Linked to ecological condition.
		Cultural, educational, spiritual and conservation values of ecosystems	Social costs of loss of spiritual or cultural attributes linked to river	Loss of spiritual or cultural attributes	Not provided.
			Societal costs of loss of biodiversity	Reduced species numbers	Linked to ecological condition.
			Educational opportunities	Loss of educational opportunities	Not provided.
			Research	Loss of unknown attributes that may provide valuable scientific information	Not provided.
		Genetic resources	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species		Not provided.

9.1.3 Biological components and processes

Biological components and processes that change in response to flow changes can, at best, be provided for the sites that the Extrapolation DSS (Step 3a – see Section 7) showed could be assessed using existing Comprehensive Reserve data (Section 8.3).

Thereafter, the ability to provide information will depend on whether the relevant components/processes were considered as part of the Reserve study. If they were not considered, then it is unlikely that sufficient data exist to allow an assessment of changes in response to flow.

Where biological components and/or processes were considered as part of the Reserve study, the method used to assess the extent to which it changes in response to the flow changes will depend on the Reserve methodology used in the Reserve study. In most instances, the specialists involved in the Reserve study should be asked to review the flow regimes associated with a catchment configuration and to predict how the biological components and/or processes would change in response to these. Methods are under development, however, to automate this aspect (e.g., Brown and Magoba, 2006). For instance, in the Olifants/Doring catchment, the DRIFT data provided by the specialists during the study were used to derive preliminary relationships between biological components and processes and different flow components. These were then used in a generic form (Brown, 2006) to provide the information in the example presented in Section 9.2. Caution should be applied as these relationships remain untested. Nonetheless, they provide an example of a possible way forward with regards to automating the provision of biological component and/or processes-flow information, i.e. not having to recall specialists.

9.1.4 Physical components and processes

Currently, a technique exists for determining the range of effective discharges necessary to maintain channel form and boundary conditions for EWRs for South African rivers (Dollar and Rowntree, 2003). The basis of the technique is that for a channel to be stable in the long-term, the amount of bed material entering a reach must equal the amount of bed material leaving the reach. Calculating the potential bed material load (PBML), and how this changes under different flow conditions (scenarios) is helpful in determining EWRs (especially for DRIFT). Computing PBML depends on the magnitude, frequency, duration and timing of flows (that determine the hydraulic conditions necessary for PBML), the bed material grain-size distribution, the type and spacing of the bed forms (form resistance), the effect of vegetation, antecedent conditions and supply.

Benda *et al.* (2002), however, make the point that sediment transport is difficult to predict accurately even though it may be done with precision. For example, hydrodynamic models that seek to predict changes in the physical dimensions of channels rely on sediment input information from contributing basins, an unresolved problem. In addition, all models are influenced by various degrees of uncertainty, assumptions and choice of model schematisation (van Vuren *et al*., 2002). Practically, it is therefore difficult to account for all these factors and hence, providing the required information on changes in physical components and processes with changing flows with a high degree of certainty without making a number of simplifying assumptions is unlikely at present. For this reason, changes in physical components and processes with changing flow conditions were not considered for the Olifants/Doring catchment. However, this should be added to the classification procedure as and when an appropriate method is devised.

9.1.5 Water quality characteristics

See Section 15.

9.1.6 Structure and organisation of biological communities

Many of the benefits derived from healthy aquatic ecosystems cannot be easily quantified. These include tourist attractions and a range of recreational activities, such as hiking, swimming and bird watching. Rather than ignore the benefits of these attributes, it will be assumed that such activities are linked in some way to the condition (or health) of the ecosystems,[33] with an A/B category representing 100% of value. It is acknowledged that this assumption is possibly more easily defended for the extremes of ecological condition, e.g. it is likely that a hiker would find an A category river more attractive than an E/F category river, and is arguably less defensible for the sometimes subtle changes between categories. Nonetheless, a direct relationship has been applied between ecological condition and the benefits derived from:

- floral and faunal scenic attractions; and
- biodiversity.

9.2 Example: Olifants/Doring catchment

9.2.1 EGSAs considered for the Olifants/Doring catchment

The EGSAs considered for the Olifants/Doring rivers are listed in Table 9.2.

Table 9.2 EGSAs considered for the Olifants/Doring rivers

EGSA		Description of value	Aspects considered
Water yield		Value derived from off-channel uses	MAR
Water use		Subsistence use of water	Change in 'fitness for use' (see Section 15)
			Dry season volumes
Waste absorption	Dilution	Treatment cost (savings); reduction in water use value (production costs), i.e. water use externality	Changes in WWTW
			Other point-source effluents
			Non-point source
Biological hazards	Macro floral	Economic costs incurred by plant invasions	Changes in abundance of riparian invader species (*Acacia* and *Eucalyptus* and *Oleander*)
		Algal blooms	Changes in risk of algal blooms
Direct attributes associated with structure and composition of biological communities	Tourism and recreation	Benefits accrued by fishing	Changes in abundance of *B. capensis* and *B. serra*
			Changes in abundance of *M. dolimieu*
		Benefits accrued by river rafting/canoeing (including large sporting events)	Not considered – but could use change in depth over rapids in the Doring River during rafting season
		Benefits accrued by scenic attractions	Changes in the visual appeal of: Nieuwoudtville waterfall Olifants River gorge Groot River gorge
			Flora and fauna – linked to category
		Societal costs of loss of biodiversity	Linked to category

The EGSAs considered for the Olifants/Doring estuary are listed in Table 9.3.

[33] See Table 10.1 for an explanation of ecological condition categories.

Table 9.3 EGSAs considered for the Olifants/Doring estuary

EGSA		Description of value	Aspects considered
Food, medicines	Fish	Subsistence or commercial use	Change in abundance of fish
Importance for other systems	Nursery areas		Change in suitability/accessibility of the estuary for in-shore fish
Direct attributes associated with structure and composition of biological communities	Fish	Benefits incurred by fishermen visiting the estuary	Change in abundance of fish
	Biodiversity	Societal costs of loss of biodiversity	Change in category (with consideration of EIS)

9.2.2 Results

9.2.2.1 Hydrological EGSAs

The changes in Dry Season Lowflows (DSLF) relative to pre-development conditions for use in determining water use in conjunction with potability are provided in Table 9.4.

Table 9.4 Percent remaining of DSLF relative to pre-development conditions for use in determining water use

Node used	Other nodes	% remaining of natural DSLF			
		A/B	B	C	D
R19[34]	R14, R16, R20, R28	0%	40%	40%	1%
R25	R1, R2, R3, R4, R5, R8, R11, R12, R17, R21, R22, R26, R27, R29, R30, R31, R32, R36, R50	0%			
R33	R7, R9, R13, R23, R40	0%			
R34	R24, R38, R39, R42, R44	0%	51%	39%	39%
R37	R15, R28, R41, R43, R45, R46, R48, R49	0%			

The changes in MAR relative to pre-development conditions for use in determining changes in river rafting potential and the scenic attractions are given in Table 9.5.

Table 9.5 Percent remaining of MAR relative to natural MAR

EGSA	Nodes	% remaining of natural MAR			
		A/B	B	C	D
Rafting	R14, R16	0	45%	18%	15%
Nieuwoudtville waterfall	No information available				
Olifants River gorge	R42	0	39%	22%	15%
Groot River gorge	R38	0	39%	22%	15%

9.2.2.2 Biological components and processes

Prototypes of GenericDRIFT databases were used to provide the changes in biological components and processes for the Olifants/Doring catchment using the data from the EWR sites established during the Olifants/Doring Reserve determination.

[34] These rivers are seasonal, and so the volume of water represented by the percentages given is low. The main difference between a B/C and D category is that the no-flow period is extended, so much as that for a D, the no flow period is effectively six months.

These combined data from:

EWR Sites 1 and 2:	representing much of the Olifants River main stem upstream of the confluence with the Doring River;
EWR Site 4 and 5:	representing much of the Doring River main stem downstream of the confluence with the Groot River; and
EWR Sites 3 and 6:	representing the Mountain Stream/Foothill reaches of the tributaries draining into the Olifants and Doring River from the Cedarberg Mountains.

An explanation of the procedures used to evaluating Biological EGSA changes in the Olifants/Doring catchment is provided in Section 9.2.2.2.

The results for the river at each node are provided in Table 9.6 and averaged for each IUA in Table 9.7. The results for the estuary are provided in Table 9.8.

Table 9.6 Changes in river biological components and processes considered in the Olifants/Doring Reserve determination relative to the hypothetical pre-development condition

IUA	Node code	EGSA	RELATIVE TO PRE-DEVELOPMENT CONDITIONS									
			Drift rating					Estimated percentage change				
Ecological condition			E/F	D	C	B	A/B	E/F	D	C	B	A/B
Doring Rangelands	R20	Large endemic fish	n/a	4.3	4.3	1.4	n/a	not assessed	20-39% retained	20-39% retained	80-100% retained	no change
		Alien vegetation	n/a	3.72	3.7	1.3	n/a	not assessed	250-500% gain	250-500% gain	1-25% gain	no change
		Algal blooms	n/a	0.5	0.5	0.4	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien fish	n/a	1.75	1.75	0.4	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
	R28	Large endemic fish	n/a	4.3	4.3	1.4	n/a	not assessed	20-39% gain	20-39% gain	80-100% retained	no change
		Alien vegetation	n/a	3.72	3.7	1.3	n/a	not assessed	250-500% gain	250-500% gain	1-25% gain	no change
		Algal blooms	n/a	0.5	0.5	0.4	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien fish	n/a	1.75	1.75	0.4	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
Knersvlakte	No data for EGSAs reported on in this table											
Kouebokkeveld	R38	Large endemic fish	n/a	3.53	3.42	0.33	n/a	not assessed	20-39 % retained	40-59% retained	no change	no change
		Alien vegetation	n/a	3.1	2.8	1.5	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	0	0	0	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	0.5	0.47	0.42	n/a	not assessed	1-25% gain	no change	no change	no change
	R39	Large endemic fish	n/a	3.53	3.42	0.33	n/a	not assessed	20-39 % retained	40-59% retained	no change	no change
		Alien vegetation	n/a	3.1	2.8	1.5	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	0	0	0	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	0.5	0.47	0.42	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
Lower Olifants Irrigation	No data for EGSAs reported on in this Table.											
OD Dryland Farming	R 13	Large endemic fish	n/a	3.25	3.25	1.75	n/a	not assessed	4-59% retained	4-59% retained	60-79% retained	no change
		Algal blooms	n/a	1.5	1.5	0	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
		Alien vegetation	n/a	2.6	2.6	2.2	n/a	not assessed	250-500% gain	250-500% gain	26-67% gain	no change
		Alien fish	n/a	1.87	1.87	1	n/a	not assessed	26-67% gain	26-67% gain	1-25% gain	no change
	R 14	Large endemic fish	n/a	4.3	4.3	1.4	n/a	not assessed	20-39% retained	20-39% retained	80-100% retained	no change
		Alien vegetation	n/a	3.72	3.7	1.3	n/a	not assessed	250-500% gain	250-500% gain	1-25% gain	no change
		Algal blooms	n/a	0.5	0.5	0.4	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien fish	n/a	1.75	1.75	0.4	n/a	not assessed	26-67% gain	26-67% gain	no change	no change

IUA	Node code	EGSA	RELATIVE TO PRE-DEVELOPMENT CONDITIONS									
			Drift rating					Estimated percentage change				
Ecological condition			E/F	D	C	B	A/B	E/F	D	C	B	A/B
	R 16	Large endemic fish	n/a	4.3	4.3	1.4	n/a	not assessed	20-39% retained	20-39% retained	80-100% retained	no change
		Alien vegetation	n/a	3.72	3.7	1.3	n/a	not assessed	250-500% gain	250-500% gain	1-25% gain	no change
		Algal blooms	n/a	0.5	0.5	0.4	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien fish	n/a	1.75	1.75	0.4	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
	R 19	Large endemic fish	n/a	4.3	4.3	1.4	n/a	not assessed	20-39% retained	20-39 % retained	80-100% retained	no change
		Alien vegetation	n/a	3.72	3.7	1.3	n/a	not assessed	250-500% gain	250-500% gain	1-25% gain	no change
		Algal blooms	n/a	0.5	0.5	0.4	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien fish	n/a	1.75	1.75	0.4	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
Upper Olifants Irrigation	R 23	Large endemic fish	n/a	3.25	3.25	1.75	n/a	not assessed	4-59% retained	4-59% retained	60-79% retained	no change
		Algal blooms	n/a	1.5	1.5	0	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
		Alien vegetation	n/a	2.6	2.6	2.2	n/a	not assessed	250-500% gain	250-500% gain	26-67% gain	no change
		Alien fish	n/a	1.87	1.87	1	n/a	not assessed	26-67% gain	26-67% gain	1-25% gain	no change
	R 24	Large endemic fish	n/a	3.53	3.42	0.33	n/a	not assessed	20-39 % retained	40-59% retained	no change	no change
		Alien vegetation	n/a	3.1	2.8	1.5	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	0	0	0	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	0.5	0.47	0.42	n/a	not assessed	1-25% gain	no change	no change	no change
	R 33	Large endemic fish	n/a	3.25	3.25	1.75	n/a	not assessed	4-59% retained	4-59% retained	60-79% retained	no change
		Algal blooms	n/a	1.5	1.5	0	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
		Alien vegetation	n/a	2.6	2.6	2.2	n/a	not assessed	250-500% gain	250-500% gain	26-67% gain	no change
		Alien fish	n/a	1.87	1.87	1	n/a	not assessed	26-67% gain	26-67% gain	1-25% gain	no change
	R 34	Large endemic fish	n/a	3.53	3.42	0.33	n/a	not assessed	20-39 % retained	40-59% retained	no change	no change
		Alien vegetation	n/a	3.1	2.8	1.5	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	0	0	0	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	0.5	0.47	0.42	n/a	not assessed	1-25% gain	no change	no change	no change
	R 40	Large endemic fish	n/a	3.25	3.25	1.75	n/a	not assessed	4-59% retained	4-59% retained	60-79% retained	no change
		Algal blooms	n/a	1.5	1.5	0	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
		Alien veg	n/a	2.6	2.6	2.2	n/a	not assessed	250-500% gain	250-500% gain	26-67% gain	no change
		Alien fish	n/a	1.87	1.87	1	n/a	not assessed	26-67% gain	26-67% gain	1-25% gain	no change
	R 42	Large endemic fish	n/a	3.53	3.42	0.33	n/a	not assessed	20-39 % retained	40-59% retained	no change	no change

IUA	Node code	EGSA	RELATIVE TO PRE-DEVELOPMENT CONDITIONS									
			Drift rating					Estimated percentage change				
Ecological condition			E/F	D	C	B	A/B	E/F	D	C	B	A/B
		Alien vegetation	n/a	3.1	2.8	1.5	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	0	0	0	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	0.5	0.47	0.42	n/a	not assessed	1-25% gain	no change	no change	no change
	R 44	Large endemic fish	n/a	3.53	3.42	0.33	n/a	not assessed	20-39 % retained	40-59% retained	no change	no change
		Alien vegetation	n/a	3.1	2.8	1.5	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	0	0	0	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	0.5	0.47	0.42	n/a	not assessed	1-25% gain	no change	no change	no change

Table 9.7 Average changes in river biological components and processes considered for each IUA in the Olifants/Doring Reserve determination relative to the hypothetical pre-development condition

IUA	Nodes	EGSA	RELATIVE TO PRE-DEVELOPMENT CONDITION									
			Drift rating					Estimated percentage change				
			E/F	D	C	B	A/B	E/F	D	C	B	A/B
Doring Rangelands	R20, R28	Large endemics	n/a	4.3	4.3	1.4	n/a	not assessed	20-39% gain	20-39% gain	80-100% retained	no change
		Alien vegetation	n/a	3.7	3.7	1.3	n/a	not assessed	250-500% gain	250-500% gain	1-25% gain	no change
		Algal blooms	n/a	0.5	0.5	0.4	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien fish	n/a	1.75	1.8	0.4	n/a	not assessed	26-67% gain	26-67% gain	no change	no change
Knersvlakte	No data for EGSAs reported on in this table											
Kouebokkeveld	R38, R39	Large endemics	n/a	3.72	3.7	1.3	n/a	not assessed	20-39% retained	40-59% retained	no change	no change
		Alien vegetation	n/a	0.5	0.5	0.4	n/a	not assessed	68-250% gain	68-250% gain	26-67% gain	no change
		Algal blooms	n/a	1.75	1.75	0.4	n/a	not assessed	no change	no change	no change	no change
		Alien fish	n/a	4.3	4.3	1.4	n/a	not assessed	1-25% gain	no change	no change	no change
Lower Olifants Irrigatic	No data for EGSAs reported on in this table											
OD Dryland Farming	R13, R14, R19	Large endemics	n/a	4.04	4.04	1.49	n/a	not assessed	20-39% retained	20-39% retained	80-100% retained	no change
		Algal blooms	n/a	0.75	0.75	0.3	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien vegetation	n/a	3.44	3.43	1.52	n/a	not assessed	250-500% gain	250-500% gain	26-67% gain	no change
		Alien fish	n/a	1.78	1.78	0.55	n/a	not assessed	26-67% gain	26-67% gain	1-25% gain	no change
Upper Olifants Irrigatic	R23, R24, R34, R40, R44	Large endemics	n/a	3.41	3.35	0.94	n/a	not assessed	40-59% retained	40-59% retained	80-100% retained	no change
		Algal blooms	n/a	0.64	0.64	0.00	n/a	not assessed	1-25% gain	1-25% gain	no change	no change
		Alien vegetation	n/a	2.89	2.71	1.80	n/a	not assessed	250-500% gain	250-500% gain	26-67% gain	no change
		Alien fish	n/a	1.17	1.16	0.65	n/a	not assessed	1-25% gain	1-25% gain	1-25% gain	no change

Table 9.8 Changes in estuary biological components and processes considered in the Olifants/Doring Reserve Determination relative to the hypothetical pre-development condition

IUA	Node code	EGSA	Estimated change in tonnes per annum			
			E/F	**D**	**C**	**B**
Ebenhaeser	E1	Estuarine Fish	Not assessed	86-99	102-116	93-107

9.2.2.3 Water quality EGSAs

Water quality EGSAs are dealt with separately in Section 15.

9.2.2.4 Direct attributes associated with structure and composition of biological communities

The estimated retained functioning and biodiversity relative to natural for each node for each of the catchment configurations is provided in Table 9.9. These estimates were averaged for each IUA and the results are provided in Table 9.10.

Table 9.9 Estimate of retained functioning and biodiversity relative to natural for each node for each of the catchment configurations

Node code	Quaternary catchment	Retained of natural functioning and biodiversity				
		PES	**REC**	**REC+Cons.**	**PES+Cons.**	**ESBC**
E		60-79%	80-90%	80-90%	80-90%	40-59%
R1	E31G	60-79%	60-79%	60-79%	60-79%	60-79%
R2	E31E	60-79%	60-79%	60-79%	60-79%	40-59%
R3	E32E	60-79%	60-79%	60-79%	60-79%	40-59%
R4	E32C	60-79%	60-79%	60-79%	60-79%	80-85%
R5	E33B	60-79%	60-79%	60-79%	60-79%	40-59%
R7	E33H	60-79%	40-59%	**90-100%**	**90-100%**	40-59%
R8	E33E	60-79%	60-79%	60-79%	60-79%	40-59%
R9	E33G	40-59%	40-59%	**90-100%**	**90-100%**	40-59%
R11	E40C	80-90%	80-90%	**90-100%**	**90-100%**	60-79%
R12	E40B	60-79%	60-79%	**90-100%**	**90-100%**	85-95%
R13	E10K	0-19%	40-59%	**90-100%**	**90-100%**	40-59%
R14	E24M	60-79%	80-90%	**90-100%**	**90-100%**	40-59%
R15	E24L	60-79%	80-90%	**90-100%**	**90-100%**	40-59%
R16	E24K	60-79%	80-90%	80-90%	60-79%	40-59%
R17	E40D	60-79%	80-90%	80-90%	60-79%	40-59%
R19	E24J	80-90%	80-90%	80-90%	80-90%	40-59%
R20	E24H	80-90%	80-90%	80-90%	80-90%	40-59%
R21	E24D	60-79%	60-79%	60-79%	60-79%	40-59%
R22	E24G	60-79%	60-79%	60-79%	60-79%	40-59%
R23	E10J	40-59%	40-59%	40-59%	40-59%	40-59%
R24	E10H	40-59%	40-59%	40-59%	40-59%	60-79%
R25	E24A	80-90%	80-90%	**90-100%**	**90-100%**	80-85%
R26	E24B	80-90%	80-90%	**90-100%**	**90-100%**	60-79%

Node code	Quaternary catchment	Retained of natural functioning and biodiversity				
		PES	REC	REC+Cons.	PES+Cons.	ESBC
R27	E23K	60-79%	60-79%	60-79%	60-79%	80-85%
R28	E22G	80-90%	80-90%	**90-100%**	**90-100%**	40-59%
R29	E23F	60-79%	60-79%	60-79%	60-79%	40-59%
R30	E23J	60-79%	60-79%	60-79%	60-79%	60-79%
R31	E23F	60-79%	60-79%	60-79%	60-79%	40-59%
R32	E23D	60-79%	60-79%	60-79%	60-79%	80-85%
R33	E10F	40-59%	40-59%	**90-100%**	**90-100%**	40-59%
R34	E10G	80-90%	80-90%	80-90%	80-90%	40-59%
R36	E22F	80-90%	80-90%	**90-100%**	**90-100%**	60-79%
R37	E21L	80-90%	80-90%	**90-100%**	**90-100%**	60-79%
R38	E21J	80-90%	80-90%	80-90%	80-90%	80-85%
R39	E21F	80-90%	80-90%	80-90%	80-90%	40-59%
R40	E10D	60-79%	60-79%	60-79%	60-79%	40-59%
R41	E21G	80-90%	80-90%	80-90%	80-90%	85-95%
R42	E10C	80-90%	80-90%	**90-100%**	**90-100%**	60-79%
R43	E21E	80-90%	80-90%	**90-100%**	**90-100%**	40-59%
R44	E10B	60-79%	80-90%	80-90%	60-79%	40-59%
R45	E21D	0-19%	40-59%	**90-100%**	**90-100%**	80-85%
R46	E21C	0-19%	40-59%	**90-100%**	**90-100%**	60-79%
R47	E10A	60-79%	80-90%	80-90%	60-79%	40-59%
R48	E21A	0-19%	40-59%	**90-100%**	**90-100%**	60-79%
R49	E21B	0-19%	40-59%	**90-100%**	**90-100%**	60-79%
R50	E22D	60-79%	60-79%	60-79%	60-79%	80-85%

Table 9.10 Estimate of retained functioning and biodiversity relative to natural for each IUA for each of the catchment configurations

IUA	Nodes	PES	REC	REC+Cons.	PES+Cons.	ESBC
Doring Rangelands	**R12, R20,** R21, R22, R27, R28, R29, R30, R31, R32, R36 R50	60-79%	60-79%	60-79%	60-79%	40-59%
Knersvlakte	R1, R2, R4, R5, **R8**	60-79%	60-79%	60-79%	60-79%	40-59%
Koue Bokkeveld	**R37**, R38, R39, R41, R43, R45, R46, R48, R49	40-59%	60-79%	60-79%	90-100%	40-59%
Lower Olifants Irrigation	**R7**, R9	60-79%	40-59%	90-100%	90-100%	40-59%
Olifants/Doring Dryland Farming	**R3**, R11, **R13**, **R14**, R15, R16, R17, R19, R25, **R26**	60-79%	80-90%	80-90%	80-90%	40-59%
Upper Olifants Irrigation	**R23**, R24, R33, R34, R40, R42, R44, R47	60-79%	60-79%	60-79%	60-79%	40-59%
Ebenezer	E1	60-79%	80-90%	80-90%	80-90%	40-59%

The hierarchical arrangement for consideration of ecological and socio-economic information at different scales opens up the opportunity for the evaluation (and optimisation) of various ecological category catchment configurations, which may deliver similar socio-economic summary values at the level of the IUA.

In order to provide EGSA information, a node must be suitable for extrapolation from sites with high-confidence Reserve data, and the EGSAs must have been considered during the Reserve determinations (Section 7.1). For the Olfants/Doring catchment, the nodes, within each IUA, which are suitable for extrapolation from sites with high-confidence Reserve data are given in Table 9.11. Effectively, no EGSA data will be available for two of the IUAs, namely Knersvlakte and Lower Olifants Irrigation.

Table 9.11 Nodes, within each IUA, which are suitable for extrapolations from sites with high-confidence Reserve data

IUA	Nodes at which EGSA information can be provided
Doring Rangelands	R20, R28
Knersvlakte	None
Koue Bokkeveld	R38, R39
Lower Olifants Irrigation	None
Olifants/Doring Dryland Farming	R13, R14, R16, R19
Upper Olifants Irrigation	R23, R24, R33, R34, R40, R42, R44
Ebenezer	E1

10 ADDITIONAL ECOLOGICAL MANAGEMENT INFORMATION

This sub-section deals with the provision of additional information to assist with the interpretation of the ecological condition and Reserve information provided in Sections 4, 7 and 9. The additional information also serves to inform future work required and in planning RDM interventions.

10.1 Non-flow related impacts

The ecological condition of aquatic resources is driven by many factors, only one of which is flow. In cases where non-flow related impacts are dominant, the chances of maintaining a desired ecological condition, without some attention to the non-flow related impacts is unlikely. Thus, where non-flow related impacts dominate, target ecological conditions should be accompanied by a flow regime (the Reserve) to maintain them AND a set of rehabilitation procedures aimed at addressing non-flow related impacts (see NWA, **S12**(**2**)(**b**)(**iii**)[35]). Even where flow-related impacts dominate, it is important to understand that ecological condition cannot be maintained in the face of escalating non-flow related impacts.

It is thus important to establish whether river condition is driven by flow- or non-flow related impacts. This can be done at a desktop level using the Habitat Integrity Assessment (HIA) (Kleynhans, 1996). In essence the HIA procedure involves the separate assessment of the instream habitat integrity and the riparian zone habitat integrity according to a number of key criteria (Table 10.1).

[35] In respect of each class of water resource, set out water uses for instream or land-based activities and which activities must be regulated or prohibited in order to protect the water resource.

Criteria used in the assessment of habitat integrity are separated into those that are flow-related and those that are non-flow related (Table 10.2). Individual scores rated for each of these criteria are summed and the ratio between flow- and non-flow related criteria are computed as a means of establishing whether river condition is determined largely by flow- or non-flow related impacts. The resulting ratio scores are interpreted as follows:

- where the ratio ≥ 1, the impacts are largely flow related; and
- where the ratio < 1, the impacts are largely non-flow related.

Criteria that are both flow- and non-flow related are excluded from the assessment. These include both bed modification and channel modification.

10.1.1 Example: Olifants/Doring catchment

This assessment should be undertaken for the entire catchment but, because individual scores of habitat integrity were only available for the Rondegat and the Olifants River within the Olifants/Doring catchment, the example was limited to the Upper Olifants Irrigation IUA, as illustrated in Figure 10.1.

Table 10.1 Criteria used in the assessment of habitat integrity (after Kleynhans, 1996)

CRITERION	RELEVANCE
Water abstraction	Direct impact on habitat type, abundance and size. Also implicated in flow, bed, channel and water quality characteristics. Riparian vegetation may be influenced by a decrease in the supply of water.
Flow modification	Consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow can have an impact on habitat attributes such as an increase in duration of low flow season, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.
Bed modification	Regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment (Gordon *et al.*, 2005). Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation is also included.
Channel modification	May be the result of a change in flow, which may alter channel characteristics causing a change in marginal instream and riparian habitat. Purposeful channel modification to improve drainage is also included.
Water quality modification	Originates from point and diffuse point sources. Measured directly or agricultural activities, human settlements and industrial activities may indicate the likelihood of modification. Aggravated by a decrease in the volume of water during low or no flow conditions.
Inundation	Destruction of riffle, rapid and riparian zone habitat. Obstruction to the movement of aquatic fauna and influences water quality and the movement of sediments (Gordon *et al*., 2005).
Exotic macrophytes	Alteration of habitat by obstruction of flow and may influence water quality. Dependent upon the species involved and scale of infestation.
Exotic aquatic fauna	The disturbance of the stream bottom during feeding may influence the water quality and increase turbidity. Dependent upon the species involved and their abundance.
Solid waste disposal	A direct anthropogenic impact, which may alter habitat structurally. Also a general indication of the misuse and mismanagement of the river.
Vegetation removal	Impairment of the buffer the vegetation forms to the movement of sediment and other catchment runoff products into the river (Gordon *et al*., 2005). Refers to physical removal for farming, firewood and overgrazing. Includes both exotic and indigenous vegetation.
Exotic vegetation encroachment	Excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Allochtonous organic matter input will also be changed. Riparian zone habitat diversity is also reduced.
Bank erosion	Decrease in bank stability will cause sedimentation and possible collapse of the riverbank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or exotic vegetation encroachment.

Table 10.2 Criteria used in the assessment of habitat integrity separated according to whether they are flow- or non-flow related

Flow-related criteria	Non-flow related criteria
Water abstraction	Water quality modifications
Flow modifications (floods and low flows)	Inundation
Exotic macrophytes	Exotic aquatic fauna
	Solid waste disposal
	Vegetation removal
	Exotic vegetation encroachment

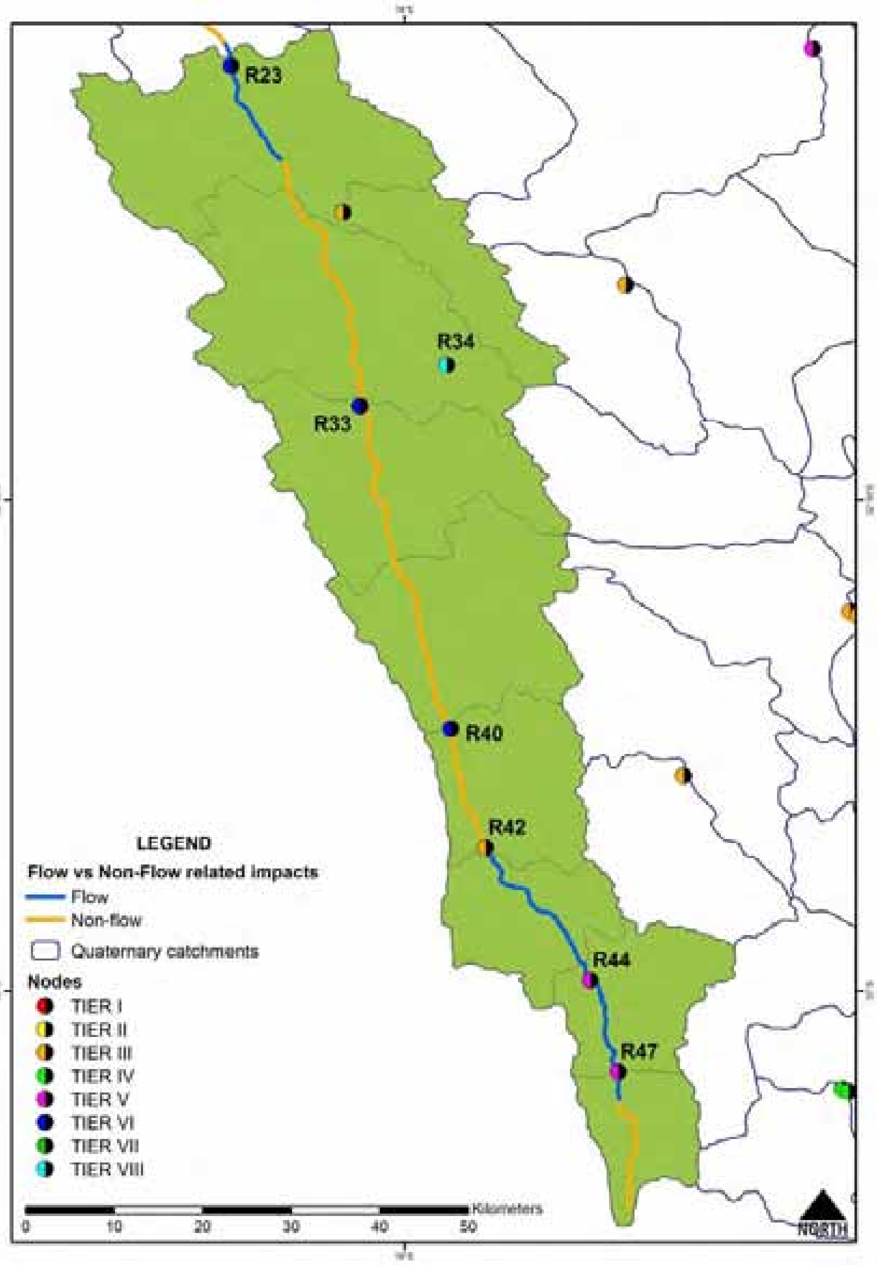

Figure 10.1 Upper Olifants Irrigation IUA showing river reaches that are driven by either flow- or non-flow related impacts

10.2 Recommended levels of confidence for Reserve determinations (after Louw *et al.*, 2006)

As discussed in Section 7, the location and characteristics of the nodes are used to assess whether existing (Intermediate and Comprehensive) EWR data can be extrapolated to them, failing which their EWRs for the WRCS will be determined using the Desktop Model.

In river reaches with a high Ecological Importance and Sensitivity (EIS), Present Ecological Status (PES) or level of use, however, use of a low confidence determination, such as the Desktop, is not appropriate. For this reason, an assessment of the recommended level of Reserve determination is required, as this will provide information as to the appropriateness of the level of confidence used for the WRCS[36].

The recommended level of confidence for a Reserve determination is estimated using a matrix table (Louw *et al.,* 2006). The X-axis is based on an importance value derived from a matrix that combines PES and EIS (Figure 10.3).

EIS \ PES	F-E	D	C	B-A
VH	3	3	4	4
H	2	2	3	4
M	1	1	2	3
L	1	1	2	3

Figure 10.2 Matrix used to determine a combined EIS and PES value on a scale of 1 to 4 (after Louw *et al*., 2006)

The Y-axis is based on an estimate of water resource stress based on water available versus existing demand. In Louw *et al*. (2006), the resource stress in a catchment is allocated a score of 1 to 4 based on the following:

5. 30% of water allocated.
6. 60% of water allocated.
7. 90% of water allocated.
8. >100% allocated.

This, however, may require some reworking as it did not adequately account for 'stress' in the Olifants/Doring catchment (Section 10.2.1.2), where consideration was required of the timing (as well as the overall volume) of abstractions.

[36] Such an assessment is actually a planning tool, and should be used to determine the appropriate levels of Reserve determination for country-wide proactive EWR determinations.

The resultant matrix (Figure 10.3) can then be used as a guide for a first estimate of the recommended level of confidence required for the EWR determination.[37] This recommendation only considers whether an area has high ecological importance and/or high stress and does not consider what data are available on which to base a Reserve determination. Paucity or lack of data may mean that an Intermediate or Comprehensive level of determination is not possible until an appropriate database has been established. Also, Louw *et al.* (2006) point out that these matrices have not been tested or calibrated.

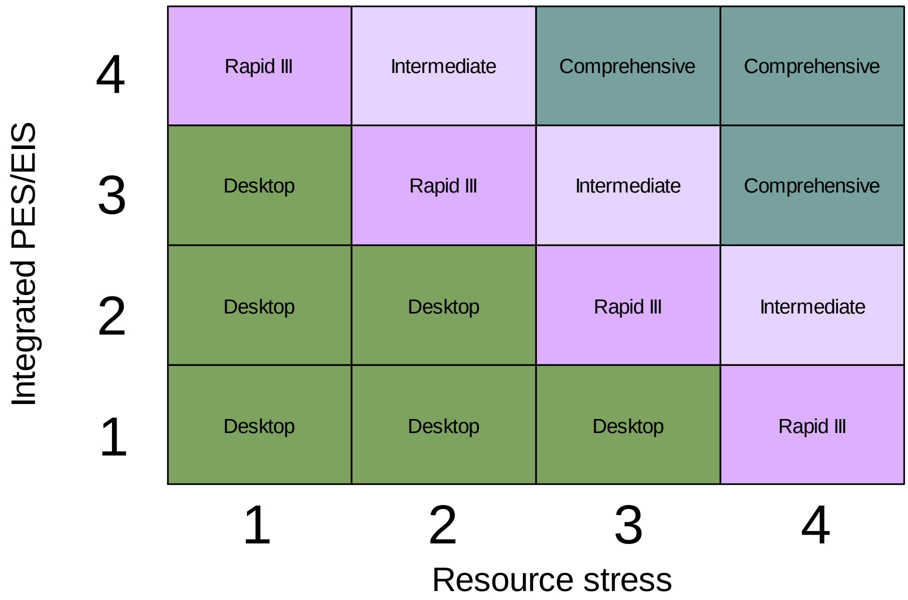

Figure 10.3 Matrix indicating the level of confidence required for the EWR determination (after Louw *et al*., 2006)

Using the matrix (Figure 10.3), areas with a 3 or 4 integrated PES/EIS score (Figure 10.3) and a 3 to 4 resource stress score will illicit a recommendation for an Intermediate or Comprehensive Reserve determination. Projected spatially, these will also provide the aquatic 'hot spots' for the main rivers in the quaternary catchments (see example of the Olifants/Doring catchment in Section 10.2.1).

10.2.1 Example: Olifants/Doring catchment

10.2.1.1 Integrated PES and EIS score

The information used for the derivation of the integrated PES and EIS score for the Olifants/Doring catchment was obtained from the desktop estimates of PES and EIS from the WSAM (Kleynhans, 2000). In the case of PES, more detailed information based on HIAs of the Olifants, Doring, Groot and Rondegat Rivers were available (Brown *et al.,* 2004). These data were used to update PES data from the national coverage.

Using the matrix in Figure 10.3, an integrated PES/EIS score between 1 and 4 was generated for each quaternary catchment for the Olifants/Doring catchment (Figure 10.4).

[37] In Louw *et al*. (2006) this is also used to determine the levels required for accompanying procedures such as Ecoclassification and monitoring. This is however not directly relevant to the WRCS.

10.2.1.2 Estimating Resource stress

Estimates of Resource stress were initially based on water use (i.e. irrigated crop requirements, population consumption, strategic bulk requirements and mining requirements) as a percentage of cumulative nMAR per quaternary catchment generated from the WSAM model. These estimates failed to highlight water stressed catchments, possibly because the highest demand for crop irrigation, which contributes substantially to water stress in the Olifants/Doring catchment, falls over the summer period (October to February). In essence, it is important to consider not only the overall volume, but the timing of water abstraction.

Water stress estimates per quaternary were therefore revised as follows:

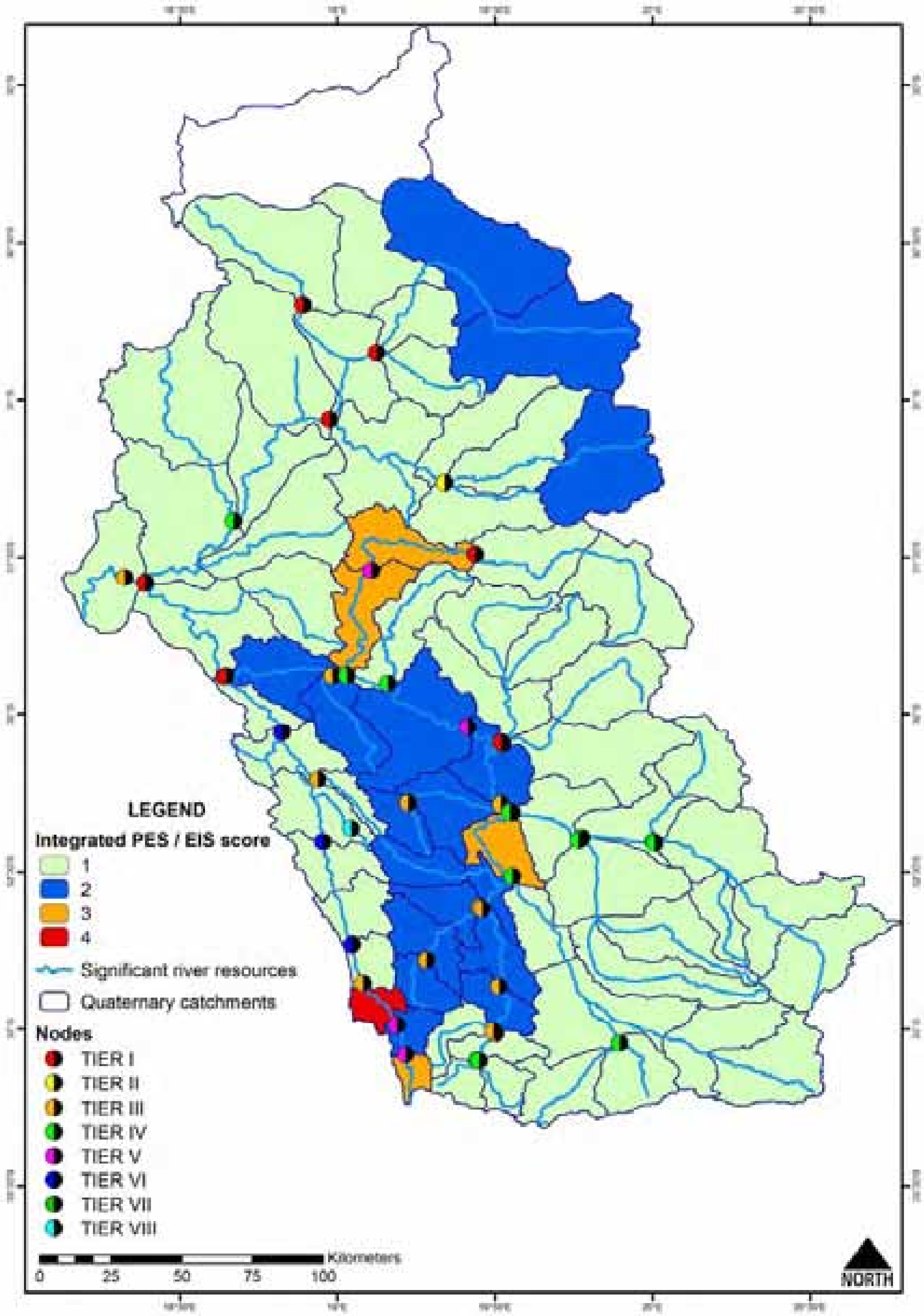

Figure 10.4 Integrated PES/EIS score per quaternary generated for the Olifants/Doring catchment

- the percentage nMAR distributed over the summer months (October to February) when crops are irrigated was calculated from WR90 data for 11 quaternary catchment, randomly distributed across the Olifants/Doring catchment (Table 10.3). These results suggested that, on average, 10% of the MAR is distributed over the summer months in the Olifants/Doring catchment;
- the cumulative nMAR distributed over the summer months (i.e. 10% of the total nMAR) was calculated for each quaternary catchment; and
- the irrigated crop requirements as a percentage of the nMAR over the summer months was calculated.

These calculations were used to develop a stress index of 1 to 4 where:

1. 0 to 30% of nMAR allocated.
2. 30 to 60% of nMAR allocated.
3. 60 to 100% of nMAR allocated.
4. >100% of nMAR allocated.

The stress indices for the Olifants/Doring catchment are shown in Figure 11.5.

Table 10.3 Percentage summer nMAR (distributed between October and February) for 11 randomly selected quaternary catchments in the Olifants/Doring catchment

Quaternary catchment	% MAR
E23J	9
E32B	9
E33G	8
E24K	7
E10G	6
E22F	21
E22D	19
E22B	13
E31H	13
E21H	10
E21L	10

The matrix illustrated in Figure 10.3 was used to recommend the level of confidence required for the EWR determination at a quaternary catchment level (Figure 10.6). This approach does not, however, take into consideration the quality of available data for undertaking EWR determinations. In particular, desktop hydrological data for quaternary catchments in the drier regions of the Olifants/Doring catchment (largely to the north e.g. the Knersvlakte and the south east e.g. the Doring Rangelands) have not been calibrated and thus the desktop may not adequately provide data for desktop level EWR determinations in these areas.

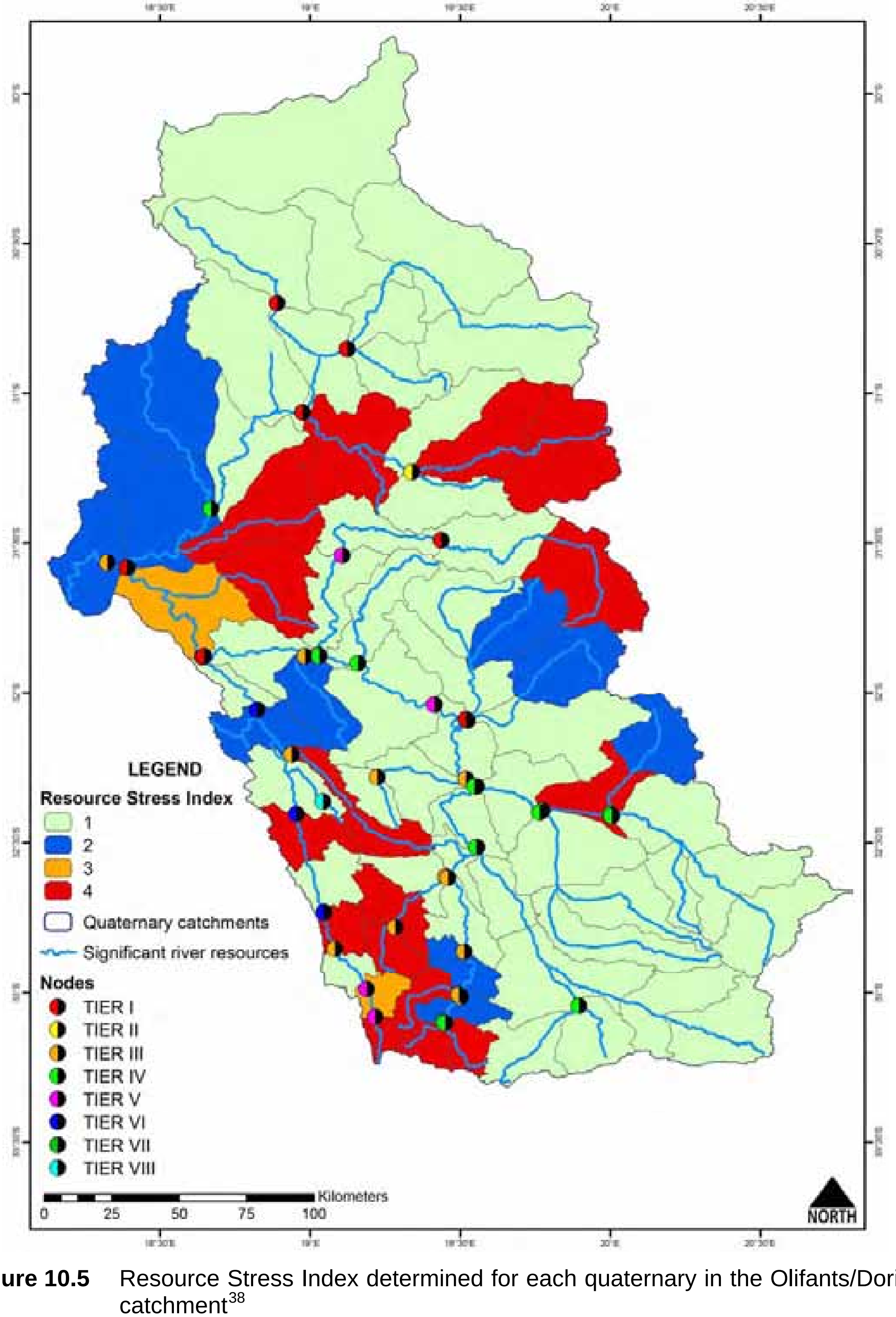

Figure 10.5 Resource Stress Index determined for each quaternary in the Olifants/Doring catchment[38]

[38] See comments in Section 10.2.2 regarding concerns about the methodology under development.

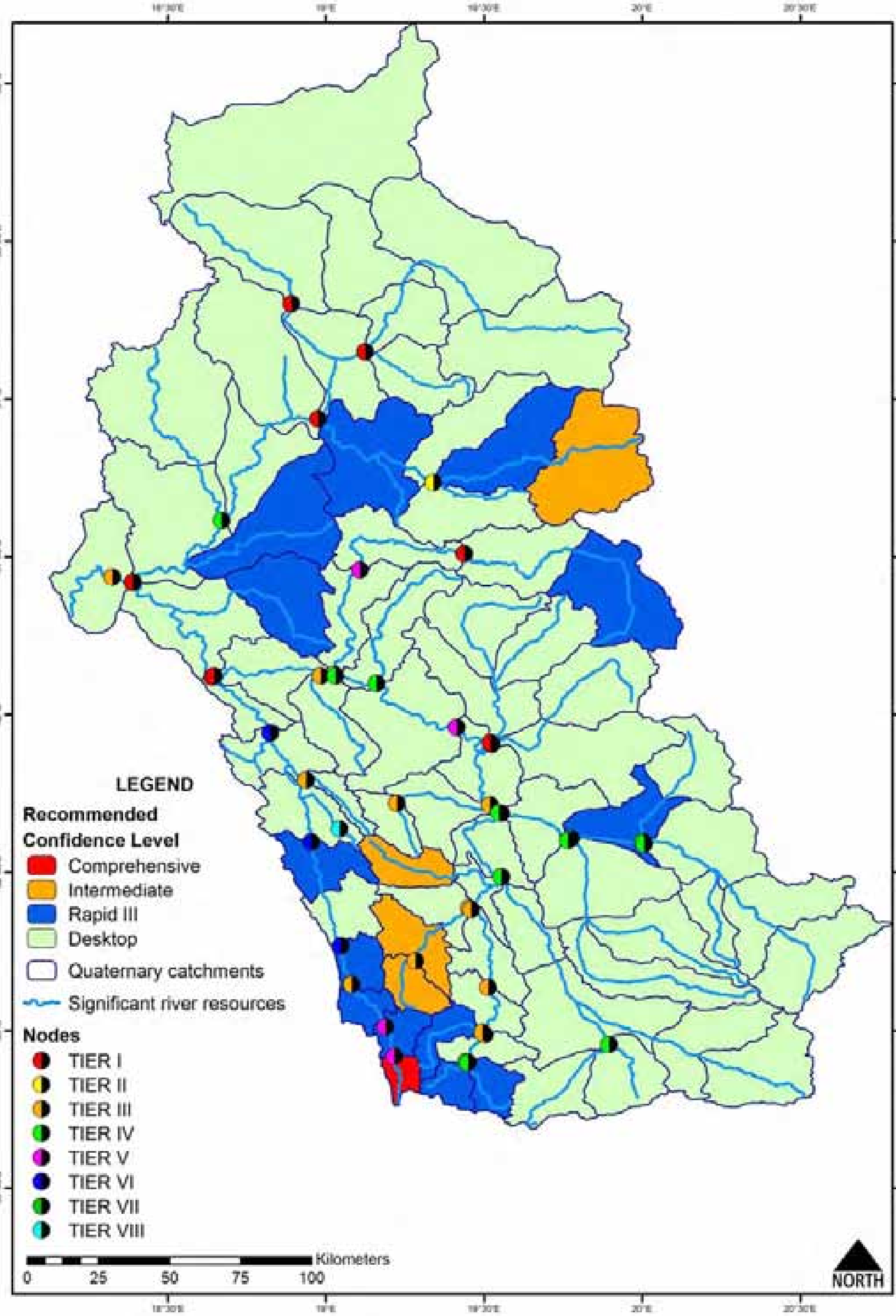

Figure 10.6 Recommended level of confidence required for the EWR determination per quaternary in the Olifants/Doring catchment

10.2.2 Comments on the method

Further development of this method should take cognisance of the following concerns and suggestions:

- a rationale is required for the integrated PES/EIS. As it stands at present, it is a subjective decision;
- proactive Comprehensive or Intermediate determinations of areas of high PES or high EIS should be undertaken as a priority to assist with planning and protection of those areas;
- despite altering the 'water stress' procedure, the results obtained for the Olifants/Doring catchment were at best conservative and at worst potentially damaging. Thus, while it is acknowledged the tool is useful, it needs to be thoroughly tested before being utilised; and
- Comprehensive Reserve determinations are required for the areas of the country for which there are currently no calibration data for the Desktop Model. For instance rivers with HydI > 6 (Figure 10.7).

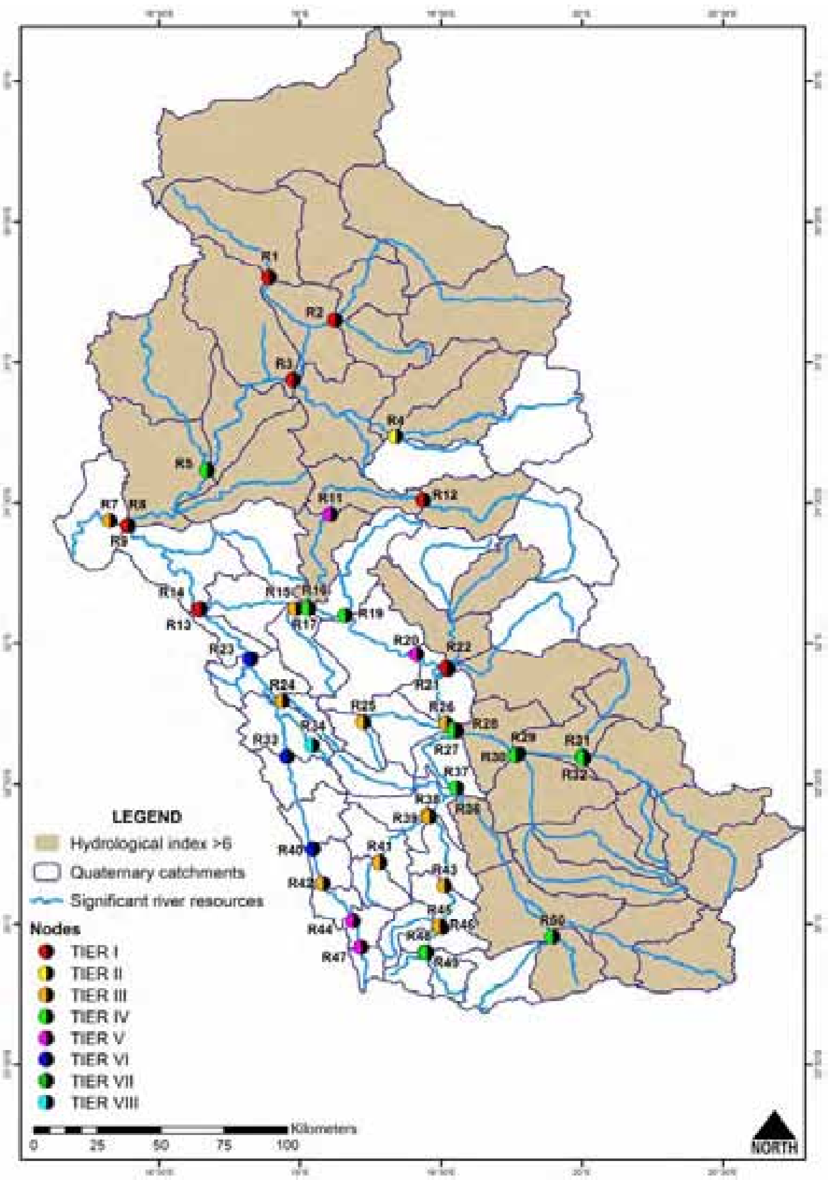

Figure 10.7 The Olifants/Doring catchment showing quaternary catchments where the Hydrological Index is ≥ 6

11 DETERMINE THE ECOLOGICAL SUSTAINABILITY BASE CONFIGURARTION SCENARIO (ESBC) THAT MEETS FEASIBILITY CRITERIA FOR WATER QUANTITY, QUALITY AND ECOLOGICAL NEEDS (STEP 4A)

11.1 Introduction

In Step 1 (Section 3), a procedure was described to define a network of significant resources and to establish a suite of biophysical and allocation nodes (Section 4.2.2). In the case of the Olifants/Doring catchment, this resulted in the delineation of 47 biophysical nodes. The nodes represent modelling points that will provide information to allow for meaningful trade-offs between different parts of the catchment in terms of the quantity (volume and distribution) and quality of water available for off-stream use, and the quantity (volume and distribution) and quality of water that remains in the resource.

Given the potential number of nodes in a catchment (e.g. 47 in the Olifants/Doring catchment), and the number of potential category configurations for each node (minimum of 4), it is evident that there will be numerous possible category catchment configurations for a target catchment during the Classification Procedure. This introduces significant complexity, given the sheer number of possible catchment configuration permutations.[39] Thus, a feasible number of representative scenarios will need to be selected for evaluation. The initial set of scenarios should be informed by ELU, future use, equity, RDM and sustainability considerations. Of these, the first three sets of scenarios are prescriptive in terms of the yield required from the system (termed planning scenarios), and the last two require a reactive response on the part of water users (termed the RDM catchment configuration scenarios and ESBC scenarios.

This sub-section deals with the procedure(s) recommended for determining the ESBC scenario) (Step 4a). Section 12 deals with the procedure(s) recommended for incorporating planning scenarios (Step 4b), while Section 13 deals with the procedure(s) for determining the RDM catchment configuration scenarios (Step 4c).

11.2 Procedure for setting the ESBC scenario and for screening the water quality feasibility (Step 4a)

11.2.1 Hydrological procedure using a pre-yield screening model

The legal requirement of an ecologically sustainable base is provided for by the Constitution, NWA and DWAF policy.[40] The NWA stipulates that a resource should be managed to ensure its protection for use. Furthermore, RDM policy states that this minimum level of health should be at least a D category condition (DWAF, 1999), or a Class III for water quality (DWAF, 1999), leading to an overall management class (MC) of 'Heavily utilised'.

In the classification procedure, provision is made for determining this minimum level of health – the ESBC. For the purposes of this report, the ESBC scenario is defined at the *lowest theoretical level of protection required for the sustainable use of the entire catchment*. It is not a target scenario but should rather inform the lowest level of protection forming part of any of the other configuration scenarios.[41] The establishment of an ESBC scenario requires utilising the links established between flow and resource condition (see Section 11.2) to predict the condition of resources (including the estuary) in a catchment by moving

[39] In the Olifants/Doring catchment, the number of possible permutations is in the region of 2^{29}.

[40] The assignment of a D category as ecologically sustainable is a *management* decision, not a decision based on scientific data.

[41] One possible exception to this is the PES – which at times is in an E/F category and where it may be illustrative to provide a configuration that retains these (lower than sustainable) classes.

sequentially upstream/downstream (and up gradient for groundwater) using a D category as the starting point at each node. This requires starting at the downstream[42] end of a catchment, and working upstream in segments (defined by nodes), at each stage determining (Figure 11.1):

a. the water quantity, distribution and quality requirements to maintain the downstream reaches in their minimum sustainable condition;
b. the ecosystem functions supporting the base condition (i.e. minimum sustainable condition) of the downstream/down gradient reaches; and
c. the water quantity, distribution and quality requirements to support the ecosystem functions identified in b.

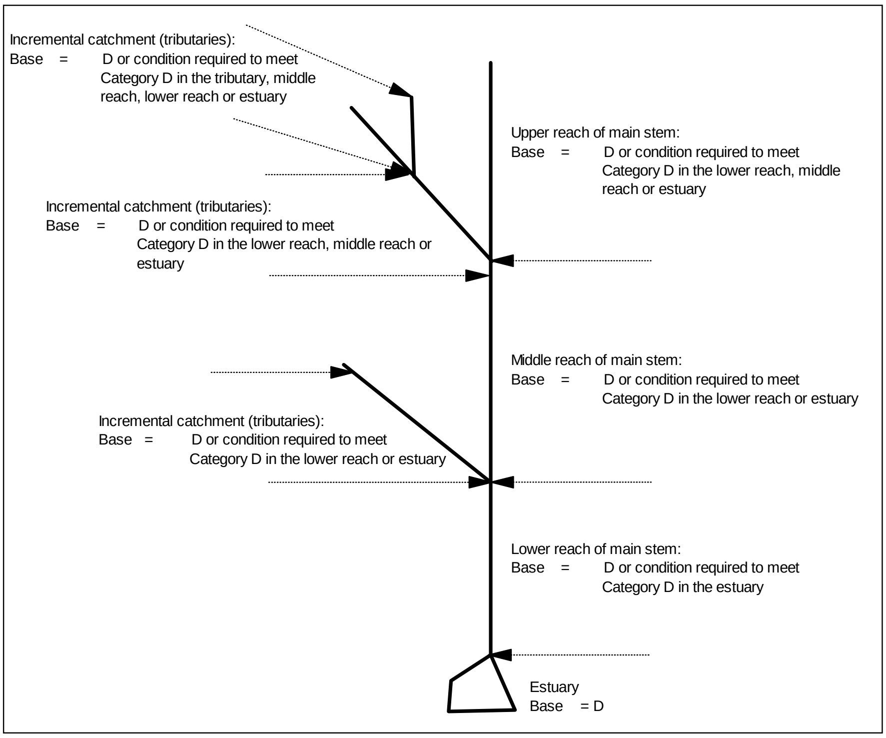

Figure 11.1 Schematic illustrating a downstream dependence on upstream condition on a simplified river system

The base condition for each resource is then established as a D category, or whatever category is required to maintain the downstream reaches in a D category. This requires, for example, the lower main stem to be maintained in at least a D category (DWAF, 1999) (Figure 11.1). However, a higher than D category could result if:

- the Reserve required to maintain a downstream node in a D category would result in a better-than-D-category condition at the upstream site, or;
- ecosystem functions supporting the D category in the estuary, such as spawning or feeding grounds for anadromous fish, require a better-than-D-category condition in the lower main stem.

It is instructive to note that if the goal is sustainable utilisation based on RDM lower limits for riverine and estuarine condition, then the options for trade-offs in the resources higher in the catchment will be constrained by the need to support a D category or higher in that resource

[42] For a given catchment, the downstream end would be the point at which the river flows into the sea, at the estuary or river mouth.

and the downstream resources. In the hypothetical example given in Figure 11.1, this could mean that the estuary and the lower and middle resources would have a base condition of a D category, but that one or more of the tributaries would need to be managed for a better-than-D category condition to ensure the essential support functions are maintained (such as provision of seeds, transfer of sediment, invertebrate larvae, or breeding opportunities for migratory fish).

Note:	Such an approach is only possible if there is a calibrated hydrological and water quality model available for the catchment, e.g. the pre-yield screening model (Section 11.3). In the absence of such, however, some coarse-level cross-checks are possible based on the nMAR requested by the EWRs (it is these that were used in the example).

Similarly, the base conditions for wetlands will be a D category, with their concomitant water requirements (quantity and quality) a D category, or whatever condition is required to maintain linked systems in a D category. Examples of linked systems include rivers (particularly in the case of floodplains, other riparian wetlands and/or high altitude seeps), other wetlands or aquifers. It should be noted that for groundwater to contribute to most surface systems (rivers, wetlands and estuaries) an aquifer should be in a fairly pristine condition, particularly close to the discharge area. This means that while a base condition of a D category may be defined for groundwater dependent wetland, the required functioning of the aquifer supporting it would be closer to an A or B category condition.

11.3 The need for a pre-yield screening model

Many of the procedures described in the document presuppose the availability of a pre-yield screening model set up for a target catchment. A prototype of this model (called '*Reserve Validation*' model) is provided in Appendix D. Its purpose is to route time series of Reserve estimates through the sub-areas of a catchment and to check whether upstream requirements (at the upstream end of a specific sub-area), combined with incremental requirements (within the sub-area) will satisfy the downstream requirements (at the outlet of the sub-area). This model should have similar functionality to the Yield Model, but should be less onerous to set-up and operate. The model should incorporate (at least) the following features:

- provide time series at nodes using a monthly time step;
- be able to deal with complex operating rules such as:
  - curtailment rules;
  - apply to any user;
  - account for supply from up sources for any month as a function of the water level in a reservoir or the flow in any channel in the system;
- use WR90 as default data, but be able to accommodate additional time series;
- allow for a wide variety of users, including ecological use;
- modelled on a user-defined priority basis; and
- allow water quality modelling of non-decaying compounds.

The water quantity component of the pre-yield screening model should be used to help establish the ESBC. This will require predicting changes in salinity for different catchment configuration scenarios. Where a more specialised water quality model is available, particularly one that can deal with decaying compounds, this should be use in conjunction with the pre-yield screening model.

The procedure for establishing the ESBC scenario is outlined in Table 11.1.

11.3.1 Ecological feasibility

The ecosystem functions supporting the downstream portions of the catchment, such as

Table 11.1 Procedure for establishment of the ESBC scenario

Procedure			
STEP	Task	Data	Explanation
I	Calculate the *cumulative* EWRs (A/B to D) for all the nodes	See Section 8.	EWRs are required for the full suite of ecological categories in order to facilitate comparisons of the implications of different ecological conditions.
II	Calculate the EWRs (A/B to D) for all the *incremental* quaternary catchments	See Section 8.	EWRs are required for the full suite of ecological categories for the incremental catchments in order to facilitate comparisons of the implications of different ecological conditions.
III	Calculate incremental evaporative losses for each quaternary	Length of main channel river reach. Average channel width. Evaporation rate (can be sourced from WR90).	In the absence of *in situ* evaporation data, evaporation was calculated based on river length, average width and regional evaporation rates.
IV	Assign all nodes a D category	Node coverage and overlay of significant river resources.	As per the sustainability requirement of the NWA and DWAF policy, all nodes (and significant resources) are initially set at a D category.
V	Test hydrological feasibility	Run 'hydrological model' using the D category EWRs (water quality and quantity) as the 'hydrology', to test whether EWRs (for a D category) for all nodes can be met.	If the EWR at a node is not met, increase the category of the upstream nodes (e.g. increase category starting at the downstream end of the catchment, working upstream in segments) until EWRs for all nodes are met, and/or, increasing the ESBC ecological category for an upstream node(s), thereby increasing the cumulative EWR, or increase the ESBC ecological category for the tributaries in a quaternary catchment, thereby increasing the incremental EWR.
VI	Ecological evaluation	Catchment conservation plan, which highlights aquatic ecosystems selected as ecological corridors. Specialist information on faunal and floral source areas and refuges.	Evaluate hydrologically-adjusted configuration and adjust categories upwards (if appropriate) to account for: • sources areas; • refuges; and • corridors. Some nodes may require a better condition to maintain nodes in a D category downstream.

spawning or feeding grounds for anadromous fish, should also be taken into consideration for the EBSC in order to establish whether upstream reaches require a better-than-D-category condition to support a downstream reach.

There is as yet no structured process for the consideration of these ecological aspects. This has not been done for the Olifants/Doring catchment. It is likely that such consideration will form part of the process for determining Freshwater Conservation targets.

11.3.2 Water quality feasibility

The water quality considerations for supporting the downstream portions of the catchment, should also be taken into consideration for the EBSC in order to establish whether upstream reaches require a better-than-D-category condition to support a downstream reach.

Unfortunately, there is as yet no structured process for the consideration of these and this has not been done for the Olifants/Doring catchment.

11.3.3 Example: Olifants/Doring catchment

The following is a worked example of the procedure for establishing the ESBC scenario for the Olifants/Doring catchment. There are 46 (50 minus R6, R10, R18 and R35, all of which are nested in the quaternary catchment represented by other nodes; see Section 4.3) river nodes (each defining the downstream end of a river reach) and one estuary node for the Olifants/Doring catchment.

11.3.3.1 Establishment of the ESBC configuration scenario

A hydrological model was not available for use in the Olifants/Doring catchment. This meant that the testing and adjusting of the ESBC configuration scenario was done on an Excel spreadsheet using the nMAR for the EWRs.

Testing of the ESBC configuration scenario should be done at the level of the whole catchment. However, to facilitate easier explanation, the example given in Figure 13.2 to Figure 13.5 is for one IUA, the Upper Olifants Irrigation Area.

In Table 11.2 the following is provided:

- PES for each node;
- ‘starting’ ecological category for each node, in this case a D category;
- cumulative annual volume of water associated with the EWR for a D category at each node;
- starting ecological category for the tributaries in each quaternary, in this case a D category;
- incremental annual volume of water associated with the EWR for a D category at each quaternary;
- evaporative losses[43] for each quaternary;
- actual annual volume of water expected at a node/quaternary boundary, which is equivalent to:
    - cumulative annual volume of water associated with the EWR for a D category at each node, plus;
    - incremental annual volume of water associated with the EWR for a D category at each quaternary, minus;
    - evaporative losses for each quaternary.

[43] And other natural losses, where applicable.

- the balance required to meet the cumulative EWR requirements at a node/quaternary boundary, i.e. negative number = deficit.

In the example provided in Table 11.2, deficits were recorded at nodes R44, R42, R40, R33 and R23. A large surplus was also recorded at R13. This surplus was not considered further here as an EWR was not stipulated for R13 (as it is currently in an E/F category, with little opportunity for improving that to a D category using flow (Brown *et al*., 2005)) and the surplus represents the amount of water available to meet downstream EWRs. In this case, it would probably be needed for the estuarine EWR. The deficits can be reduced by:

- increasing the ESBC ecological category for an upstream node(s), thereby increasing the cumulative EWR, or:
- increasing the ESBC ecological category for the tributaries in a quaternary catchment, thereby increasing the incremental EWR.

Clearly these adjustments cannot be made without knowledge of the catchment and consideration of the various constraints to adjustment of ecological condition, including but not necessary limited to, non-flow related impacts. The following information can assist in the deliberations:

- PES;
- Freshwater Conservation targets.

For instance, where an increase in ESBC ecological condition is required, selection of the nodes or tributaries that require adjustment could be guided by the PES. In this regard, it would make more sense to increase the ESBC ecological category where PES is in a C or B category, rather than where PES is in a D category. Similarly, nodes or tributaries targeted for conservation should receive preference when the ESBC ecological category is raised.

Table 11.2 ESBC starting point – all nodes and incremental catchments in D category. Values in $10^6 m^3$

Quat. Cat.	Node	PES (main channel)	EcoCat. (main channel)	EWR (main channel cum.)	Inc. category	Inc. EWR	Evap.	Actual flow	Balance
E10A	R47	C	D	11.55	D	11.55		11.55	0
E10B	R44	C	D	26.6	D	12.948		24.498	-2.102
E10C	R42	B	D	33.93	D	8		32.498	-1.432
E10D	R40	C	D	43.185	D	9.1		41.598	-1.587
E10E		D	D		D	9.7			
E10F	R33	D	D	71.649	D	9.7		60.998	-10.651
E10G		E/F	D		D	12.7	-0.		
E10H	R24	D	D	7.938	D	5.98	-1.	7.938	
E10J	R23	D	D	88.9	D	6	-0.	87.636	-1.264
E10K	R13	E/F	D		D	5.7	-1.	93.336	93.336

In Table 11.3, a combination of these options was used, namely:

- the ESBC ecological condition of node R42 was improved from a D category to a C category, and in so doing the EWR for that node was increased from to 33.93 to 41.6 million cubic metres (MCM); and
- the ESBC ecological conditions of the tributaries in quaternary catchments E10B, E10C and E10F were improved from a D category to a C category, and in so doing

the EWRs for those quaternary catchments were raised from 12.95 to 15.97, 8 to 11.457, and 9.7 to 12.07 MCM, respectively.

The adjustments eliminated the deficits for R44 and R40 and reduced the other deficits. Thus, additional adjustments were necessary (Table 11.3). To eliminate the remaining deficits in Table 11.3, the following adjustments were made (Table 11.4):

- the ESBC ecological condition of the tributaries in quaternary catchment E10C was improved from a C category to a B category, increasing the EWR from 11.457 to 15.108 MCM; and
- the ESBC ecological condition of the tributaries in quaternary catchment E10H was improved from a D to a C category, increasing the EWR from 4.58 to 7.9 MCM.

These adjustments eliminated all deficits, and thus represent the end point for the ESBC category. The resultant ESBC for the Olifants/Doring catchment is illustrated in

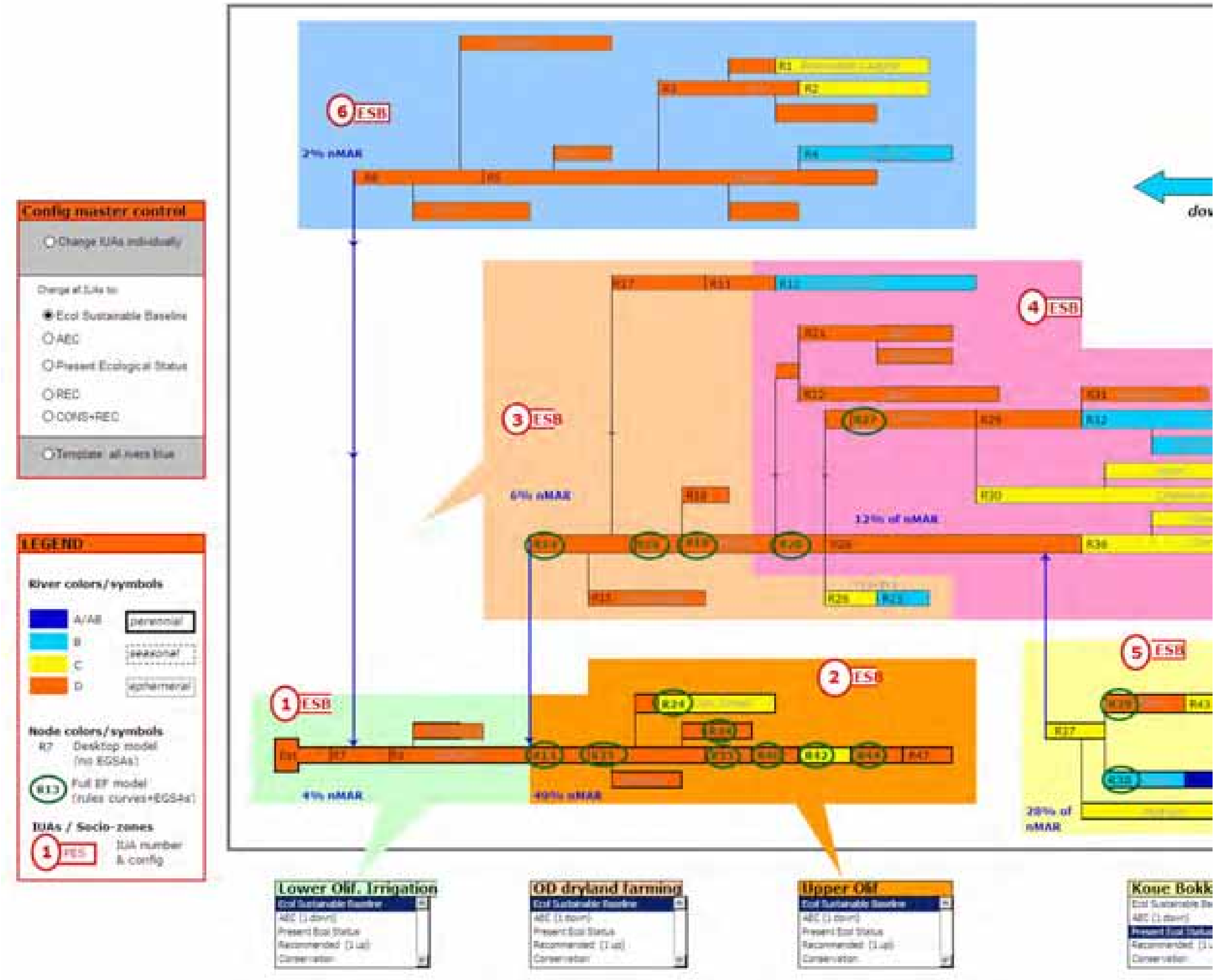

Figure 11.2.

Table 11.3 ESBC mid-point - adjustments to ecological condition in some nodes/incremental catchments. Values in $10^6 m^3$

Quat. Cat.	Node	PES (main channel)	EcoCat. (main channel)	EWR (main channel cum.)	Inc. category	Inc. EWR	Evap.	Actual flow	Balance
E10A	R47	C	D	11.55	D	11.55		11.55	0
E10B	R44	C	D	26.6	C	15.97		27.52	0.92
E10C	R42	B	C	41.6	C	11.457		38.977	-2.623
E10D	R40	C	D	43.185	D	9.1		48.077	4.892
E10E		D			D	9.7			
E10F	R33	D	D	71.649	C	12.07		69.847	-1.802
E10G		E/F	D		D	12.7	-0		
E10H	R24	D	D	5.98	D	5.98	-1	4.58	-1.4
E10J				88.9	D	6	-0	91.927	3.027
E10K	R13	E/F	D		D	5.7	-1	96.127	96.127

Table 11.4 ESBC end point – all nodes and incremental catchments in D-category. Values in $10^6 m^3$

Quat. Cat.	Node	PES (main channel)	EcoCat. (main channel)	EWR (main channel cum.)	Inc. category	Inc. EWR	Evap.	Actual flow	Balance
E10A	R47	C	D	11.55	D	11.55		11.55	0
E10B	R44	C	D	26.6	C	15.97		27.52	0.92
E10C	R42	B	C	41.6	B	15.108		42.628	1.028
E10D	R40	C	D	43.185	D	9.1		51.728	8.543
E10E		D			D	9.7			
E10F	R33	D	D	71.649	C	12.07		73.498	1.849
E10G		E/F	D		D	12.7	-0		
E10H	R24	D	D	5.98	C	7.9	-1	6.5	0.52
E10J				88.9	D	6	-0	97.498	8.598
E10K	R13	E/F	D		D	5.7	-1	101.698	101.698

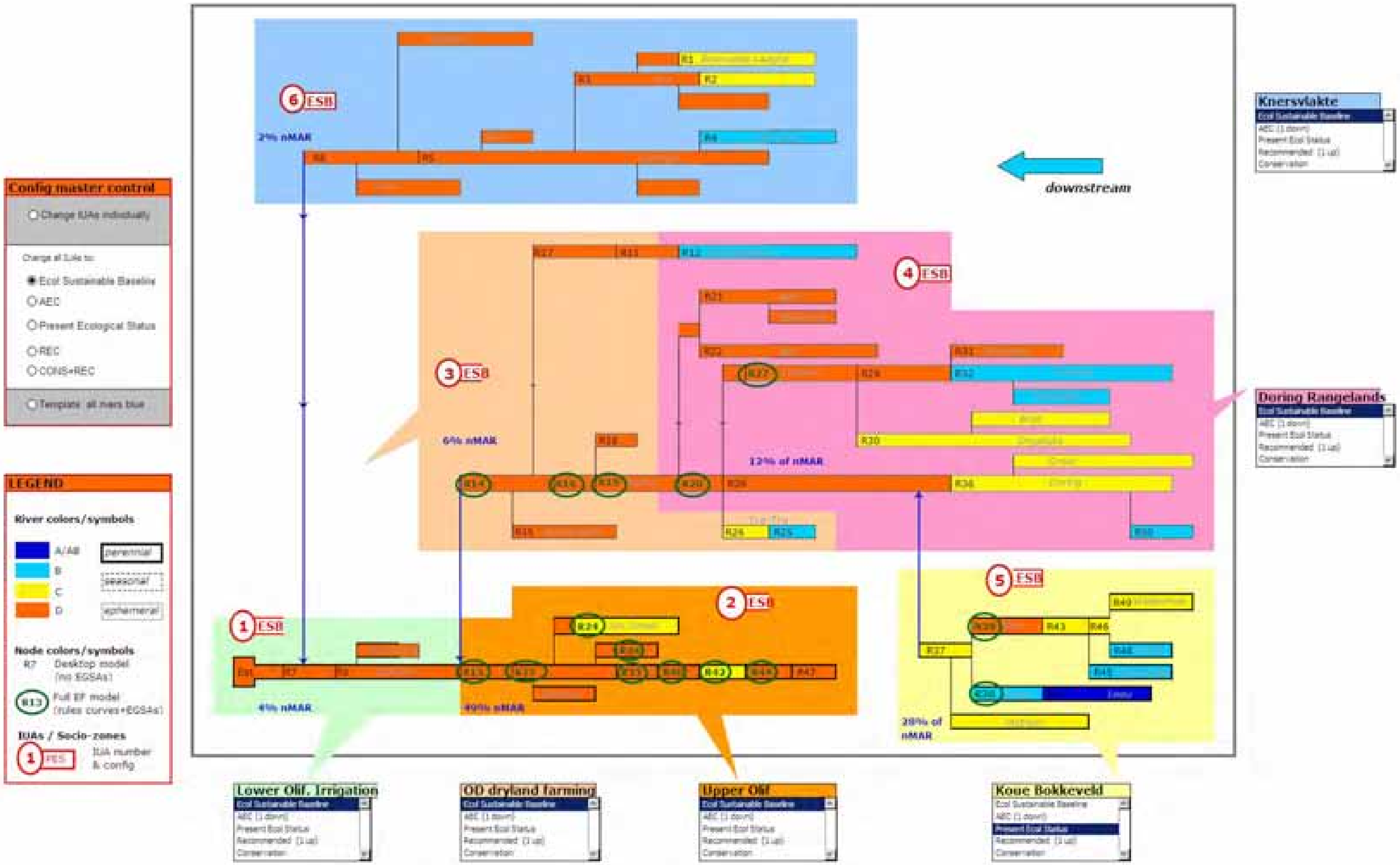

Figure 11.2 Schematic representation of the ESBC for the Olifants/Doring catchment

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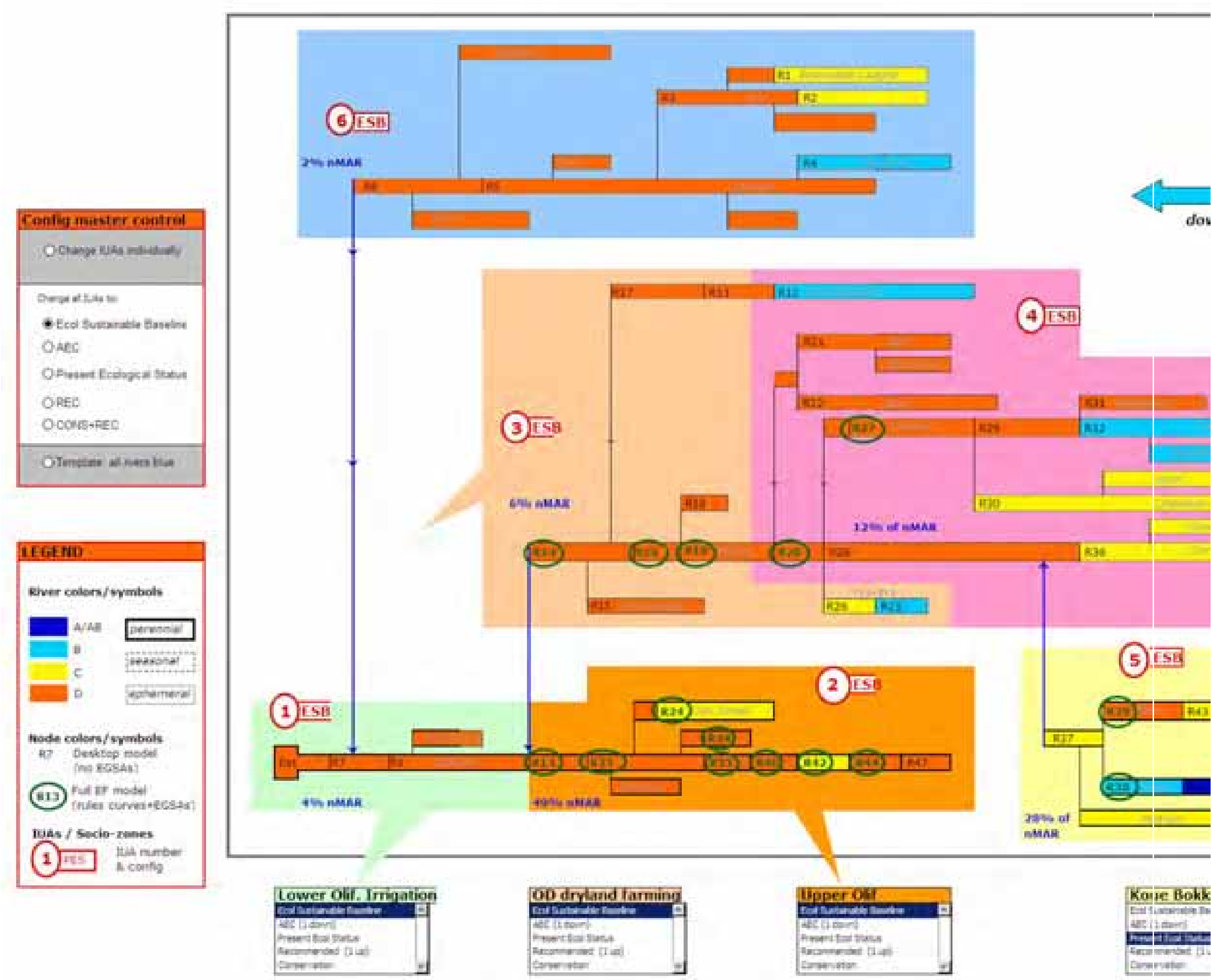

Figure 11.2 it is clear that, in order to protect EWR requirements at the downstream end of the catchment, the flow contributions (EWRs) from the upstream portions also need to be stipulated.

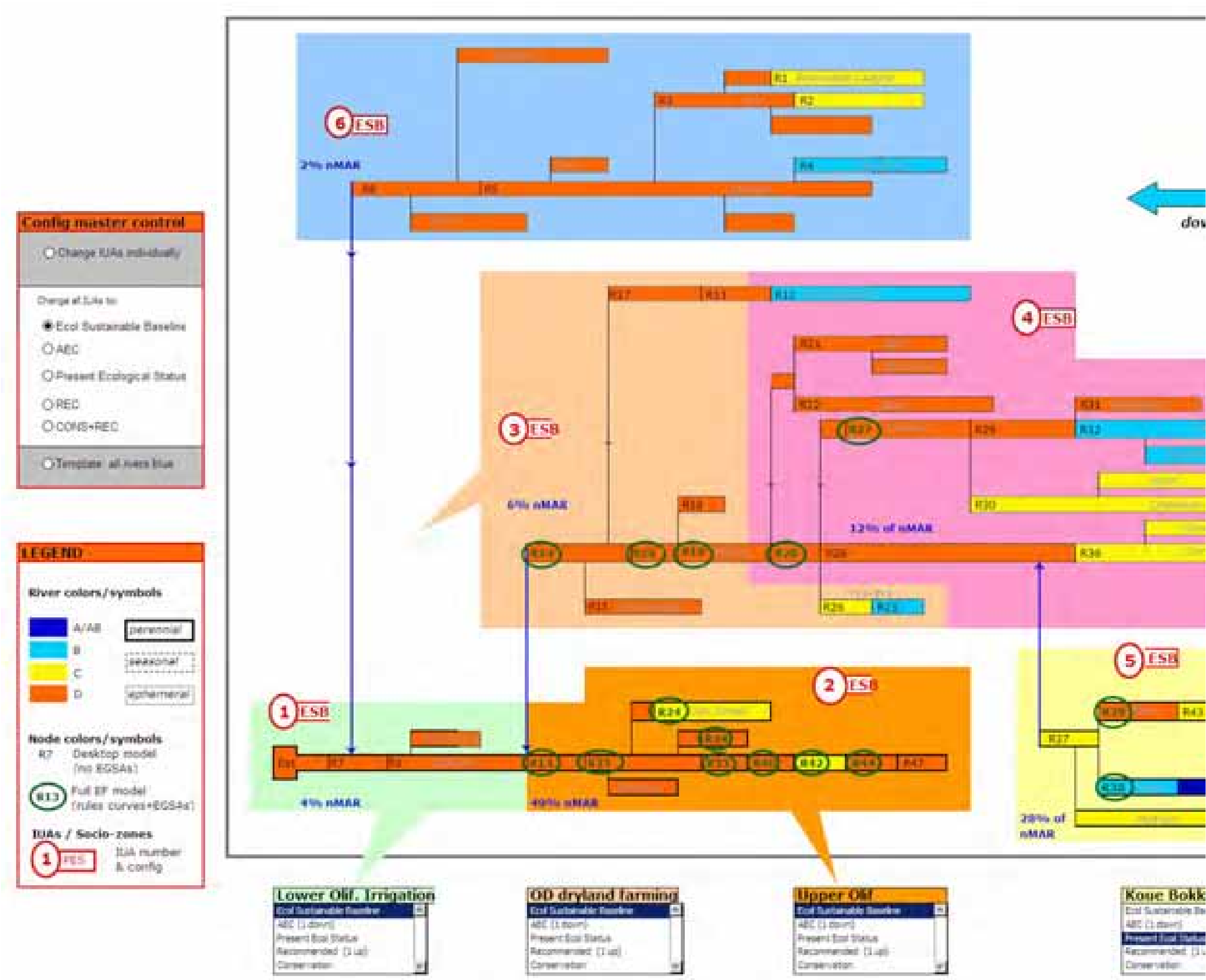

Figure 11.2 only shows the main stems through the quaternaries, however, the contributions from the incremental catchment (e.g. Table 11.4) will also need to be determined.

12 INCORPORATE THE PLANNING SCENARIOS (FUTURE USE, EQUITY CONSIDERATIONS AND EXISTING LAWFUL USE) (STEP 4B)

In Step 1 (Section 3), a procedure was described to define a network of significant resources and to establish a suite of biophysical and *allocation nodes* (see Section 4.3). The allocation nodes need to be used as the basis for incorporating the planning scenarios (e.g. future use, equity considerations, ELU) into the catchment configuration scenarios (Step 4c – see Section 13). The generation of planning scenarios occurs outside the classification procedure, but will need to be incorporated into the classification procedure and matched to the allocation nodes established in Step 1 (see Section 4). As a minimum, the planning scenarios will need to:

- determine the quantity (volume and distribution) and quality of water that remains in the resource at each node; and
- evaluate the quantity (volume and distribution) and quality of water to determine the ecological category that would result.

This information is slightly different from the RDM catchment configuration scenarios (Step 4c – see Section 13) and the ESBC scenario (Step 4a – see Section 11). The RDM and ESBC scenarios need to:

- determine the ecological category at each node and the EWR requirements for maintaining that category; and
- evaluate the yield that would result.

The procedure for Step 4b needs to be developed and incorporated into the classification procedure as and when required.

13 PROCEDURE FOR ESTABLISHING THE RDM CONFIGURATION SCENARIOS (STEP 4C)

The selection of suitable, representative RDM catchment configuration scenarios and the ESBC scenario should be done in a transparent and consistent manner and should be aligned with existing Reserve determination studies. It is important to point out, however, that the RDM configuration scenarios and ESBC scenario are not intended for presentation to Stakeholders (see Joubert *et al*., 2007; Step 6) in their unadjusted form. They are static configurations constructed as a starting point for the hydrological (yield) analysis.

13.1 Procedure for establishing the RDM configuration scenarios (Step 4c)

The recommended approach for establishing the suite of RDM catchment configuration scenarios to be provided for hydrological analysis in Step 5 (see Section 0) is based on that used in major RDM studies, e.g. Thukela. It is grounded in EcoClassification (Kleynhans *et al.,* 2005) and provides for the initial establishment of five catchment configuration scenarios. These are:

- ESBC configuration (Section 11);
- PES catchment configuration, i.e. all reaches represented by nodes with EWRs to maintain PES;
- Recommended Ecological Category (REC) configuration, i.e. reaches represented by nodes with EWRs to maintain REC;
- Freshwater Conservation targets overlain on REC configuration; and
- Freshwater Conservation targets overlain on PES catchment configuration.

The procedure for establishing RDM catchment configuration scenarios is outlined in Table 13.1 and Figure 13.1.

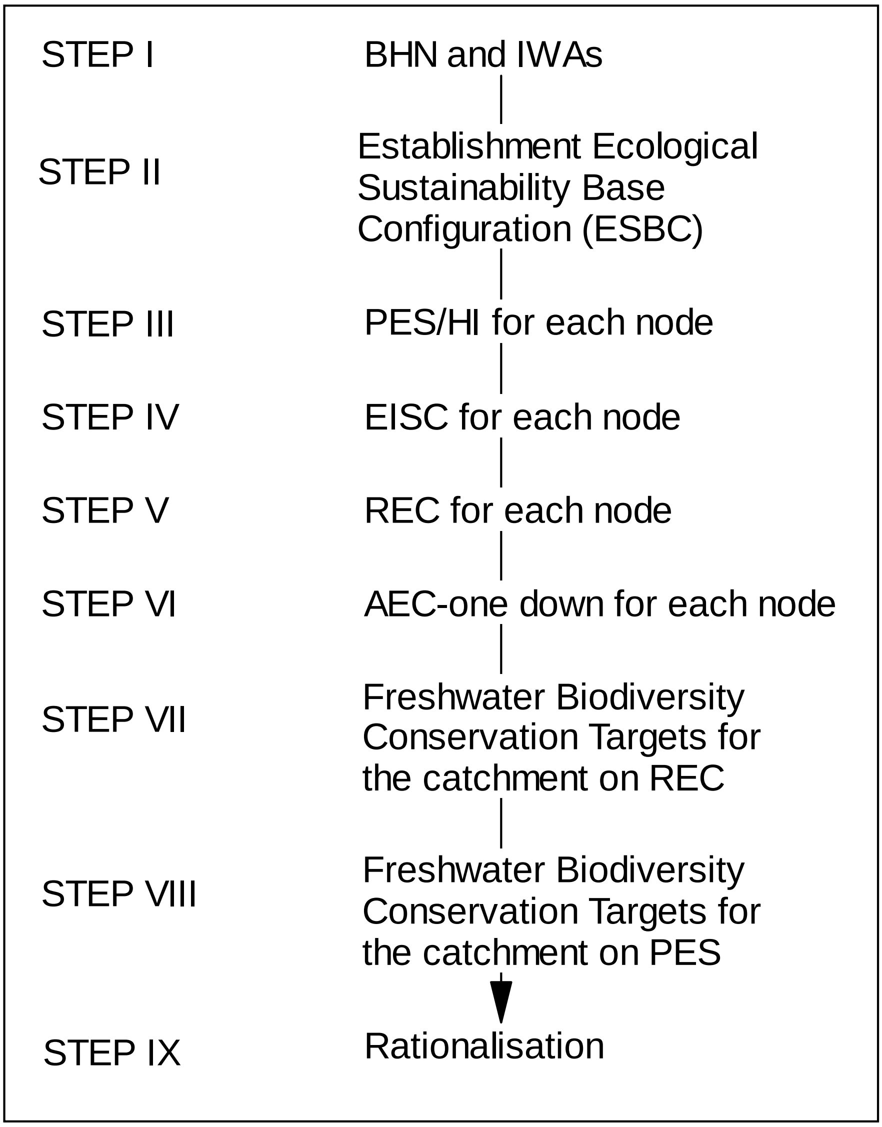

Figure 13.1 Summary of the procedure for establishing the RDM configuration scenarios

Table 13.1 Procedure for establishing the RDM configuration scenarios

Procedure for RDM configuration establishment				
STEP	**Data/GIS layers**	**Filtering process/additional explanation**	**Explanation**	**Outcome**
I	International Water Agreements (IWAs) and Basic Human Needs (BHNs)	Collect data on IWAs and BHN in the targeted catchment.	Assign categories to each node or specific demands that need to be met identified according to requirements for meeting IWAs and BHNs.	Selection of nodes with fixed EWR/yield that are not open to negotiation in the Classification Process
II	ESBC scenario	See Section 11.2		ESBC scenario adjusted at relevant nodes in terms of hydrological feasibility (water quality and quantity) and accommodation of ecological processes (i.e. source areas, refuges and corridors)
III	PES/HI	Use national PES/HI information as base, and augment with local data where applicable. Adjust where necessary according to ESBC.	Use same GIS layer as in Section 4.3.7	PES/HI for each biophysical node – PES/HI catchment configuration scenario
IV	EISC		Use same GIS layer as in Section 4.3.6	EISC for each biophysical node
V	Determine REC for each node	See Section 8.2	If EIS is High or Very high then ecological aim should be to improve the river, and the REC is set at one category higher than PES, adjust where necessary according to ESBC	REC for each biophysical node - REC catchment configuration Scenario
VI and VII	Obtain rivers coverage selected for achieving Freshwater Conservation targets	See Section	Assign A/B category to each node selected as Freshwater Conservation target. Ensure that all river reaches identified as important for longitudinal connectivity are assigned a minimum of a C category	Freshwater Conservation targets overlain on PES and REC: 1. REC and Freshwater Conservation target catchment configuration scenario. 2. PES and Freshwater Conservation target catchment configuration scenario.
VIII	Rationalise	Compare and cross-check the resultant matrix of nodes/configurations/ECs	Remove: • one of two or more identical configurations; and • one of two or more configurations that are likely to yield similar socio-economic outputs (in this instance select more optimal ecological configuration).	Rationalised set of RDM catchment configurations

13.1.1 Example: Olifants/Doring catchment

The catchment configurations for the network of significant resources defined for the Olifants/Doring catchment in Section 3 is provided in Table 13.2. For a Classification Process, these will need to be augmented with the category configuration for the incremental catchments (see explanation for ESBC in Section 11).

Nodes for which the configuration notations are presented in bold in Table 13.2 are nodes where the ESBC category exceeds that of one or more of the categories in another configuration scenario. For a Classification Process this would require adjustments of the categories in other configurations so that the ESBC represented the minimum category of that node for an RDM configuration.

Table 13.2 RDM scenario configuration table: PES, REC, Freshwater Conservation target and ESBC catchment configurations for the Olifants/Doring catchment

Node code	Quaternary catchment	Node order	Catchment category configuration					
			EIS	PES	REC	REC+ Cons..	PES+ Cons..	ESBC
E		Olifants Estuary	VERY HIGH	C	B	B	B	D
R1	E31G	Rooi_1	MODERATE	C	C	C	C	C
R2	E31E	Krom_1	MODERATE	C	C	C	C	C
R3	E32E	Dor(2)_1	MODERATE	C	C	C	C	D
R4	**E32C**	**Hant_1**	**MODERATE**	**C**	**C**	**C**	**C**	**B**
R5	E33B	Sout_3	MODERATE	C	C	C	C	D
R7	E33H	Oli_1	MODERATE	D	D	AB	AB	D
R8	E33E	Sout_1	MODERATE	C	C	C	C	D
R9	E33G	Oli_2	MODERATE	D	D	AB	AB	D
R11	E40C	Oor_2	HIGH	B	B	AB	AB	C
R12	**E40B**	**Oor_3**	**MODERATE**	**C**	**C**	**AB**	**AB**	**AB**
R13	E10K	Oli_3	MODERATE	E/F	D	AB	AB	D
R14[44]	E24M	Dor_1	HIGH	C	B	AB	AB	D
R15	E24L	Bran_1	HIGH	C	B	AB	AB	D
R16	E24K	Dor_2	HIGH	C	B	B	C	D
R17	E40D	Oor_1	HIGH	C	B	B	B	D
R19	E24J	Dor_3	HIGH	B	B	B	B	D
R20	E24H	Dor_4	HIGH	B	B	B	B	D
R21	E24D	Bos_1	LOW	C	C	C	C	D
R22	E24G	Wolf_1	LOW	C	C	C	C	D
R23	E10J	Oli_4	MODERATE	D	D	D	D	D
R24	E10H	Jan_1	MODERATE	D	D	D	D	C
R25	E24A	Tra_2	LOW	B	B	AB	AB	B
R26	E24B	Tra_1	LOW	B	B	AB	AB	C
R27	**E23K**	**Tank_1**	**LOW**	**C**	**C**	**C**	**C**	**B**
R28	E22G	Dor_5	VERY HIGH	B	B	AB	AB	D
R29	E23F	Tank_2	LOW	C	C	C	C	D
R30	E23J	Ong_1	LOW	C	C	C	C	C

[44] Note PES for R14 and R16 do not reflect Reserve results. The PES for nodes has not been updated in earlier Sections of the report.

Node code	Quaternary catchment	Node order	Catchment category configuration					
			EIS	PES	REC	REC+ Cons..	PES+ Cons..	ESBC
R31	E23F	Reno_1	LOW	C	C	C	C	D
R32	**E23D**	**Tank_3**	**LOW**	**C**	**C**	**C**	**C**	**B**
R33	E10F	Oli_5	MODERATE	D	D	AB	AB	D
R33	E10G (inc)	Ron_1	MODERATE	B	B	B	B	B
R36	E22F	Dor_6	LOW	B	B	AB	AB	C
R37	E21L	Gro_1	LOW	B	B	AB	AB	C
R38	E21J	Gro_2	LOW	B	B	B	B	B
R39	E21F	Riet_1	LOW	B	B	B	B	D
R40	E10D	Oli_6	MODERATE	C	C	C	C	D
R41	**E21G**	**Gro_3**	**LOW**	**B**	**B**	**B**	**B**	**AB**
R42	E10C	Oli_7	VERY HIGH	B	B	AB	AB	C
R43	E21E	Riet_2	LOW	B	B	AB	AB	C
R44	E10B	Oli_7	HIGH	C	B	B	C	D
R45	E21D	Hou_1	LOW	E/F	D	AB	AB	B
R46	E21C	Win_1	LOW	E/F	D	AB	AB	C
R47	E10A	Oli_9	HIGH	C	B	B	C	D
R48	**E21A**	**Krui_1**	**LOW**	**E/F**	**D**	**AB**	**AB**	**C**
R49	**E21B**	**Wel_1**	**LOW**	**E/F**	**D**	**AB**	**AB**	**C**
R50	E22D	Dor_7	LOW	C	C	C	C	B

Each pre-testing configuration is depicted individually in Figure 13.2 to Figure 13.5.

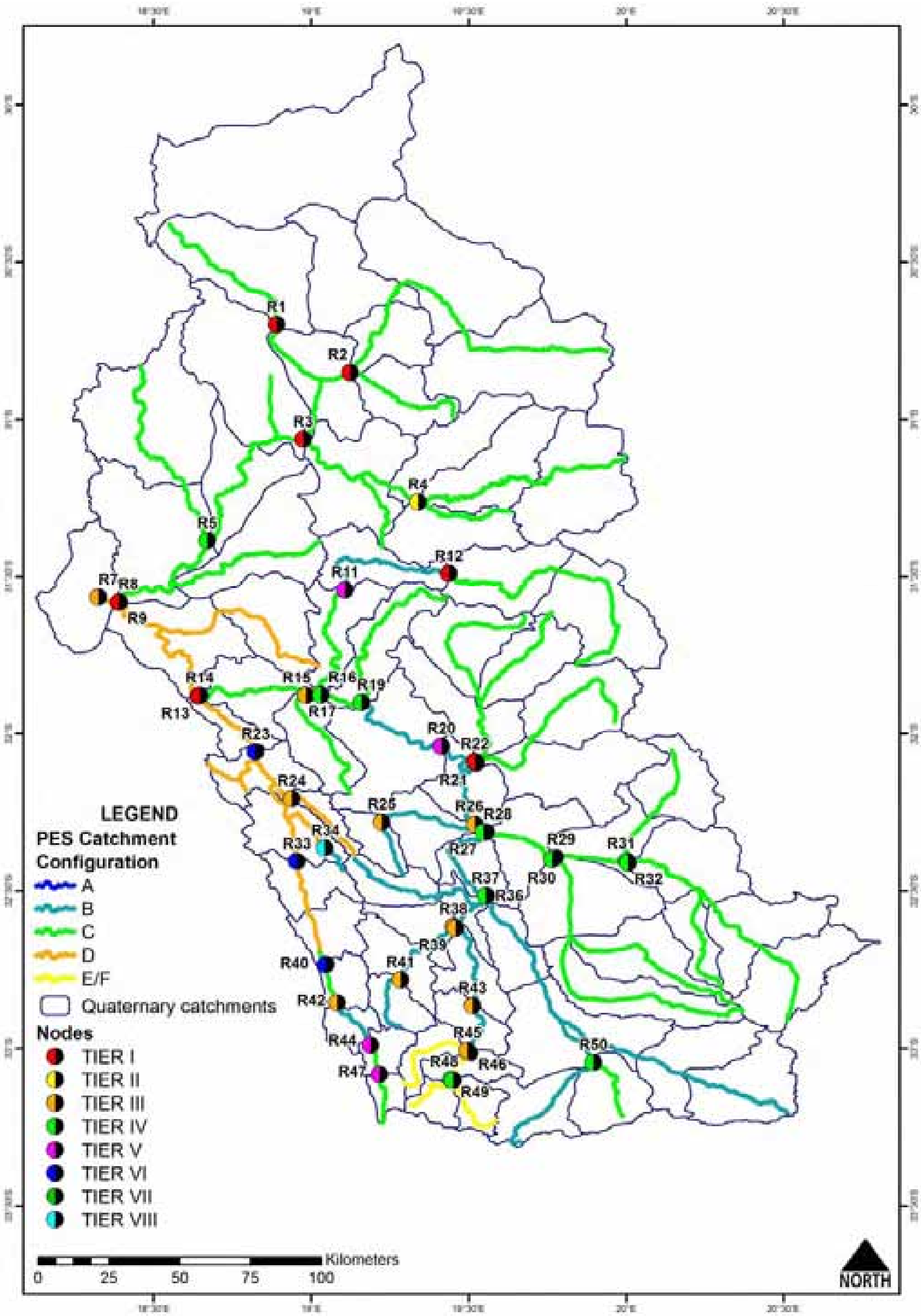

Figure 13.2 Colour-coded depiction of PES catchment configuration

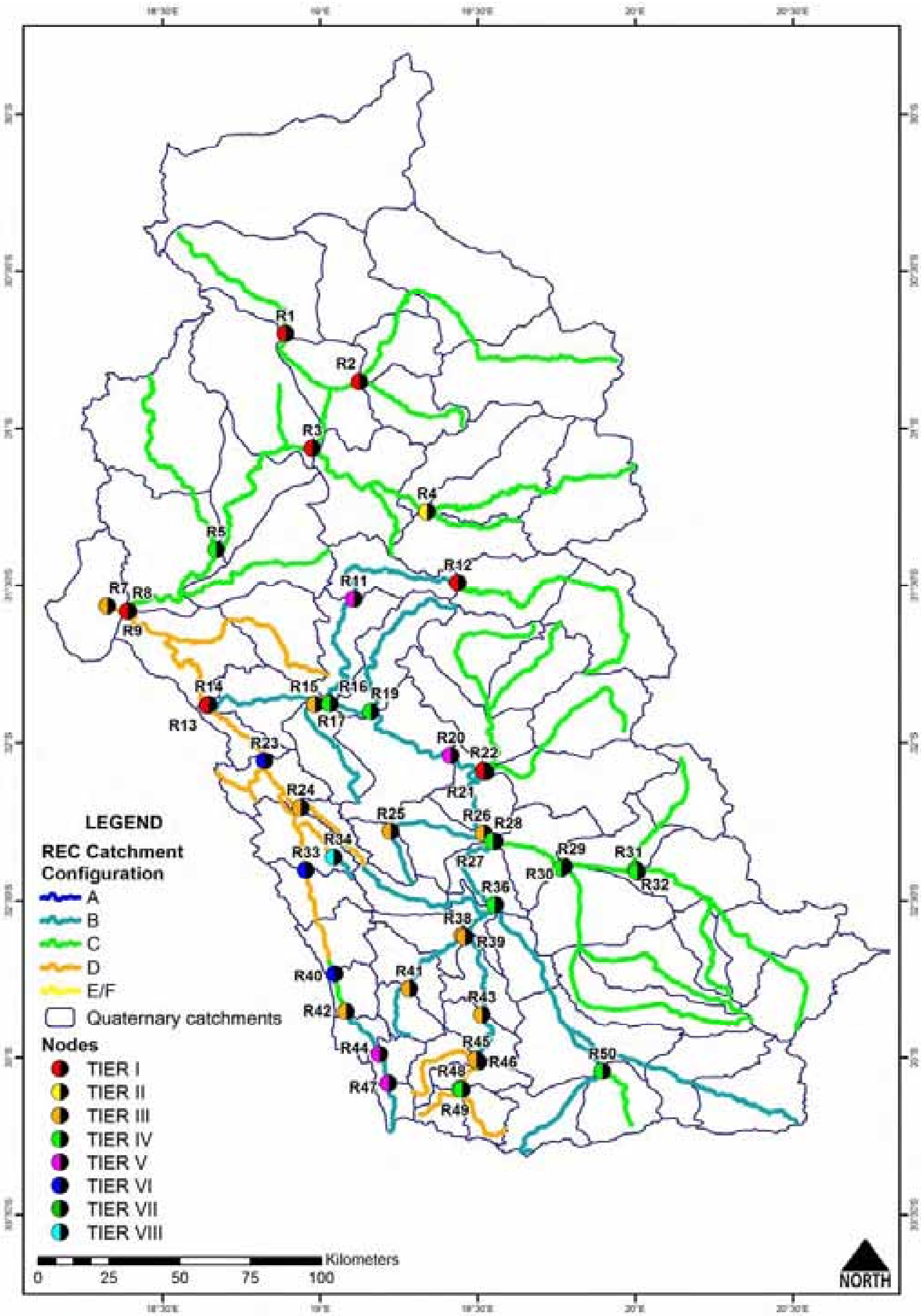

Figure 13.3 Colour-coded depiction of REC catchment configuration

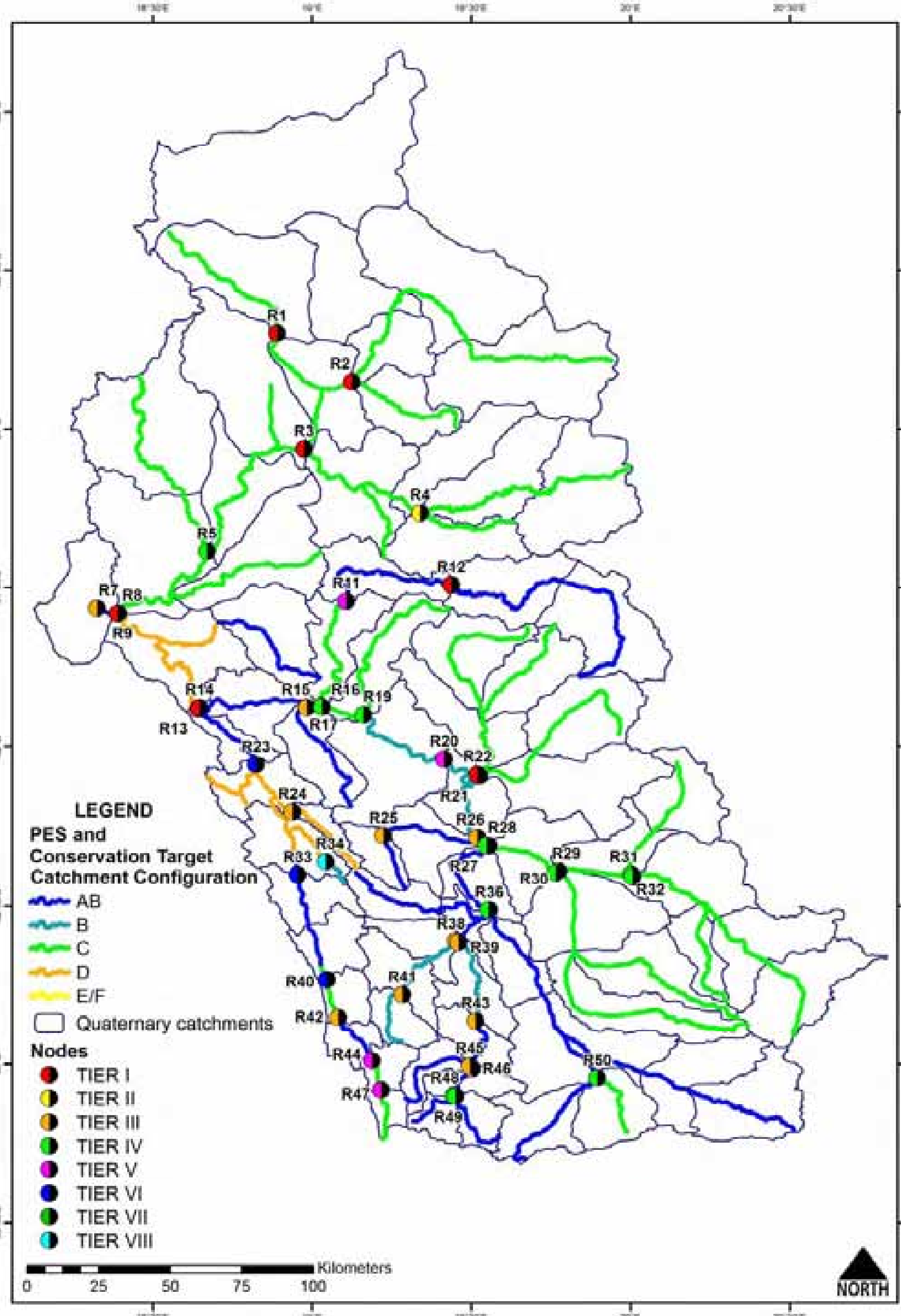

Figure 13.4 Colour-coded depiction of PES plus Freshwater Conservation targets catchment configuration

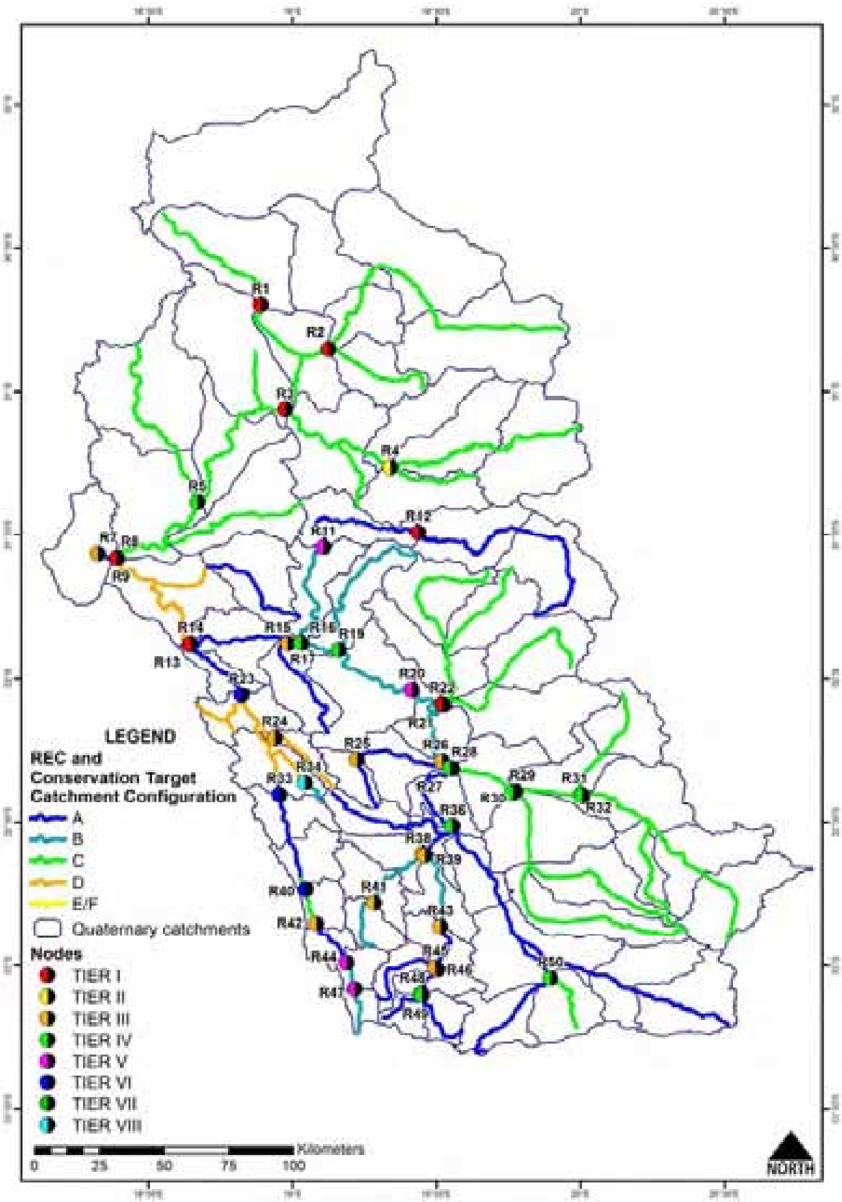

Figure 13.5 Colour-coded depiction of REC plus Freshwater Conservation targets catchment configuration

14 RUN A YIELD MODEL FOR ESBC SCENARIO AND OTHER SCENARIOS AND ADJUST THE SCENARIOS IF NECESSARY (STEP 5A)

Step 5a involves running a Yield Model for the ESBC and other catchment configuration scenarios generated in Step 4 (see Section 13), and testing their operational feasibility given the current water supply infrastructure and ELU. This procedure is beyond the scope of this project, but forms part of the classification procedure during the Classification Process.

15 ASSESS THE WATER QUALITY IMPLICATIONS (FITNESS FOR USE) FOR ALL USERS (STEP 5B)

In order to assess the water quality implications of the catchment configuration scenarios generated in Step 4 (see Section 13), it is necessary to assess the present-day water quality status (in a catchment targeted for classification), and determine the degree to which it meets user requirements (i.e. assess 'fitness for use' for each scenario for all users). This allows for an assessment of how a particular catchment configuration scenario would impact on water quality, and would allow for an assessment of whether the scenario meets the 'fitness for use' for different users.

The procedures for assessing the present-day water quality status and consequences of different catchment configuration scenarios for a resource (in this case, the procedure was developed for rivers[45]) are provided in Table 15.1 and discussed in Section 15.1. A worked example is provided in Section 15.2.

15.1 Procedures for assessing the present-day water quality status for water users

Not all water user sectors have the same water quality requirements, or are concerned about the same water quality constituents. For example, domestic water users are concerned about safe drinking water supplies (e.g. bacteriological water quality), while irrigation farmers may be concerned about the build-up of salts in the irrigated soils (salinisation). The objective in developing this procedure is therefore to determine the 'fitness for use' of the present-day water quality for water user sectors[46] or sub-sectors for each IUA for a targeted catchment. DWAF (1996) categorises user sectors into:

1. Domestic water users i.e. BHN; including
    a. drinking (health);
    b. food preparation;
    c. bathing; and
    d. laundry.

2. Agricultural water users; including
    a. live stock watering;
    b. irrigation; and
    c. aquaculture.

3. Industrial water users; including
    a. category 1 (high water quality requirement);
    b. category 2 (intermediate water quality requirement);
    c. category 3 (at least equivalent to domestic water quality requirement); and
    d. category 4 (low water quality requirement).

4. Recreational water users; including
    a. full contact;
    b. intermediate contact; and
    c. non-contact

[45] As there are currently no tools or procedures for assessing the present-day water quality status and implications of different catchment configuration scenarios for wetlands, estuaries and groundwater, these will need to be developed and incorporated into the classification procedure as and when they become available.

[46] i.e. excludes aquatic ecosystem requirements.

Table 15.1 Procedures for assessing the present-day water quality status and the implications for water users

STEP	Action	Data/tools	Explanation	Outcome
I	**ASSESS THE PRESENT-DAY WATER QUALITY STATUS FOR ALL USERS**			‘Fitness for use’ of the present–day water quality for water user sectors or sub-sectors, excluding ecosystems, present within each IUA.
Ia	Identify the water user sectors and sub-sectors present in each IUA	WSAM database. Internal Strategic Perspective (ISP) documents. Water Resource Situation Assessment (WRSA) reports. River basin or catchment situation assessment studies.	See list of water users in Section 15.2.1.1.	
Ib	Identify water users with stricter requirements than those listed in the South African Water Quality Guidelines (SAWQG) (DWAF, 1996)		See Section 15.2.1.2and Section 15.2.1.3.	
Ic	Where necessary, modify the generic water quality requirements to reflect the more stringent requirements			
Id	Assemble water quality data and/or water quality indices for all the IUAs	WRSAs.[47] The present-day water quality status data being developed for the WR2005 project.[48] Catchment and water quality assessments. DWAF Water Management System (WMS) water quality database.	Data are sparse in many areas. However, it is anticipated that the WR2005 project will assist in this regard, as it will provide water quality data at each quaternary, albeit at a low confidence.	
Ie	Rate the present-day water quality state per water user sector and per variable	RWQO Model (DWAF, 2006) or equivalent tool using the generic water quality requirements or a modification of it as appropriate.	The ‘fitness for use’ is categorised as one of the following (DWAF, 2006): Ideal. Acceptable. Tolerable. Unacceptable. Summarise the user-derived water quality status for each IUA.	

[47] A water quality index can be calculated for each quaternary using TDS and based on the fitness for domestic and irrigation water use. The index classifies the present-day water quality (1994 to 1998) as ‘ideal’, ‘good’, ‘marginal’, ‘poor’ and ‘unacceptable’. This is suitable for present-day ‘fitness for use’ assessment but not for quantitative predictions.

[48] As part of this project, a database is being developed that lists the median and 95th percentiles for all quaternaries for pH, NO_3+NO_2-N, PO_4, F, SO_4 and TDS. A rating is also provided to describe the confidence in the data.

STEP	Action	Data/tools	Explanation	Outcome
II	**ASSESS THE RIVER WATER QUALITY IMPLICATIONS (FITNESS FOR USE) FOR ALL USERS**			
IIa	Predict the TDS concentrations at the IUA outflow nodes using the pre-yield screening model (Section 11.3)	Pre-yield screening model and/or other appropriate water quality model.	Run the water quality component of the pre-yield screening model with the inputs from the ESBC scenario (Step 4a – see Section 11) and/or a specific catchment configuration scenario (Steps 4b and 4c – see Section 12 and 13).	Summary of the predicted salinity concentrations at the IUA outflow nodes.
IIb	Check salinity concentrations at the IUA outflow nodes against the water quality requirements of water users in the (downstream) IUA	The RWQO Model or equivalent tool.	Check whether the catchment configuration scenario being evaluated results in a change in the overall 'fitness for use' rating/class, or the 'fitness for use' rating for a specific user sector.	Water quality implications of catchment configuration scenarios
IIc	Predict the concentrations of other constituents at the IUA outflow nodes.	Pre-yield screening model and/or other appropriate water quality model.	Supplement the salinity assessment with a qualitative description of implications for other constituents based on specialist knowledge of water quality behaviour under different catchment configuration scenarios.	
IId	Check concentrations of other constituents at the IUA outflow nodes against the water quality requirements of water users in the (downstream) IUA	The RWQO Model or equivalent tool.	Check whether the catchment configuration scenario being evaluated results in a change in the overall 'fitness for use' for a specific user sector (including ecosystem use).	
IIe	Assess options, and if possible, apply the default objective - not allow further water quality deterioration (i.e. maintain water quality in at least it's present-day state)		If a specific catchment configuration scenario results in a poorer water quality for users, then the catchment configuration scenario can be modified by changing a combination of three options. These are: • provide more water for dilution (implying a better ecological category); • change the salt loads from the point- and non-point sources (implying management intervention to reduce loads); and • change water user requirements (implying water users have to accept a poorer quality water and cope with the consequences). Iterate using the pre-yield screening model until a satisfactory solution is achieved for each catchment configuration scenario.	
IIf	Package data and provide to socio-economist for use in Steps 5c and 5d.			

In order to assess present-day 'fitness for use', the water users within a specific IUA must be identified, their water quality requirements determined, and compared to the present-day water quality status. 'Fitness for use' is divided into four categories[49] (DWAF, 2006):

1. Ideal.
2. Acceptable.
3. Tolerable.
4. Unacceptable.

The procedure for assessing the present-day water quality status for water users are presented in Table 15.1. The procedures for assessing the water quality implications (fitness for use) for all users are also presented in Table 15.1.

15.2 Example: Olifants/Doring catchment

15.2.1 Assess the present-day water quality status for all users

15.2.1.1 Identify water user sectors and sub-sectors present in each IUA

The Olifants/Doorn WMA ISP (DWAF, 2004b) summarises the existing water users and their use requirements per sub-area, based on a 1:50 year (98%) level of assurance of supply (Table 15.2). This is currently the best estimate of water usage in the Olifants/Doring catchment.

The ISP (DWAF, 2005b) divided the catchment into the sub-areas and quaternary catchments as shown in Table 15.2.

Domestic water users - The main towns in the Lower Olifants (E33) and Upper Olifants (E10) rely on water from the Olifants River Government Water Scheme, which draws water from Clanwilliam Dam and/or the canal system. These are Citrusdal that gets water from the Olifants River and groundwater, Clanwilliam that gets water from Clanwilliam Dam and the Jan Dissels River, and the towns of Vredendal, Vanrhynsdorp, Lutzville, Ebenhaezer and Klawer that abstract water from the canal.

The primary source of water for towns in the Sandveld (G30), Kromme (E31), Goerap (F60), and Oorlogskloof (E40) is groundwater.

Agricultural water users - Agricultural activities in this sector include a wide variety of crop types, many of which are high value produce (PGWC, 2004). The cultivation of wine and table grapes, rooibos tea, citrus, deciduous fruit, wheat, potatoes, flower cultivation and wildflower harvesting, livestock and fisheries contribute to the sector. Wine and dried fruit are important value-added products.

The mean annual precipitation over much of the Olifants/Doring area is less than 200mm, with the result that except for the wetter southwest, the climate is not suitable for large-scale dryland farming. Only about 4% of the land area in the WMA is used for dryland farming. More than 90% of the land is used as grazing for livestock, predominantly for sheep and goats.

The irrigation agriculture sector is by far the largest water use sector with estimated requirements of about 95% (356 million m^3/a) of the total requirements. The scheduled area under the Olifants River canal system is 11 500 ha with an irrigation quota of 12 400

[49] For example, a total dissolved salts (TDS) concentration of 400 mg/l would be rated as 'Ideal' for domestic water users and 'Acceptable' for irrigation water users because irrigation users have stricter water quality requirements.

m^3/ha/a. Although it is estimated that a total area of about 497 km^2 of land is under irrigation, some of this is irrigated only in years when sufficient water is available. It is estimated that an average area of about 400 km^2 of crops grown under irrigation is harvested annually.

In the Doring River catchment, an often-found method of abstracting floodwater for private irrigation is the construction of a series of parallel bunds almost at right angles to the river. Floodwater is then diverted onto the lands both to wet the lands and to deposit the rich silt in the water as fertilizer. This method of irrigation is known as “saaidam” irrigation (DWAF, 1998).

Mining and industrial water users - The only major mine in the area is the Namakwa Sands heavy minerals mine which is situated on the coast in the north-west of the WMA and is supplied with water via an allocation out of the Olifants River canal. There are also several granite quarrying operations in the vicinities of Vredendal and Vanrhynsdorp.

Table 15.2 Water user requirements (in MCM per annum for the year 2000) at 1:50 year assurance for the Olifants/Doring catchment (DWAF, 2005b)

Sub-area	Quaternary catchments	Irrigation	Urban (1)	Rural (1)	Mining and bulk industry (2)	Afforestation (3)	Total local requirements	Transfers out	Grand Total
Upper Olifants	E10A - E10G	100	1	1	0	1	103	94 (4)	197
Koue Bokkeveld	E21A - E2	65	0	1	0	0	66	0	66
Doring	E22, E23, E24A-M, E40A-D	13	1	1	0	0	15	0	15
Knersvlakte	E31A-H, E32, E33A-F, F60	3	0	1	3	0	7	0	7
Lower Olifants	E10H-K, E33F-E33H	140	3	1	0	0	144	4 (5)	148
Sandveld		35	2	1	0	0	38	0	38
Total for WMA		**356**	**7**	**6**	**3**	**1**	**373**	**0**	**373**

(1) Includes component of the Reserve for BHN at 25 l/c/d.
(2) Mining and bulk industrial water uses, which are not part of urban systems.
(3) Quantities given refer to impact on yield only.
(4) Transfers out of the Upper Olifants of 94 million m^3/a for downstream irrigation, mainly via the Lower Olifants River canal.
(5) Transfers out of the Lower Olifants of 4 million m^3/a consist of a transfer of 2.5 million m^3/a to meet the Namakwa Sands mining requirement, and 0.4 million m^3/a to northern Sandveld urban use. The rest is provision for losses.

15.2.1.2 Identify water users with stricter requirements than those listed in the SAWQG

The generic water quality requirements of two of the key user sectors, irrigation and domestic water use, and their 'fitness for use' categories (DWAF, 2006) are summarised in Table 15.3 and Table 15.4.

Table 15.3 Generic water quality guidelines for Agricultural Use (Irrigation) (after DWAF, 1996)[50]

VARIABLE	UNITS	IDEAL[51]	ACCEPTABLE	TOLERABLE	UNACCEPTABLE
PHYSICAL[52]					
Total Suspended Solids	mg/l	50	75	100	>100
CHEMICAL					
Chloride	mg/l	100	137.5	175	>175
Electrical Conductivity	mS/m	40	90	270	>270
Fluoride	mg/l	2.0	8.5	15.0	>15.0
pH (upper)		8.4	8.4	8.4	>8.4
pH (lower)		6.5	6.5	6.5	<6.5
Sodium Absorption Ratio	mmol/l	2.0	8.5	15.0	>15.0
Sodium	mg/l	70.0	92.5	115.0	>115.0
Aluminium	mg/l	5.0	12.5	20.0	>20.0
Arsenic	mg/l	0.1	1.05	2.0	>2.0
Beryllium	mg/l	0.1	0.3	0.5	>0.5
Boron	mg/l	0.5	0.75	1.0	>1.0
Cadmium	mg/l	0.01	0.03	0.05	>0.05
Chromium VI	mg/l	0.1	0.56	1.0	>1.0
Cobalt	mg/l	0.05	2.75	5.0	>5.0
Copper	mg/l	0.2	2.6	5.0	>5.0
Iron	mg/l	5.0	12.5	20.0	>20.0
Lead	mg/l	0.2	1.1	2.0	>2.0
Lithium	mg/l	2.5	2.5	2.5	>2.5
Manganese	mg/l	0.02	5.1	10.0	>10.0
Molybdenum	mg/l	0.01	0.03	0.05	>0.05
Nickel	mg/l	0.2	1.1	2.0	>2.0
Selenium	mg/l	0.02	0.04	0.05	>0.05
Uranium	mg/l	0.01	0.06	0.1	>0.1
Vanadium	mg/l	0.1	0.56	1.0	>1.0
Zinc	mg/l	1.0	3.0	5.0	>5.0
BIOLOGICAL					
Faecal coliforms	per 100ml	1	500	1000	>1000

50 The limits presented do not take into account site-specific conditions.
51 The 'Ideal' water quality is equated to the Target Water Quality Range (TWQR) provided in DWAF (1996).
52 The generic water quality guidelines are recommended for use in determining the present-day and desired water user category at a low confidence desktop and rapid approach.

Table 15.4 Generic water quality guidelines for Domestic Use (after DWAF, 1996)

VARIABLE	UNITS	IDEAL	ACCEPTABLE	TOLERABLE	UNACCEPTABLE
PHYSICAL					
Hardness	mg $CaCO_3$	200	300	600	>600
Turbidity	NTU	0.1	1	20	>20
CHEMICAL					
Calcium	mg/l	80	150	300	>300
Chloride	mg/l	100	200	600	>600
Chlorine (upper)	mg/l	0.6	0.8	1.0	>1.0
Chlorine (lower)	mg/l	0.3	0.2	0.1	<0.1
Electrical Conductivity	mS/m	70	150	370	>370
Fluoride	mg/l	0.7	1.0	1.5	>1.5
Magnesium	mg/l	70	100	200	>200
Nitrate + Nitrite	mg N/l	6.0	10.0	20.0	>20.0
pH (upper)		9.5	10.0	10.5	>10.5
pH (lower)		5.0	4.5	4.0	<4.0
Potassium	mg/l	25	50	100	>100
Sodium	mg/l	100	200	400	>400
Sulphate	mg/l	200	400	600	>600
Total Dissolved Solids (TDS)	mg/l	450	1000	2400	>2400
Arsenic	mg/l	0.01	0.05	0.2	>0.2
Cadmium	mg/l	0	0.01	0.02	>0.02
Copper	mg/l	1.0	1.3	2.0	>2.0
Iron	mg/l	0.5	1.0	5.0	>5.0
Manganese	mg/l	0.1	0.4	4	>4
Zinc	mg/l	20	20	20	>20
BIOLOGICAL					
Total coliforms	per 100ml	0	10	100	>100
Faecal coliforms	per 100ml	0	1	10	>10

15.2.1.3 Where necessary, modify the generic water quality requirements to reflect the more stringent requirement user sector

In PGWC (2004) the Provincial Department of Agriculture used a site-specific classification for salinity (Table 15.5) that is more stringent than the SAWQG for Irrigation Agriculture to specify the water quality requirements for the Olifants irrigation area and to assess the ‘fitness for use’ of the water (PGWC, 2004).

Table 15.5 Salinity ratings for irrigation in the Olifants River (PGWC, 2004). The values in brackets represent the generic SAWQG values for irrigation

Salinity hazard	EC (mS/m)	TDS (mg/l)	Applicability
Low (Ideal*)	10 – 25 *(<40)*	64 – 160 *(<260)*	Can be used on most soils with little likelihood that soil salinity will develop. Some leaching (irrigation to remove salts) is required but this occurs under normal irrigation practices except in soil of extremely low permeability.
Medium (Acceptable*)	25 – 75 *(40-90)*	160 – 480 *(260-585)*	Can be used for irrigation if moderate leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
High (Tolerable*)	75 – 225 *(90-270)*	480 – 1 440 *(585-1755)*	Not to be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.
Very high (Unacceptable*)	≥ 225 *(>270)*	≥ 1 440 *(>1755)*	Not suitable for irrigation water under most conditions.

* The equivalent water use categories (Ideal, Acceptable, Tolerable, Unacceptable) were added to the original table.

The PGWC (2004) values were therefore used to assess the 'fitness for use' for irrigation users for TDS. Similar site-specific tables were developed for Sodicity, Chloride and Boron (PGWC, 2004).

15.2.1.4 Assemble water quality data and/or water quality indices for all IUAs

Routine DWAF river and reservoir water quality monitoring points for the Olifants/Doring catchment are listed in Table 15.6. There are fairly good water quality data records at Clanwilliam Dam (E1R002Q01 and E1H008), Bulshoek Dam (E1R001 and E1H007), and in the middle and lower parts of the Doring River (E2H002 and E2H003). However, the water quality data records are very poor in the rivers of the Knersvlakte, Oorlogskloof River, the tributaries of the Doring River and the lower Olifants River (PGWC, 2004).

15.2.1.5 Rate the present-day state per water user sector and per variable

The monitoring points selected to characterise the water quality status at the outflow to the IUAs are presented in Table 15.7. Data for the period 1999 to 2005 were used to characterise the present-day water quality status.

Table 15.6 Routine river and reservoir water quality monitoring points in the Olifants/Doring catchment and an indication of the data record at each monitoring point

Monitoring point	Location	Latitude	Longitude	Drainage region	Number of samples	First sample date	Last sample date
E1H006Q01 Jan Dissels River At Clanwilliam Commonage	Jan Dissels	-32.2122	18.9364	E10	402	04/01/1978	23/12/2005
E1H007Q01 Bulshoek Dam On Olifants River: Left Canal	Left Canal From Bulshoek Dam	-31.9958	18.7875	E10	118	10/03/1972	23/11/2005
E1H011Q01 Clanwilliam Dam On Olifants River: Down Stream We	Olifants - Drainage Region E	-32.1847	18.8750	E10	202	29/06/1972	23/12/2005
E1H013Q01 Olifants River At Citrusdal	Olifants River (E1)	-32.5958	19.0094	E10	51	19/07/1995	01/10/2002
E1R001Q01 Bulshoek Dam On Olifants River: Near Dam Wall	Bulshoek Dam	-31.9958	18.7875	E10	296	29/06/1972	05/01/2006
E1R002Q01 Clanwilliam Dam On Olifants River: Near Dam Wall	Clanwilliam Dam	-32.1847	18.8750	E10	243	03/04/1968	05/01/2006
E2H002Q01 At Elands Drift Aspoort On Doringrivier	Doringrivier - Drainage Region E2	-32.5028	19.5358	E22	253	02/03/1973	24/10/2005
E2H003Q01 At Melkboom On Doringrivier	Doringrivier - Drainage Region E2	-31.8603	18.6875	E24	631	13/05/1972	06/12/2005
E2H006Q01 Kruis River At De Kruis	Kruis River (E2)	-33.1486	19.3736	E21	2	18/09/1972	06/12/1979
E2H007Q01 Leeu River At Leeuw Rivier	Leeu River (E2)	-32.7806	19.2847	E21	478	27/04/1977	10/10/2005
E2H010Q01 Kruis River At Ebenezer	Kruis River (E2)	-33.1153	19.3925	E21	323	20/09/1982	29/03/2004
E3H001Q01 Troe-Troe River At Farm 256/Troe-Troe	Troe Troe River (E3)	-31.6297	18.6947	E33	5	21/07/1987	30/08/2005
E3H002Q01 Hantams River At Brakke Rivier/Tweefontein	Hantams	-31.2550	19.4714	E32	7	16/03/1990	21/10/1991
E4H003Q01 Koebee River At Kobe	Koebee (E4)	-31.6444	19.0589	E40	0		
E4R001Q01 Karee Dam On Karee River: Near Dam Wall	Karee Dam	-31.4278	19.7892	E40	168	02/05/1977	24/10/2005
G3h001Q01 Kruis River At Tweekuilen/Eendekuil	Kruis River (G3)	-32.6014	19.7506	E23	302	08/05/1970	11/10/2005
E2H016 Olifants River At Lutzville	Olifants - Drainage Region E	-31.5653	18.3306	E33	35	11/12/2002	05/04/2005
EWR1 At N7 Heksrivier On Olifants	Olifants - Drainage Region E	-32.4461	18.9600	E10	6	01/12/2003	15/09/2004

Monitoring point	Location	Latitude	Longitude	Drainage region	Number of samples	First sample date	Last sample date
EWR2 At Zypherfontein Downstream Of Cascade Pools On Olifant	Olifants - Drainage Region E	-31.9662	18.7411	E10	3	28/11/2003	04/08/2004
EWR3 Steem Rug Upstream Of Forestry Village At Graveyard	Rondegat River-Drainage Region E10g	-32.3627	19.0436	E10	6	29/11/2003	03/08/2004
EWR4 At Uitspan Kraal On Doringrivier	Doringrivier - Drainage Region E2	-32.0402	19.4149	E24	3	28/11/2003	05/08/2004
EWR6 At Tuins Kloof Upstream Of Mount Cedar On Grootrivier	Grootrivier - Drainage Region E21j	-32.6592	19.3964	E21	3	01/12/2003	03/08/2004
EWR5 At Ou Drif On Doringrivier	Doringrivier - Drainage Region E2	-31.8574	18.9126	E24	13	05/03/2004	13/08/2004
Clanwilliam At Road Brigde Downstream Of WWTW Outfall	Jan Dissels	-32.1749	18.8963	E10	1	15/09/2004	15/09/2004
Citrusdal At Northern Border Of Golf Course	Citrusdal Discharge Channel To Olifants	-32.5867	19.0059	E10	1	15/09/2004	15/09/2004
Interval 1 Jan Dissels River Ptn Boskloof	Interval 1 Jan Dissels Rivier Ptn Boskloof	-32.2000	18.9600	E10	2	21/09/2005	21/09/2005
Interval 2 Jan Dissels Rivier Ptn Boskloof	Interval 2 Jan Dissels Rivier Ptn Boskloof	-32.2100	18.9800	E10	2	21/09/2005	21/09/2005
Kliprivier Ptn Jan Dissels Rivier Ptn Boskloof	Kliprivier - Drainage Region E10h	-32.1900	18.9600	E10	2	21/09/2005	21/09/2005
Cmnt-Ceres-Mr800a-Low Water Bridge At Fairfield Farm	Modder River-Drainage Region H10c	-33.1889	19.2897	E10	5	08/09/2004	26/10/2005

Table 15.7 Monitoring points selected to characterise the water quality at the outflows from the IUAs

IUA	Outlet no.	Quaternary no.	Monitoring point	Comment
Doring Rangelands (1)	R12	E40B	E4R001	Only one sampling point, E4R001, in this IUA. Fair observed data record but no flow data to develop concentration/flow relationship.
Doring Rangelands (2)	R20	E24H	E4R001	No monitoring points, assumed to be same as E4R001, low confidence assessment.
Knersvlakte	R8	E33E	E3H002	There is only one monitoring point in the Knersvlakte with 7 observations. Low confidence assessment.
Koue Bokkeveld	R37	E21L	E2H002	Good data record, sufficient data to develop concentration/flow relationship.
Lower Olifants	R7	E33H	E2H016	One monitoring point E2H016 at Lutzville. TDS may be affected by saline intrusions from the sea during spring tides.
Olifants/Doring Dryland farming (1)	R14	E24M	E2H003	Good data at E2H003 to develop concentration/flow relationship.
Olifants/Doring farming (2)	R26	E24B	E2H002	Water quality in the TraTra River was assumed to be the same as those observed at E2H002 close by.
Upper Olifants	R23	E10J	E1H011	Assumed same as outflow from Clanwilliam Dam. No flow data at Bulshoek to develop a concentration/flow relationship used total outflow from Clanwilliam Dam.

To demonstrate the concept of rating the present-day water quality status, the median and 95th percentile values were calculated for seven variables that are of concern to irrigation and domestic water users. The data period selected was for 1999 to 2005. These were classified (Table 15.8) using the generic water quality guidelines for irrigation (Table 15.3) and domestic water use (Table 15.4) and the site-specific guidelines for TDS (Table 15.5). For some variables such as NH_4-N and PO_4-P no guidelines were specified for domestic or irrigation water use.

Table 15.8 ‘Fitness for use’ classification of selected variables at the key monitoring points in the Olifants/Doring catchment

Sampling point	Variable	N	50%tile	95%tile	50%tile Irrigation	50%tile Domestic	95%tile Irrigation	95%tile Domestic
E1H011Q01	pH	91	6.86	7.4445		Ideal		Ideal
E1H011Q01	NO_3+NO_2-N	90	0.055	0.37825		Ideal		Ideal
E1H011Q01	NH_4-N	90	0.02	0.1001				
E1H011Q01	F-Diss	90	0.1	0.13955		Ideal		Ideal
E1H011Q01	PO_4-P	90	0.016	0.05785				
E1H011Q01	SO_4-Diss	91	4.227	8.9095		Ideal		Ideal
E1H011Q01	TDS	90	50.1375	80.51725	Ideal	Ideal	Ideal	Ideal
E1R001Q01	pH	201	7.07	7.517		Ideal		Ideal
E1R001Q01	NO_3+NO_2-N	201	0.137	0.394		Ideal		Ideal
E1R001Q01	NH_4-N	201	0.02	0.081				
E1R001Q01	F-Diss	201	0.05	0.13		Ideal		Ideal
E1R001Q01	PO_4-P	201	0.014	0.041				
E1R001Q01	SO_4-Diss	201	7.84	14.376		Ideal		Ideal
E1R001Q01	TDS	201	67	123.322	Ideal	Ideal	Ideal	Ideal
E1R002Q01	pH	120	6.8625	7.48205		Ideal		Ideal
E1R002Q01	$NO_{3+}NO_2$-N	120	0.055	0.3472		Ideal		Ideal
E1R002Q01	NH4-N	120	0.02	0.137				
E1R002Q01	F-Diss	66	0.1	0.16975		Ideal		Ideal
E1R002Q01	PO_4-P	120	0.015	0.06115				
E1R002Q01	SO_4-Diss	66	5.0555	12.1615		Ideal		Ideal
E1R002Q01	TDS	66	51	69.2965	Ideal	Ideal	Ideal	Ideal
E2H002Q01	pH	111	7.07	7.6745		Ideal		Ideal
E2H002Q01	NO_3+NO_2-N	110	0.04	0.21785		Ideal		Ideal
E2H002Q01	NH_4-N	111	0.02	0.066				
E2H002Q01	F-Diss	111	0.104	0.1625		Ideal		Ideal
E2H002Q01	PO_4-P	110	0.017	0.0494				
E2H002Q01	SO_4-Diss	111	7	14.0445		Ideal		Ideal
E2H002Q01	TDS	109	48	95.2	Ideal	Ideal	Ideal	Ideal

Sampling point	Variable	N	50%tile	95%tile	50%tile Irrigation	50%tile Domestic	95%tile Irrigation	95%tile Domestic
E2H003Q01	pH	240	7.5925	8.15135		Ideal		Ideal
E2H003Q01	NO_3+NO_2-N	240	0.04	0.37255		Ideal		Ideal
E2H003Q01	NH_4-N	240	0.02	0.0605				
E2H003Q01	F-Diss	240	0.13	0.3124		Ideal		Ideal
E2H003Q01	PO_4-P	240	0.017	0.059				
E2H003Q01	SO_4-Diss	240	18.984	85.26		Ideal		Ideal
E2H003Q01	TDS	240	160.738	671.4	Acceptable	Ideal	Tolerable	Acceptable
E4R001Q01	pH	46	7.9035	8.60475		Ideal		Ideal
E4R001Q01	NO_3+NO_2-N	46	0.0565	1.29975		Ideal		Ideal
E4R001Q01	NH_4-N	46	0.0285	0.4865				
E4R001Q01	F-Diss	46	0.159	0.262		Ideal		Ideal
E4R001Q01	PO_4-P	46	0.0295	0.16975				
E4R001Q01	SO_4-Diss	46	10.692	23.02375		Ideal		Ideal
E4R001Q01	TDS	46	171.038	275.7615	Acceptable	Ideal	Acceptable	Ideal
E2H016	pH	35	8.209	8.4758		Ideal		Ideal
E2H016	NO_3+NO_2-N	35	0.055	0.5165		Ideal		Ideal
E2H016	NH_4-N	35	0.04	0.0636				
E2H016	F-Diss	35	0.838	1.0741		Acceptable		Tolerable
E2H016	PO_4-P	34	0.0645	0.1994				
E2H016	SO_4-Diss	35	374.433	615.6608		Acceptable		Unacceptable
E2H016	TDS	34	2273.95	3502.228	Unacceptable	Tolerable	Unacceptable	Unacceptable

Table 15.8 shows that for the water quality variables assessed, water quality fell within an 'Ideal' quality range for most of the monitoring points except for the lower Doring River (E2H003Q01), Caledon Dam (E4R001Q01) and the lower Olifants River at Lutzville (E2H016). The information in the table also demonstrates that in terms of TDS, irrigation water users are more sensitive than domestic water users to elevated salt concentrations.

15.2.2 Assess the water quality implications (fitness for use) for all users

15.2.2.1 Predict the TDS concentrations at the IUA outflow nodes

Assessing the water quality implications of a specific catchment configuration scenario requires simulating the TDS concentrations at the outflows of the IUAs using a pre-yield screening model or a salinity model (e.g. WQT[53] or WQ2000[54]). Given the resource constraints of this project, setting up a salinity simulation model proved impossible. However, an empirical approach to estimate the TDS concentrations at the outflow of each IUA was developed. This required:

- determining an empirical relationship between flow and TDS concentrations for the key monitoring points (for example Figure 15.1);
- using the predicted flow duration curves generated with the pre-yield screening model at the outflow of the IUA to estimate a TDS concentration distribution (for example Figure 15.2);
- calculating the 95th percentile TDS concentrations for a specific scenario; and
- comparing it to the user requirements to assess the potential water quality implications.

This approach is, however, dependent on sufficient flow and TDS concentration data to develop the TDS/flow relationships. No relations could be developed for the Doring Rangeland (no observed flow data available), Knersvlakte (only 7 paired flow/TDS data points), or the lower Olifants (no observed flow data available).

[53] Water Quality TDS is a monthly hydrosalinity model specifically designed to be driven by the same natural flows that drive the Water Resources Yield Model and the Water Resources Planning Model.
[54] WQ2000 model was developed as a planning tool, and provides an interface between the user, a database containing quaternary catchment information, the WQT model and DWAF's GIS viewer.

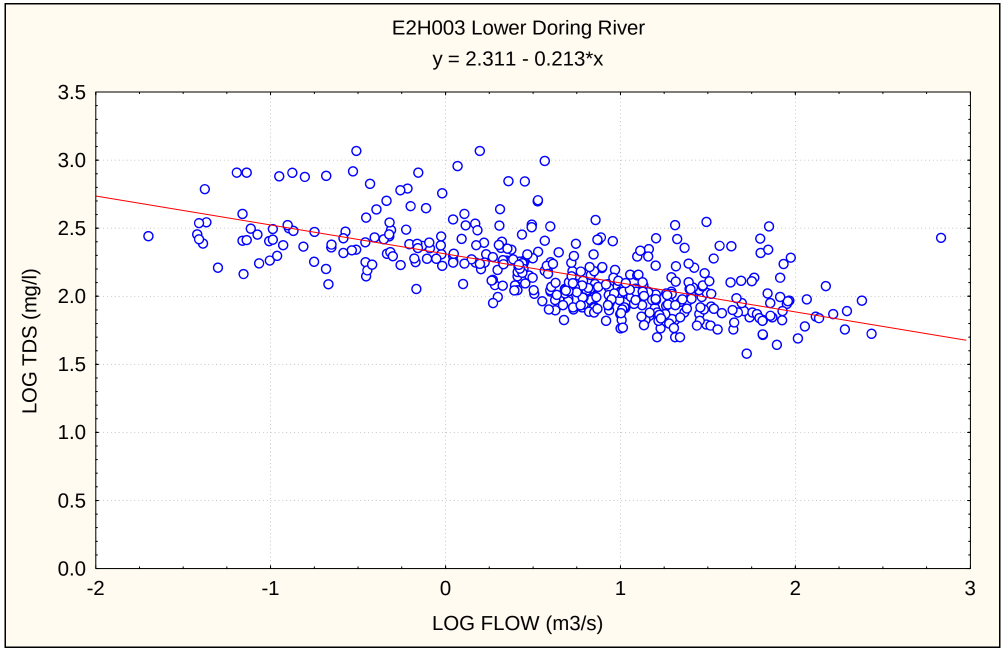

Figure 15.1 Log-log plot of flow and TDS concentrations at E2H003 (lower Doring River)

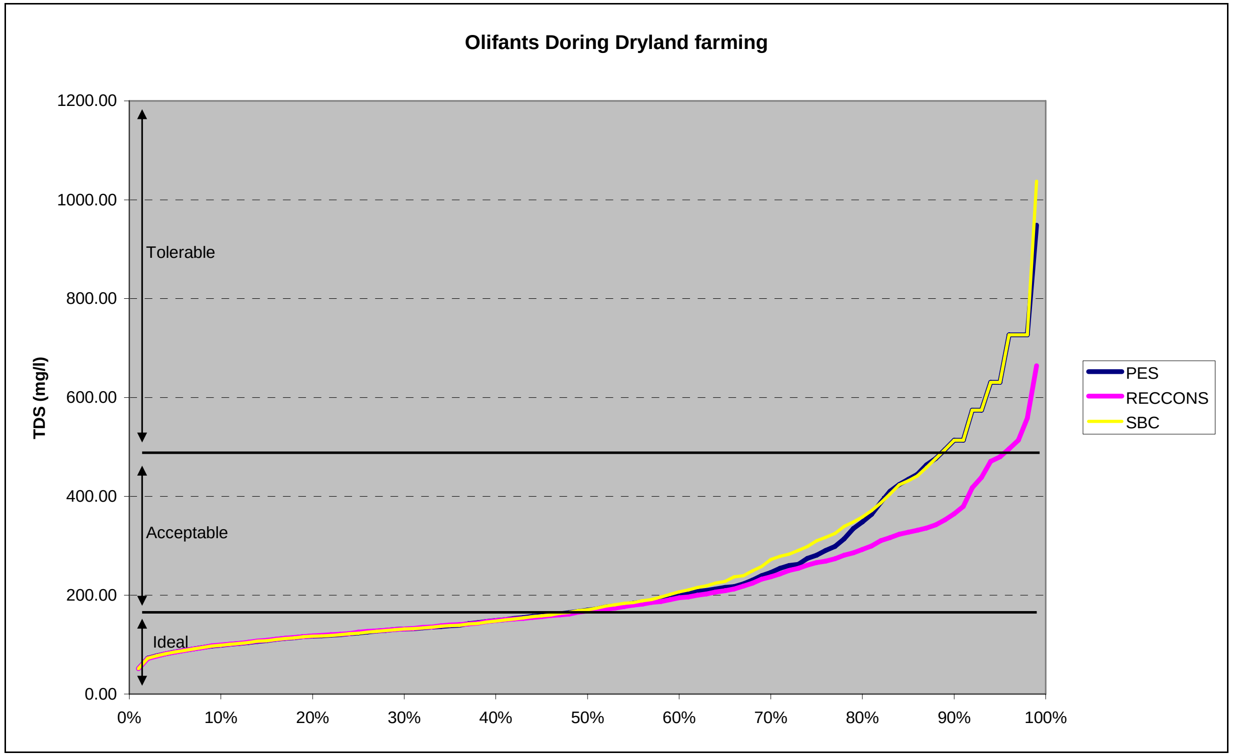

Figure 15.2 Estimated flow duration curve for TDS concentrations for the three catchment configuration scenarios

15.2.2.2 Check salinity concentrations at the IUA outflow nodes against the water quality requirements of water users in the (downstream) IUA

The 95th percentile values of the estimated TDS concentrations at the outflow of each IUA were either:

- calculated from the TDS concentrations that were estimated from the flow duration curves for three selected catchment configuration scenarios; or
- the present-day 95th percentile was used where no flow-concentration relationships could be developed due to a lack of data.

The 95th percentile was selected because it is the statistic that DWAF uses to assess compliance to a specific water quality targets or objectives (DWAF, 2006). These values were then compared to the TDS guidelines for irrigation because irrigation is the most sensitive user in terms of salinity (Table 15.9). A TDS category was then assigned to the scenario.

15.2.2.3 Predict the concentrations of other constituents at the IUA outflow nodes

The concentrations of other key constituents were not predicted given time and budget constraints, as well as the lack of good data sets in the areas where poor water quality was experienced (e.g. the Olifants River downstream of Bulshoek Dam and downstream of the Doring River confluence).

15.2.2.4 Check concentrations of other constituents at the IUA outflow nodes against the water quality requirements of water users in the (downstream) IUA

This was not done for the Olifants/Doring catchment as the concentrations for other constituents of concern were not assessed.

15.2.2.5 Assess options

Utilising the empirical assessment method (see Section 15.2.2.1), none of the catchment configuration scenarios evidenced a change in the 'fitness for use' categories for irrigation. However, this method is not sensitive to changes in flow, especially if the flow scenarios generated for the different catchment configuration scenarios are similar.

15.2.2.6 Package data and provide to Socio-economist for application in Steps 5c and 5d of the classification procedure

For the Olifants/Doring catchment, it was agreed with the Socio-economist that the implications of TDS would be assessed based on the additional water that would be needed to meet the calculated leaching requirement. That is the excess volume of water required to leach salts from the soil. Many soils in the Olifants/Doring catchment are saline and require leaching to decrease the soluble salt content for sustainable crop production under irrigation (PGWC, 2003). The additional water required for leaching (LR) is calculated as the electrical conductivity of the irrigation water (EC_{iw}) divided by the electrical conductivity of the drainage water (EC_{dw}) (Equation 1).

$$LR = EC_{iw} / EC_{dw}$$ **Equation 1**

For field crops an EC_{dw} of 800 mS/m is generally considered as the upper limit of salt tolerance. However, PGWC (2003) recommend that an EC_{dw} of 400 mS/m be used for the Olifants/Doring catchment. The leaching requirements were therefore calculated for the 95th percentile TDS concentrations and estimated for the different catchment configuration scenarios. This information was packaged for the socio-economist and is shown in

Table 15.10.

Table 15.9 **'**Fitness for use' categories for the TDS concentrations for the present-day state for three catchment configuration scenarios (PES, REC+Cons. and ESBC)

Location				Present-day state	PES	REC+Cons.	ESBC	Irrigation category per scenario			
IUA	Node	Quat.	Point	95th%ile mg/l	95th%ile mg/l	95th%ile mg/l	95th%ile mg/l	Present-day state	PES	REC+Cons.	ESBC
Doring Rangelands (1)	R12	E40B	E4R001	265.4	265.0	265.0	265.0	Acceptable	Acceptable	Acceptable	Acceptable
Doring Rangelands (2)	R20	E24H	E4R001	265.4	265.0	265.0	265.0	Acceptable	Acceptable	Acceptable	Acceptable
Knersvlakte	R8	E33E	E3H002	738.1	738.1	738.1	738.1	Tolerable	Tolerable	Tolerable	Tolerable
Koue Bokkeveld	R37	E21L	E2H002	90.7	67.9	65.7	67.7	Ideal	Ideal	Ideal	Ideal
Lower Olifants	R7	E33H	E2H016	3502.2	3502.2	3502.2	3502.2	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Olifants/Doring Dryland farming (1)	R14	E24M	E2H003	609.9	630.5	481.0	630.5	Tolerable	Tolerable	Tolerable	Tolerable
Olifants/Doring Dryland farming (2)	R26	E24B	E2H002	90.7	67.9	65.7	67.7	Ideal	Ideal	Ideal	Ideal
Upper Olifants	R23	E10J	E1H011	70.9	48.5	51.1	48.5	Ideal	Ideal	Ideal	Ideal

Table 15.10 Leaching requirements calculated from the 95th percentile TDS concentrations for the present-day state for the three catchment configuration scenarios (PES, REC+Cons. and ESBC)

Location				**Present-day state**	**PES**	**REC+Cons.**	**ESBC**	**Leaching requirement**			
IUA	**Node**	**Quat.**	**Point**	**95%**	**95%**	**95%**	**95%**				
				mg/l	**mg/l**	**mg/l**	**mg/l**	**Present-day state**	**PES**	**REC+Cons.**	**ESBC**
Doring Rangelands (1)	R12	E40B	E4R001	265.4	265.0	265.0	265.0	10.2%	10.2%	10.2%	10.2%
Doring Rangelands (2)	R20	E24H	E4R001	265.4	265.0	265.0	265.0	10.2%	10.2%	10.2%	10.2%
Knersvlakte	R8	E33E	E3H002	738.1	738.1	738.1	738.1	28.4%	28.4%	28.4%	28.4%
Koue Bokkeveld	R37	E21L	E2H002	90.7	67.9	65.7	67.7	3.5%	2.6%	2.5%	2.6%
Lower Olifants	R7	E33H	E2H016	3502.2	3502.2	3502.2	3502.2	134.7%	134.7%	134.7%	134.7%
Olifants/Doring Dryland farming (1)	R14	E24M	E2H003	609.9	630.5	481.0	630.5	23.5%	24.2%	18.5%	24.2%
Olifants/Doring Dryland farming (2)	R26	E24B	E2H002	90.7	67.9	65.7	67.7	3.5%	2.6%	2.5%	2.6%
Upper Olifants	R23	E10J	E1H011	70.9	48.5	51.1	48.5	2.7%	1.9%	2.0%	1.9%

16 REPORT ON THE IAU-SCALE ECOLOGICAL CONDITION AND AGGREGATE IMPACTS FOR EACH PRELIMINARY SCENARIO (STEP 5C)

It is important that the information and the procedures used to report on the ecological condition of an IUA (i.e. the IUA Class) for each catchment configuration scenario are sufficiently precise so as to ensure consistent designation of classes in different catchments by different individuals. Many of these are already captured in the procedures for information provision in Steps 1 to 4 of the classification procedure. The final step, however, of summarising these data into an IUA Class is addressed here.

To ensure consistency, summarising these data into an IUA Class will eventually need to be governed by a set of agreed guidelines. It is recommended that the nature and content of these guidelines be developed through implementation of the WRCS, as it is important to have a clear understanding of all their implications before finalisation.

To assist with the development of the guidelines, a preliminary set of guidelines has been developed and is presented in Table 16.1.

Table 16.1 Preliminary guidelines for the calculation of the IUA Class for a scenario

IUA class		**Percentage category representation at units represented by biophysical nodes in an IUA**				
		≥A/B	**≥B**	**≥C**	**≥D**	**<D**
Class 1		≥40	≥60	≥80	≥99	-
Class 2		-	≥40	≥70	≥95	-
Class 3	**Either**	-	-	≥30	≥80	-
	Or		-	-	100	-

Using these rules and the catchment configurations presented in Table 13.2, the IUA Class assignations in Table 16.2 would apply.

Table 16.2 IUA Class assignations for catchment configurations

IUA	**Configuration**		
	PES	**REC+Cons.**	**ESBC**
Doring Rangelands	Class 3	Class 2	Class 3
Estuary	Class 2	Class 1	Class 3
Knersvlakte	Class 3	Class 3	Class 3
Kouebokkeveld	Failed	Class 1	Class 2
Lower Olifants Irrigation Area	Class 3	Class 1	Class 3
Olifants Doring Drylands	Class 2	Class 1	Class 3
Upper Olifants Irrigation Area	Class 3	Class 2	Class 2

The PES catchment configuration for the Kouebokkeveld (Table 16.2) failed in the PES Class allocation because the PES data that were available for this study indicate that 47% of the river lengths that were assessed in the Kouebokkeveld fell into an E/F category. This failure could be attributed to the rules for Class 3 being too strict. However, it is debatable whether, in the light of the NWA, a 47% prevalence of E/F category rivers should be an acceptable target for an IUA.

17 USEFUL ADDITIONAL TOOLS AND INFORMATION

In developing the ecological, hydrological and water quality considerations for the WRCS the following data and tools were identified as potentially useful for the process. While the use of some of these tools has been illustrated, several require further development, which is beyond the scope of this study.

Data:

- updated WR90 data. Currently underway as WR 2005,
- quaternary level water quality information. This is currently being incorporated into WR 2005,
- detailed targets for freshwater biodiversity conservation including river reaches for conservation, attention to longitudinal linkages and EWR allocations required for the priority reaches,
- ground-truthed assessment of habitat integrity (or relevant procedure for the specific ecosystem) for all significant resources,
- Comprehensive EWRs for seasonal and ephemeral river ecosystems,
- macro-reach classification of river reaches on a national scale, and
- where Reserve studies are undertaken, EWRs for all ecological categories (A/B to D).

EWR methods:

- Comprehensive Reserve methods for ephemeral rivers and wetlands,
- Desktop Reserve methods for estuaries, wetlands and ephemeral rivers,
- implementable Reserve determination and protection measures to protect important groundwater/surface water areas of interaction, and
- tool for generating EGSA change information without recalling specialists.

Other:

- a water balance model that will allow for setting the ESBC and checking 'signed-off' Reserve requirements for a catchment as a whole,
- standardised lists of discipline-specific components for consideration by specialists in Reserve determinations. This list should include important EGSAs in the study area,
- GIS covers of alien riparian vegetation, and
- national inventory of aquatic resource(s) availability and use.

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APPENDIX A

ECOREGIONS LEVEL I USED IN THE OLIFANTS/DORING CATCHMENT

Level 1 Ecoregions representing > 5% of catchment area.

Main attributes	**21 Great Karoo**
Terrain Morphology: Broad division (Primary)	**Plains, Low Relief**, Plains Moderate Relief, Lowlands, Hills and Mountains, Moderate and High Relief, Open Hills, Lowlands, Mountains, Moderate to High Relief, **Closed Hills, Mountains, Moderate and High Relief,** Table-Lands: Moderate and High Relief.
Vegetation types (dominant types in bold) (Primary)	Valley Thicket, Spekboom Succulent Thicket (limited), **Central Nama Karoo,** Eastern Mixed Nama Karoo, **Great Nama Karoo,** Upper Nama Karoo, Bushmanland Nama Karoo (limited), Lowland Succulent Karoo, Upland Succulent Karoo, Escarpment Mountain Renosterveld.
Altitude (m a.m.s.l) (secondary)	300-1700, 1700-1900 limited
MAP (mm) (modify/ second?)	0 to 500
Coefficient of Variation (% of annual precipitation)	30 to >40
Rainfall concentration index	15 to 64
Rainfall seasonality	Very late summer to winter
Mean annual temp. (°C)	10 to 20
Mean daily max. temp. (°C): February	26 to >32
Mean daily max. temp. (°C): July	<10 to 22
Mean daily min. temp. (°C): February	10 to 17
Mean daily min temp. (°C): July	0 to 7
Median annual simulated runoff (mm) for quaternary catchment	<5 to 40, 40 to 60 (limited)

Main attributes	**23 Western Folded Mountains**
Terrain Morphology: Broad division (Primary)	Plains, Low Relief (limited), Plains Moderate Relief (limited), Lowlands, Hills and Mountains, Moderate and High Relief, **Closed Hills, Mountains, Moderate and High Relief,** Table-Lands: Moderate and High Relief.
Vegetation types (dominant types in bold) (Secondary)	**Mountain Fynbos,** Central Mountain Renosterveld, West Coast Renosterveld (very limited), Little Succulent Karoo, Upland Succulent Karoo (very limited), Strandveld Succulent Karoo (very limited), Central Nama Karoo (1 patch).
Altitude (m a.m.s.l) (secondary)	300-1700
MAP (mm) (modify)	200 to 1500
Coefficient of Variation (% of annual precipitation)	<20 to 39
Rainfall concentration index	50 to >65
Rainfall seasonality	Winter
Mean annual temp. (°C)	10 to 20
Mean daily max. temp. (°C): February	20 to 32
Mean daily max. temp. (°C): July	<10 to 20
Mean daily min. temp. (°C): February	8 to 17
Mean daily min temp. (°C): July	0 to 7
Median annual simulated runoff (mm) for quaternary catchment	<5 (limited), 5 to >250

Main attributes	**25 Western Coastal Belt**
Terrain Morphology: Broad division (primary)	**Plains, Low Relief**, Plains Moderate Relief, Closed Hills, Mountains, Moderate and High Relief.
Vegetation types (dominant types in bold) (Secondary)	**Lowland Succulent Karoo**, Upland Succulent Karoo (limited), Strandveld Succulent Karoo.
Altitude (m a.m.s.l) (Secondary)	0-700
MAP (mm) (modify)	0 to 300
Coefficient of Variation (% of annual precipitation)	35 to >40
Rainfall concentration index	45 to 64
Rainfall seasonality	Winter
Mean annual temp. (°C)	16 to 22
Mean daily max. temp. (°C): February	24 to >32
Mean daily max. temp. (°C): July	16 to 22
Mean daily min. temp. (°C): February	14 to 17
Mean daily min temp. (°C): July	4 to 9
Median annual simulated runoff (mm) for quaternary catchment	<5

Main attributes	**26 Nama Karoo**
Terrain Morphology: Broad division (Primary)	Plains, Low Relief**,** **Plains Moderate Relief,** **Lowlands, Hills and Mountains, Moderate and High Relief,** Open Hills, Lowlands, Mountains, Moderate to High Relief, Closed Hills, Mountains, Moderate and High Relief.
Vegetation types (dominant types in bold) (Primary)	Eastern Mixed Nama Karoo, Upper Nama Karoo, **Bushmanland Nama Karoo,** Orange River Nama Karoo.
Altitude (m a.m.s.l) (secondary)	300-1700
MAP (mm) (modify)	0 to 500
Coefficient of Variation (% of annual precipitation)	30 to >40
Rainfall concentration index	15 to >65
Rainfall seasonality	Late to very late summer to Winter
Mean annual temp. (°C)	12 to 20
Mean daily max. temp. (°C): February	26 to >32
Mean daily max. temp. (°C): July	10 to 20
Mean daily min. temp. (°C): February	12 to 17
Mean daily min. temp. (°C): July	0 to 5
Median annual simulated runoff (mm) for quaternary catchment	<5 to 60

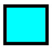
APPENDIX B

KEY TO NODE SYMBOLS

River Nodes: are coded numerically but preceded by a capital "R" to distinguish river nodes from other aquatic ecosystem nodes.

Symbolises river nodes on maps according to a set of tiers which define the criteria used for the designation of nodes. A different colour denotes a different tier.

Estuarine Nodes: are coded numerically but preceded by a capital "E" to distinguish estuarine nodes from other aquatic ecosystem nodes.



Symbolises estuarine nodes on maps. A different colour denotes a different estuary.

Groundwater nodes: are coded numerically but preceded by "GW" to distinguish them from aquatic ecosystem nodes.

Symbolises groundwater nodes on maps according to a set of tiers that define the criteria used for the designation of groundwater nodes. A different colour denotes a different tier.

Wetland nodes: are coded numerically but preceded by "W" to distinguish them from other aquatic ecosystem nodes.

Symbolises wetland nodes on maps according to a set of tiers that define the criteria used for the designation of wetland nodes. A different colour denotes a different tier.

APPENDIX C

GEOMORPHOLOGICAL ZONATION OF RIVER CHANNELS

(after Rowntree and Wadeson, 1999; 2000)[55]

Longitudinal Zone	Macro-reach Characteristics	Characteristic Channel Features
	Gradient class	
A. Zonation associated with 'normal' profile		
Source zone	not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peat hydromorphic soils.
Mountain headwater stream	>0.1	A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	0.04 - 0.09	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Mountain stream (transitional)	0.02 - 0.039	Moderately steep stream dominated by bedrock or boulder. Reach types include plane-bed, pool-rapid or pool-riffle. Confined or semi-confined valley floor with limited floodplain development.
Upper Foothills	0.005 – 0.019	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane-bed, pool-riffle, or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel or cobble often present.
Lower Foothills	0.001 - 0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool-riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Floodplain often present.
Lowland river	0.0001 – 0.001	Low gradient alluvial fine bed channel, typically regime reach type. May be confined, but fully developed meandering pattern within a distinct floodplain develops in unconfined reaches where there is an increased silt content in bed or banks.
B. Additional zones associated with a rejuvenated profile		
Rejuvenated bedrock cascades	>0.02	Moderate to steep gradient, confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.
Rejuvenated foothills	0.001 – 0.02	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro-channel activated only during infrequent flood events. A limited flood- plain may be present between the active and macro-channel.
Upland flood plain	<0.005	An upland low gradient channel, often associated with uplifted plateau areas, as occur beneath the eastern escarpment.

[55] These zones have been determined by DWAF for the 1:500 000 rivers coverage for the whole of South Africa, and are available on request from DWAF.

APPENDIX D

RESERVE ESTIMATES VALIDATION MODEL

The purpose of this model (called '*Reserve Validation*' model) is to route time series of Reserve estimates through the sub-areas of a catchment and to check whether upstream requirements (at the upstream end of a specific sub-area), combined with incremental requirements (within the sub-area) will satisfy the downstream requirements (at the outlet of the sub-area).

The model needs to allow for the generation of Reserve estimates using the Desktop Reserve model, as well as being able to generate a Reserve estimate based on a user defined table of requirements (as may be generated from a higher confidence estimate). In the latter case, the table of requirements (monthly distributions of maintenance and drought low flows and maintenance high flows) would be converted to a time series using a defined set of assurance rules and the natural flow time series. In the former case the Desktop model (with default parameters or locally calibrated parameters) would be used to generate the table of requirements.

Setting the model up within SPATSIM requires that the sub-area links are identified using a text type attribute that specifies the sub-area that is downstream of any other sub-area. These relationships are already established in SPATSIM and are stored using an attribute called 'Downstream Area'. Starting the model requires that this attribute be highlighted. The 'Identify Upstream Elements' icon is then clicked and then the most downstream sub-area for the required basin is identified and clicked. This will highlight all the upstream catchments and allow the user to start setting up the model.

The inputs to the model are as follows:

Catchment ID name: A text type attribute that is used to identify the sub-areas in the catchment.

Incremental natural flow time series: A time series attribute of monthly flow volumes (Mm^3), representing the incremental sub-area contribution to flow.

Cumulative natural flow time series: A time series attribute of monthly flow volumes (Mm^3), representing the cumulative flow at a sub-area outlet and including losses through channel evaporation or seepage. If this input is not available or not specified, the cumulative flows will be calculated using the incremental flow data and the simple loss model (see next set of inputs).

Reserve category: An integer attribute representing the initial Reserve category (0=A, 1=A/B, etc.). This can be changed during the running of the model, but note that this will mean that Desktop estimates will be generated.

Incremental catchment area: A real attribute representing the catchment area of each sub-area in km^2. The cumulative areas are calculated from these values and the spatial linkages.

Mean annual rainfall: A real attribute for the mean annual rainfall (MAP mm).

Mean annual evaporation: A real attribute for the mean annual evaporation (MAE mm).

ERC Parameter data: A 2D array attribute (table of data of type '*Desktop Model (V2) Category Dependant Parameter Values*') that provides the Desktop model parameters for each ERC (A to D). These are normally fixed values and not region specific. However, as an array is read in for each sub-area, there can be spatial variations in these parameters if they have been re-calibrated.

Incremental single parameters: A 1D array attribute (of type '*Desktop Model (V2) Single Parameter Values*') of Desktop model parameters, including the region number and baseflow separation parameters. These are appropriate for the incremental sub-areas (i.e. no influence from upstream areas).

Cumulative single parameters: A 1D array attribute (of type '*Desktop Model (V2) Single Parameter Values*') of Desktop model parameters, including the region number and baseflow separation parameters. These are appropriate for the cumulative area (i.e. including influences from upstream areas).

Incremental monthly distributions: A 2D array (of type '*Desktop Model (V2) Monthly Distributions*') of Desktop model assurance parameters that convert Reserve monthly tables into assurance rules. They are region specific and this input requirement refers to the incremental area.

Cumulative monthly distributions: A 2D array (of type '*Desktop Model (V2) Monthly Distributions*') of Desktop model assurance parameters that convert Reserve monthly tables into assurance rules. They are region specific and this input requirement refers to the cumulative area.

Incremental Reserve table: An optional input of a 2D array (of type '*Reserve Table (Extended High Flows) Monthly IFR Requirements in m^3/S or durations*') of Reserve table requirements (the model assumes that the extended table format with 6 flood categories is used) that will over-ride the Desktop estimates if data are available for any sub-area.

Cumulative Reserve table: An optional input of a 2D array (of type '*Reserve Table (Extended High Flows) Monthly IFR Requirements in m^3/S or durations*') of Reserve table requirements (the model assumes that the extended table format with 6 flood categories is used) that will over-ride the Desktop estimates if data are available for any sub-area.

At present there is a single output and that represents the time series of deficits for each sub-area. A deficit is defined as the difference between the cumulative requirement at a sub-area outlet and the sum of the cumulative requirement at the upstream end plus the incremental requirement less any losses.

If the incremental flows are used in the model to estimate cumulative flows, the losses from upstream cumulative flow that occur in any sub-area are estimated using the following equation:

$$\text{Mean Annual Losses (Mm}^3\text{)} =$$

$$\text{(MAE – MAP)} * 0.001 * (0.0045 * \text{inc\_area}^{0.5} * \text{cum\_area}^{0.32})$$

Where $\text{inc\_area}^{0.5}$ is used to represent the length of the channel within a sub-area, while $\text{cum\_area}^{0.32}$ is used to represent the channel width, with cum-area being the total catchment area upstream of the current sub-area. One twelfth of this estimated mean annual loss volume is applied equally to all months in the time series. It is used during the accumulation of the incremental flows if the cumulative flows are not read from SPATSIM. The losses estimate used in any sub-area to reduce upstream Reserve requirements is based on the difference between the downstream cumulative flows and the sun of the upstream cumulative flows and the local incremental flow. Reserve loss estimates are therefore consistent with the input natural flow data.

Figure 1 shows the main screen with 6 button options that are available once the input data have been loaded.

The ‘Generate cumulative flows from incremental’ needs to be used to generate cumulative flows if they have not been input, or if it is decided to use the simple loss model. Clicking this button automatically runs the Desktop model for all sites and performs the flow routing.

The ‘Run Desktop model’ generates the incremental and cumulative Reserves for the input ERCs (or those listed in the table) and temporarily stores them. Clicking this button performs the flow routing as well.

The ‘Route Flows’ button compares and checks the cumulative Reserves and generates the data for the No. Deficit and Deficit/Month columns. The No. Deficit lists the number of months when the cumulative requirement at the sub-area outlet is greater than the sum of the upstream cumulative requirement plus the incremental requirement minus the losses. The Deficit/Month lists the mean monthly deficit in Mm^3 (the mean is based on all months and includes those with no deficit). The ‘Check Inc/Cum Reserve’ simply lists the time series of requirements so that these can be visually compared to requirements generated outside this model (by the SPATSIM or stand-alone version of the Desktop model, for example). As this procedure is called automatically by the previous two, it should not be necessary to use the button.

If the ERC is changed within the table (using A, A/B, B, B/C, C, C/D or D), the ‘Save/Set ERC’ button can be used to store this information and then the ‘Run Desktop Model’ and ‘Route Flows’ buttons are used to update the validity check.

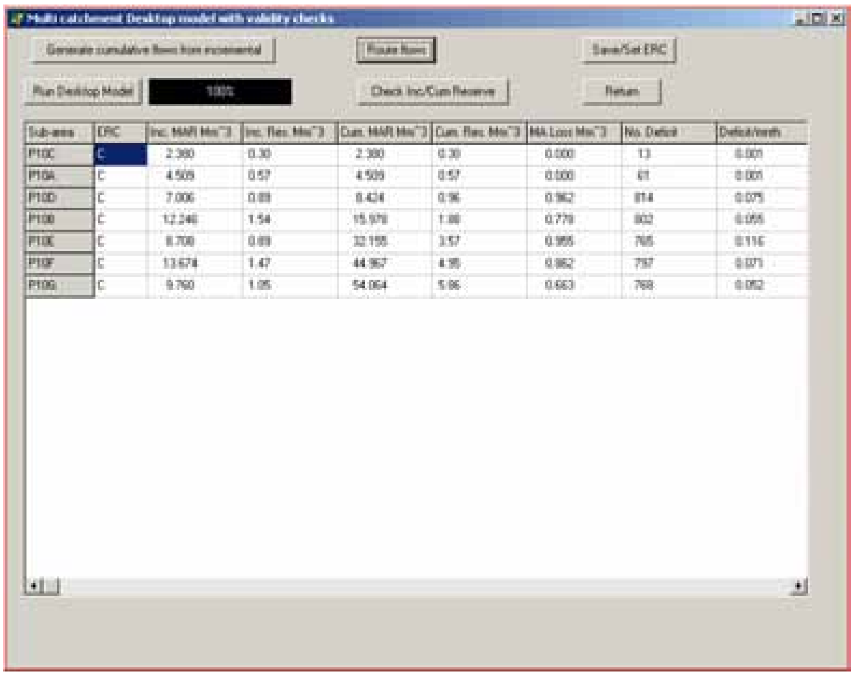


Figure 1 Main screen for the model

One of the things to be careful of is that the incremental and cumulative natural flows that are part of a SPATSIM database are consistent with each other (i.e. have been generated using the same model and with the same approach). If they are not then it is quite possible that false deficits will be generated.

A further possible problem may occur when the simple loss model is used to generate the cumulative flows. The mean monthly losses are subtracted from all monthly flows, while in reality higher flows may lose proportionally higher losses. There is no simple way of estimating channel losses reliably and it should be recognized that the simple approach used will not always generate totally realistic answers.

If more detailed analyses of the deficits are required, simply save the data and use the graphical display facilities of TSOFT to evaluate the time series of deficits, compared with (for example) the cumulative Reserve at the same site.

Installing the new files

The new files are distributed in a zip file with the name res_valid.zip. When all the files are unzipped, place them in the following sub-directories under the main SPATSIM folder.

Res-valid.exe: put in the SPATSIM\bin directory.

Res_valid.req: put in the SPATSIM\text_data directory.