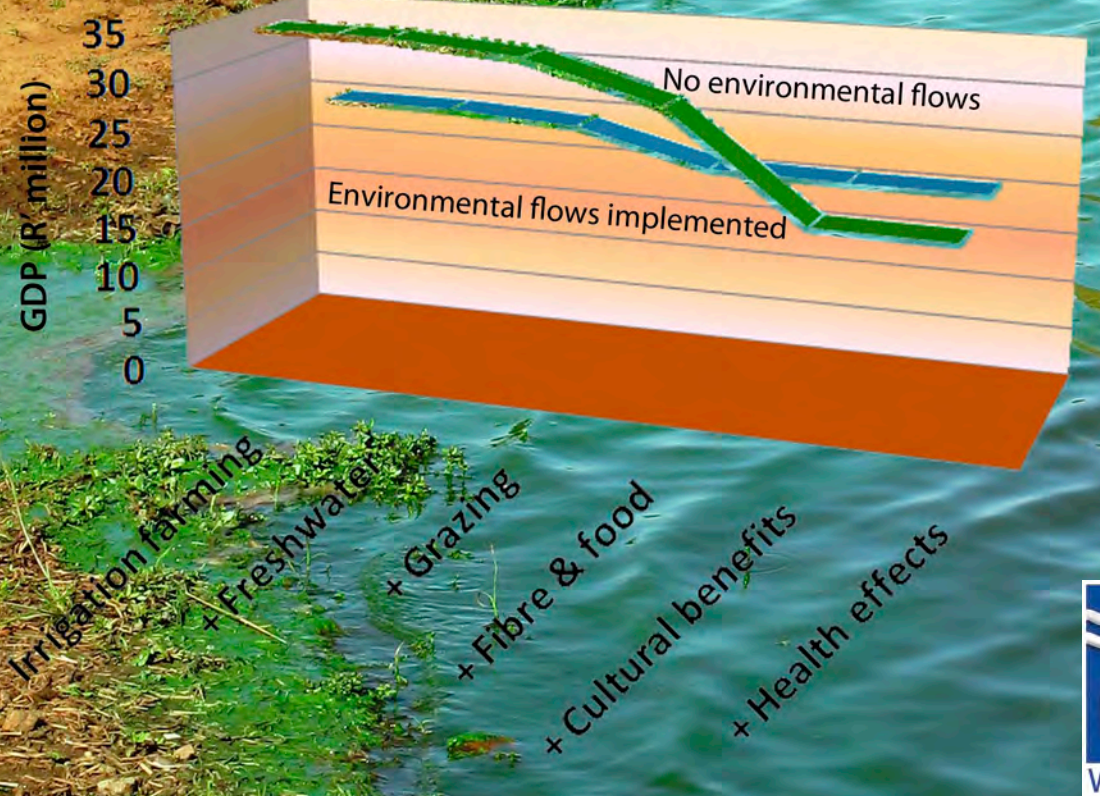
Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures

AE Ginsburg, JG Crafford & KR Harris
with contributions from
M Wilkinson & D Mashimbye



WATER RESEARCH COMMISSION

TT 462/10

Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures

Report to the
Water Research Commission

by

AE Ginsburg JG Crafford & KR Harris
With contributions from
M Wilkinson and D Mashimbye

Prime Africa Consultants

WRC Report No. TT 462/10

JULY 2010

Obtainable from:

Water Research Commission
Private Bag X03
Gezina
0031

The publication of this report emanates from a project entitled: *Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures* (WRC Project No. K5/1644).

The contract for this report was entered into by CIC International but during the course of the project the company's name changed to Prime Africa Consulting.

Disclaimer

This report has been reviewed by the Water Research Commission (WRC) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the WRC, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Cover photographs provided by Aimee Ginsburg and Melanie Wilkinson

ISBN 978-1-77005-997-9
Printed in the Republic of South Africa

Executive Summary

Document purpose

This document provides a Framework and Manual to guide practitioners conducting the evaluation of aquatic ecosystem services required in establishing Resource Directed Measures for the protection of water resources in any Water Management Area (WMA) or subsidiary catchment.

This document integrates a complex set of disciplines, approaches and methods and is therefore structured into four parts: (1) an introduction to and overview of the Framework; (2) the Manual; (3) a case studies part; and (4) a supplementary information part. The Manual describes the detailed tasks within each phase required for the evaluation process. The supplementary information part is a series of Annexures which provide background information to the execution part (manual).

The Framework consists of four phases, each with a number of tasks:

Phase 1: Systems analysis
Phase 2: Assessment of ecological change
Phase 3: Valuation of ecosystem services
Phase 4: Evaluation of trade-offs

The user is guided in a step-by-step manner through each phase.

Problem statement

The Manual is based upon a framework which can be used to evaluate the trade-offs in allocating water to various beneficial uses, including use of water by aquatic ecosystems.

The point of departure for this Framework is the National Water Act (NWA, No 36 of 1998), which promotes "the integrated management of water resources with the participation of all stakeholders" (NWA 1998). The National Water Resource Strategy (NWRS; DWAF 2004) is an instrument of policy following from NWA and "aims to strike a balance between the use of resources for livelihoods and conservation of the resource to sustain its functions for future generations, and promotes social equity, environmental sustainability and economic efficiency".

This is a process that invariably requires negotiation of *trade-offs* around the protection, use, development, conservation, management and control of water resources that deliver benefits to a wide range of stakeholders with diverse interests.

These trade-offs are principally between the resource quality on the one hand and the beneficial use of water on the other. “To give effect to the interrelated objectives of sustainability and equity” the NWRS adopts “an approach to managing water resources... that introduces measures to protect water resources by setting objectives for the desired condition of these water resources, and putting measures in place to control water use to limit impacts to acceptable levels” (NWRS). The NWRS adopts two complementary strategies to achieve this balance:

a) Resource Directed Measures (RDM) that undertake to protect water resources by setting goals and objectives for the desired condition[1] of water resources in aquatic ecosystems; and
b) Source Directed Controls (SDC) that specify criteria for controlling water resource use activities and their impacts on aquatic ecosystems.

The crux of the RDM, and the basis of water resource management in South Africa, is the determination of a Management Class (MC) which prescribes what the quality and overall health of the water resource should be. The MC is defined in terms of the resource quality that must be maintained. Resource quality includes water quantity and quality, as well as the “character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota” (DWAF 2003). Management Classes are determined using the Water Resource Classification System (WRCS)[2]. The overall objective of the WRCS is to classify water resources in terms of Class I (Minimally used), Class II (Moderately used), Class III (Heavily used) (Dollar et al., 2007). Based on the MC for each significant water resource, the Reserve[3] and the resource quality objectives (RQOs) for that water resource are prescribed.

The WRCS is in harmony with the Reserve determination procedure that was developed in the face of urgent needs to address compulsory licensing and water allocations issues. At present, the ecological Reserve determination procedure determines a recommended EcoStatus Category[4] (EC; sometimes called ecological category) which is taken to be the preliminary Management Class of

---

[1] An awkward term that often raises queries - but refers to the way society (in general or a particular group) regards the ecological condition of the water resource with respect to the its fitness-for-use status for particular uses. Different segments of society may disagree on what the desired state must be, depending on what they think the function of the water resource should be. Effective public participation is therefore important to the determination of the desired state.

[2] At the time of writing this report, the WRCS was in final draft format, and had not yet been gazetted by the Minister.

[3] “The Reserve includes the water quantity and quality required to meet basic human needs, and to protect aquatic ecosystems. It has priority over all water uses, and the requirements of the Reserve must be met before water quantity and quality can be allocated for other uses” (DWAF 2003).

[4] In line with the Parsons and Wentzel (2007), the terms 'class' is reserved to mean the management class of a water resource, while to avoid confusion the term 'category' is used to for all grouping of water resources (i.e. water resource 'categories' and Reserve categories) prior to public participation (Step 6 in the WRCS).

the water resource (Dollar et al., 2007). These categories are determined by the RDM assessment team using a range of well researched and tested tools (Hannart and Hughes, 2003; Brown et al., 2006; Kleynhans and Louw, 2007). Figure A illustrates the relationship between the Reserve categories and Management Classes.

Class I Minimally used	**Class II Moderately used**		**Class III Heavily used**		**Management Classes**
Excellent	Good		Fair	Poor	**Water Resource Classification**
A Minimal	**B** Minimal	**C** Moderate	**D** Heavy	**E/F** Unacceptable	**Ecological Categories User Impact**
Unmodified	Slightly modified	Moderately modified	Considerably modified	Critically modified	**Ecological condition**

Figure A. Diagram of a proposed system of water resource classification and its relationship to other interim classification systems (adapted from Palmer et al., 2004; Parsons and Wentzel, 2007; Dollar et al., 2007). Each ecological category (A-E/F or natural to unacceptable) is defined by numerical and descriptive objectives termed ecological specifications (ecospecs), which are combined with the requirements of users (userspecs) into resource quality objectives (RQOs) and define a set of associated management classes (Class I-III). The A-E classification is generally restricted to defining ecological categories while the Excellent-Poor nomenclature has been used to define water quality ecospecs as well as to describe management classes that combine both userspecs and ecospecs.

Aquatic ecosystem services comprise all the environmental goods and services produced by a water resource, that provide benefits to people and that therefore contribute to human well-being (Fisher et al., 2008). While utilisation of the resource provides socio-economic benefits, such as fresh water; over-utilisation could compromise ecosystem integrity, which results in dis-benefits, or socio-economic costs, for instance a loss in natural water purification services. There is therefore a direct relationship between water resource quality and aquatic ecosystem services.

Furthermore, a water resource produces a bundle of aquatic ecosystem services. Such a bundle of services could include, by example, fresh water, water purification, natural hazard alleviation, aesthetic services and others as defined later in this report. When a MC changes (usually as a result of the implementation of a project or policy), it is likely that the bundle of aquatic ecosystem services would also change, with some benefits increasing and others decreasing. Benefits vary depending on the nature of the resource and the nature of its use; and so ecosystem services provided will vary case by case.

These changes in benefits would affect various beneficiary groups, and results in trade-offs.

The WRCS therefore outlines the implications of different MCs, which are based on specific water resource management scenarios for a particular water resource, to facilitate informed decision-making about trade-offs.

This Framework and Manual explores how these scenarios and their associated trade-offs should be evaluated.

The Framework and Manual

A key consideration in the development of the Framework has been integration with existing (other) frameworks, approaches and methodologies in the RDM domain and its related disciplines. The Framework was therefore designed to prevent duplication of effort, to minimise the development of new and complex approaches and methodologies, and to integrate with existing analyses and processes.

This Framework therefore adopts:

- Best practices of the Reserve determination and WRCS processes;
- Best practices in the definition and classification of ecosystem services; and
- Best practices of economic valuation (including environmental economic valuation).

The crux to solving the problem to linking ecological classification (following from the Reserve determination and WRCS processes) and the economic value of ecosystem services supplied by the resource, necessitated the introduction of two key aspects:

- The adoption of an ecosystem approach and application of the Millennium Ecosystems Assessment (MA) framework for defining the benefits yielded by the ecosystem (i.e. ecosystem services) (taking in account subsequent work in the definition and classification of ecosystem services); and
- The adoption of comparative risk assessment (CRA) methodology to develop the causal chains linking ecological production to the defined ecosystem services.

Inherent to the ecosystem approach of the MA is the understanding that socio-ecological systems are complex and dynamic. Management interventions will: be based on incomplete knowledge or understanding of ecosystem functioning; have unforeseen feedbacks over the long term; be insufficient for coping with continuous change and future shocks; and be unable to account for all social, economic and ecological influences at multiple scales (MA, 2003; Pollard et al., 2008). But methodologies that take all these characteristics of socio-ecological systems into account (such as comparative risk assessment) hold greater potential for identifying and adapting management approaches that increase a system's resilience and adaptive capacity and set the system on a more sustainable trajectory (Resilience Alliance, 2007a, b; Pollard et al., 2008).

A four phased Framework, set out in Figure B below, forms the logical construct that accommodates the above considerations. This four phased approach ensures a systematic approach to evaluating the changes in the ecological category of aquatic ecosystems. This simplified overview does not intend to mask the considerable complexities in the causal links between these stages and although presented sequentially, the process has an iterative nature.

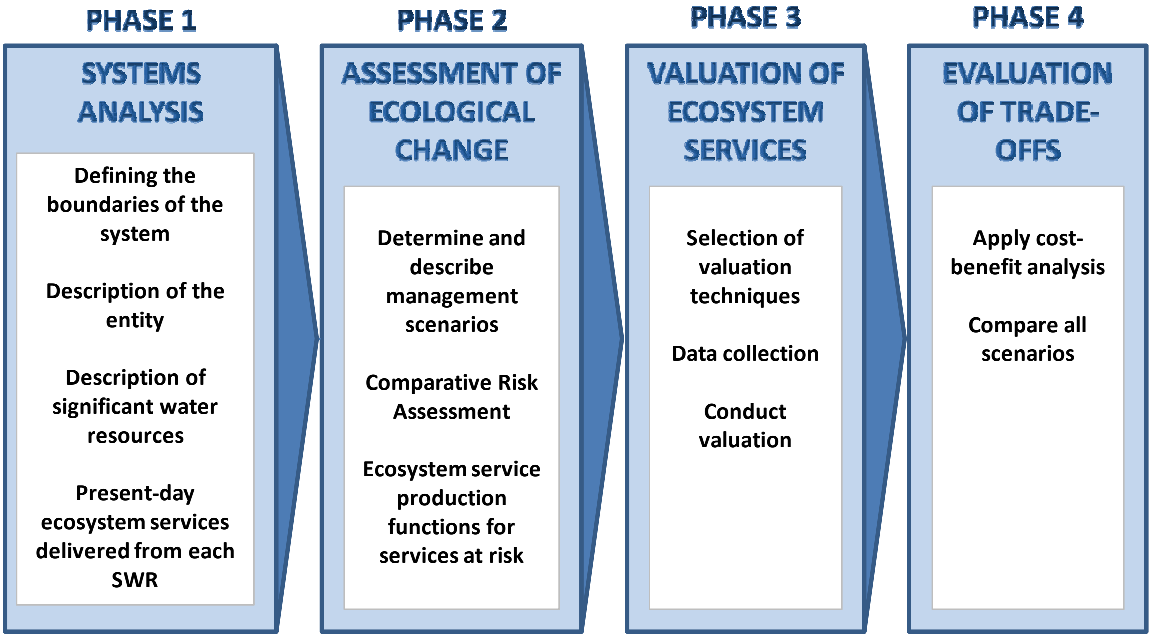


Figure B. Simplified overview of the WRC aquatic ecosystem service evaluation framework

Phase 1, the systems analysis, achieves the following objectives:

- It defines the system that is subject to enquiry,
- It assembles all relevant and valid scientific information about the system,
- It describes the management scenarios, which provide the options for water resources management and water infrastructure operations.

The first two steps of Phase 2 take place largely in a workshop environment, where domain experts evaluate the agreed upon scenarios in terms of their feasibility, gaining agreement that scenarios are reasonable and suitably different to explore a range of management options and the consequences thereof. The EcoClassification methodology, combined with Comparative Risk Assessment (CRA), are used here for assessing, comparing, ranking and formally describing the risks in an environment where different aquatic ecosystem services are at risk, and for each of which different kinds and depths of data are available. Using the CRA method, experts may formulate the chains of causality between a development activity or management scenario, the resulting change in ecosystem assets and effect on ecosystem services[5]. In addition, the CRA serves to rate the consequences associated with the subsequent environmental effects and its uncertainty. Chains of causality exist between ecosystem assets, drivers that impact upon them, ecosystem services and the benefits that are derived from these services. When these chains are defined and quantified through the selection and measurement of appropriate indicators, they form the bases for the development of production functions for each ecosystem service.

In Phase 3 the production functions developed in Phase 2 are integrated into socio-economic demand functions. A wide variety of valuation techniques exist through which to estimate demand. These are discussed in detail in the accompanying Manual.

In Phase 4, the different water resource management scenarios are compared, using the combined outputs of Phase 2 and 3. These form a set of trade-offs of costs and benefits that are evaluated through cost-benefit analyses. The CBA informs two types of decision-making (a) whether a particular scenario is worthwhile being pursued and (b) where more than one scenario option is available, which of these are more beneficial. A particular management scenario or project/activity is worthwhile being pursued if the net present social value is positive. The more beneficial project option has a higher net present social value.

This Framework and Manual can be used with any assessment of ecosystem services in aquatic ecosystems (i.e. in rivers, wetlands, groundwater, estuaries or marine environments). Linkages with the WRCS will be highlighted for convenient comparison and combined usage. It is important to note that the WRCS has not been gazetted yet and may still undergo some changes during finalisation.

By reviewing most recent and relevant literature, nationally and internationally, we provide a Manual for valuing ecosystem services that:

- is based on best scientific knowledge;
- is considerate of the complex adaptive social-ecological systems that deliver ecosystem services;
- exemplifies the need for intelligent thought in each case;
- proposes comparative risk assessment as a useful tool in prioritizing risks to ecosystem service provision and as a means of scaling down to the requisite simplicity;
- makes hypotheses explicit in order to test assumptions and facilitate learning;

[5] From here on in, the report refers to “aquatic ecosystem services” simply as “ecosystem services”.

- evaluates available methodologies and techniques for valuation in an objective manner;
- all the while being cognizant that this is a stepping stone in the continued pathway of learning around ecosystem service valuation;
- adopts a pragmatic approach which encourages practitioners in learning and adaptive analyses; and
- considers the aquatic ecosystem services benefits accruing to all beneficiaries, while accommodating a public participation process.

This Framework and Manual provides a comprehensive review and guide that:

- can be applied to any water resource;
- serve to support the WRCS;
- provides guidance on the integration of the current Reserve determination process with the WRCS;
- provides a causal description and understanding of aquatic ecosystems, the ecosystem services they support and the effects of water resource management on these;
- clarifies the valuation of ecosystem services delivered by aquatic ecosystems for RDM; and
- provides best practise while avoiding being overly prescriptive.

In addition, the Manual allows for desktop, rapid, intermediate or comprehensive studies that are consistent with the requirements of the WRCS.

Case studies

The document concludes with two case studies. The first is a rapid study conducted in the Steelpoort catchment area, and the second simulates a large intermediate to comprehensive study done on the construction of a hypothetical project in the Sand River catchment.

Both case studies are for demonstration purposes only, and do not include detailed description of all assumptions, methodological steps followed and other diligence conducted.

The Steelpoort catchment study demonstrates how an assessment may be conducted using a small budget.

The Sand River study compares two scenarios, the first allocates the water from a new dam to an irrigation scheme with large social benefit, leaving a small ecological Reserve, whereas the second allocates less water to the irrigation scheme and more to the ecological Reserve.

In the case of the Sand River Catchment, without consideration of the value of ecosystem services lost, Scenario 1 (Management Class III and Ecological Category C/D) is the favoured option. However, after adding the full cost of ecosystem services, Scenario 2 (Management Class II and EcoClass B) becomes the favoured option.

Key conclusion

It is (a) not possible and (b) irresponsible to attempt to assign a categorical set of values to a generic Management Class or river Ecological Category. Every water management scenario, applied to different river systems, will have unique environmental effects which have to be quantified in a diligent manner, following the guidelines of this Framework and Manual.

Recommendations for further research

Through the development of this Framework and Manual, a number of opportunities worthy of further exploration were identified and include:

- Collation of evidence of the linkages between biodiversity, ecosystem change and ecosystem service delivery that are specific, or applicable, to southern African aquatic ecosystems (similar to the review by Balmford et al., 2008). This would provide a source of evidence for production functions and models of ecosystems services (with different levels of complexity and data inputs for different levels of Reserve determination). The data collected and analysed by RDM specialists, particularly through the EcoClassification Process and other models, should be explored to: clarify what site-specific data relevant to ecosystem service production functions is available; and/or isolate additions or slight alterations to the type of data collected by the specialists. This would highlight gaps in knowledge and evidence of linkages between ecological components, ecosystem services and benefits to human well-being. A particular need in such research is likely to be in relation to:

    identifying changes in the regulating ecosystem services, as amongst the most important environmental consequence of human activities, and the relationship of these changes to thresholds and the resilience of the system;
    links to human vulnerability, i.e. where thresholds to ecological change in a system will affect the delivery of ecosystem services necessary for economic growth, redress of inequality and poverty alleviation would be compromised; and
    improving our ability to track the effect of these on human well-being.

- The exploration of risk terminology as a basis for dialogue in the management of the allocation and use of water resources requires further exploration. The concept of risk to ecosystem services is more broadly understandable to a wide range of stakeholders than statements on how ecosystem components will change. This is important in the communication of trade-offs and the implications thereof when it comes to stakeholder participation. Such research will develop insights into the strategic management of dialogue in complex decision making contexts and the importance of this for sustaining water resources in a dynamic and uncertain global environment.
- Aquatic ecosystem services evaluation needs to link with collateral decisions in the domains of biodiversity and land management, and such a linkage would in turn offer efficiency gains through minimizing redundancy in the evaluations as well a supporting necessary meta-analysis.
- As the WRCS is implemented, one would expect trade-offs to be continually changing. The Framework proposed here has to be continually assessed and improved, where necessary, to adapt to the changing environment.

Acknowledgements

This report was authored by Aimee Ginsburg, Mr Jackie Crafford, Mr Kyle Harris supported by Ms Melanie Wilkinson[6], Ms Dineo Mashimbye[1], Ms Retha Stassen[7], Dr Fred Kruger[8], Dr Dirk Roux[9], Dr Mark Keith and Ms Ernita van Wyk[10].

In addition, a number of persons and organizations contributed kindly and significantly to the efforts of the project team.

The Water Research Commission is gratefully acknowledged for financial support.

We would further like to thank Dr Harry Biggs of the Kruger National Park, Professor Kevin Rogers and Mr. Craig McLoughlin of the University of the Witwatersrand, Dr Laurence Kruger and Karen Vickers of OTS Skukuza, Dr. Sharon Pollard of AWARD, Steve Mitchell of the WRC, for their interest and support, particularly through the Comparative Risk Assessment workshop.

Prof Rashid Hassan of the University of Pretoria and Prof Charles Perrings of Arizona State University are also acknowledged for many of the insights provided to the project team.

The Organisation for Tropical Studies (OTS) participated during the valuation phase of the study, where 20 students assisted with primary data gathering. We would like to specially acknowledge the contribution of Vuyi Matokazi, an OTS student and employee of SANParks. She died in September 2008.

Finally also, a special word of thanks to Prof Charles Breen, who contributed significant time with the project team members to test concepts and act as a soundboard.

[6] Sustento Development Services

[7] JMM Stassen and Associates

[8] Fred Kruger and Associates

[9] Monash University

[10] South African National Biodiversity Institute

Table of Contents

List of Boxes

List of Tables

List of Figures

Acronyms

ADE	Aquifer-dependent ecosystem
Asgi-SA	Accelerated and Shared Growth Initiative – South Africa
AWARD	Association for Water and Rural Development
BBM	Building Block Methodology
BCA	Benefit-cost analysis
BHNR	Basic Human Needs Reserve
Billion	10^9
BTM	Benefit Transfer Method
CBA	Cost-benefit analysis
CE	Critically endangered
CEBC	Centre for Evidence-Based Conservation
CGE	Computable General Equilibrium model
CIC	CIC International, the former name of Prime Africa Consultants
CMA	Catchment Management Agency
CRA	Comparative Risk Assessment
CS	Consumer Surplus
CSIR	Council for Scientific and Industrial Research (South Africa)
CVM	Contingent Valuation Method
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DRIFT	Downstream Response to Imposed Flow Transformations
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry[11]
E	Endangered
EBE	Evidence based ecology
EC	EcoStatus Class
EEA	Environmental Economic Account
EGSA	Environmental Goods, Services and Attributes
EISC	Ecological importance and sensitivity categories
ELU	Existing Lawful Use
EMC	Ecological Management Class
ERA	Ecological Risk Assessment
ERE	Environmental-and-Resource-Economics
ES	Ecosystem Service
ESBC	Ecologically Sustainable Base Configuration
EWR	Ecological Water Requirement
FHSR	Flow Habitat Stressor Response
GDP	Gross Domestic Product
GGP	Gross Geographic Product

[11] During the completion of this project, the Department of Water Affairs and Forestry (DWAF) changed its name to the Department of Water Affairs (DWA). This report uses both the DWA and DWAF acronyms, as appropriate, to refer to the Department and/or publications by the Department.

GIS	Geographic Information System
ha	hectare
HGM	Hydrogeomorphic classification system for wetlands
HI	Hydrological Index
IBT	Inter-basin transfer
IC	Intermediate Consumption
IMF	International Monetary Fund
I-O	Input-Output table
IPCC	Intergovernmental Panel on Climate Change
ISP	Internal Strategic Perspective
IUA	Integrated Unit of Analysis
IWRM	Integrated Water Resources Management
K	Capital
km	kilometer
KNP	Kruger National Park
L	Land
m	meter
MA	Millennium Ecosystems Assessment
MAE	Mean annual evaporation
MAP	Mean annual precipitation
MAR	Mean Annual Runoff
MC	Management Class
MCA	Multi-criteria analysis
MOA	Memorandum of Agreement
MRU	Management Resource Unit
NEMBA	National Environmental Management: Biodiversity Act, No. 10 of 2004
NEMPAA	National Environmental Management: Protected Areas Act. No. 57 of 2003
NHRA	National Heritage Resources Act, No 25 of 1999
NPV	Net Present Value
NPSV	Net Present Social Value
NRA	Natural Resource Account
NRC	National Research Council (US)
NWA	National Water Act
NWRS	National Water Resources Strategy
NYC	New York City
NYS	New York State
OECD	Organisation for Economic Cooperation and Development
PES	Payments for Ecosystem Services
PES	Present Ecological Status
PFES	Payments for Ecosystem Services
Q	Quantity
QC	Quaternary catchment

RAU	Reserve Assessment Unit
RC	Recommended Class
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RHP	River Health Programme
RQO	Resource Quality Objectives
RU	Resource Unit
SA	South Africa
SAB	Scientific Advisory Board (USA)
SAM	Social Accounting Matrix
SASQAF	South African Statistical Quality Assessment Framework
SDC	Source-directed controls
SEM	Structural Equation Modelling
SES	Socio-ecological system
SEZ	Socio-economic zone
SMS	Safe minimum standard
SPATSIM	Spatial and Time Series Information Modelling
SRC	Sand River Catchment
StatsSA	Statistics South Africa
SWR	Significant Water Resource
TCM	Travel Cost Method
TEV	Total economic value
TPC	Thresholds of Potential Concern
USA	United States of America
VAD	Value Added
V-STEEP	Conservation planning protocol (Rogers, 2007)
WfW	Working for Water Programme of DWA
WMA	Water Management Area
WMI	Water Management Initiative (USA)
WRA	Water Resource Account
WRC	Water Research Commission
WRCS	Water Resources Classification System
WRYM	Water Resources Yield Model
WSAM	Water Situation Assessment Model
WTA	Willingness-to-accept
WTP	Willingness-to-pay

PART I: FRAMEWORK

"It is becoming increasingly apparent that the ability of nations and societies to develop and prosper is linked directly to their ability to develop, utilize, and protect their water resources (DWAF and WRC 1996). Water resources are the cornerstone of industrial development and agricultural production, as well as being useful in the transportation of goods, production of energy, and enhancement of the quality of life through recreational opportunities (DWAF and WRC 1996). Thus most economies rely on their river systems and underground water resources for their development" (Walmsley, 2007).

1.1. Introduction

This document provides a framework through which to evaluate the trade-offs in allocating water to various beneficial uses, including beneficial use of water by aquatic ecosystems. The point of departure for this framework is the National Water Act (NWA 1998).

South Africa has some of the best water legislation in the world. At the core of the NWA, proclaimed in 1998, is the recognition that "water is a scarce and precious resource that belongs to all the people of South Africa. It also recognises that the ultimate goal of water resource management is to achieve the sustainable use of water for the benefit of all South Africans" (DWAF undated). The NWA thus "aims to protect, use, develop, conserve, manage and control water resources[12] as a whole, promoting the integrated management of water resources with the participation of all stakeholders" (NWA 1998).

The National Water Resource Strategy (NWRS; DWAF 2004) is an instrument of policy following from NWA. The NWRS adopts an approach to water resources management called integrated water resources management (IWRM). It defines IWRM as "… a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. IWRM therefore aims to strike a balance between the use of resources for livelihoods and conservation of the resource to sustain its functions for future generations, and promotes social equity, environmental sustainability and economic efficiency".

This is a large and complex task. It is also a process that invariably requires negotiation of *trade-offs* around the protection, use, development, conservation,

[12] The NWA (No 36 of 1998) has a broad definition of a **water resource**, which is here taken to be a set of aquatic ecosystems (including the riparian habitat). The Act does not define the term aquatic ecosystem. Under law, the common meaning must then apply. The Oxford English Dictionary defines aquatic as "of or relating to water". Parsons and Wentzel (2007) define aquatic ecosystems "as the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation".

management and control of water resources that deliver benefits to a wide range of stakeholders with diverse interests. These trade-offs are principally between the resource quality on the one hand and the beneficial use of water on the other. “To give effect to the interrelated objectives of sustainability and equity” the NWRS adopts “an approach to managing water resources... that introduces measures to protect water resources by setting objectives for the desired condition of resources, and putting measures in place to control water use to limit impacts to acceptable levels” (DWAF 2004). The framework to achieve this objective of protecting water resources while optimising its utilisation in a sustainable and equitable manner is provided in the National Water Resource Strategy (NWRS)[13]. The NWRS adopts two complementary strategies to achieve this balance:

a) Resource Directed Measures (RDM) that undertake to protect water resources by setting goals and objectives for the desired condition of water resources in aquatic ecosystems; and
b) Source Directed Controls (SDC) that specify criteria for controlling water resource use activities and their impacts on aquatic ecosystems.

The crux of the RDM, and the basis of water resource management in South Africa, is the determination of a Management Class (MC) which prescribes what the quality and overall health of the water resource should be. The MC is defined in terms of the resource quality that must be maintained. Resource quality includes the water quantity and quality, as well as the “character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota” (DWAF 2003). Management Classes are determined using the Water Resource Classification System (WRCS). The overall objective of the WRCS is to classify water resources in terms of Class I (minimally used), Class II (moderately used), Class III (heavily used) (Dollar et al., 2007). Based on the MC for each significant water resource, the Reserve[14] and the resource quality objectives (RQOs) for that resource are prescribed.

The management class for a given water resource can only be set after a catchment visioning and public participation process (thus taking into account technical input from water resource managers, specialists, as well as stakeholders and other social and economic factors). At the time of writing the WRCS had been drafted, public comment received but has not yet been gazetted. In the interim, a process for Reserve determination was developed in the face of urgent need to address compulsory licensing and water allocations issues, and only considers the ecological component of the Reserve. At present, the ecological Reserve

[13] See Annexure 1 for a comprehensive policy field analysis.

[14] “The Reserve includes the water quantity and quality required to meet basic human needs, and to protect aquatic ecosystems. It has priority over all water uses, and the requirements of the Reserve must be met before water quantity and quality can be allocated for other uses” (DWAF 2003).

determination assessment produces a recommended EcoStatus Category[15] (EC) which is taken to be the preliminary ecological Management Class of the water resource (Dollar et al., 2007).These categories are determined by the Reserve determination assessment team using a range of well researched and tested tools (Kleynhans and Louw, 2007). Figure 1 illustrates the relationship between the Reserve categories and Management Classes.

Class I Minimally used	**Class II Moderately used**		**Class III Heavily used**		**Management Classes**
Excellent	Good		Fair	Poor	**Water Resource Classification**
A Minimal	**B** Minimal	**C** Moderate	**D** Heavy	**E/F** Unacceptable	**Ecological Categories User Impact**
Unmodified	Slightly modified	Moderately modified	Considerably modified	Critically modified	**Ecological condition**

Figure 1. Diagram of a proposed system of water resource classification and its relationship to other interim classification systems (adapted from Palmer et al., 2004; Parsons and Wentzel, 2007; Dollar et al., 2007). Each ecological category (A-E or Excellent-Poor) is defined by numerical and descriptive objectives termed ecological specifications (ecospecs), which are combined with the requirements of users (userspecs) into resource quality objectives (RQOs), which define a set of associated management classes (Class I-III). The A-E classification is generally restricted to defining environmental categories while the Excellent-Poor nomenclature has been used to define water quality ecospecs as well as to describe management classes that combine both userspecs and ecospecs.

Utilisation of the resource provides economic and social benefits. Benefits are measured by ecosystem services, defined as *the aspects of ecosystems that are utilized by people to produce human well-being* (Fisher et al., 2008). Thus ecosystem services are the aspects of ecosystems (including ecosystem organisation or structure as well as process and/or functions) that are utilized by people to produce human well-being (MA, 2005; Fisher et al., 2008, 2009). Utilisation may be direct or indirect. This framework provides a discussion on the definition of ecosystem services (see Box 3). Some ecosystem services are well known, such as food, freshwater, fibre or aesthetic appreciation of an environment, while others are less well known, such as soil formation, water purification, nutrient cycling or flood regulation.

[15] In line with the Parsons and Wentzel (2007), the terms 'class' is reserved to mean the management class of a water resource, while to avoid confusion the term 'category' is used to for all grouping of water resources (i.e. water resource 'categories' and Reserve categories) prior to public participation (Step 6 in the WRCS).

While utilisation of the resource provides economic and social benefits; it also has the potential to compromise ecosystem integrity, which has economic and social costs. Intuitively, one would expect that a river reach yielding relatively high economic benefits might be in a poor ecological state. In other words, financial gain has been traded off against the health of the aquatic ecosystem. One would however also expect that the reduced health of the aquatic ecosystem would have long term negative effects. Through the RDM, aquatic ecosystems have been recognized as users with a right to water, captured by the determination of an ecological Reserve. Clearly it would be beneficial to analyze and quantify the benefits received from aquatic ecosystems so as to better estimate the costs of the loss of those benefits as well as the trade-offs between management scenarios.

These ecosystem services can be valued using environmental and resource economic (ERE) techniques. There are several reasons why it is important to value the benefits derived from ecosystem services. Five of the most regular cited reasons include:

1. It highlights the contribution ecosystems make to human well-being and the dependence of different groups of beneficiaries upon them;
2. Integration between natural and social sciences allow for better facilitation of the policy and decision making processes;
3. Understanding the value or the importance that beneficiaries place on the natural environment motivates the business case for the environment and allows for budgetary processes to be properly prioritised;
4. Our Constitution compels us to take reasonable measures to protect the environment for the use of future generations. In order to accomplish this, it is necessary to gather information on how current environmental degradation will impact on future beneficiaries; and
5. The final reason is that the increasing scarcity of high quality natural capital and the resultant pressure on the rate of supply of ecosystem services is becoming a limiting factor to development. This requires investment into natural capital and a reprioritisation of economic objectives in light of these scarcities (DEFRA, 2007; Natural Value, 2008).

The values that people assign to resources are integral to decisions. Understanding how a change in MC might affect the benefits they receive and ultimately how they value the resource in question is key to proper consideration of trade-offs and good decision making.

There is a relationship between the water resource quality and ecosystem services. Benefits vary depending on the type of water resource, the nature of its use, and the ecosystem services it provides. These will vary case by case. This is why a management class is determined for each significant water resource in

South Africa. This is done through the WRCS, where water resource management scenarios are used to consider the implications of different MC's on specific water resources. Scenario evaluation facilitates informed decision-making about trade-offs as:

- It could assist in wider communication with stakeholders (easier to make a case if in terms of human well-being) – the determination of the MC through public participation is dependent to some extent on discussion of trade-offs in terms that can be understood across the board of stakeholders.
- It improves negotiation and cooperation. Careful consideration of a common property resource means considering all stakeholders and evaluating the costs and benefits of resource use on beneficiaries of ecosystem services. This requires negotiation and dialogue – understanding the risks to services for different beneficiaries associated with changing MC is one of the first steps towards effective participation of stakeholders, and an important prerequisite to effective management.
- Finally an ecosystem services approach is an ecosystems approach that helps the analyst capture the full range of ecosystem effects more systematically, and links these effects to human well-being.

In summary, levels of protection in the RDM are defined by the categories of management class for each water resource while utilisation is defined by the services yielded by the aquatic ecosystems in each management class. These services are of an intermediate- and a final consumption nature. It is therefore recognised that net benefits yielded by aquatic ecosystems may be optimised in the long run by trade-offs between different classes of ecological, social and economic benefits. Considering the requirements from legislation and the scarce nature of water resources, we need a framework for valuing ecosystem services that can:

- illustrate the linkages between change in the management class of a water resource and aquatic ecosystem services that will be provided;
- illustrate the linkages between ecosystem services and human well-being; and
- deliver a valuation of these ecosystem services that aids decision-making through improved dialogue and trade-off analysis.

1.2. Scoping the science: Frameworks for valuing ecosystem services

Following a detailed literature review (Prime Africa, 2008), the case studies most significant to this project, are those from Australia, the United States of America and Latin America, where the valuation and evaluation of ecosystem services led to apparently successful conservation initiatives and natural resource management, which were implemented through a range of policy instruments. A number of lessons can be learnt from these case studies.

The concept of ‘ecosystem services’ has been useful as it relates to the way many people think about their environments, in terms of the benefits they receive and the ways in which they can utilize natural resources (Fisher et al., 2008). Ecosystem services have thus served as a basis for the evaluation of the economic consequences of biodiversity loss (Costanza et al., 1997; de Groot et al., 2002; MA, 2003; Pagiola et al., 2004; Balmford et al., 2008) and habitat alteration (CIC, 2007; CIC, 2009a,b).

The demand for ecosystem services is so great that the need for trade-offs among services, and regularly between biodiversity conservation and economic growth, are accepted implicitly (MA, 2003). While there is growing awareness and convergence of opinion that the complex decisions on ecosystem services trade-offs must be well-informed, how these trade-offs are considered and implemented is an ongoing effort (MA, 2003). In seeking to optimise one service, such as water provision for irrigation and domestic use (and thereby contributing to food and water security in the vicinity), we alter the delivery of other services through building dams, changing flow patterns, altering nutrient cycling and decreasing the water retention and flood regulation of a catchment (affecting the livelihoods of communities downstream). Depending on the sustainability of these actions, we alter the likely suite (or bundle) of ecosystem services enjoyed by future generations too. A consistent consideration of ecosystem services in a spatial context (and temporal context) provides necessary information of beneficiaries, change in the distribution of services from which they benefit and links to impacts on their livelihoods and human well-being. Effective assessment of the risk to these services and valuation of them support consistent evaluation of their trade-offs.

Data and knowledge are always lacking. There are numerous missing links in the chain of causality between the condition of specific natural assets, the flow of ecosystem services and effects on human well-being. The existence of the links is not in question however.

In many of the initiatives researched, although due diligence is shown, recommendations still had to be implemented in the face of scientific and economic uncertainty, and were accompanied by significant negotiation. Frameworks and assessments that are transparent, scientifically and economically diligent (see evidence-based ecology discussed in section 1.3.1 below) facilitate decision-making that can be defended in court, even under conditions of uncertainty. As a specific case in point, regardless of scientific uncertainty the diligence conducted in the case of the Mono Lake in Los Angeles was of such a nature that a Superior Court found in favour of ecosystem services (Loomis, 1995).

Ecosystems have thresholds in terms of the delivery of ecosystem services that are real, difficult to quantify and often only realised once they have been passed. Crossing thresholds could result in a change in state, and the non-delivery of certain ecosystem services important to economic growth and social development. The degree of uncertainty as to the exact position of thresholds, and the risks of exceeding limits of sustainability necessitate the precautionary principle (DWAF, 2007a).

A large body of literature on various aspects of environmental resource economics is available. Some authors are ecologists turned economists, and other are economists turned ecologist. Subsequently, literature identifies manifold definitions, approaches, techniques and applications. It is important that definitions and meanings are made explicit (see box 3 in section 1.2.3 below).

Many ecologists are sceptical of some of the economic findings (McCauley, 2006) and vice versa (Bockstael et al., 2000). Much of this debate centres on the intrinsic value of ecosystems. Some environmentalists argue that species have value independent of any value they have to human beings. They call this intrinsic value. This frequently reflects a moral position on the right of all species to exist. Intrinsic value, and indeed this moral position, cannot be valued and has no place being valued. It is best encapsulated in legislation. For this reason and others, a clear understanding of the policy, plans and programmes relevant to an ecosystem services assessment are integral in the evaluation of trade-offs related to ecosystem services. Arguments for biodiversity conservation to ensure the continued delivery of ecosystem services are “in addition to, not in place of, ethical and scientific ones (Costanza et al., 1997; Daily, 1997; Turner et al., 2000; MA, 2005; Costanza, 2006)” (Fisher et al., 2008).

In a comprehensive environmental and resource economics assessment, at least half the project work must be conducted before the actual valuation can proceed. Determining demand for ecosystem services is often easier than understanding the supply of ecosystem services. This is because economic data is often more easily gathered as humans are part of social systems that keep records and from which information can be gathered. However the supply of ecosystem services from complex ecological systems responding to a multiplicity of drivers, feedbacks and cumulative effects and the linkage between their delivery and human well-being is more difficult. A clear description (argument) of the chains of causality is needed for the determination of how change in aquatic ecosystems translates into change in ecosystem services and associated benefits.

Up to 2005, most ecosystem services studies used the so-called total economic value (TEV) nomenclature to define and classify ecosystem services. TEV is a typology of the value of ecosystem services (referred to in the TEV framework as environmental goods and services) into direct and indirect, use and non-use value, including option, bequest and existence value. Although used extensively and accurately in many cases, it appears that the TEV approach risks double accounting largely because the chain of causality of ecosystem services is not made explicit, and ecosystem processes and functioning intermediate to the provision of final benefits are sometimes double-accounted. TEV is an example of a valuation *framework/methodology*, which is different to valuation *techniques* which are the economic tools such as hedonic pricing, travel-cost method. However, the MA framework, published in 2005, incorporates TEV but is an improvement thereon by making the chain of causality and intermediate and final consumption services more explicit. Further review and discussion on the operational definition of ecosystem services is provided in Fisher et al. (2008, 2009), Boyd and Banzaf (2007) and Wallace (2007).

The MA framework is widely accepted, contributed to by more than 1,360 international experts, and has broadly changed the way the interaction between social and ecological systems is thought about. The key outputs of the MA have been published in five technical volumes and six synthesis reports. These contain a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide (such clean water, food, forest products, flood control, and natural resources) and the options to restore, conserve or enhance the sustainable use of ecosystems (MA, 2007). "By connecting ecological functioning, ecosystem processes, ecosystem services and the production of marketed goods and services it has identified ecological change as an economic problem" (Perrings, 2006). The same valuation techniques discussed in the paragraph above remain relevant.

Given the intellectual capital of the world's top ecologists and economists invested into the development of the MA, and the significant contribution by many South African authors, these key outputs should form the basis for the development of a framework for the assessment of aquatic ecosystems in South Africa. The MA framework is discussed briefly below, as is the draft WRCS, which also provides a framework for valuation of aquatic ecosystem services.

1.2.1. The MA framework

"*The goal of the Millennium Ecosystem Assessment (MA) was to establish the scientific basis for actions needed to enhance the contribution of ecosystems to human well-being without undermining their long-term productivity*" (MA, 2003).

The MA provides a sound and well established framework for the assessment of ecosystem services and the benefits to human well-being. The MA established the concept of ecosystem services as an essential model for linking the functioning of ecosystems to human welfare benefits (Balmford et al., 2008). The definition and categorisation of ecosystem services in the MA built upon previous work by leading authors such as Daily (1997), Costanza et al. (1997), and De Groot et al. (2002). Ecosystems are considered to be assets that yield a flow of services of benefit to people, much like other capital stocks. The MA distinguishes between four categories of ecosystem services:

- **Provisioning services** are the most familiar category of benefit, often referred to as ecosystem 'goods', such as foods, fuels, fibers, biochemicals, medicine, and genetic material, that are in many cases: *directly* consumed; subject to reasonably *well-defined property rights* (even in the case of genetic or biochemical material where patent rights protect novel products drawn from ecosystems); and are *priced in the market*.
- **Cultural services** are the less familiar services such as religious, spiritual, inspirational and aesthetic well-being derived from ecosystems, recreation, and traditional and scientific knowledge that are: mainly passive or non-use values of ecological resources (*non-consumptive uses*); that have *poorly-developed markets* (with the exception of ecotourism); and *poorly-defined property rights* (most cultural services are regulated by traditional customs, rights and obligations); but are still *used directly* by people and are therefore open to valuation.
- **Regulating services** are services, such as water purification, air quality regulation, climate regulation, disease regulation, or natural hazard regulation, that affect the impact of shocks and stresses to socio-ecological systems and are: public goods (globally in the case of disease or climate regulation) meaning that they "offer non-exclusive and non-rival benefits to particular communities" (Perrings, 2006); and are thus frequently undervalued in economic markets; many of these are *indirectly used* being intermediate in the provision of cultural or provisioning services.
- **Supporting services** are an additional set of ecosystem services referred to in the MA, such as nutrient and water cycling, soil formation and primary production, that capture the basic ecosystem functions and processes that underpin all other services and thus: are embedded in those other services (*indirectly used*); and are not evaluated separately (CIC, 2007).

A detailed description of these services is provided in Annexure 2.

Figure 2 provides a schematic of the MA conceptual framework and illustrates the direct and indirect drivers of change in ecosystems that result in changes in ecosystem services:

- indirect drivers of change, such as increased demand for services as a result of population growth, economic growth, changes in socio-political systems, scientific and technological developments, or changes in individual choices (lifestyle); or
- direct drivers of change, including changes in land cover, introduction of alien invasive species, external inputs through fertilisation, pesticides or irrigation, climate change, over-utilisation of particular resources or natural drivers such as evolution, adaptation, and tectonic movement.

The influence of and feedbacks between human well-being, drivers of change and ecosystem services are demonstrated in Figure 2. For instance, increased demand of water by upstream water users reduces water supplied downstream, resulting in changes in water quality, riparian zones, aquatic biodiversity and direct and indirect effects to a suite of ecosystem services to downstream beneficiaries. This problem can be exacerbated by the degradation of catchments affecting the capability of aquatic ecosystems to provide services and regulate natural and human-induced stressors and shocks to socio-ecological systems. The degradation of ecosystems in a bid to maximise the delivery of a small group of services, such as agricultural crops for food, water supply or grazing, jeopardises the delivery of other ecosystem services. It also often jeopardises the sustainable supply of the ecosystem services that are being maximised. Therefore, human well-being[16] is affected not only by the gap between the supply and demand of ecosystem services, but also by the diminished prospects for sustainable development thus increasing vulnerability of individuals and communities.

To illustrate this important point, degraded catchments, such as some of those in the former homelands of the Eastern Cape where the concentration of people and the lack of development of infrastructure and education during South Africa's pervious political dispensation has resulted in not only a reduced natural capital in terms of loss of top soil, productive land and reduced water quality, but also increased the vulnerability of local people by exacerbating the risks of floods, erosion, crop failure and water-borne disease. The effects of degradation and

---

[16] "Human well-being is a human experience that includes the basic materials for a good life, freedom of choice and action, health, good social relationships, a sense of cultural identity, and a sense of security. The sense of well-being is strongly dependent on the specific cultural, geographical, and historical context in which different human societies develop, and is determined by cultural-socioeconomic processes as well as by the provision of ecosystem services. However, the well-being of the vast majority of human societies is based more or less directly on the sustained delivery of fundamental ecosystem services, such as the production of food, fuel, and shelter, the regulation of the quality and quantity of water supply, the control of natural hazards, etc." (Diaz et al. 2006).

changes in ecosystem services are felt most acutely by rural communities rather than urban populations and have the most direct and extreme effect on poor people, who have to rely more directly on services from ecosystems and often lack access to alternative services making them more vulnerable to shocks and stressors.

Humans, and their cultural diversity, are recognised as an integral part of socio-ecological systems and human well-being is the central focus for assessment. Inherent to this 'ecosystem approach' of the MA is the understanding that socio-ecological systems are complex and dynamic "with the changing human condition serving to both directly and indirectly drive change in ecosystems and with changes in ecosystems causing changes in human well-being. At the same time, many other factors independent of the environment change the human condition, and many natural forces influence ecosystems" (MA, 2003).

Perturbations resulting from ecosystem change propagate through systems spatially, affecting local people as well as downstream users, and temporally, affecting current and future users. A multi-scale approach to assessment is required for proper evaluation of driving forces internal and external to the system in question and the differential effect of ecosystem changes on different areas and populations within a system, i.e. upstream and downstream communities.

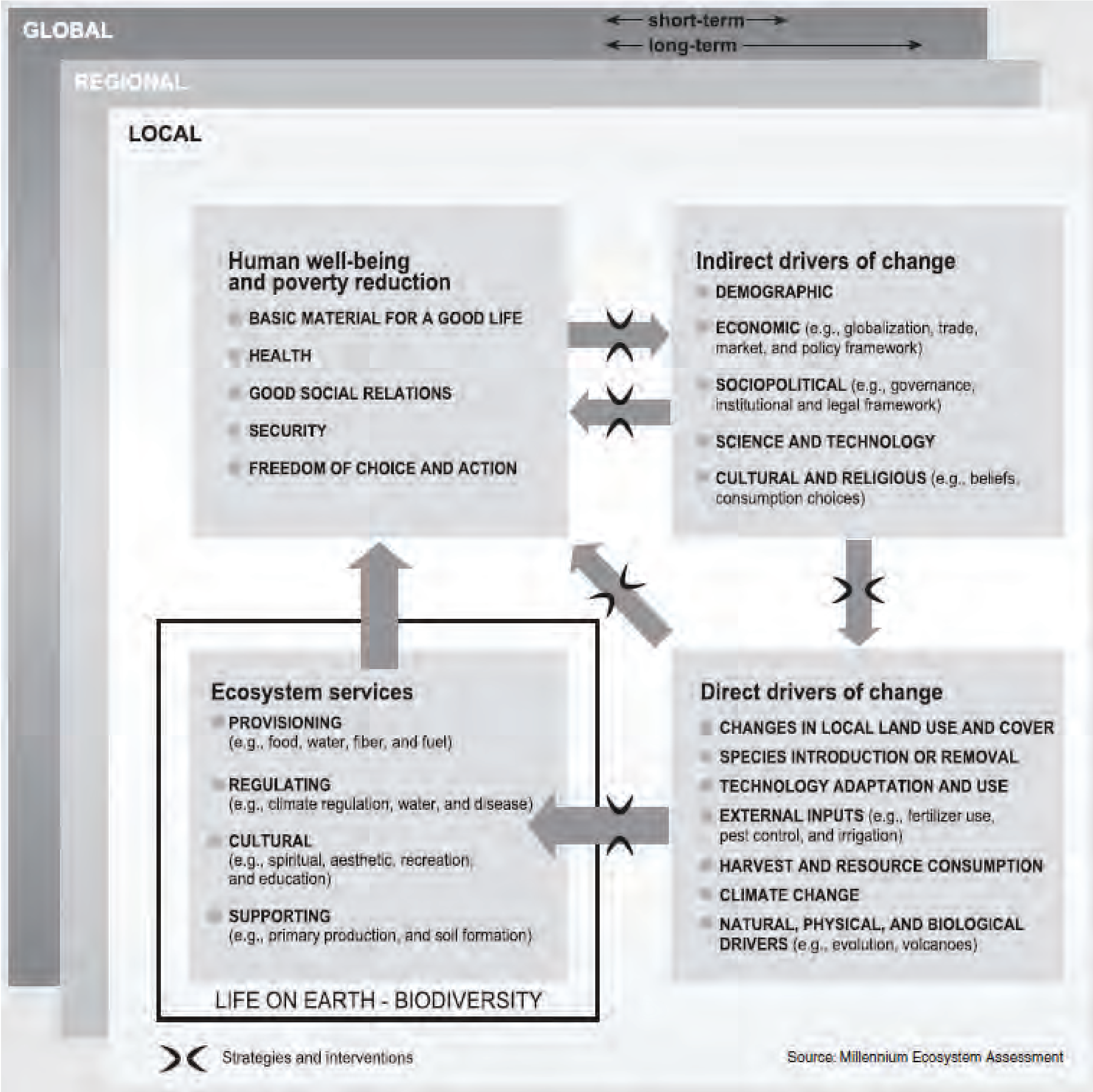


Figure 2. Conceptual framework of the Millennium Ecosystem Assessment (MA, 2003)

The MA conceptual framework thus lays the thinking of a causal chain between drivers of change in ecosystems, the delivery and distribution of ecosystem services and the benefits to human well-being.

i. Importance of the definition of ecosystem services

There is general consensus on the broad definition of ecosystem services in the MA as “the benefits people obtain from ecosystems” (MA, 2005). This definition is deliberately general but needs to be more specifically defined to provide an operational definition for use in valuation, management or accounting (Boyd and Banzhaf, 2007; Fisher et al., 2008, 2009).

Fisher et al. (2008), drawing from Boyd and Banzhaf (2007), propose that “ecosystem services are the aspects of ecosystems utilised (actively or passively) to produce human well-being". The characteristics key to proper valuation of ecosystem services lie in this definition (as described in Fisher et al., 2009) where ecosystem services are (1) ecological phenomena (including ecosystem organization or structure as well as ecosystem process and/or functions) that are (2) consumed/utilized by society either directly or indirectly.

Table 1. Various terms used in the literature regarding ecosystems and ecosystem services (adapted from Fisher et al., 2009). Terms are grouped in recognition of the links among ecosystem organization, the operation of ecosystems, and the outcomes that provide human benefits.

Organization	Operation	Outcome
Stock	Flows	Services
Structure	Function(ing)	Goods
Infrastructure	Services	Benefits
Pattern	Process	
Capital		Income
Attributes*		
Natural asset		

The definition of ecosystem services as ecological phenomena, which include ecosystem organisation, structure, process and/or function, provides some explanation for the variety of terms used in the literature to describe ecosystem services. Fisher et al. (2009) offer a way to systematise the various terms that have been applied to ecosystems and ecosystem services. Table 1 highlights two important messages, that (a) it is important that assessments are clear regarding what is defined as an ecosystem service and (b) that there is a difference between the organisation (physical constitution) of an ecosystem, the process or functioning (operation) of an ecosystem, and the outcome or link to human well-being. The latter introduces an important concept, that some ecosystem services (ecological phenomena) are intermediate to the delivery of others (Boyd and Banzhaf, 2007; Wallace, 2007; Fisher et al., 2008, 2009).

This notion of intermediate versus final consumption ecosystem services is crucial in the context of valuation and avoiding double accounting (as explained in more detail below). For instance nutrient cycling and water regulation and erosion regulation (intermediate services) interact to deliver water flow, nutrients and a certain range of sediment loads to a downstream estuary which supports a large fishery and beautiful estuarine environment (food provision and recreation are the final services). In this example, the value of water regulation, nutrient cycling and erosion regulation would be captured in the benefits yielded by recreation and subsistence fishing service. The fish as well as the safe and healthy shoreline and water body are the benefits that are the endpoints that have a direct effect on human well-being.

Boyd and Banzhaf (2007) highlight another important distinction, between ecosystem services and benefits. As explained above, ecosystem services are the ecological phenomena, but benefits are defined as "the thing that has direct impact on human welfare" (Fisher et al., 2009). In other words, benefits are generated by ecosystem services, but typically in combination with other forms of capital input. For instance human activity and hard work, human knowledge, and/or built infrastructure (Figure 3). *Fisher et al. (2009) use the example of recreation. Recreation is an ecosystem service that Boyd and Banzhaf (2007) suggest is better described as a benefit with multiple inputs. These inputs may include "human, social or built capital inputs necessary for recreation" (Fisher et al., 2009). "Ecosystem services that may help produce a recreation benefit" could include a number of ecological processes such as water regulation and erosion regulation, and ecological components such as forests, rivers and beautiful vistas" (Fisher et al., 2009)*.

One intermediate service may also input into multiple benefits (for instance water regulation is intermediate to flood protection and avoided damage or injury, water provision for multiple purposes, riparian subsistence agriculture, downstream aquatic ecosystems and recreation).

Fisher et al. (2008) argue that "by separating ecosystem services into intermediate and final services and benefits, we explicitly understand that in accounting and valuation exercises only the benefits generated by the final services can be aggregated, and hence, avoid double counting". Although intermediate services are valued through final services and benefits, they are important to consider, especially with regards to their long-term sustainability and the effects of changes in these services on final services (in terms of resilience and thresholds). This has numerous important valuation and trade-off implications.

Figure 3 uses the MA ecosystem services classification, which allows for the logical analysis of the causal chains producing ecosystem services and provides a framework that illustrates the concept of intermediate and final services. There are several classifications of ecosystem services (such as Daily, 1997; Norberg, 1999; de Groot et al., 2002; MA, 2003; Balmford et al., 2008), some of which can help avoid double accounting, but as yet, no agreed method for categorization (Box 1; MA, 2003; DEFRA, 2007; Fisher et al., 2009). Debate in the literature confirms that a single classification of ecosystem services is not as important as an agreed definition of ecosystem services is (Boyd and Banzhaf, 2007; Costanza, 2008; Wallace, 2007; Fisher et al., 2008; 2009; Fisher and Turner, 2008). However a classification is useful.

A classification of ecosystem services by Balmford et al. (2009) proposes possible improvements on the MA in terms of the distinction between core beneficial processes, beneficial services and benefits. It clarifies that some regulating services as defined in MA (2005) are sometimes final services that have direct and indirect benefits to human well-being. Although diligence on the part of experienced assessors achieves the same, classification is useful to avoid confusion regarding intermediate and final services and can be important to ensuring that all ecosystem services are considered. This said, any classification should be used intelligently and with diligence.

It is clear from the above that the definition and classification of ecosystem services is an evolutionary process. However the MA framework sufficiently assists to address the two key requirements for environmental resource economic valuation:

1) it enables diligent and comprehensive analysis of all the benefits provided by aquatic ecosystems to humans; and
2) it allows for the logical analysis of the causal chains producing these ecosystem services.

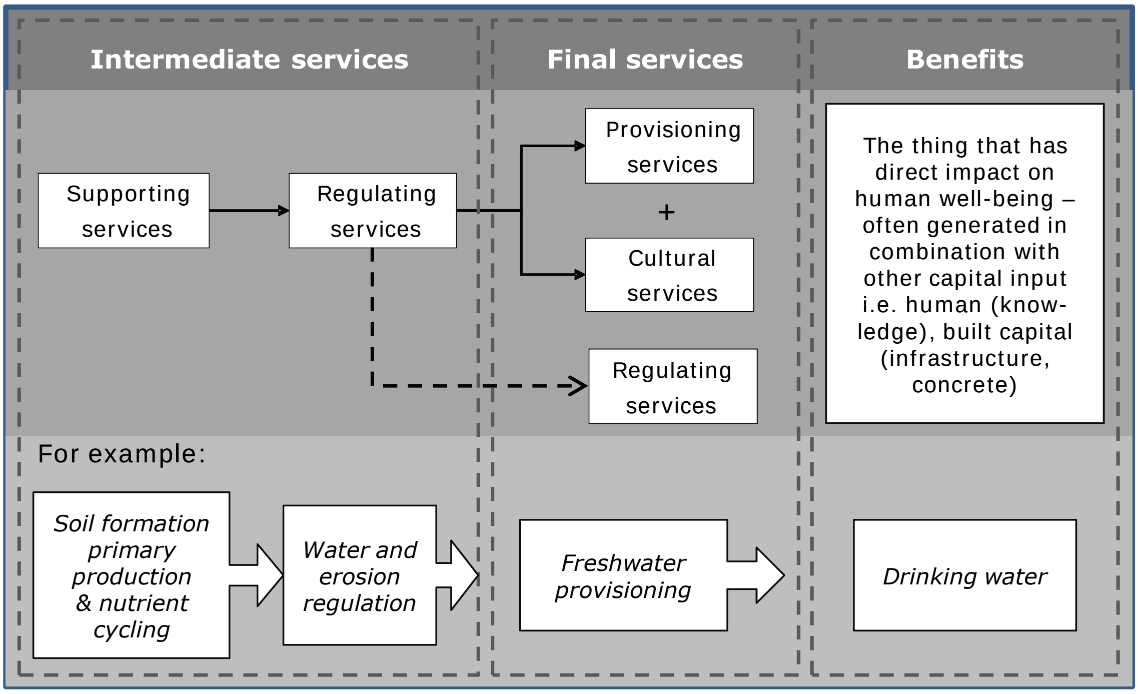


Figure 3. **The distinction between intermediate services, final services and benefits (adapted from Fisher et al., 2008) illustrated by the stylised relationship between supporting, regulating, provisioning and cultural services as defined by the Millennium Ecosystem Assessment (MA) (Perrings, 2007; Hassan, 2007) and simplified example.**

Ecosystem functions, processes, diversity or components become services if there are human beneficiaries of them. Without direct or indirect utilization or consumption by humans, these ecological processes and function(ing) have intrinsic value recognized through the social decision to conserve ecological processes or biodiversity, through legislation and regulative authorities mandated to do so. Human beneficiaries value ecosystems services differently as they are located in different geographic areas, and have different cultural and socio-economic needs (Boyd and Banzhaf, 2007; Fisher et al., 2008). The distribution of ecosystem services to different populations and generations is key to the analysis of trade-offs in water resource management and must be defined.

Box 1. Debate around the classification of ecosystem services

There are several ways in which ecosystem services have been categorized (such as Daily, 1997; Norberg, 1999;de Groot et al., 2002; MA, 2003; Balmford et al., 2008). As yet, there is no agreed method for categorizing ecosystem services (MA, 2003; DEFRA, 2007; Fisher et al., 2009), although the need for continued development of the ecosystem services concept and classification for valuation have been addressed in a flourish of papers by several lead authors (Boyd and Banzhaf, 2007; Costanza, 2008; Wallace, 2007; Fisher et al., 2008, 2009; Fisher and Turner, 2008; Fisher et al. in press- a, b). This can be confusing but does not prohibit our ability to identify, assess and value aquatic ecosystem services. Recent debate in the literature confirms that a single classification of ecosystem services is not important (although an agreed *definition* of ecosystem services is – see Box 3), as it depends on the context for decision-making (Fisher et al., 2009; Costanza et al., 2008). Different decision contexts and motivations influence how ecosystem services are classified (Fisher et al., 2009).

In the context of valuation, the key is that only end services, which offer final benefits (direct or indirect) to humans, are valued. Services that are intermediate to the provision of final benefits are important to consider, especially with regards their long-term sustainability and the effects of changes in these services on final services (resilience and thresholds – see section 1.2.1), but should not be valued (Fisher et al., 2008).

Although diligence on the part of experienced assessors achieves the same, classification is useful to avoid confusion regarding intermediate and final services and can be important to ensuring that all ecosystem services are considered. This said, any classification should be used intelligently and with diligence.

With valuation as our context for decision-making there are three noteworthy classifications of ecosystem services: the Total Economic Valuation (TEV) classification; the Millennium Ecosystem Assessment framework and most recently The Economics of Ecosystems and Biodiversity (TEEB) (Sukhdev, 2008; Balmford et al., 2008).

The TEV is a well-established, extensively used classification that is explained in detail in Annexure 3. It is susceptible to double-accounting (see section 1.2). The MA incorporates TEV but is an improvement thereon by making the chain of causality and intermediate and final services more explicit. The MA framework has therefore widely been accepted as a useful starting point for the valuation of ecosystem services (DEFRA, 2007). The MA has numerous strengths, however it was neither intended as a static document (Sachs and Reid, 2006; Fisher et al., 2009), nor developed solely as a valuation exercise (Balmford et al., 2008). The classification itself is not entirely appropriate for economic valuation unless there is more specific consideration of intermediate and final services as described in section 1.2.2, Fisher et al. (2009) and illustrated in CIC (2007, 2008 and 2009).

The MA (2003) recognises that there is overlap in some ecosystem service categories, such as erosion control, which "can be categorized as both a supporting and a regulating service, depending on the time scale and immediacy of their impact on people". There is sometimes greatest ambiguity in the regulating services, where some of these are intermediate to the delivery of provisioning and cultural services, while others provide benefits to human well-being that are not explicitly captured in provisioning and cultural ecosystem service categories. This is illustrated in Balmford et al., 2008 and an example includes human health benefits such as avoidance of injury. Due to this ambiguity, there is a risk of both double accounting (by valuing regulatory services intermediate to the provision of other services) and under-valuing (by not specifically listing some of the benefits from regulating services such as avoided injury through natural hazard regulation).

It is clear from the above that the definition of ecosystem services is an evolutionary process, although good progress and suggestions in work by Fisher et al., 2008 and 2009. However the MA framework sufficiently assists to address the two key requirements for environmental resource economic valuation:

3) it enables diligent and comprehensive analysis of all the benefits provided by aquatic ecosystems to humans; and
4) it allows for the logical analysis of the causal chains producing these ecosystem services.

1.2.2. Water Resource Classification System (WRCS)

The WRCS[17] is the framework for the determination of the management class, resource quality objectives defining the Reserve for all significant water resources. It consists of five volumes detailing a 7-step resource classification procedure (DWAF, 2007a; as detailed in Figure 4 and detailed in Annexure 1) which includes a set of guidelines and procedures for determining the desired characteristics of a water resource. Each different set of desired characteristics is represented by a Management Class (MC), which outlines those attributes that the custodian (DWAF) and society would require of each water resource.

The 7-step resource classification procedure is as follows (this summary includes the sub-steps relevant to evaluation):

Step 1: Delineate integrated unit of analysis (IUAs), describe the status quo of the water resources:-

- Identification of system, components and the state of water resources, including information on the reference condition
- aggregation and presentation of economic, social and ecological data at a catchment level for alternate scenarios

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

- Through the first step, the stakeholders for the catchment are identified.
- The ecosystem values to be considered are determined. For each of these necessary ecological and economic data are collected so that the linkages between condition and value can be made.

Step 3: Quantify the Ecological Water Requirements and changes in non-water quality Ecosystem Goods, Services and Attributes (EGSA) (EGSA are what the MA framework defines as ecosystem services):-

- Nodes are determined and rule curves created in expert workshops and for each node, and a range of ecological categories the change in EGSAs is calculated.

---

[17] At the time of writing this report, the WRCS was in final draft format, and had not yet been gazetted by the Minister.

Step 4: Determine an Ecologically Sustainable Base Configuration scenario and establish the starter configuration scenarios[18]:

- Scenarios are created,
- Describing the ecological and biophysical implications, the groundwater implications, and the social implications of different scenarios.

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

- Using yield model and other models, the different scenarios are compared in terms of their EGSAs. The changes in aquatic ecosystems are valued.

Step 6: Evaluate the scenarios with stakeholders

- predicting changes in economic value from implications of different scenarios ensure that the appropriate economic, social and ecological criteria are considered in the Classification Process.

Step 7: Gazette the class configuration

The WRCS is to follow these principles:

- Principle 1: Balance and trade-off for optimal use
- Principle 2: Sustainability
- Principle 3: National interest and consistency
- Principle 4: Transparency
- Principle 5: Implementability
- Principle 6: Interdependency of the hydrological cycle
- Principle 7: Legally defensible and scientifically robust
- Principle 8: Management scales
- Principle 9: Auditable and enforceable
- Principle 10: Lowest level of contestation and the highest level of legitimacy
- Principle 11: Utilisation of existing tools, data and information.

Principle 2: Sustainability is directly relevant here. In the WRCS, it is "... recognised that there is a sustainability baseline (or threshold) that if crossed, could result in the non-delivery of the goods, services and attributes necessary for economic growth, poverty alleviation and the redress of historical inequality. As there is a degree of uncertainty as to the exact position of this baseline, and as the risks exceeding the limits of sustainability are considerable, the precautionary principle will be applied."

The WRCS thus recognizes that this balance will require trade-offs in any resource-management decision. The WRCS should therefore clearly outline the implications of different MCs to facilitate informed decision-making about trade-offs. Valuation is thus required and the procedure for which is partly outlined in

[18] By scenarios is meant the optional or alternate sets of trade-off options for the integrated water resources management available for a given significant water resource.

the WRCS (Turpie et al., 2007). This Framework and Manual provides a comprehensive review and guide that will serve to support and clarify the valuation of ecosystem services delivered by aquatic ecosystems for RDM. Box 2 describes the overlap between the WRCS and the existing ecological Reserve determination procedure.

Box 2. Overlap of WRCS with the existing ecological Reserve determination procedure

As already mentioned in section 1.1, the WRCS was preceded by a procedure for ecological Reserve determination, which was required to deal with the urgent need for the determination of the Reserve in order to go ahead with compulsory licensing. This process is better known and developed as it has been in use for a number of years and applied in numerous catchments.

The ecological Reserve determination procedure is however complementary and integratable with the Classification process. The ecological Reserve determination procedure essentially determines a component of the fuller Classification process, namely the ecological Reserve, while the Classification process also takes into account the user specifications for Reserve. Thus the Classification process place greater explicit emphasis on incorporating socio-economic information that relate the use and value of aquatic ecosystems to water resource quality in all of its steps. Due to the delay in gazetting the WRCS however, socio-economic information has been incorporated into the Reserve determination procedure in a number of assessments. The approaches followed for this integration of socio-economic considerations into the ecological Reserve determination procedure has varied slightly but are broadly comparable with the approach recommended in the draft WRCS.

In order to determine the ecological Reserve, the Present Ecological State (PES; health or integrity) and recommended Ecological Category (REC) another process called the EcoClassification process (‘Ecological Classification process’) is applied. The detail of this process is given in Kleynhans and Louw (2007). Its place in the ecological Reserve determination procedure is explained in Louw and Hughes (2002). Until the WRCS is gazetted and the Classification process applied, the recommended Ecological Category (EC) and its Ecological Water Requirement (EWR) as determined through the ecological Reserve determination procedure are taken to be the preliminary ecological Management Class (EMC) and ecological Reserve of the water resource.

The 7-step WRCS process is outlined in Figure 4 alongside the 8-step ecological Reserve determination procedure.

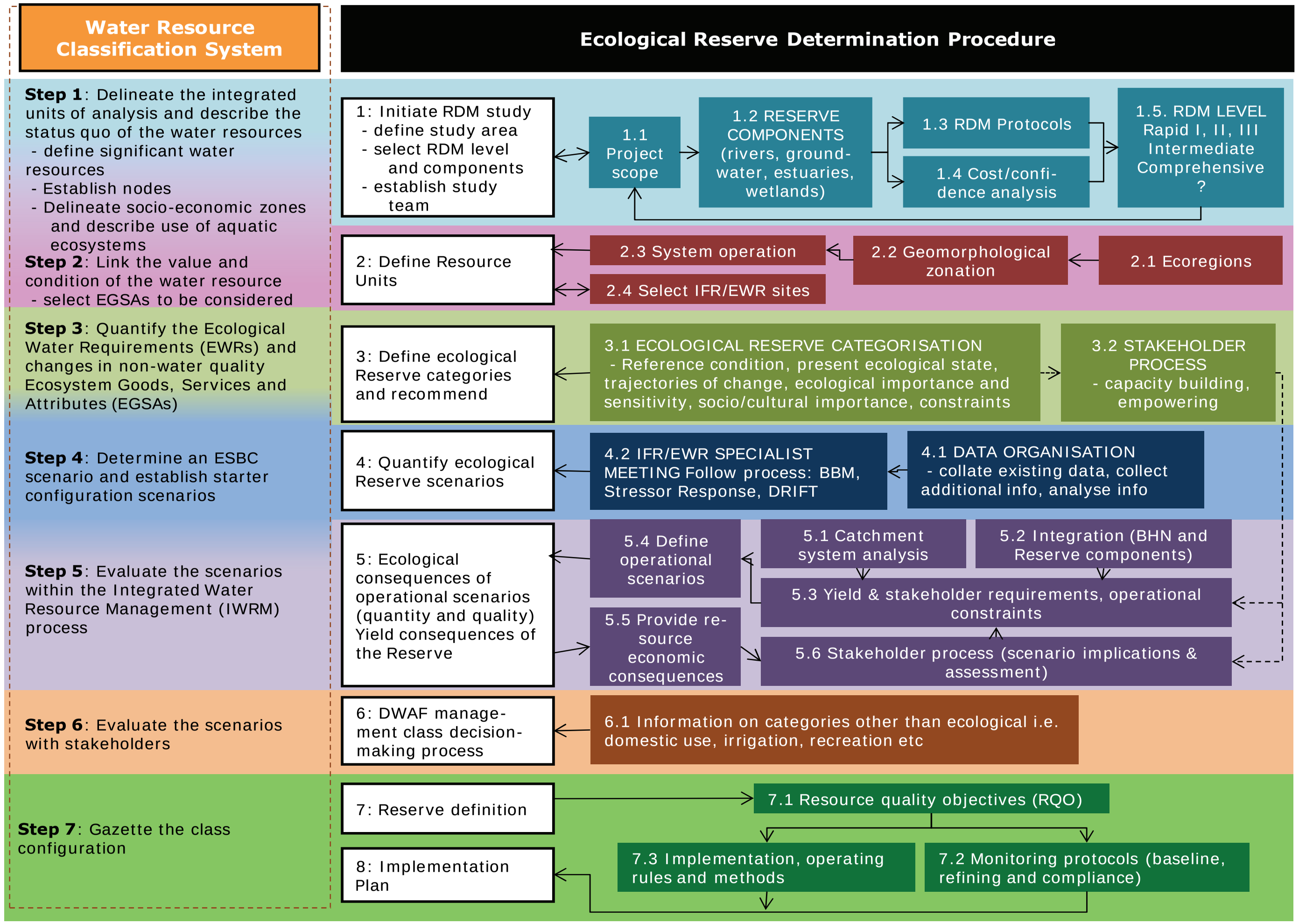


Figure 4. Outline of and relationship between the Water Resource Classification System (WRCS) and the ecological Reserve determination procedure (adapted from Dollar et al., 2007; Louw and Hughes, 2002). Each step of the Reserve determination procedure is represented by its own colour. Shading of these colours under the WRCS indicates some overlap between steps of the WRCS and where they occur in the Reserve determination.

1.2.3. *Collation of lessons from frameworks*

The valuation of ecosystem services requires the integration of different disciplines. Practitioners of these disciplines make use of different frameworks to simplify complex issues of water resource management. The MA and the WRCS represent two such frameworks. Comparison between them and other frameworks illustrates that they are compatible in many ways. This compatibility is because they both learn from existing literature and frameworks, and both offering an 'impact pathway'[19] approach to the valuation of ecosystem services (DEFRA 2007). The basic goal of the impact pathway is to establish a baseline, identify potential drivers of change, quantify effects on specific ecosystem services, and assess the effects on human well-being and value changes in ecosystem services.

There are some differences between the MA and WRCS including the order of their respective steps and possibly certain aspects of the detailed methodology recommended by the two frameworks. Thus embedded in these frameworks are various techniques and principles important to effective valuation of ecosystem services (through the MA) and RDM assessment (through the WRCS). The challenge is to value aquatic ecosystem services for RDM without generating new frameworks, but rather gleaning the basic requirements for assessment and providing a framework that serves to simplify the complexities of this task. Any framework should strive to encompass the many disciplines involved, maintain high scientific standards and manage information to provide a scientific record of the work done. Below we outline a framework of environmental-resource economic evaluation of aquatic ecosystem services.

Box 3. Clarifying what ecosystem services are

A large body of literature on various aspects of the valuation of ecosystems and their services is available. Some authors are ecologists turned economists, and other are economists turned ecologist. Subsequently, literature identifies manifold definitions, approaches, techniques and applications. Before going further, it is important to clarify what we mean by ecosystem services and consider the various terms used for ecosystem services.

The idea that ecosystems were providing humans with services of benefit to their well-being can be traced back to the 1800s (Mooney and Ehrlich, 1997). Despite the long history of the concept and broad agreement on the general idea of ecosystem services, Fisher et al. (2009) point out that there are still important differences between definitions of the term 'ecosystem services' (see their paper for a comparison of some of the most commonly used ecosystem services definitions).

Arguably one of the most well known definitions of ecosystem services is from the Millennium Ecosystem Assessment (MA, 2005) where *ecosystem services are the benefits people obtain from ecosystems* (although Daily (1997) and Costanza et al. (1997) are also well known). Indeed this is in line with the definition of *environmental goods and services* in the National Environmental Management Protected Areas Act (NEMPAA, No. 57 of 2003) "as including the benefits obtained from ecosystems such as food, fuel and fibre and genetic resources; benefits from the regulation of ecosystem processes such as climate regulation, disease and flood

[19] Also see the cause-effect diagrams described in Claassen et al. (2001)

control and detoxification; and cultural non-material benefits obtained from ecosystems such as benefits of a spiritual, recreational, aesthetic, inspirational, educational, community and symbolic nature".

The characteristics key to proper valuation of ecosystem services lie in this definition (as described in Fisher et al., 2009) where ecosystem services are (1) ecological phenomena (including ecosystem organization or structure as well as ecosystem process and/or functions) that are (2) consumed/utilized by society either directly or indirectly. There are no services without human beneficiaries. Without direct or indirect utilization or consumption by humans, ecological phenomena as defined have intrinsic value recognized through the social decision to conserve ecological processes , just as biodiversity, through legislation (e.g. NEMPAA, NEMBA, NHRA) and regulative authorities mandated to do so (e.g. SANBI through national and bioregional plans). The distinction can be made between benefits and services (like Boyd and Banzhaf, 2007), but importantly, unlike Boyd & Banzhaf (2007) ecosystem services can be indirect and do not have to be physical organization or structure but can be process/function.

Critical consideration and review of terminology already used in the literature is recommended to avoid confusion and added complexity. Table 1 reviews the various terms used in the literature and highlight that end ecosystem services can be referred to as services, goods and/or benefit.

Table 2. Various terms used in the literature regarding ecosystems and ecosystem services (adapted from Fisher et al., 2009). Terms are grouped in recognition of the links among ecosystem organization, the operation of ecosystems, and the outcomes that provide human benefits.

Organization	Operation	Outcome
Stock	Flows	Services
Structure	Function(ing)	Goods
Infrastructure	Services	Benefits
Pattern	Process	
Capital		Income
Attributes*		
Natural asset		

* A term originating from Aylward and Barbier (1992) and used in the WRCS

Some literature has referred to ecosystem services as **ecosystem attributes**. Rogers (2007) has developed a protocol for determining the desired state of an ecosystem(s) under management. A key aspect of this protocol is the definition of vital attributes of the system, and is in fact the environmental assets of the system. The WRCS also refers to ecosystem attributes (DWAF 2007), but apply this term to designate a certain set of ecosystem services, rather than ecosystem assets. This definition may cause confusion. See the Glossary for further definitions of important ecosystem services related terminology.

In summary, a clear understanding of the concept is fundamental to the use of the ecosystem services concept for valuation and in decision making (MA, 2003; Fisher et al., 2009). It is evident that a consistent and operational definition of what ecosystem services is required to:

a) allow meaningful comparisons across different projects, policy contexts, time and space (Boyd and Banzhaf, 2007; Fisher et al., 2009); and
b) provide clear boundaries for the characteristics of concern (Fisher et al., 2007).

1.3. Aquatic ecosystem service evaluation framework: a four-phased approach

This section provides a practical guide to the four phases[20] of the WRC aquatic ecosystem service valuation framework. These phases are summarised as:

1. Systems analysis
2. Assessment of ecological change
3. Valuation of ecosystem services
4. Evaluation of trade-offs

Following these phases will ensure a systematic approach to accounting for changes in the ecological category of aquatic ecosystems. It is recognised that there are considerable complexities in understanding and assessing the causal links between a change in ecological category[21], its effects on ecosystems and related services and then valuing these effects in economic terms. Integrated working with hydrologists, fluvial geomorphologists, aquatic biologists, policy makers and economists will be essential in implementing this approach in practise. “By adopting a systematic approach to consideration of the services, the decision-maker can ensure that a holistic approach to the ecosystem is taken” (DEFRA, 2007).

Figure 5 illustrates a simplified overview of the WRC aquatic ecosystem service evaluation framework linking the changes to ecosystems from the preliminary systems analysis as a result of different management scenarios, to changes in the provision of services. It looks at how these services relate to benefits to human well-being translated into economic value using economic valuation techniques so as to evaluate trade-offs between different water resource management scenarios. This simplified overview does not mean to mask the considerable complexities in the causal links between these stages and although presented sequentially, the process has an iterative nature.

---

[20] The term ‘phase’ has been used here to avoid confusion with the ‘steps’ in the WRCS.

[21] We use the term ecological category here, as a Management Class is only thus defined after it has been gazetted by the Minister.

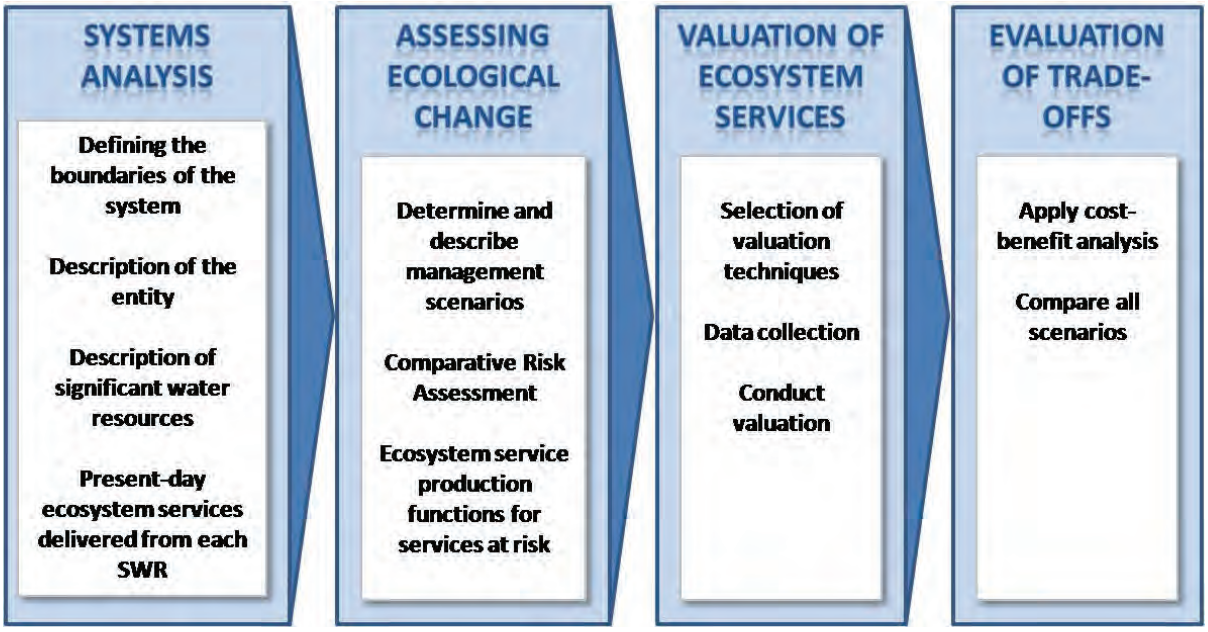


Figure 5. Simplified overview of the WRC aquatic ecosystem service evaluation framework

1.3.1. System analysis

The evaluation methodology requires an understanding and prediction of the environmental effects of a project on a system subject to development, or in the case of this application, of the environmental effects of a water resources management scenario on the catchment subject to evaluation.

This is achieved through a systems analysis with the following objectives:

- Spatial and temporal delineation of the system that is subject to enquiry;
- Collation of all relevant and valid scientific information about the system; and
- Description of significant water resources and the ecosystem services they provide as well as how resources are managed.
- Description of the management scenarios, which provide the options for water resources management and water infrastructure operations.

The definition of the system subject to enquiry frames the case-specific analysis required for the assessment and enables the identification of the system and the activities/management to which it will be subject. This will confine the analysis to what are necessary, avoiding unnecessary and confusing generalisations. In addition the problem description must communicate to the analyst the magnitude and importance of the issues that arise from the proposal.

Once the boundaries of the system have been defined, an ecosystem description, through the collation of relevant and valid scientific information about the system, must provide an understanding and prediction of the environmental effects of a water resources management on the catchment subject to evaluation.

The overall outcome of the ecosystem description is an understanding of ecosystems services provided by the aquatic ecosystems through a description of the following:

- biophysical attributes (some of which we later identify as assets), such as biotic communities and abiotic components of ecosystems (e.g. soil, substrates)
- ecological processes, which are the biophysical processes that determine the direction, rate and fate of flows of energy, material and information (i.e. behavioural display) through the system;
- system feedback controls, which are information flows in the system that govern the way the system responds to environmental effects, including positive feedback (dampens environmental effects) or negative feedbacks (amplify environmental effects) (e.g. consider global warming and cloud formation);
- inputs of materials and energy into (e.g. water and sediments in rivers) and outputs from the system (e.g. same as inputs but also the material components of ecosystem services).

The systems analysis is the inference engine for environmental resource economics and crucial as the baseline from which ecological change is compared. An important tool in the systems analysis is evidence-based ecology.

The methodology of evidence-based ecology is a complete or partial set of methods that are employed to deliver the required and predefined assessment. As adapted for the WRC aquatic ecosystem services evaluation framework, it involves the following, in approximate sequence of execution:

- terms of reference formulation for a systematic review: framing the problem
- execution of a systematic review
- formulation and validation of the ecosystems model
- peer review, and
- assessment of uncertainties.

The latter three points here also relate to the approach of the comparative risk assessment used in Phase 2. A systematic review begins in Phase 1 where available evidence is used in the systems description, but the formulation and validation of the ecosystem model, peer review and assessment of uncertainties are finalised through Phase 2. Evidence-based ecology is particularly effective in testing understanding and finding evidence for the way ecosystems work. It is a means of “knowledge transfer involving systematic review and dissemination of evidence on effectiveness of interventions at the practical and policy levels" (CEBC 2006). See box 4 for further detail on evidence-based ecology.

Box 4. Evidence-based ecology

Evidence-based ecology[22] derives its name from the field of evidence-based medicine, the discipline that has evolved as a scientific basis for improved diagnosis and treatment in the medical field. Several universities around the world now have programmes or centres in evidence-based ecology, focusing on conservation policies or programmes, and other fields. It is the "... framework for knowledge transfer involving systematic review and dissemination of evidence on effectiveness of interventions at the practical and policy levels" (CEBC 2006).

As a discipline, evidence-based ecology offers substantial improvements to the environmental assessment process, in all its stages. It is stronger than mere scientific advice as it provides the best available body of scientific knowledge, compiled in a way that is usable to a decision at hand, for a specific case. In terms of standard of proof, it will provide information that is clear and convincing evidence of the state of the ecosystem or process relevant to a decision. The information will be acceptable to the reasonable expert as the best available scientific information on the issue at hand.

The principal features of evidence-based ecology are that it is executed using available resources, is scientific, and delivers a timely outcome for a specified policy or development case. It provides a framework for scientific due diligence. The outcome will be logically sound, and the logic will be clear and explicit.

Finally, evidence-based ecology requires explicit treatment of the scientific uncertainties in the case at hand.

Caveat

Evidence-based ecology places substantial emphasis on providing evidence. The approach has worked well in medicine, but in complex and adaptive socio-ecological systems, it is necessary to go beyond that (personal communication Harry Biggs). Has the available evidence been meaningfully and diligently considered? And beyond that, has the unique situation of the system in question been meaningfully considered? The application of evidence-based ecology together with comparative risk assessment (explained in section 1.3.2) ensures that all available evidence is drawn together with tacit knowledge and relevant opinion.

1.3.2. Assessment of ecological changes

A description of the options for water resources management and water infrastructure operations is given in the form of determining and describing management scenarios for the system in question. This description combined with the ecosystem analysis set the scene upon which the outcomes of the environmental effects can be predicted.

Scenarios are agreed upon in a scenarios planning workshop which confirms the feasibility of proposed scenarios, gaining agreement that scenarios are reasonable and suitably different to explore a range of management options and the consequences there of.

Following the development of scenarios, the consequences of these scenarios on the ecological components of the aquatic ecosystems in question are assessed in an

---

[22] We adapted the term EBE from the concept of evidence-based conservation (EBC), as defined by the Centre for Evidence-Based Conservation (CEBC) at the University of Bangor (UK). The CEBC developed a methodology for evidence-based conservation which is a modification from that established in the field of health care research and practice (http://www.cebc.bangor.ac.uk/cebcbackground.php).

Ecological Consequences workshop. This workshop brings together an interdisciplinary group of RDM specialists in a workshop setting that provides a suitable environment for the application of comparative risk assessment (CRA).

CRA is a method for assessing, comparing, ranking and describing formally the risks in an environment with different elements at risk, and for each of which different kinds and depths of information is available. Outputs of the EcoClassification Process (e.g. ecological category-specific rule curves, summary tables and modified time series) are used by the RDM specialists to assess and describe the ecological consequences of different water resource management scenarios.

Using the CRA method, these outputs and the interdisciplinary group of RDM specialists formulate descriptions of the chains of causality between the ecological consequences of different management scenarios and changes to the ecosystem services that the aquatic ecosystems provide. The consequences are rated in terms of risk to ecosystem services provision and are accompanied by a statement of certainty.

CRA is a method now widely accepted as an approach to deal a heterogeneous problem, with environmental and developmental complexity, and where there is a necessary reliance on drawing together information from both explicit scientific sources, together with tacit knowledge and relevant opinion (e.g. Lemly, 1997; Peterson and Hulting, 2004; O'Laughlin, 2005; Kruger and Wilkinson, 2006; and Kruger et al., 2006; see box 5). It provides a “structured approach that describes, explains and organizes scientific facts, laws and relationships and provides a sound basis to determine sufficient protection measures and to develop utilization strategies” (Claasen et al., 2001).

It is akin to Ecological Risk Assessment (ERA), which is the process of predicting or estimating the likelihood and magnitude of adverse ecological effects that may arise as a result of one or more threats (e.g. Van Dam et al., 2006).

The comparative ecological risk assessment (CRA) has been successfully applied to combine best available biophysical data and expert opinion into biophysical modeling and prediction, as a precursor to environmental resource economics valuation (CIC 2007).

The output of CRA is a prioritised list of risks, with full diagnostic and causal descriptions for each priority risk (Claasen et al., 2001). It provides an assessment and ranking of risks to an ecosystem that arise from its exposure to one or more hazards, where the elements at risk are the different ecosystem assets and services identified in the systems description. In this manual, this is assessed separately for each water resource management scenario.

Ecosystem services rely on physical ecosystem assets which could include natural features such as habitats, gradient, physical structures, wetlands, species or other assets. A change in one or more of these assets[23] will cause a change in the system as a whole and impact upon the delivery of ecosystem services in some way. The accurate identification of ecosystem assets can be a complex process, and requires a combination of literature review and expert consultation. A method such Comparative Risk Assessment (CRA) has proven to be a valuable tool for rigorous and consistent asset identification (CIC 2007). CRA will be discussed in detail in section 1.3.2 below.
The outcome of the CRA is a description of the effect of the change in aquatic ecosystem structure and function (measured through change in the ecological category of different ecosystem components) in terms of the risk to ecosystem services under each scenario considered. Ecological change is translated into change in the delivery of ecosystem services through an ecological production function (US NAS 2004). “Risk assessment ensures that scientific rigour underpins a risk management decision in the face of uncertainty” (Claasen et al., 2001).

Chains of causality exist between ecosystem assets, ecosystem services, the benefits humans receive from ecosystem services and the drivers that impact on them. When these chains are defined and quantified through the selection and measurement of appropriate indicators, they form the basis for the development of production functions for each ecosystem service. Production functions are developed only for ecosystem services that are considered to be at medium, high or very high risk in each scenario.

A production function is a non-linear mathematical function of input factors of production. Every ecosystem service can be described by a unique production function which quantifies the chain of causality between ecosystem assets and other variables (proposed resource quality objectives) that impact on their production, as follows:

$$ES_i = f(EA_k;\ \text{proposed}\ RQO_j) \qquad (1)$$

where ES_i is the ecosystem service in question, EA_k is the ecosystem asset(s) associated with the provision of the ecosystem service; and RQO_j refers to the resource quality objective, which we propose could be, where relevant, an indicator or production function input variable, related to the ecosystem service.

The advantage of production functions is that it quantifies non-linear production curves, in other words, ecosystem assets and proposed resource quality objectives are non-

[23] Some literature has referred to ecosystem services as ecosystem attributes. Rogers (2007) has developed a protocol for determining the desired state of an ecosystem(s) under management. A key aspect of this protocol is the definition of vital attributes of the system, and is in fact the environmental assets of the system. See box 3 for further discussion on terminology.

linearly related ecosystem service production. Production functions therefore have the potential to deal with variability in ecosystem functioning and therefore ecosystem resilience and threshold conditions.

Some ecosystem services enter final consumption and some are utilised through intermediate consumption (these terms will be described in more detail in the Manual). In the latter case, one ecosystem service may be a production input to another ecosystem service. For example, the regulating service of *water regulation* is an input to the provisioning service of *fresh water*:

$$ES_{fresh\text{-}water} = f(ES_{water\text{-}regulation};\ EA_k;\ \text{proposed } RQO_j) \qquad (2)$$

Furthermore, the production process for other economic goods and services, such as foods, fuels and fibres, combines both a set of natural processes and a set of managed processes, in which the independent variables are the set of produced factors of production (capital stocks), environmental factors of production (usually approximated by "land") and labour. In symbolic notation this looks as follows:

$$Q = g(K, L, f(ES)) \qquad (3)$$

OR

Output = f(capital, labour, services derived from ecosystems).

The change in welfare (output) of the change in ecosystem services due to development or other management options can therefore be measured by the value of that change. The social opportunity cost of developments that change ecosystems accordingly includes the value of the resulting change in ecosystem services. This makes it possible to evaluate environmental impacts alongside the other costs and benefits of the management scenarios, and so to estimate the net present social value of distinct management scenarios (can include development options) *inclusive of environmental effects* (Perrings, 2007).

In many cases there will be further data requirements to establish production functions, but the level of data used will be consonant with the level of Reserve determination[24]. Only in the comprehensive Reserve determination may there be funds and time available for further data collection.

[24] There are four different levels of Reserve determination (namely desktop, rapid, intermediate and comprehensive), each with its own Ecological Water Requirement (EWR) method and EcoClassification process (DWAF 1999), which vary in the level of detail and effort required in assessing water resources. See Phase 1 in the Manual for further detail.

Data and knowledge required to determine production functions are gathered through data collection (only possible at comprehensive level of Reserve determination), knowledge harvesting of existing data (all levels) and evidence-based ecology (all levels – Box 5).

Box 5. Knowledge harvesting through CRA

While evidence-based ecology is a framework for knowledge transfer of explicit knowledge, knowledge harvesting offers a holistic, proprietary, and comprehensive approach to transforming implicit, intuitive knowledge to explicit knowledge that is transferrable to others.

The approach is a relatively new one in the well established field of knowledge management and is gaining wide acceptance. The approach was developed by Larry T. Wilson of Knowledge Harvesting, Inc. and it can be seen as a "strategic solution to knowledge creation as it synthesizes the advantages of technology with the relevance of a context" (Kothuri, 2002).

The full process of Knowledge Harvesting is explained in Wilson and Frappaolo (1999) and includes: identification of knowledge, elicitation of knowledge, capture of knowledge, organization of knowledge, application of knowledge, recording of knowledge, sharing of knowledge, evaluation of the knowledge creation process, and improvement of the knowledge creation process.

Knowledge harvesting is an emerging tool with definite application in ERE.

1.3.3. Valuation of ecosystem services

Ecosystem services are a finite set of beneficial services produced by the environment, for direct and indirect consumption by humans. The valuation of ecosystem services quantifies these benefits.

A wide variety of valuation techniques exist. These are discussed in detail in the accompanying manual.

Ecosystem services are translated to value by an economic valuation function (or demand function) (US NAS 2004).

"Demand" is an economic principle that describes a consumer's desire and willingness to pay a price for a specific good or service. Demand functions for ecosystem services (or demand curves) are mathematical functions that have a particular ecosystem service as a dependent variable, and regulatory and or supporting ecosystem services, and other demand variables as independent variables.

These functions therefore link production functions to the cost-benefit analysis.

Demand functions are constructed from time-series or cross-sectional data, using econometric modelling techniques and software.
Demand functions can be constructed using two approaches:

- observed behaviour, and
- hypothetical behaviour.

In the observed behaviour approach, demand functions are based upon human behaviour which is either directly or indirectly observed.

Direct observed behaviour methods derive estimates of value from the observed market behaviour of producers and consumers. These methods are applicable where ecosystem services are privately owned (i.e. not public goods), are traded in functioning markets, and where market prices can therefore be observed.

Indirect observed behaviour methods are used where market prices are not available, which is often the case for most ecosystem services. Data are gathered from observed market behaviour of surrogate markets, which is hypothesized to have a direct relationship with the particular ecosystem value. Examples of these methods include hedonic pricing and travel cost. Also included under these methods are the cost-based methods of evaluation. These methods include replacement cost and damage cost methods.

Hedonic pricing uses statistical techniques to unpack property prices into the implicit prices for each of attributes, including ecosystem assets and services.

Travel cost method (TCM) uses the observed costs paid to travel to a destination or make use of an ecosystem service, to derive demand functions for that destination or service.

In the hypothetical behaviour approach, people's responses to direct questions describing hypothetical markets or situations are used to infer value. This is also often referred to as choice modelling. People are normally asked what they would be willing to pay for a particular ecosystem service. The contingent valuation method (CVM) uses a direct hypothetical method. Conjoint analysis and contingent ranking uses an indirect hypothetical method.

1.3.4. Evaluation trade-offs

Different water resource management scenarios result in a set of changes in the net benefits for economic goods and services and for ecosystem services. These are a set of trade-offs. To evaluate the combined effect of these trade-offs, an evaluation framework is required.

A large number of such evaluation frameworks exist. These include, cost-benefit analysis (CBA), multi-criteria analysis (MCA), cost-effectiveness analysis, portfolio theory, game theory, public finance theory, behavioural decision theory, policy exercises, focus groups, simulation-gaming, and ethical and cultural prescriptive rules

(MA, 2003). In literature, CBA and MCA are most commonly recommended to although CBA is by far the most commonly applied.

A cost-benefit analysis (CBA) assesses the net social benefits of a scenario over time. A net present social value (NPSV) is derived, through discounting, from the flow of costs and benefits over time, and is then used to assess project options. Financial, social and environmental costs and benefits incurred by a society are measured in a CBA. This is as opposed to an investment decision, where financial returns of an individual entity are often the only concern.

CBA informs two types of decision-making (a) whether a project is worthwhile to be pursued and (b) where more than one project option is available, which of these are more beneficial. A project is worthwhile to be pursued if the net present social value is positive. The more beneficial project option has a higher net present social value.

Whereas a cost-benefit analysis (CBA) is effectively an aggregate of valuation estimates of ecological services, multi-criteria analysis (MCA) is a decision-making tool designed for facilitated solutions to complex problems. There are a number of multi-criteria techniques but the main aim of multi-criteria decision analyses is "not to discover a solution, but to construct or create a set of relations amongst actions that better inform the actors taking part in a decision process".

From this it is clear that the results of a CBA may provide data into an MCA, and that, for utilitarian-based valuation as envisaged in projects of this nature, the CBA remains the suitable evaluation framework[25].

The valuation techniques discussed in the section above are used to estimate the changes in costs and benefits resulting from the various scenarios.

1.4 Summary

This framework and manual can be used with any assessment of ecosystem services in aquatic ecosystems. Linkages with the WRCS will be highlighted for convenient comparison and combined usage. But the WRCS has not been gazetted yet and may still undergo some changes.

By reviewing most recent and relevant literature, globally and nationally we provide a manual for valuing ecosystem services that:

- is based on best scientific knowledge;
- is considerate of the complex adaptive social-ecological systems that deliver ecosystem services;

[25] CIC International. 2007. Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures, Water Research Commission

- exemplifies the need for intelligent thought in each case;
- proposes comparative risk assessment as a useful tool in prioritizing risks to ecosystem service provision and as a means of scaling down to the requisite simplicity;
- makes assumptions made explicit in order to test assumptions and so facilitate learning;
- evaluates available methodologies and techniques for valuation in an objective manner;
- all the while being cognizant that this is a stepping stone in the continued pathway of learning around ecosystem service valuation;
- is not overly prescriptive, and adopts a pragmatic approach which encourages practitioners in learning and adaptive analyses; and
- considers the aquatic ecosystem services benefits accruing to all beneficiaries, while accommodating a public participation process.

This Framework and Manual provides a comprehensive review and guide that serves to support the WRCS and clarify the valuation of ecosystem services delivered by aquatic ecosystems for RDM.

1.4.1. Standards and transparency

To ensure repeatable results that can stand up in court, a number of standards are relevant.

Terminology used, methods applied and outputs delivered must be consonant with national plans and law. This would include for instance Asgi-SA, the National Environmental Management Act (1998), the National Environmental Management: Biodiversity Act (2004) and the South African Statistical Quality Assessment Framework (SASQAF).

The approach followed and methods applied should be consistent with best international practise. The Millennium Ecosystems Assessment (MA) provides the most advance guidelines on approach. The United Nations and its agents and various international centres of excellence provide international guidelines on various methodologies such as cost-benefit analysis, comparative risk assessment and evidence-based ecology (see section 1.5.1).

The technical work done should be of best international standards. This includes ecological analysis and economic analysis. It is therefore important to have a competent environmental and resource economics (ERE) team, who do not only have the ability to conduct sound work, but who can also act as critical internal peer reviewers.

And finally, all analysis should maintain a transparent, heterogeneous, balanced, interdisciplinary, consultative and participatory approach to policy evaluation and building of the evidence-base (Scrieciu, 2007).

1.4.2. Consistency

Consistency with existing legislation and approaches is important. The Framework and Manual links with the RDM process as follows:

- it specifies the methodology for the description of the ecological and biophysical implications for aquatic ecosystems of different scenarios (and especially, provide for effective and efficient benefits transfer);
- it provides the framework for the aggregation and presentation of economic, social and ecological data at a catchment level for alternate scenarios;
- it generates the cost-benefit analysis for the integrated decision-analysis tool, and;
- it contains the elements needed to support the identification of stakeholders for a catchment, stakeholder consultation process, and a template for information on the economic, social and ecological implications of different scenarios for a decision on a MC.

The methods and procedures set out below are consonant with the concepts, definitions, requirements, standards and procedural steps contained in the following legislation and national programmes:

- The National Water Act and its amendments (available at
- www.info.gov.za/gazette/acts/1998/a36-98.pdf)
- The National Water Resource Strategy (DWAF 2004, available at www.dwaf.gov.za/Documents/Policies/NWRS/Default.htm)
- The guidelines for Catchment Management Strategies (DWAF 2007b, available at www.dwaf.gov.za/Documents/Other/CMA/CMSFeb07/CMSFeb07Ed1Ch1.pdf)
- The Water Resource Classification System (DWAF 2007a, available at www.dwaf.gov.za/rdm/documents/waterresourcedocs.asp)
- The National Environmental Management: Biodiversity Act (available at www.info.gov.za/gazette/acts/2004/a10-04.pdf)
- the National Biodiversity Strategy and Action Plan (available at www.environment.gov.za/ProjProg/ProjProg/2004Jun10/natStrategy_26052004.html#) and the
- River Health Programme (www.csir.co.za/rhp).

In addition, the Framework uses and builds key approaches and methods developed by various practitioners that come out of contemporary science and guidelines:

- various approaches and frameworks proposed by the Millennium Ecosystems Assessment (MA);

- resilience thinking as described in Walker and Salt (2006) and outline in guidelines and manuals developed by the Resilience Alliance (Resilience Alliance, 2007a, b);
- the holistic approach and method to environmental flow assessments to rivers as in King et al. (2003) called DRIFT (the Downstream Response to Imposed Flow Transformation). DRIFT incorporates four modules: a biophysical module, a sociological module, a scenario-development module and a economic module which together allow the assessment of alternative resource protection options; and
- Comparative Risk Assessment;
- Evidence-based ecology;
- various environmental-and-resource-economic techniques; and
- cost-benefit-analysis.

1.4.3. Opportunities

Through the development of this Framework and Manual, a number of opportunities worthy of further exploration were identified and include:

- Collation of evidence of the linkages between biodiversity, ecosystem change and ecosystem service delivery (similar to the review by Balmford et al., 2008), specific, or applicable, to southern African aquatic ecosystems. This would provide a source of evidence for production functions and models of ecosystems services (with different levels of complexity and data inputs for different levels of Reserve determination). The data collected and analysed by RDM specialists, particularly through the EcoClassification Process and other models, should be explored to: clarify what site-specific data relevant to ecosystem service production functions is available; and/or isolate additions or slight alterations to the type of data collected by the specialists. This would also highlight gaps in knowledge and evidence of linkages between ecological components, ecosystem services and benefits to human well-being. A particular need in such research is likely to be in relation to:

    identifying changes in the regulating ecosystem services, as amongst the most important environmental consequence of human activities, and the relationship of these changes to thresholds and the resilience of the system;

    links to human vulnerability, i.e. where thresholds to ecological change in a system will affect the delivery of ecosystem services necessary for economic growth, redress of inequality and poverty alleviation would be compromised; and

    improving our ability to track the effect of these on human well-being.
- The exploration of risk terminology as a basis for dialogue in the management of the allocation and use of water resources requires further exploration. The

concept of risk to ecosystem services is more broadly understandable to a wide range of stakeholders than statements on how ecosystem components will change. This is important in to communication of trade-offs and the implications thereof when it comes to stakeholder participation. Such research will develop insights into the strategic management of dialogue in complex decision making contexts and the importance of this for sustaining water resources in a dynamic and uncertain global environment.

- Aquatic ecosystem services evaluation needs to link with collateral decisions in the domains of biodiversity and land management, and such a linkage would in turn offer efficiency gains through minimizing redundancy in the evaluations as well a supporting necessary meta-analysis.
- As the WRCS is implemented, one would expect trade-offs to be continually changing. The Framework proposed here has to be continually assessed and improved, where necessary, to adapt to the changing environment.

1.4.4. Conclusion

Inherent to the ecosystem approach of the MA is the understanding that socio-ecological systems are complex and dynamic. Management interventions will: be based on incomplete knowledge or understanding of ecosystem functioning; have unforeseen feedbacks over the long term; be insufficient for coping with continuous change and future shocks; and be unable to account for all social, economic and ecological influences at multiple scales (MA, 2003; Pollard et al., 2008). But management approaches that take all these characteristics of socio-ecological systems into account have greater potential for management that increases a system's resilience and adaptive capacity and set the system on a more sustainable trajectory (Resilience Alliance, 2007a, b; Pollard et al., 2008).

PART II: MANUAL

This Manual stipulates the methods and procedures to be employed in the evaluation of trade-offs arising from decisions about the application of resource directed measures in the protection of any given water resource, as required in Chapter 3 of the NWA. Figure 6 presents the outline of the Manual in terms of the project activities, methods used and outputs.

The evaluation of aquatic ecosystem services for Resource Directed Measures (RDM) is largely aligned with the Water Resource Classification System (WRCS), which was designed to determine the Management Class (MC), Reserve and Resource Quality Objectives (RQO) (as per the National Water Resource Strategy (NWRS) prescribed in terms of the National Water Act (NWA)).

Methods used	Project activities	Outputs
Phase 1. Systems analysis		
Extensive literature survey EcoClassification process	1A. Bounding the system 1B. Systems description of the entity 1C. Describe SWR 1D. Describe ecosystem services in each SWR and identify assets	Introductory document to the CRA
Phase 2. Assessing ecological change		
EcoClassification process	2A. Determine and describe management scenarios	Introductory CRA document
Comparative Risk Assessment	2B. Facilitated expert ecosystem analysis	Prioritised list of ecosystem services at risk
Evidence-based ecology	2C. Specification of ecosystem services production functions	Ecosystem service production function
Phase 3. Value ecosystem services		
ERE fieldwork and techniques	3A. Selection of valuation techniques	Ecosystem service demand functions
Database and spreadsheet modeling	3B. Data collection	Ecosystem services costs
Value-added analysis	3C. Conduct valuation	Other costs and benefits
Phase 4. Evaluate optional scenarios		
Cost-benefit analysis	4A. Options evaluation	Final results: ecosystem value

Figure 6. Outline of the Manual in terms of the project activities, methods used and outputs.

PHASE 1 – Systems analysis

The preliminary systems analysis is intended to provide an understanding and prediction of the environmental effects of a change in the condition of water resources as a result of management scenarios that alter the ecological components of water resources, where ecological components refer to hydrology, geomorphology, biota (fish and invertebrates) and water quality of water resource. ‘System’ refers to the socio-ecological system[26].

The preliminary system analysis is crucial to setting the context and baseline for the valuation of ecosystem services. It has four parts to it:

Phase		Description
1	Preliminary systems analysis	
A	Bounding the system	A problem statement bounds the assessment spatially and temporally such that the study area, level of Reserve determination, and metasystem can be defined.
B	Description of the entity	A sound conceptual understanding of the ecological, social and economic conditions of the entity is required to produce definitive statements about the ecological and socio-economic characteristics of the entity.
C	Define the significant water resources in each integrated unit of analysis	The delineation and description of significant water resources (SWR) in each integrated unit of analysis (IUA) are important to valuation of ecosystem services.
D	Determine present-day ecosystem services delivered from each SWR	Determination of present-day aquatic ecosystem services utilised and who the beneficiaries are.

Linkage to other components of RDM

Phase 1 is in line with Step 1a-f in the WRCS. The approach in Phase 1 differs from Step 1g-j in the following ways:

- Step 1g: terminology of ecosystem services, and the value of uses of aquatic ecosystems are not determined here

[26] IWRM acknowledges an ecosystem approach to water resource management. Water resources “cannot be considered separately from the people who use and manage” them (NWRS), thus integrated water resources management (IWRM) recognises water resources as part of socio-ecological systems, whose connectivity is exhibited over wide ranging spatial and temporal scales. Socio-ecological systems are naturally dynamic, and thus changes in resource quality result in changes in composition, structure and functioning of water resources that are often unpredictable.

- Step 1h and 1j: use of SWR and not integrated units of analysis (IUA)
- Step 1i: the socio-economic framework and decision-analysis framework applied is that of the MA and environmental and resource economics (ERE)

1A. Defining the boundaries of the system

When assessing ecosystem services it is important to bound the analysis spatially and temporally (MA, 2003). The purpose of boundary definition is therefore to specify the extent of the predictions to be made for the system that is subject to change in space and time and involves at least the following elements:

- the problem description (Terms of Reference)
- the geographical entity which will be affected by the change in water resource management including all areas to which direct environmental effects will extend;
- the level of RDM assessment required (level of confidence) for the study;
- the metasystem (i.e. all significant populations, processes or resources outside the boundaries of the entity that will be affected by changes within the entity); and
- the study team to undertake the assessment.

i. Problem description (~Terms of Reference)

The problem description is the starting point for formulating questions that must be answered in the assessment as a whole. The system analysis requires a problem description, or Terms of Reference, that:

- frames the case-specific analysis required for the assessment;
- communicate to the analyst the magnitude and importance of the issues that arise from the proposal;
- enables the analyst to identify the system and the management and activities to which it will be subject;
- confines the analysis to what is necessary, avoiding unnecessary and confusing generalizations;
- states the date at which the assessment of the entity began and ended; and
- is used to ascertain whether the assessment has been completed to specification.

ii. Delineation of the study area (entity)

The entity is the geographical entity within which the development is to occur including all areas to which direct environmental effects will extend and potentially result in a change in resource quality[27].

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

This should largely be defined in the Terms of Reference and is usually defined by the area undergoing compulsory licensing, or the scale or extent of the proposed application (Parson and Wentzel, 2007). It can be complicated by inter-basin transfers and return flows in areas where irrigation water is extracted from one water resource and return flows are upstream of the abstraction point or flow into another catchment.

An RDM assessment is usually commissioned for a Water Management Area (WMA[28]) or primary catchment[29], although Reserve determination may be required for smaller regions. It is however always defined by catchment boundaries. The basic unit of RDM assessments is the quaternary catchment, which usually represents the smallest unit for which a management class is determined.

iii. Level of RDM assessment

Insufficient data, as well as time and funding constraints for data collection are a reality. The standards and principles of transparency described in section 1.4.1 of the Framework highlight the importance of not attaching false levels of confidence to assessments. The level of RDM assessment determines the degree of confidence and data requirements of the ERE assessment.

There are different levels of RDM assessment, each with their own Ecological Water Requirement (EWR) method and EcoClassification process (DWAF 1999). These EWR methods vary in level of detail and effort required in assessing water resources, and are referred to as desktop, rapid, intermediate and comprehensive (Table 3).

Table 3. Description of the levels of RDM assessment (DWAF 1999; Kleynhans and Louw, 2007; Parsons and Wentzel, 2007)

Assessment level	Description	Data source
Desktop estimates	These are of the class and Reserve and are undertaken for water quantity only, have very low confidence, and were designed for use in the National Water Balance Model only.	National scale data sets supported by expert information and local knowledge
Rapid I, II, and III determinations	These are of the class and Reserve, are undertaken for water quantity and quality, have low confidence (based on desktop estimates and a single field assessment), and are used for individual licensing for small impacts in unstressed catchments of low importance and sensitivity.	National scale data sets supported by expert information and local knowledge

28 WMA is an area established as a management unit in the national water resource strategy within which a catchment management agency will conduct the protection, use, development, conservation, management and control of water resources (NWA 1998). They are not congruent with primary catchments but are largely congruent with the boundaries of quaternary catchments.

29 A catchment (synonymous with the term river basin) is the area from which any rainfall will drain into the watercourse, contributing to the runoff at a particular point in a river system; a primary catchment is the area from which a river with all its tributaries drains from out of origin to sea.

Assessment level	Description	Data source
Intermediate determinations	This is of the class, Reserve and relevant resource quality objectives for habitat and biota involve a medium confidence determination using specialist field studies, usually two field assessments, and are used for individual licensing in relatively unstressed catchments.	Site-specific data
Comprehensive determination	This is of the class, Reserve and resource quality objectives for habitat, biota, water uses and land-based activities is a fairly high confidence determination based on extensive field data, four field assessments, and is used for all compulsory licensing and in individual licensing, for large impacts in any catchment or small to large impacts in very important and/or sensitive catchments.	Site-specific data

The decision regarding the level of RDM is usually made by the RDM Directorate, but may be adjusted following the detailed description of the entity (Phase 1B). A Scoping Study, in the form of a Desktop RDM assessment, may be commissioned to help determine the level of RDM assessment.

The tools required for RDM determination at these various levels are in different stages of development for rivers, groundwater, wetlands and estuaries (DWAF 1999). They are most advanced for rivers (DWAF 1999; Kleynhans and Louw, 2007) and groundwater (Parsons and Wentzel, 2007).

iv. Metasystem

The metasystem is defined broadly as all significant populations, processes or resources outside the boundaries of the entity that will be affected by changes within the entity. This is equivalent to the ecological footprint of the project and includes those economic sectors at local, regional and national levels (sometimes, global, such as in the case of greenhouse-gas emissions). In the metasystem, the analysis may be limited to proxy analysis, e.g. by using emission indices.

It is important to have a multi-scale approach to assessment in order to properly evaluate the driving forces internal and external to the system in question (MA, 2003; Walker and Salt, 2006; Resilience Alliance, 2007a).

The boundaries of the metasystem are conceptual but sometimes may be mapped (e.g. the boundaries of a larger catchment within which the entity falls).

v. Study team

The determination of the study team is a DWAF management task, which is carried out by the RDM Directorate and the assigned RDM Study Manager. Resource economists involved in the valuation of ecosystem services should be included in the RDM assessment from the beginning in order to:

- understand the problem;
- gather the necessary information;
- be involved in the creation of management scenarios and to understand the biological and operational reasons behind different scenarios; and
- liaise with other disciplinary experts in order to effectively develop production functions of the linkages between change in the aquatic ecosystem and the provision of ecosystem services.

1B. Description of the entity

A sound conceptual understanding of the ecological, social and economic conditions of the entity is required. This must be done in such a way that reader understands everything that is relevant to the environmental effects that may arise from the project.

Therefore, the purpose of this phase is to:

- provide a description, in words as well as schematically (e.g. tables, diagrams and algorithms), of the ecological characteristics of the entity to
    - understand the current state and functioning of the ecosystem within the entity and
    - interpret the assessment the report will contain and to identify areas of similar ecological characteristics;
- provide a description of the socio-economic characteristics of the entity to identify areas of similar socio-economic characteristics; and
- to identify the uses of water and the ecosystem services provided by aquatic ecosystems.

The objectives of the system analysis are to provide a logical framework for an understanding of the following:

- biophysical attributes (some of which we later identify as assets)
    - substrates (e.g. soil, geological substrates or sediments) on which
    - biogeochemical and other ecological processes depend, and
    - the biotic communities within the ecosystem.
- ecological processes
    - all the biophysical processes within the system
    - that determine the direction, rate and fate
    - of the flows of energy and material through the system
- system feedback controls
    - The system feedback controls are essentially information flows in the system that govern the way the system responds to environmental effects.

Feedback controls may dampen (positive feedback) or amplify (negative feedback) environmental effects (but consider global warming and cloud formation)

- inputs and outputs to and from the system

  The inputs are the major inflows of materials and energy such as water and sediment in a river.

  The outputs are diverse and may be the same flows but would include the material components of ecosystem services.

The outcome is to be a definitive statement about the ecological and socio-economic characteristics of the entity. Ecological characteristics are described for the entity as a whole. Social and economic characteristics of the entity are described per socio-economic zone (as identified in Step 1 of the WRCS).

This description should come from best available data sources and the information should be adequate to determine the RDM to the level specified in the Terms of Reference. It should contain no more than is required to meet this purpose.

Provide maps and figures to support the description where possible. All maps should include the following basic information: main rivers, major arterial roads, major towns and quaternary catchment boundaries.

Information included here as well as later in this analysis may and in most occasions will be imperfect. The assessment should therefore include statements of uncertainties that arise from such imperfections.

In the context of the RDM assessment, much of the data are collated by disciplinary experts. These data are:

- collected in an iterative fashion from the scoping assessment to EcoClassification process; and
- dependent on the level of Reserve determination.

Table 4 below provides a summary of social, ecological and economic data relevant to the description of the entity and ecosystem services.

Linkage to other components of RDM

This section is divided broadly into two parts:

- ecological characteristics of the entity, which will feed into Steps 1c, d, and broadly 1h;
- socio-economic characteristics of the entity, which relate to Steps 1a, b, e and partly to Steps 1f and g, and broadly feeds into Step 1h.

Table 4. Guidelines of social, ecological and economic data relevant to the description of the entity.

Data	Relevance to ecosystem services	Examples of data sources*
Ecological characteristics		
Physiography and geomorphology	Background data to systems analysis: topographical (elevation, slope and aspect) and geomorphological data	Geomorphological river zones (Rowntree and Wadeson, 1999); Geomorphological provinces (as in Nel et al., 2004)
Climate 	This section should provide climatic information that serves to (a) support the identification of the Reference Condition of the entity (b) understand the long-term climatic determinants of the state of water resources within the entity and the range of variation in that state. Temperature and rainfall affect water quality with consequences to biota.	Agroclimatological Atlas of South Africa
Geology and soils	Soil and soil processes are underpin all other ecosystem services in some way. Useful information in this category includes susceptibility to erosion, erosion rates, permeability, infiltration, weathering, bedrock types, and groundwater characteristics.	Internal Strategic Perspectives (ISP) for the WMA; Land Types from the Institute for Soil, Climate and Water; GAI, SA Stratigraphic System of geological formations
Hydrology 	Background data to systems analysis: interested in mean annual runoff (MAR), temporal variability in river flows (hydrological index), trends and patterns, present ecological status (PES) and ecological importance and sensitivity category (EISC); ecological water requirements (EWR) information (if available); dam volumes, yield, flow rates, water resource width, depth and profile.	WR90; Default PES and EISC in the WSAM; Hydrological index (HI; Hughes and Hannart, 2003)
Geohydrology	Want to understand the movement of water underground, quality of groundwater, sources and incidents of contamination, surface-groundwater interaction, including groundwater contribution to baseflow and aquifer-dependent ecosystems (ADE)	ADE (Colvin et al., 2007)

Water quality 	Again water quality data is key to RDM but of importance to ES, is exceedance of water quality criteria according to SA Water Quality Criteria Guidelines as this affects Human Health and activities, limiting use of the water; trends in water quality	Water Management System (WMS) data; SAWQG (DWAF 1996)
Vegetation types	Vegetation types inform species composition, carbon sequestration rates, conservation status, and vulnerability to disturbance. Presence and abundance of alien invasives; plant species utilised by people and quantification of use. Area of natural remaining vegetation type is an indicator of the ecological integrity of the catchment. Alien invasives;	Vegetation types (Mucina and Rutherford, 2004); national land cover; VEGRAI
River ecoregions	Background data to systems analysis: River ecoregions represent regions within which there is relative similarity in the mosaic of ecosystems and ecosystem components (biotic and abiotic, aquatic and terrestrial). Rivers grouped together in a particular ecoregion are more similar to one another than to rivers in other ecoregions" (Roux et al., 2008).	Ecoregions (Kleynhans et al., 2005); River Health Program (www.csir.co.za/rhp)
Biodiversity assessment	Regions that fall within or are part of critical biodiversity areas (priority areas) identified in national and/or regional conservation assessments are an indicator of biodiversity importance, conservation status of rivers. For both terrestrial, marine and aquatic ecosystems, provide information relating to any of the following questions (if relevant to water resources): • What are the biotic communities at issue? • What are the composition, structure and dynamics of each? • What keystone and functional roles? • Are there threatened or endemic species in aquatic ecosystems? • What are the status and trends in alien invasive species? • Species of use – medicinal, harvesting, etc.?	National Spatial Biodiversity Assessment; bioregional or provincial conservation plans; protected areas database (DWAF)

Socio-economic characteristics [$] – description of the land use patterns, present socio-economic status, and water use within the entity		
Economic indicators	Gross domestic product (GDP), level of employment, poverty indicators, general description of economic infrastructure (including land use – see below)	
Land-use patterns	Discuss land use associated with each land-cover type briefly with respect to its water demands, sustainability, and effects on aquatic ecosystems.	National Land Cover data (according to Rouget et al., 2004)
Demographic information	Provides socio-economic data on the beneficiaries of ecosystem services, and their level of consumption. Where possible information should be gathered at the ward level (wards with less than 5% of their area within the entity can be excluded): • Population density, distribution, urban/rural, gender, age composition, household size, household heads, and population structure • Fertility rates and child mortality • Gender issues, other vulnerable groups (refugees)	Statistics South Africa Census Data
Household income	A description of household income which can be used to determine categories such as poor and non-poor communities; formal and informal employment tells us about, although tenuous, dependence of beneficiaries on ecosystem services, and social resilience in terms of vulnerability to shocks and stressors.	Statistics South Africa Census Data
Human capital	Level of education	
Social capital	Community cohesion and organizational skills reflecting the degree to which communities are organized and is useful for assessing the success of mitigation measures required to implement RDMs.	

Water use by sector	Water use and water demands per sector. In combination with available water yield, determine the water balance (which is crucial to the determination of RDM and fundamental to the description of the scenarios).	ISP for the WMA; hydrological model
Role players[30]	These are the beneficiaries of ecosystem services. They may be benefited directly or indirectly at different scales.	From socio-economic information already collected; formal process of application?
History of the entity	Analysis of past states and functioning in order to understand how the functioning of the system at present will have been affected by events and trends in the past; and also to provide a historical frame within which to appraise the dimensions of the environmental effects of the proposed project (e.g. flood and drought cycles). Such a history contributes to the determination of the Reference Condition[31] of the water resources. Knowledge of the reference condition is important for considering how much the system has changed already, and providing insight into resilience possible thresholds.	Variety of sources
Policy, plans & programmes	Relevant policy, plans and programmes applicable to an area	

 = Time series data recommended

* Examples of data sources refer to national data sources. It is not an exhaustive list and finer scale; regional data offer other sources of data.

$ Ecological characteristics are described for entity as a whole. Social and economic characteristics of the entity are described per socio-economic zone (as identified Step 1 of the WRCS).

[30] According to DWAF (2007a), role-players are those “who by virtue of their identity, influence decisions”. This is obviously a broad group, including stakeholders, the public and interested & affected parties. Stakeholders are “those parties that are directly affected by decisions and outcomes of a decision”, while interested and affected parties (I&APs) are “a particular group of persons who have an interest in, or are affected by, a particular intervention” (DWAF 2007a).

[31] The reference condition is an important component in the EcoClassification process describing “the condition of the site, river reach or delineation prior to anthropogenic change and is formulated for each component considered in EcoStatus determination (fish, aquatic invertebrates, riparian vegetation, water quality, geomorphology and hydrology)” (Kleynhans and Louw 2007).

1C. Describe the significant water resources (SWR)

This section identifies the delineation of areas sufficiently different to warrant their own RDM assessment. These areas are described (and become the assets that will be assessed in the comparative risk assessment in Phase 2). Due to the considerable number of terms used to describe the different ways in which the entity can be divided, a brief discussion and comparison of this terminology is provided in Box 6.

Box 6. Considering terminology: IUAs, RUs and SWRs

The National Water Act (Act No. 36 of 1998) states that the Minister of Water Affairs and Forestry is responsible for determining the Management Class, Reserve and Resource Quality Objectives for "all or part of every water resource considered to be significant". The Act uses but does not define the term '*significant water resource'*.

DWAF (1999) suggests that the term 'significant', as it is used in Chapter 3 of the Act, relates to the **geographic extent** of a water resource[32] for which a MC, Reserve and RQO (RDM) must be determined, rather than the importance of one water resource in comparison to another, as all water resources should be protected.

It would not be practical to determine RDM for water resources that are very small and/or have similar properties, nor would it be helpful to determine RDM for very large, diverse areas (i.e. primary or secondary catchments) (DWAF 1999). The implication is "that RDM assessment should be undertaken at **a "significant" scale"**, which delineates water resources in a practical way "as those that are significant from a 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" (Dollar et al., 2007). Significant resources may include:

- mainstream rivers in each quaternary catchment;
- estuaries, as identified by a nationally-defensible estuarine classification system;
- wetlands, as identified by a nationally-defensible wetlands classification system;
- aquifers, as identified by a nationally-defensible groundwater classification system; and
- any other resources considered significant.

These resources may be defined at different scales. Therefore the geographic boundaries of each significant water resource unit need to be clearly delineated (see Figure B1 below). Additionally, the national WRCS introduces the term ***integrated unit of analysis*** (IUA). This term was put forward as a broader-scale unit of assessment for evaluating the socio-economic implications of different catchment configuration scenarios and to report on the ecological category at a sub-catchment scale. The determination of an IUA is a combination of socio-economic zones and the watershed boundaries, within which ecological information is provided at a finer scale (Brown et al., 2007).

To explain this, an IUA is illustrated in Figure B1 representing one socio-economic zone in which agricultural and rural land uses predominate. Its boundaries become those of the quaternary catchments for the purposes of the assessment. The mainstem rivers in each quaternary catchment (QC) are sufficiently different to warrant

[32] NWA (1998) recognises that water resources "include watercourses, surface water, estuaries and aquifers". A water course means "a river or spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows; and any collection of water which the Minister may, by notice in the Government Gazette, declare to be a watercourse. Reference to a watercourse includes, where relevant, its bed and banks".

their own RDM assessment and therefore are two significant water resources. The wetland in this example is endorheic (meaning it has closed drainage, lacking any outlet) and qualifies as a SWR, requiring a Management Class, Reserve and RQO of its own. There are two geohydrological regions in the example, which are separate groundwater resource units and thus qualify for their own Reserve, management class and RQOs. Finally the estuary is also classified as a SWR.

The national WRCS has only been implemented recently and is still a draft so might still undergo revisions. The NWA requires compulsory licensing be undertaken before water could be allocated for use. This compulsory licensing requires the Reserve be determined for a water resource, so in order not stall development while waiting for the development of the WRCS, a process of Reserve determinations has been developed and used. In the absence of the WRCS, these Reserve determination studies have used their own terminology, which for clarity purposes is explained further.

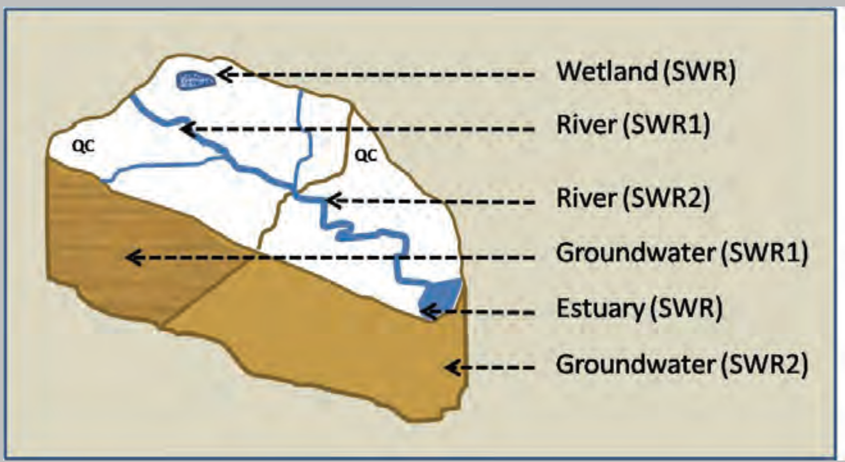


Figure 7. Illustration of integrated unit of analysis with six significant water resources identified for which each must have its own management class, Reserve and RQO

The SWRs in Figure 7 are equivalent to the *resource units* referred to in many Reserve determination studies and in the *Groundwater RDM Manual* (DWAF 1999, volume 3; Parson and Wentzel, 2007). In more recent Reserve determination studies, resource units have been prefixed with 'natural', 'management' or termed a Reserve Assessment Unit. These distinctions in the delineation of the catchment recognise that resource units are determined based on aggregations or considerations of different ecological, social and economic data. The delineation of natural resource units are based on biophysical information. Management resource units take into account management requirements (e.g. where large dams or transfer schemes occur). The final delineation is reliant on a process of considering expert judgement, consultation and local knowledge. Thus Management Resource Units can be further delineated into even smaller assessment units, namely Reserve Assessment Units (RAU), if for example a change in land use within a MRU warrants a different RDM assessment (e.g. river flows from degraded land area into a large protected area such as the Kruger National Park) (Water for Africa 2008a). Thus, a resource unit does not always align with catchment boundaries.

This Framework and Manual uses the terminology of the WRCS.

i. Describe each Integrated unit of analysis (IUA)

The determination of an IUA is a combination of socio-economic zones and the watershed boundaries, within which ecological information is provided at a finer scale. This determination is described in Step 1h of the WRCS.

Provide a summary of the ecological and socio-economic information gathered for each IUA.

ii. Describe the SWR in each IUA

The objective of defining a network of significant water resources is to identify resources for which a MC, Reserve and RQOs will be determined within the entity. The identification of significant water resources is achieved through consultation with the study team (including expert judgement, local knowledge and relevant spatial data) or from a prior classification of water resources within the entity. The level of the RDM predetermines to some extent the type of information used to delineate the SWRs[33], such as EcoRegions, stream classification, habitat integrity, water quality, groundwater and/or water resource infrastructure.

The delineation and description of SWR in each IUA are important to the valuation of ecosystem services as these become the *assets at risk* assessed in the Comparative Risk Assessment (see Phase 2B below). The asset is equivalent to the physical component of the ecosystem upon which a flow of ecosystem services depends. This dependence is sometimes tenuous, but the SWRs are the level at which change in ecological condition is measured. Change in any of the ecological components that describe ecological category (hydrology, geomorphology, water quality, vegetation or biota; Kleynhans and Louw, 2007) become part of the production function (described in Phase 2C below). List and describe each significant water resource within the entity.

1D. Determine the present-day ecosystem services delivered from each significant water resource

For regulating, provisioning and cultural services, identify the ecosystem services for each significant water resource as well as the beneficiaries of each service, according to Table 5 below. It is important to remember that this classification provides a useful guide to the assessment of ecosystem services but must be considered diligently and with cognisance that ecosystem service assessment is case specific. An individual case may warrant:

- Further division of any one category (e.g. food provisioning might include subsistence dryland agriculture, harvested food such as fish or game meat, etc.)
- Additional ecosystem services (e.g. human health as an end service of disease regulation and natural hazard regulation, or the provision of clay for medicinal or craft use and sand mining as a renewable resource in certain rivers). For the beneficiaries' assessment, follow the socio-economic module in DRIFT (Brown et al., 2006).

[33] For instance, at a rapid RDM level the SWRs are determined based largely on ecoregions and obvious operational information (if relevant), while comprehensive RDM take account of other social, ecological and economic data.

Qualify (and if possible quantify) the utilisation of ecosystem services within each significant water resource in table form (such as in Table 5). This forms the basis for assessment of ecosystem service change under different management scenarios. It might change slightly following discussion with various RDM specialists in the ecological consequences workshop or as further evidence comes to light.

Table 5. List of ecosystem services in the present-day entity populated with a description of resource use (e.g. subsistence, commercial, etc.) and beneficiaries

Category of ecosystem service	Type of service in the category	IUA 1 SWR 1	IUA 1 SWR 2	IUA 2 SWR 3	IUA 2 SWR 4
Regulating	Air Quality regulation				
	Climate regulation				
	Water regulation				
	Erosion regulation				
	Water purification and waste treatment				
	Disease regulation				
	Pest regulation/Biological control				
	Pollination				
	Detoxification				
	Natural hazard regulation				
Provisioning	Food				
	Fresh water				
	Wood and fibre				
	Biochemical and pharmaceutical products				
	Genetic resources				
Cultural	Cultural diversity				
	Spiritual and religious values				
	Knowledge systems (traditional and formal)				
	Educational values				
	Inspiration				
	Aesthetic values				
	Social relations				
	Sense of place				
	Cultural heritage values				
	Recreation and ecotourism				

PHASE 2: Assessment of ecological change

This phase is the assessment of ecological change as a result of different water resource management scenarios in terms of the change in the delivery of ecosystem services. It includes three sub-phases as summarised below:

Phase		Description
2	Assessing ecological change	
A	Determine and describe the management scenarios	Scenarios are used to explore the consequences of a range of potential management options.
B	Determine and describe ecological consequences of scenarios and assess risk to ecosystem services	Comparative Risk Assessment (CRA) provides a systematic and transparent approach to assessing the risk to the delivery of multiple ecosystem services as a function of the likelihood and consequence of the hazards posed by a particular management scenario to which the ecosystem services are exposed.
C	Specification of ecosystem service production functions for services at risk	Leading from the CRA, each ecosystem service at medium, high or very high risk is described by a production functions

2A. Determine and describe management scenarios

Scenarios are used to explore the consequences of a range of potential management options.

Management scenarios may include, but are not limited to:

i. A minimum standards scenario;
ii. Other management scenarios determined through consultation with the study team and other stakeholders based on basic principles laid out in the WRCS or Reserve determination process (and explained briefly below).

Scenarios are agreed upon in a scenarios planning workshop which confirms the feasibility of proposed scenarios, gaining agreement that scenarios are reasonable and suitably different to explore a range of management options and the consequences there of.

i. Minimum standards scenario

This scenario represents the state of the water resource as it would be when RQOs are such that the minimum requirements in the National Water Act are met to achieve sustainable, equitable and efficient management. The legal requirement for this scenario is provided for by the Constitution, NWA and DWAF policy (Dollar et al., 2007).

This scenario is referred to as the Ecologically Sustainable Base Configuration (ESBC) in the WRCS and is defined as "a hydrologically (water quality and quantity) and ecologically tested scenario that defines the lowest theoretical level of protection required for the sustainable use of the entire catchment [entity]" (Step 4a in Dollar et al., 2007). RDM policy states "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 MC of 'Heavily utilised'" (Dollar et al., 2007). The ESBC scenario must meet feasibility criteria for water quantity, water quality, and ecological needs.

This scenario is not necessarily a target scenario, but is needed to inform "the lowest level of protection required for any of the other configuration scenarios" (Dollar et al., 2007).

ii. Management scenarios

Referred to as starter catchment configuration scenarios in the WRCS, these scenarios provide a range of scenarios that can be evaluated in Phase 2B (Step 5 of WRCS). The aim of these scenarios is to:

- "establish a feasible number of catchment configuration scenarios for assessment by the regulator (DWAF) and the stakeholders;
- to incorporate planning scenarios, (which are prescriptive in terms of the yield required from the system to meet) future use, equity considerations and Existing Lawful Use (ELU); and
- to establish RDM starter catchment configuration scenarios guided by the EcoClassification procedure" (Dollar et al., 2007).

According to the WRCS, the procedure of establishing these catchment configurations must, at a minimum, take the following into account:

- International Water Agreements (IWAs) and basic human needs;
- ESBC scenario;
- Present Ecological Status (PES)/Habitat Integrity at each node (this is the base scenario against which alternatives are to be evaluated);
- EISC at each node;
- Recommended Ecological Category (REC) at each node (this represents the state of the water resource as it would be to achieve desired biodiversity protection and social redistribution of water use);
- Freshwater Conservation targets (overlain on the REC and PES scenarios); and
- a rationalisation process (where beliefs, social institutions and individual actors consider possible management scenarios logical and orderly).

For each scenario, the links established between flow and resource condition are used to predict the condition of assets in a SWR. Step 4 of the WRCS details how this is done. The desired ecological category for each scenario is used as the starting point at downstream end of the entity (e.g. ecological category D in the case of the ESBC). Moving sequentially upstream (or up gradient in the case of groundwater), node by node, the following are determined:

a) the water quantity, distribution and quality requirements to maintain the downstream reaches in the stated ecological condition;
b) the regulating and supporting services supporting the ecological category of the downstream/down gradient reaches; and
c) the quantity, distribution and quality requirements to support these ecosystem services.

iii. Select the period of analysis

This is the time period, in years, over which the evaluation will take place.

This provides the basis for an effective comparative risk assessment.

Linkage to other components of RDM

This phase is in line with Step 4 of the WRCS, which requires the determination of the ESBC and to establish starter catchment configuration scenarios.

2B. Determine and describe the ecological consequences of scenarios and assess risks to ecosystem services

Following the finalisation of the management scenarios, the ecological consequences of each management scenario are discussed and determined for each of the driver and response ecological components (as defined by Kleynhans and Louw, 2007).
The consequence of the management scenario is the change in the ecosystem service arising from the environmental effect of the water resources management on the exposed asset. Thus, the system analysis (Phase 1) sets the scene upon which the outcomes of the environmental effects of the management scenarios (described in phase 2A) can be predicted and ecosystems services at risk prioritized through a comparative risk assessment. The combination of a workshop environment and interdisciplinary group of RDM specialists provides the basis for effective comparative risk assessment.

Key inputs to the CRA are Steps 3 and 4 of the WRCS. Step 3 includes the determination of Environmental Water Requirements (EWR[34]) for all ecological categories in each scenario. This is an intensive and comprehensive process that represents the bulk of the EcoClassification process in which ecological category-specific rule curves, summary tables and modified time series are generated for each ecological category for each node[35]. These outputs of the EcoClassification Process[36] are used by the RDM specialists to assess and describe the ecological consequences of different water resource management scenarios. The process relies on automated and specialist consultation input (through an interdisciplinary group of specialists in a workshop setting). It makes used of a variety of models and methodologies, many of which involve informed input from specialists and expert-based cause and effect descriptions. Notable approaches in the South African context include:

- the Desktop Model (Hughes and Hannart, 2003), also known as SPATSIM, which assimilates habitat stressor responses to hydrological change (in rapid Reserve determination assessments, only SPATSIM and BBM are used);
- The EcoStatus suite of models (or indices) namely the Hydrological Driver Assessment Index (HAI), Geomorphology Driver Assessment Index (GAI), Physico-chemical Driver Assessment Index (PAI), Fish Response Assessment

[34] EWR is one of the preliminary RQOs. Preliminary RQO's are of two kinds:

a) independent driver variables that govern the biophysical response to the quality of the resource, for example, flow variables and
b) dependent response variables which express the ecological response to change in the driver variables, for example, fish species diversity.

[35] A node is a modelling point representative of the upstream reach or area of an aquatic ecosystem for which a RDM is being assessed. Each SWR is represented by at least one node.

[36] EcoClassification is not to be confused with the Classification System as described in the National Water Act (No. 36 of 1998). "The Classification System considers a range of different issues in Integrated Water Resources Management in the process of determining the class of a river, one of which is ecological" (Heath 2006).

Index (FRAI), Macro Invertebrate Response Assessment Index (MIRAI), and Riparian Vegetation Response Assessment Index (VEGRAI)

- Flow Habitat Stressor Response (FHSR) models that relate changes in hydraulic conditions to changes in biota and habitat (better in low flow cases, used in Intermediate and Comprehensive Reserve determinations);
- Downstream Response to Instream Flow Transformations (DRIFT) (Brown et al., 2006[37]), often used to set high flow (does better in flood cases, used in Intermediate and Comprehensive Reserve determinations).

FHSR and DRIFT methods "focus on identifying the size, duration and timing of specific flows and flow patterns that are considered to be the most important for maintaining the key ecological drivers (hydrology, geomorphology and water quality) and the key biological response indicators (riparian vegetation, aquatic invertebrates and fish), within a defined length of river, referred to as a Resource Unit, in a particular condition, or Ecological Category (EC)" (determined using the EcoStatus suite of models) (Heath, 2006[38]). Flow results are used as input to the Water Resource Yield Model (WRYM).

These models and causal descriptions form the basis of production functions. Using a Comparative Risk Assessment they can be related to consequences of the management scenario to change in ecosystem services arising from the environmental effect of the water resources management on the exposed asset.

During one or more EWR workshops the present ecological condition and ecological condition under all scenarios are discussed and determined at each node in all SWR for each of the different specialist components of the EcoClassification process. These workshops, involving all relevant experts, should be extended to allow time for the Comparative Risk Assessment (CRA) as a facilitated process of expert assessment of the causal descriptions of ecosystem services at risk.

Ecosystem service risk is the function of the likelihood and consequence of the hazards[39] posed by a particular management scenario to which the ecosystem service is exposed. For this study, an environmental asset is equivalent to a component of the ecosystem, as listed above. Thus:

Risk to ecosystem service = f(likelihood, consequence)
of environmental effect on an ecosystem asset.

---

[37] Brown, C., C. Pemberton, A. Birkhead, A. Bok, C. Boucher, E. Dollar, W. Harding, W. Kamish, J. King, B. Paxton and S. Ractliffe. 2006. In support of water-resource planning – highlighting key management issues using DRIFT: A case study. Water SA 32(2): 181-192

[38] Heath, R. G. 2006. Letaba Catchment Reserve Determination Study – Briefing Document. February 2006. DWAF Report No. RDM/B800/00/CON/COMP/1304

[39] A hazard is an event that can cause harm.

With the system analysis as a basis, these inputs provide critical information for the CRA in order to provide an identification and description of the following:

i. The environmental assets and ecosystem services at risk under each scenario;
ii. The description of how management scenarios effect water resources putting environmental assets and ecosystem services at risk;
iii. The assessed quantum of risk of each scenario-asset-service interaction, derived from the assessed likelihood and consequence of a specified interaction or risk scenario (including a level of uncertainty of each scenario-asset-service interaction assessment); to produce
iv. A prioritized list of ecosystem services ranked by risk for each option.

The outcome of the CRA is a preliminary identification and description of effect-response functions (ecological production functions) for each relevant priority risk.

i. Comparative Risk Assessment (CRA)

This initially sounds complicated but the CRA is a systematic way of clearly describing the effects of ecological change on human well-being that is transparent, clearly recorded and repeatable. The CRA provides an objective process for prioritizing risks, and therefore the nature and extent of ecosystem effects resulting from development, captured in a risk description for each asset. A risk assessment provides a "deeper understanding of meaning and context of associated risk" (Claasen et al., 2001).

Environmental assets and ecosystem services at risk under each scenario at each node

As described in the Framework, Comparative Risk Analysis (CRA) provides a systematic consideration of the risks posed to each SWR (ecosystem asset) in terms of the impact on ecosystem services under each scenario at each node.

So, a CRA is:

- undertaken for each IUA, in which
- the assets being assessed are the SWRs, which are
- exposed to different management scenarios, that
- affect the delivery of ecosystem services (from each SWR per IUA).

In this way, the assessment of a change in ecosystems services as a result of a change in management scenario is specific to the SWR is question and bound spatially (within the IUA) and temporally (the timeframe must be defined).

In this step, the combination of the IUA, SWR and scenario become the headings for each CRA to be completed. For instance, a CRA must be completed for River SWR under all scenarios in each IUA (in which there is a change in the ecological condition). If groundwater is considered simultaneously, the same is true for groundwater resources.

And so on for estuaries and wetlands. Thus if there are 4 IUAs, 3 scenarios and only considering river resources, the CRA for ecosystem services are required under 12 different asset-service combinations.

Environmental effect description of management scenarios

The management scenarios identified in Phase 2A pose a variety of hazards to the SWR and the ecosystem services it delivers. Any management scenario that results in a change from present ecological condition will result in changes to the delivery and distribution of ecosystem services.

While the scenarios have been described in Phase 2A, here the environmental effect description of each management scenario in relation to the delivery of ecosystem services is given. The objective of this description is to be specific and precise about the changes to ecosystem drivers (hydrology, geomorphology, physico-chemical) and response variables (fish, aquatic invertebrates and riparian vegetation) (following Kleynhans and Louw, 2007) as this guides the assessment of ecosystem services to follow.

Risk of each scenario-asset-service interaction

With the assets and scenarios spatially and temporally bound, the effect of the scenario on each asset in terms of ecosystem service delivery is assessed.

For each scenario-asset combination, the ecosystem services identified in phase 1D are assessed. Table 10 provides a guide to ecosystem services provided by different types of aquatic ecosystems.

For each scenario-asset-service combination, the question asked is ‘What is the likelihood that this ecosystem service in this significant water resource will be affected under this scenario? What would be the consequences of this scenario in this significant water resource to the delivery of this ecosystem service?’

The likelihood is the probability of the scenario having an effect on the asset. Likelihood takes into account an element of uncertainty, in that the likelihood that an ecosystem service will be affected under the scenario in question over a specified time frame is rated. Uncertainty with regards to the knowledge upon which the statements or connections between scenario-asset-service linkage are made, is also stated explicitly for each CRA. This level of certainty (e.g. high, medium or low) is a statement based on the expert’s judgement of the certainty of and confidence in the risk assessment. For example, a low level of certainty indicates that evidence to bear out the assessment is weak or lacking.

Table 6. Qualitative and quantitative classes of likelihood of a scenario (environmental effect, or resultant change in the flow of an ecosystem service) eventuating from a management decision and of having an environmental consequence to a service from an environmental asset in the ecosystem adapted from the classification adopted by the IPCC (2007).

Likelihood rating	Assessed probability of occurrence	Description
Almost certain	> 90%	Extremely or very likely, or virtually certain. Is expected to occur.
Likely	> 66%	Will probably occur
Possible	> 50%	Might occur; more likely than not
Unlikely	< 50%	May occur
Very unlikely	< 10%	Could occur
Extremely unlikely	< 5%	May occur only in exceptional circumstances

The consequence is the change in the service from the environmental effect of the management scenario on the exposed asset. The assessment of consequences can follow, or adapt in an appropriate manner, the severity ratings in King et al. (2003) (Table 7).

Table 7. Qualitative measures of consequence to environmental services in an ecosystem arising from the hazards linked to a management decision.

Level of consequence		Environmental effect
1	Severe	Substantial permanent loss of environmental service, requiring mitigation or offset.
2	Major	Major effect on the on the asset or service, that will require several years to recover, and substantial mitigation.
3	Moderate	Serious effect on the on the asset or service, that will take a few years to recover, but with no or little mitigation.
4	Minor	Discernable effect on the asset or service, but with rapid recovery, not requiring mitigation.
5	Insignificant	A negligible effect on the asset or service.

During the CRA it is useful to identify all appropriate compensation measures (mitigation and offsets).

The level of risk is the product of likelihood and consequence in the event of an environmental effect on an asset. Figure 8 combines the likelihood and consequence rating to determine risk as:

- Low (L) requiring no to little response;
- Medium (M) requiring local level response;
- High (H) requiring regional level response; or
- Very High (VH) requiring national level response.

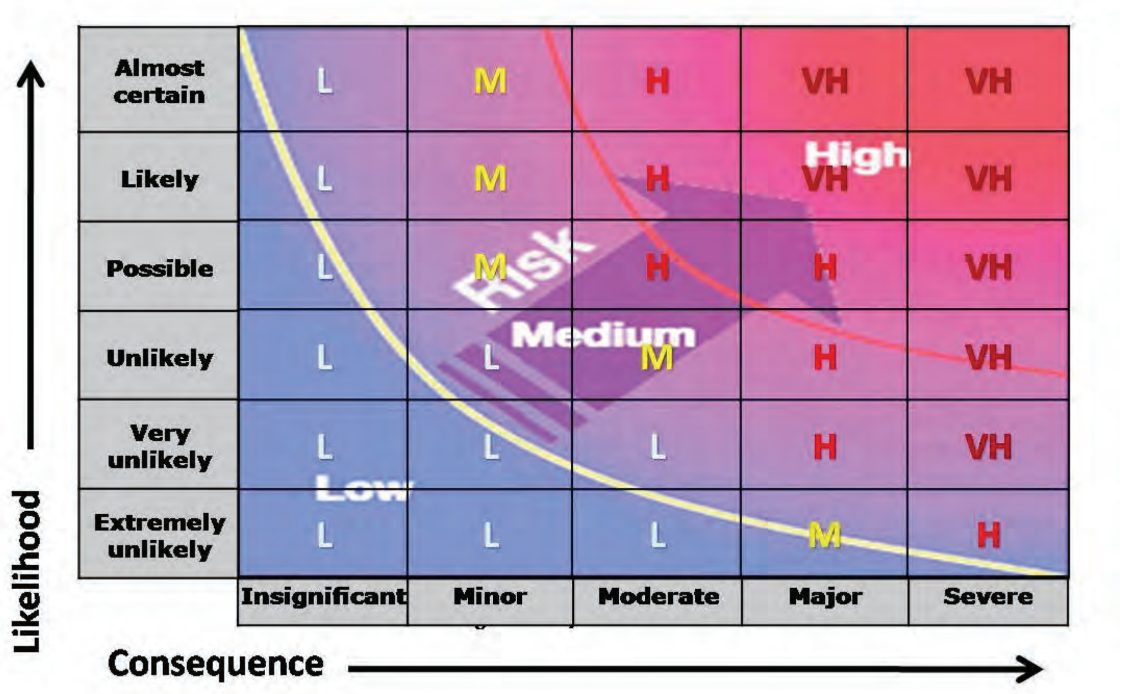


Figure 8. Levels of risk, assessed as the product of likelihood and consequence in the event of an environmental effect on an ecosystem asset (Adapted from Australian/New Zealand Standard on Risk Management (2004)).

The outcome of the CRA should include:

- Description of the environmental effect statement, including hazard and effect statement, scope of consequence, outcome statement and likelihood of outcome.
- Table of ecosystem services with the likelihood and consequence of environmental effect, and the level of risk (see Figure 8).
- Statement of the level of certainty associated to the above risk assessment, based on the availability of existing evidence and certainty of expert knowledge.

In Table 8 an additional column is added, when possible and relevant, to describe a sub-set of assets within each SWR. Although the CRA is done for each SWR, in real terms it is the different components, processes and feedbacks that make up the ecosystem, as well as its emergent properties such as its self-organising capacity that are put at risk under different management scenarios. These components, processes and feedbacks of the ecosystem are referred to broadly as assets. Changes in these assets will result in changes to ecosystem services. Valuation requires quantification of the change in ecosystem service provision as a result of effects on these ecosystem components, processes or feedbacks, which then link directly or indirectly to service delivery. For this reason, it is useful to specify components, processes or feedbacks that will be placed at risk relevant to each ecosystem service.

It is useful if physical assets are mutually exclusive as much as possible. The NWA suggests the following delineations of significant water resources:

- Riparian habitats;
- Instream channel;
- Wetlands (e.g. lacustrine, palustrine);
- Water bodies in lakes or elsewhere;
- Any source-directed infrastructure (water resource infrastructure such as minor dams, major dams, farm dams, canals, and any other water resource infrastructure considered significant)[40].

However functional classifications of inland wetland types might be more useful, such as the hydrogeomorphic (HGM) classification system advocated in DWAF (2007c). HGM uses landform (their geomorphological or landscape settings) and hydrology (water flows into, through and out of wetland systems) as "two fundamental features that determine the existence of all wetlands" (DWAF 2007c). Under this classification wetland types include rivers (including the active channel and riparian zone), lakes, unchanneled valley bottoms, channelled valley bottoms, meandering floodplains, seepage wetlands, depressional pans and flats (after Rountee and Batchelor, in prep in DWAF 2007c).

Each significant water resource should be identified and described and specific ecosystem assets described where relevant and possible.

[40] These are 'assets'

Table 8. The result of the comparative risk assessment is recorded for each scenario-asset-service combination, including listing a subset of assets within each SWR affected, and a statement of uncertainty.

Category of ecosystem service	Type of service in the category	Sub-set of assets affected	IUA 1 SWR 1			Sub-set of assets affected	IUA 1 SWR 2			Sub-set of assets affected	IUA 2 SWR 1			Sub-set of assets affected	IUA x SWR x		
			L	C	R		L	C	R		L	C	R		L	C	R
Regulating	Air Quality regulation																
	Climate regulation																
	Water regulation																
	Erosion regulation																
	Water purification, waste treatment																
	Disease regulation																
	Pest regulation/Biological control																
	Pollination																
	Detoxification																
	Natural hazard regulation																
Provisioning	Food																
	Fresh water																
	Wood and fibre																
	Biochemical, pharmaceutical products																
	Genetic resources																
Cultural	Cultural diversity																
	Spiritual and religious values																
	Knowledge systems																
	Educational values																
	Inspiration																
	Aesthetic values																
	Social relations																
	Sense of place																
	Cultural heritage values																
	Recreation and ecotourism																
Statement of certainty for each scenario-asset combination																	

Prioritised ecosystem services at risk

Provide a table that summarises the results of the CRA for each scenario-asset in terms of the level of risk posed to each ecosystem service according to Table 9.

Only ecosystem services that are of medium, high or very high risk are assessed further (i.e. valued).

Table 9. Priority Risk Table: Summary of priority risks to each ecosystem service for each scenario-asset combination.

Category of ecosystem service	Type of service in the category	IUA 1									IUA 2 – n		
		SWR 1			SWR 2			SWR 3			SWR 1 – n		
		Scen 1	Scen 2	Scen n	Scen 1	Scen 2	Scen n	Scen 1	Scen 2	Scen n	Scen 1	Scen 2	Scen n
Regulating	Air Quality regulation												
	Climate regulation												
	Water regulation												
	Erosion regulation												
	Water purification and waste treatment												
	Disease regulation												
	Pest regulation/Biological control												
	Pollination												
	Detoxification												
	Natural hazard regulation												
Provisioning	Food												
	Fresh water												
	Wood and fibre												
	Biochemical, pharmaceutical products												
	Genetic resources												
Cultural	Cultural diversity												
	Spiritual and religious values												
	Knowledge systems												
	Educational values												
	Inspiration												
	Aesthetic values												
	Social relations												
	Sense of place												
	Cultural heritage values												
	Recreation and ecotourism												
Statement of certainty for each scenario-asset combination													

2C. Specification of ecosystem services production functions

The key output of the CRA is a description of each risk, including the underlying chain of causality between environmental effect and its consequence. This provides a preliminary identification and description of the effect-response function for each relevant priority risk. Thus from the Priority Risk Table, develop systems models that allow the effects of the RDM to be predicted in terms of changes in ecosystem services, and hence the production functions required for valuation of ecosystem services.

Causality chains are described qualitatively as the relationship between ecosystem services (as the dependent variables) and ecological change and ecosystem assets.

Ecological production functions are the quantitative description of the causality chains.

Production function should be based, as far as possible, on scientific evidence. The diligence required in the estimation of these functions will depend upon the level of risk and the nature of the study (whether comprehensive, intermediate or rapid).

Further available ecological data, commensurate with the level of Reserve determination, to meet data requirements is gathered through:

- data collection (comprehensive level possibly)
- knowledge harvesting of existing data (all levels)
- evidence-based ecology (all levels)

For comprehensive assessments, system dynamics modelling, such as structural equation modelling (SEM) or dynamic causal modeling, provide an abstract model that uses cause and effect logic to describe the behaviour of a system and can be used to develop production functions. There are a variety of tools for determining production functions. Models serve to simplify complex systems to a representation of our understanding of the system. Requisite simplicity is important for the success of the production function approach (i.e. avoid unnecessary complexity).

Figure 9 provides a schematic of the causal relationships that require modelling in the production function. The linear illustration does not mean to mask the considerable complexities in the causal links and feedback loops that exist. In the context of RDM, catchment management scenarios drive change in aquatic ecosystems. The ecological response to catchment management is largely determined by the relationships between organisms and local hydraulic variables. “Without an understanding of how hydrology and biotic processes interact to sustain ecosystem functioning and the provision of ecosystem services, it will be difficult to place either an ecological or social value on alternative water management scenarios" (Strange et al., 1999). Evidence of relationships between the ecosystem components, which are driver variables namely hydrology, geomorphology, and physico-chemical variables and response variables namely fish, aquatic invertebrates and riparian vegetation (as per Kleynhans and Louw, 2007), is relatively good (illustrated by the numerous WRC and other reports, articles and models). Comparatively little effort has gone into understanding the indirect linkages between ecological functioning, ecosystem services and the production and consumption of marketed goods and services" (Perrings, 2007).

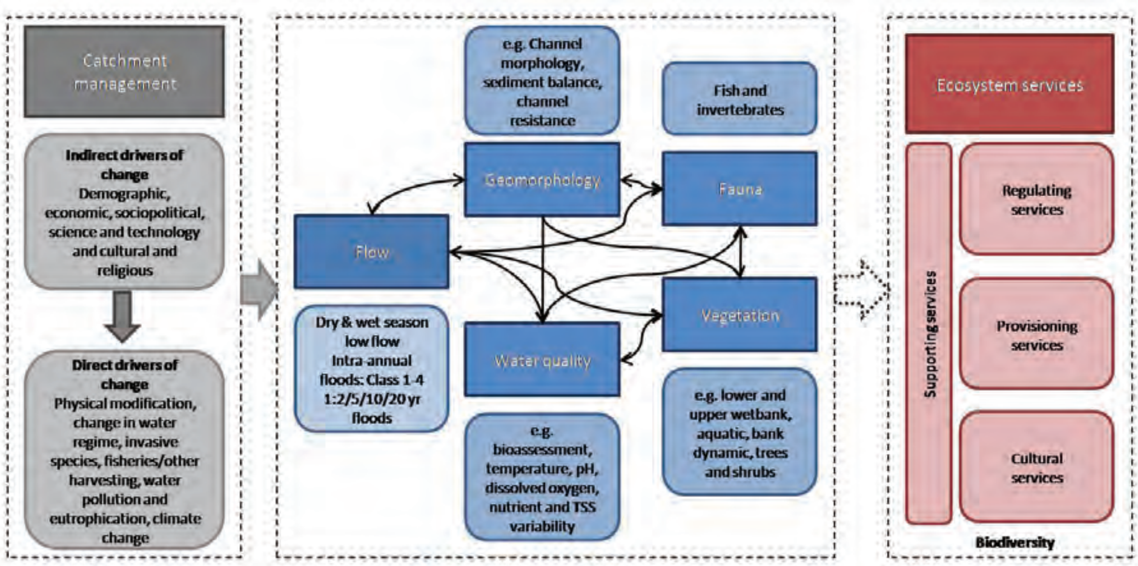


Figure 9. Schematic of the causal relationships that require modelling in the production function

Not directly illustrated in Figure 9 is the linkage from human well-being, through ecosystem services as benefits people receive. Changes in the distribution and supply of these services feedback to the indirect and direct drivers of catchment management (as illustrated in the MA conceptual framework). This approach provides a benefit of public participation and our ability for improved dialogue around the consequences of ecological change to human well-being in catchment management.

While broad relationships exist between the decline in the management class of a river and the types of services delivered, the effects of the distribution and sustainability of those services and the overall resilience of the system require case specific analysis in most instances. Not least because socio-ecological systems are complex and interactions and feedbacks between ecological components further complicate the effect on ecosystem services. Pollard et al. (2008) provides one of the few South African examples of modelling the socio-ecological system of the Sand River Catchment, through a resilience assessment of catchment and the consequences to ecosystem services.

Recent literature, such as Balmford et al. (2008) provide collations of evidence of the linkages between biodiversity and ecosystem service delivery, but similar collations of evidence specific to aquatic ecosystems (and specific to South or southern Africa) are still required. A particular need in such research is in relation to:

- identifying changes in the regulating ecosystem services, as amongst the most important environmental consequence of human activities, and the relationship of these changes to thresholds and the resilience of the system;
- thresholds to ecological change in a system after which the delivery of ecosystem services necessary for economic growth, redress of inequality and poverty alleviation would be compromised; and
- improving our inability to track the effect of these on human well-being.

Considering the constraints in evidence on the causal linkages between ecosystem change and ecosystem service delivery, the inclusion of local and expert knowledge in the CRA is key to developing the best production functions possible.

Ecological production functions are a function of input factors of production. Every ecosystem service can be described by a unique production function which quantifies the chain of causality between ecosystem assets and other variables. Claassen et al. (2001) provides guidelines on developing a cause-effect diagram to facilitate understanding and communication. These cause-effect diagrams essential provide a hypothesis on how ecological change may result in change in the delivery of ecosystem services. The ‘endpoint’ in these cause-effect diagrams would be each ecosystem service. The development of production functions for ecosystem services may aid in specifying or recommending thresholds for potential concern (TPC) or proposing resource quality objectives that would be useful in the Reserve determination procedure and WRCS (DWAF 2007a).

Table 10. Ecosystem services provided by different types of aquatic ecosystems categorized according to the Millennium Ecosystem Assessment scheme (MA, 2005).

Category of ecosystem service	Type of service in the category	Description of service	Type of aquatic ecosystem				
			Rivers	**Wetlands**	**Riparian zones**	**Estuaries**	**Ground-water**
Regulating	Air quality regulation	Ecosystems both contribute and extract chemicals from the atmosphere that influence many aspects of air quality.	No	Yes	Yes	No	No
	Climate regulation	Ecosystems may influence climate both locally and globally (e.g. locally, land cover changes can affect temperature and precipitation; globally, ecosystems play an important role in the carbon cycle).	No	Yes	Yes	Yes	No
	Water regulation	The timing and magnitude of runoff and flooding can be strongly influenced by changes in land cover, including in particular changes in the water storage potential of the system such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.	Yes	Yes	Yes	No	No
	Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.	Yes	Yes	Yes	No	No
	Water purification and waste treatment	Ecosystems can be a source of impurities in freshwater but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems	Yes	Yes	Yes	No	Yes
	Disease regulation	Changes in ecosystems can directly change the abundance of human pathogens such as cholera and can alter the abundance of disease vectors such as mosquitoes.	Yes	Yes	Yes	Yes	No
	Pest regulation/Biological control	Ecosystem changes affect the prevalence of crop and livestock pests and diseases.	Yes	Yes	Yes	No	No

Category of ecosystem service	Type of service in the category	Description of service	Type of aquatic ecosystem				
			Rivers	Wetlands	Riparian zones	Estuaries	Ground-water
	Pollination	Ecosystems that support pollinators are often important to the success of economies and genetic diversity. Refers to animal-assisted pollination, done by bees, rather than wind pollination	No	Yes	Yes	Yes	No
	Seed dispersal	Aquatic habitats may often support seed dispersing birds and other animals	No	Yes	Yes	No	No
	Natural hazard regulation	Flood control, storm protection.	No	Yes	Yes	Yes	No
Provisioning	Food	Provision of food from crops, livestock, marine and freshwater capture fisheries, aquaculture or wild plant and animal food products	Yes	Yes	Yes	Yes	No
	Fresh water	Ecosystems provide storage and retention of water for domestic, industrial, and agricultural use	Yes	Yes	No	No	Yes
	Fibre and fuel	Direct benefits from wood for timber and pulp, biomass energy (fuelwood and charcoal consumption) and from the production of agricultural fibers such as cotton, silk and hemp	No	Yes	Yes	Yes	No
	Minerals (sand/pebbles, clay)						
	Biochemical and pharmaceutical products	Ecosystems provide natural products that have been used for biochemicals and pharmaceuticals and other natural products (such as cosmetics, personal care, bioremediation, biomonitoring and ecological restoration.	Yes	Yes	Yes	Yes	No
	Genetic resources	The exploration of biodiversity for new products and industries, such as medicine, genes for plant pathogen resistance or ornamentals. Conserving genetic diversity maintains the potential to yield larger future benefits and ensures options for adapting to changing environments.	Yes	Yes	Yes	Yes	No

Category of ecosystem service	Type of service in the category	Description of service	Type of aquatic ecosystem				
			Rivers	**Wetlands**	**Riparian zones**	**Estuaries**	**Ground-water**
Cultural	Spiritual and inspirational values	Many people attach spiritual and religious values to ecosystems or their components and ecosystems provide a rich source of inspiration for such activities as art, folklore, national symbols, architecture and advertising.	Yes	Yes	Yes	Yes	Yes
	Knowledge systems (traditional and formal)	Ecosystems influence the types of knowledge systems developed by different cultures.	Yes	Yes	Yes	Yes	Yes
	Educational values	Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.	Yes	Yes	Yes	Yes	Yes
	Aesthetic values	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, 'scenic drives' and the selection of housing locations.	Yes	Yes	Yes	Yes	Yes
	Sense of place	Many people value the 'sense of place' that is associated with recognized features of their environment. The identity of some communities depends on their attachment to the ecosystems and their surroundings.	Yes	Yes	Yes	Yes	Yes
	Cultural heritage values	Many societies place high value on the maintenance of either historically important landscapes ("cultural landscapes") or culturally significant species that serve to remind us of our historic roots	Yes	Yes	Yes	Yes	Yes
	Recreational	People often choose the location for spending their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area	Yes	Yes	Yes	Yes	Yes

PHASE 3: Valuation

The environment provides a wide variety of ecosystem services to society. Some of these services are considered “free” that is, they are not paid for. However, this does not mean that they are not valuable, as the true value of these goods and services are only realised once their service is lost (Natural Value 2009).

Ecosystem services are the aspects of ecosystems that are utilized by people to produce human well-being (Fisher et al., 2008, 2009) where the aspects of ecosystems include ecosystem organisation or structure as well as process and/or functions that are utilized (directly or indirectly) by people to produce human well-being.

Several different definitions exist on what exactly value is; the MA recognizes two concepts of value: utilitarian value and non-utilitarian value. Utilitarian value is the utility or benefit people derive from the current use (both direct and indirect) of ecosystem services (use values) as well as the ecosystem services that they are currently not using (non-use values).

Economic valuation techniques may be used to determine whether the net utilitarian value of converting an ecosystem outweighs the net utilitarian value of its current services. In other words, economic valuation techniques will assist in the evaluation of the trade-offs between the various development options.

Non-utilitarian value is based upon various ethical, cultural, religious and philosophical considerations which may deem ecosystem services to have intrinsic value. Intrinsic values are revealed by the social opinion of particular beneficiaries of that service. Intrinsic value decisions have a political basis and are made by parliaments, legislators or regulatory agencies mandated to do so by law. Therefore, the sanctions for violating laws recognizing and ecosystem asset’s intrinsic value may be regarded as a measure of the degree of intrinsic value ascribed to them (MA, 2003).

In this Manual, we apply, by definition the utilitarian definition to value.

a. Ecosystem services, economic theory and some key concepts

Box 7 provides an overview of some key economic concepts as they relate to ecosystem services. It highlights three key insights, which we recommend be explored in greater detail in Fisher et al. (2008), which best covers the issues.

Box 7. Economic Framework Ecosystem Services: What Can We Do? (directly extracted from Fisher et al. (2008))

"Economics is essentially the study of how humanity provides for itself (Heilbroner, 1968), and humanity largely provides for itself partly by using natural systems as production inputs. Therefore, an economic framework for ecosystem service research is logical. In Fig. 2, we adapted a conceptual framework from Pearce, (2007) that links ecosystem services to human welfare with a simple supply-and-demand relationship. The x-axis represents the level of ecosystem service provision, aggregated here across services for a particular area. The y-axis measures marginal human welfare (here in monetary terms, but other metrics, such as lives saved, could be used). The downward-sloping demand curve, $D_{ES(M)}$, refers to marketed ecosystem service benefits, such as timber and fish, where the dollar value represents the market's willingness to pay for one more unit, i.e. the marginal value. Thus, as ecosystems are converted and supply decreases (moving left on the x-axis), the value we ascribe to the next unit increases (moving up the y-axis). $D_{ES(MNM)}$ is the demand curve for all ecosystem service benefits, including those that are not traded, such as flood protection. Because most ecosystem services are nonmarket services (public goods), we expect the $D_{ES(MNM)}$ demand curve to be considerably above the $D_{ES(M)}$ curve.

As for the supply curve, MC_{ES} represents the marginal cost of acquiring and managing additional units of ecosystems, such as hectares of land, as well as the marginal value of any opportunity costs (from forgoing alternative uses). The positive slopes reflect the expectation that providing each additional increment of an ecosystem service will be increasingly costly. In this figure, we also suggest that the rate of this increase could itself increase (the second derivative is positive). The safe minimum standard (SMS), or the minimum quantity of ecosystem structure and process (including diversity, populations, interactions, etc.), that is required to maintain a well-functioning ecosystem capable of supplying services. There is high uncertainty about just where this level is, and it surely will be different for different ecosystem services (Dobson et al., 2006). The two points ES_{MIN} and ES_{OPT} come from something called the equimarginal principle in economics, where the cost of providing an extra unit (of ecosystem services) is equal to the benefits gained from that unit (demand). For example, ESMIN is the point where only marketed services of a landscape are provided (demanded).
The marginal cost of providing that last unit of demand (i.e., cost of management, land purchases, and so on) is equal to the gains you receive from providing it. If you were to provide any more, the cost would outweigh the benefit. So, if trees only have value as marketed timber, the market will only pay for plantations and will not likely produce the optimal level of forest diversity and cover (ES_{OPT}) to supply other services such as biodiversity existence or perhaps even water regulation. A few general implications of considering ecosystem services within this economic framework emerge: (1) There is a fundamental uncertainty regarding the minimum level of ecosystem structure needed to provide a continual flow of services (SMS, infrastructure value). (2) A serious under-provision of ecosystem services will occur if only market benefits are considered, i.e. $ES_{MIN} < ES_{OPT}$.

Similar to the uncertainty surrounding a safe minimum standard level, $D_{ES(MNM)}$ will be difficult to make operational, since we will likely never be able to capture the true value of ecosystem service provision. Therefore, any demand curve for (or valuation attached to) ecosystem services would represent a lower bound. Further, monetary valuation is not always necessary or desirable. The y-axis could represent an index like vulnerability, lives saved, or happiness, depending on what the policy question is that drives the research. Understanding trade-offs or cost effectiveness does not require monetizing the benefits, which can be difficult and imprecise (see Kahneman et al., 1993; Bateman et al., 1997a, b).

Here we focus on three key insights from this framework that should help to operationalise ecosystem services research as a decision support system. They are, as noted on [figure 10], (1) the importance of marginal ecosystem service assessments, (2) understanding and investigation of a safe minimum standard level of ecosystem structure and function, and (3) the importance of capturing the benefits provided by non-marketed ecosystem services, through some type of institutional arrangement.

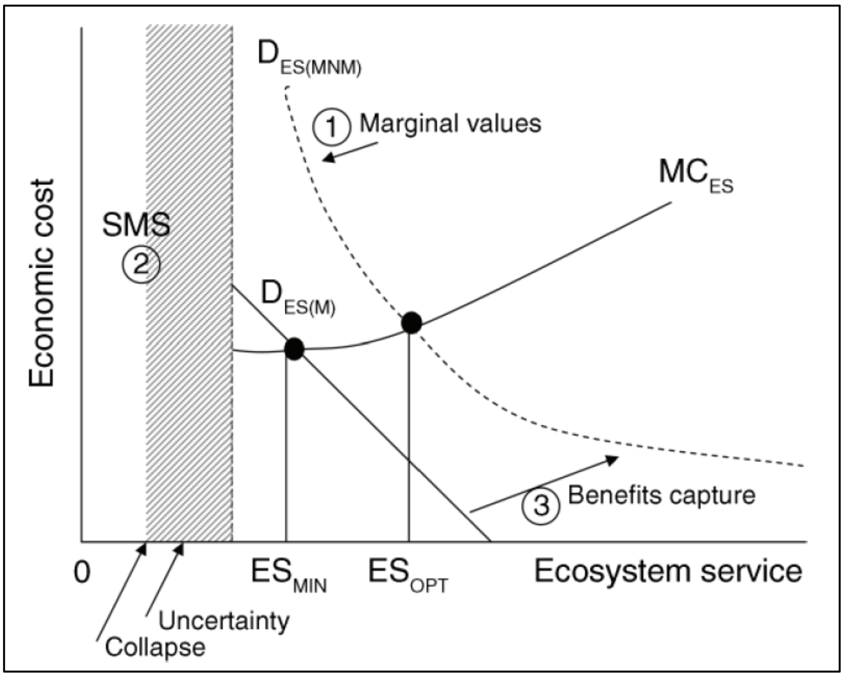


Figure 10. An economic framework for ecosystem service provision offers three main insights for policy relevant research. (1) Ecosystem services should be studied as marginal changes in landscapes or seascapes. Researchers should ask questions such as ''Does the conversion of one more hectare of forest to agriculture represent a beneficial trade-off?'' This should lead to further questions of ''Who benefits/loses?'' and ''Where is the benefit realized?'' (2) At some level of degradation most systems will collapse. Knowing where this point is (safe minimum standard [SMS], i.e. some minimum level of structure or process) is crucial for point 1 (appropriate evaluation) and point 3 (policy integration). (3) Because most ecosystem services are public goods, the market will not provide an optimal level but only $D_{ES(M)}$, the demand curve (for marketed ecosystem service benefits). For optimal ecosystem service provision we need mechanisms to provide for nonmarket services, moving to $D_{ES(MNM)}$, the demand curve for all ecosystem service benefits, both marketed and non-marketed. The supply curve, MC_{ES}, represents the marginal cost of acquiring and managing additional units of ecosystems; ES_{MIN} is the point where only marketed services of a landscape are provided (demanded); ES_{OPT} is the optimal level of forest diversity and cover to supply other services. For an explanation of terms, see Economic framework ecosystem services: What can we do?

The table below summarises the sub-phases within this phase.

Phase		Description
3	Valuation of ecosystem services	
3A	Selection of valuation techniques	Appropriate valuation techniques are required for valuation of project benefits and valuation of the effects on ecosystem services. These techniques may vary depending on the nature of the evaluation (comprehensive, intermediate or rapid).
3B	Data collection	Collect socio-economic data and the required primary and secondary data to support the valuation process.
3C	Conduct valuation	Apply each of the identified valuation techniques and integrate with the relevant production functions.

3A. Selection of valuation techniques

A variety of valuation techniques may be applied to value the costs and benefits resulting from changes in the production of provisioning and cultural services (and their underlying regulatory and supporting services).

The selection of the most appropriate valuation techniques depend on:

- Whether it is suited to appropriately value the project benefits and the provisioning and cultural services, i.e. whether it can provide valuation outputs that are useful in decision-making.
- Whether it can be used to capture and model the effect of changes in production variables, especially where regulatory services are affected.
- The data available, and/or budget available for primary data collection. These techniques may vary depending on the nature of the evaluation (comprehensive, intermediate or rapid). The benefit transfer option may be selected in the case of a rapid evaluation.
- Production function evidence available (if sufficient evidence is not available, ecological and other production processes may have to modelled).

Identify the appropriate valuation techniques required for every priority ecosystem service: in the selection of valuation techniques, ensure that double accounting do not take place (see other problems and pitfalls in Box 8). Proper definition of ecosystem services and benefits is also important to avoiding double accounting (see Box 3 in the framework).

Three sets of valuation techniques exist:

- hypothetical behaviour methods of valuation;
- observed behaviour methods of valuation; and
- benefits transfer.

All three sets of valuation techniques are discussed in subsequent sections below, additional techniques such as demand curve approaches are also discussed.

According to Natural Value (2008) economic valuation techniques can be divided into demand curve approaches and non-demand curve approaches. Demand curve approaches are welfare measures in the sense that the implications of changes in environmental quality or attributes on society can be assessed. In addition, values are derived rather than prices. Non-demand approaches are easier to estimate than demand curve approaches, and are generally more appropriate when there are not large disparities between price and value.

Valuation approaches can be divided into hypothetical behaviour approach and observed behaviour approach.

Non-demand curve approaches consist of the following valuation techniques; market price, preventative expenditure, replacement costs, human capital and effect on production which fall under the assumed preference methods.

When considering applying a valuation technique several practical considerations need be taken into account. These include:

1. Budgetary restrictions;
2. Availability of data and the selection of an appropriate framework;
3. Consideration of the appropriate technique considering the data and the given context; and
4. Natural assets may produce more than one ecosystem service and each ecosystem service may require more than valuation technique.

See Natural Value (2008) for a more detailed explanation.

A brief description is given for a selection framework, Figure 4 taken from Natural Value (2008) is based on a framework developed by Blignaut and Lumby (2004). This framework categorises values on the basis of the nature and availability of prices (Blignaut and Lumby, 2004). Five categories are distinguished:

1. Market prices,
2. Shadow prices,
3. Direct proxies,
4. Indirect proxies,
5. No proxies at all.

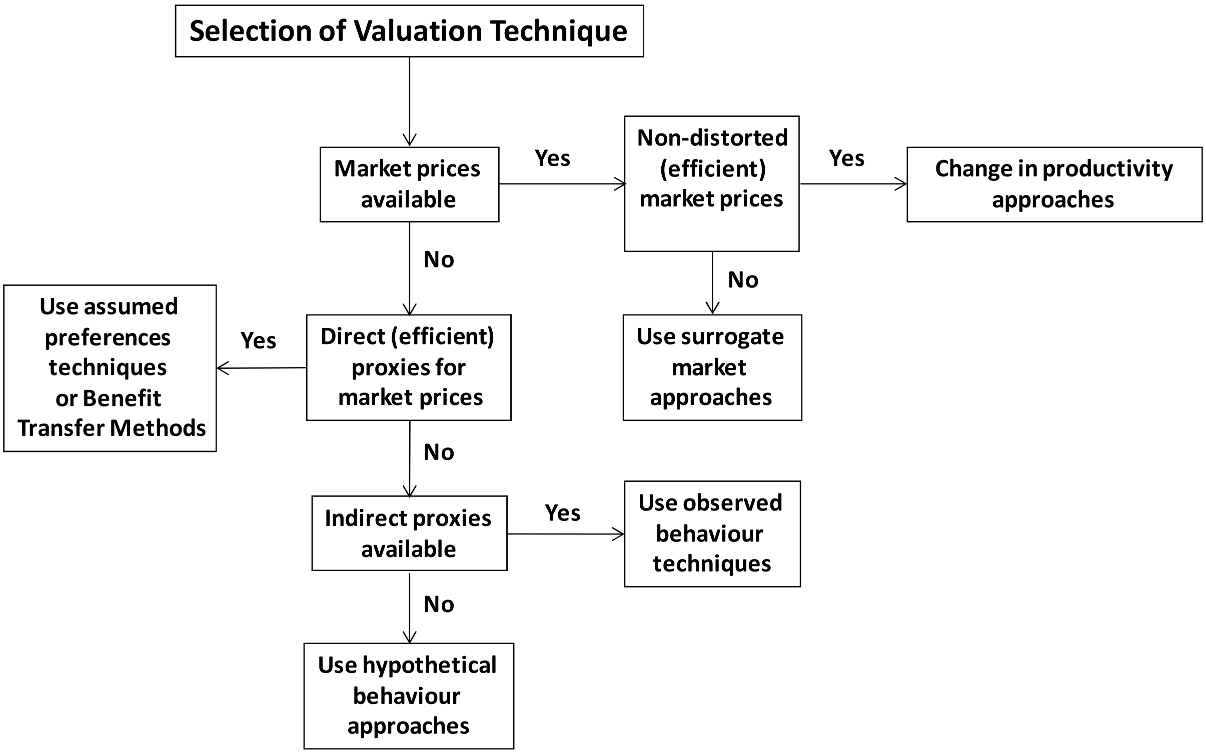


Figure 11. Selecting a valuation technique. Source: Blignaut and Lumby (2004) and Natural Value (2008)

The framework works as follows:

- If market values are available, then changes in productivity techniques can be employed,
- If non-distorted (efficient) market prices are not available, then surrogate market approaches such as the travel cost and hedonic pricing methods can be used
- If market prices are not available, but direct (efficient) proxies are, a variety of assumed preference techniques such as damage cost, replacement cost, cost of illness or other benefit transfer methods (BTM) can be used
- When indirect proxies are available, observed behaviour techniques such as the travel cost and hedonic pricing methods can be used
- If no market prices or proxies exist, hypothetical behaviour methods such as contingent valuation methods or conjoint analysis methods can be used.

It is often necessary to use a combination of valuation techniques rather than a single technique to value ecosystem services.

Descriptions of the valuation techniques follow below.

i. Hypothetical behaviour approach

In this approach, people's responses to direct questions describing hypothetical markets or situations are used to infer value. This is also often referred to as choice modelling. People are normally asked what they would be willing to pay for a particular ecosystem service.

Examples of this approach include the contingent valuation method (CVM) and conjoint analysis.

Contingent valuation

CVM are estimate economic values for based on surveyed interview data. Interviewees are presented with hypothetical scenarios and are asked how much they would be willing to pay (WTP) for a specific ecosystem service or their willingness to accept (WTA) as compensation for the loss of ecosystem services.
This method is best used when environmental changes have no impact on market behaviour, when it is not possible to observe preferences directly and when the population in the sample is representative and interested in the subject of the valuation.

Data required for the method is collected in the form of a survey in which a scenario is presented and which gathers a respondent's WTP and socioeconomic data. The method is data intensive and requires cross-sectional data on the dependent and independent variables described above for a sample of affected population.

Conjoint analysis

Conjoint analysis is based on the concept that values are derived from the attributes of a particular good or situation. Conjoint analysis is similar to contingent valuation, in that it is a hypothetical method. However, it differs from contingent valuation in that it asks interviewees to state a preference between different groups of environmental services of different attributes. This method is appropriate for the valuation of any type of ecosystem service. The data requirements for this method are data intensive and require cross-sectional data on the dependent and independent variables described above for a sample of affected population.

ii. Observed behaviour approach

Within this approach, valuation may be based upon human behaviour which is either directly or indirectly observed.

Direct observed behaviour methods derive estimates of value from the observed market behaviour of producers and consumers. These methods are applicable where ecosystem services are privately owned (i.e. not public goods), are traded in functioning markets, and where market prices can therefore be observed.

Indirect observed behaviour methods are used where market prices are not available, which is often the case for most ecosystem services. Data are gathered from observed market behaviour of surrogate markets, which is hypothesized to have a direct relationship with the particular ecosystem value. Examples of these methods include hedonic pricing and travel cost. Also included under these methods are the cost-based methods of evaluation. These methods include replacement cost and damage cost methods.

Examples of this approach include the hedonic pricing method and the travel cost method (TCM).

Hedonic pricing

The hedonic pricing method estimates the proportion of property value attributable to the proximity of the property to an ecosystem. The method uses statistical techniques to unpack property prices into the implicit prices for each of attributes, including ecosystem assets and services. This method can be used for a variety of applications including proximity of properties to sources of traffic, proximity of environmental features and environmental hazards.

The hedonic method is data intensive and requires cross-sectional and time series data on the dependent and independent variables described above for all property transactions available for a region. Hedonic pricing is less effective where environmental effects cannot be visually observed, i.e. productivity and groundwater impacts.

Travel cost method (TCM)

Travel cost uses the observed costs paid to travel to a destination or make use of an ecosystem service, to derive demand functions for that destination or service. Travel cost reveals the cost of time, travel and related expenses that recreational and ecotourism visitors to an ecosystem location are willing to incur during their visit. Individual travel cost, combined with the total number of visits to the site, provides an estimate of the total value of recreational use from the site. The travel cost method is data intensive and requires cross-sectional data on the dependent and independent variables described above for a sample of the visiting population.

The technique is appropriate when ecosystem services have a recreational benefit such as woodlands, national parks and coastal areas or where there is no charge for the ecosystem service or the cost is low.

iii. Benefits transfer

This approach uses the estimates obtained for ecosystem services in one or more contexts (i.e. in other studies) to value the same ecosystem service in another context.

It is our impression that this approach has been abused somewhat in literature as some authors have used this approach as a license to pick and choose previously published values to be applied to their own studies.

The underlying assumption of benefit-transfer is that humans within a certain geographic area/culture/population behave similarly, and therefore certain elements of their behaviour, as estimated through a demand curve, may be transferable from one location to another. In the cases where this is true, valuation may be simplified and speeded up by using the results of a previous study.

The major strengths associated with benefit transfers is that a detailed valuation study is not required and that the technique is not as complex when compared to other techniques. However, results obtained from this technique may be inaccurate when the correct assumptions are not employed (Nature Value, 2008).

Benefit transfer may have a very important role to play in the future of aquatic ecosystem valuation, but the results must be scientifically adequate.

iv. Assumed Preference Methods

Market price

The market price method estimates value of ecosystem services traded in commercial markets. It uses standard economic techniques for measuring the economic benefits from marketed goods, based on the quantities purchased and supplied at different prices. It relies on market prices and administered tariffs, combined with quantity and quality information.

The market price method is data intensive and requires cross-sectional and or time series data on the dependent and independent variables described above for a sample of the visiting population.

Preventative expenditure

This technique is also known as the averting behaviour technique. This technique values the environmental change through costs of preventing or mitigating a loss or a change in behaviour to achieve greater environmental quality (Nature Value, 2008).

Replacement costs

Replacement cost estimate value of ecosystem services based on the cost of replacing ecosystem services. This does not provide strict measures of economic values, which are generally based on consumer’s willingness to pay for a service.

Engineering and environmental engineering data and costs are required.

Damage costs

Damage cost estimate value of ecosystem services based on the cost of damage associated with the loss of an ecosystem service. This does not provide strict measures of economic values, which are generally based on consumer's willingness to pay for a service. Instead these costs reflect, environmental damage, clean-up costs, criminal and civil convictions and other liabilities.

Engineering and environmental engineering data and costs are required.

Human capital

This approach measures the cost of bad health as a result of environmental change. More specifically, this cost measures the associated effects on the productivity of labour. This technique is closely linked with the cost of illness method (COI) which measures sickness related costs such as costs of medicines, doctor visits and hospitalisation.

The COI technique is appropriate to value the cost of pollution related morbidity and the human capital technique is used to value loss of earnings due to mortality (Nature Value, 2008).

Effect on production

The objective of this valuation technique is to assess the physical change in production and to place an economic value with the prevailing market prices (Natural Value, 2008).

Box 8. Problems associated with economic valuation

Although used extensively and accurately in many cases, it appears that the TEV approach risks double accounting largely because the chain of causality of ecosystem services is not made explicit, and ecosystem processes and functioning intermediate to the provision of final benefits are sometimes valued. For example, water purification is categorised as an indirect use and is valued, while the provisioning of fresh water is categorised as a direct use value and is also valued. The value of the direct and indirect use is thus valued leading to a double accounting scenario.

This is somewhat mitigated within the MA framework, by valuing only the provisioning services (the goods or products obtained from ecosystems) and cultural services (the non-material benefits obtained from ecosystems).

Various other general problems are associated with valuation techniques in general and these are presented in Table 1 below. The Table is taken directly from Natural Value (2009) which is adapted from Pagiola et al., 2004.

Table 11. Problems and pitfalls associated with ecosystem valuation techniques	
Use net benefits, not gross benefits	Failing to consider the costs involved in using resources (the cost of harvesting products, for example, or the cost of piping water from its source to the user) results in an over-estimate of the value of ecosystem services.
Include opportunity costs	The cost of an action is not limited to the out-of-pocket costs involved in implementing it. It also includes the opportunity costs resulting from the foregone benefits of alternative actions (or inaction). Omitting opportunity costs makes actions seem much more attractive than they really are.
Do not use replacement costs	… unless you can demonstrate (i) that the replacement service is equivalent in quality and magnitude to the ecosystem service being valued, (ii) that the replacement is the least-cost way of replacing the service, and (iii) that people would actually be willing to pay the replacement cost to obtain the service.
Do not use benefits transfer	… unless the context of the original valuation is extremely similar to the context you are interested in. Even then, proceed with caution. However, it is a good idea to compare the results with those obtained elsewhere.
Do not use value estimates based on small changes in service availability to assess the consequences of large changes in service availability	Economic value estimates are not independent of the scale of the analysis. Value estimates are almost always made for small ('marginal') changes in service availability and should not be used when contemplating large changes.
Be careful about double counting	Many valuation techniques measure the same thing in different ways. For example, the value of clean water might be measured by the avoided health care costs or by a survey of consumer WTP for clean water. But consumer WTP for clean water is due (at least in part) to their desire not to fall sick, so these two results should not be added together. If they are, the value of clean water will be over-estimated.
Do not include global benefits when the analysis is from a national perspective	More specifically, only consider benefits (or costs) that affect the group from whose perspective the analysis is done. Including benefits which are primarily global in nature in an analysis undertaken from a national perspective is a particularly common form for this mistake, and results in an over-estimate of the benefits to the country.
Adjust for price distortions	… when conducting the analysis from the perspective of society as a whole, but not when conducting the analysis from the perspective of an individual group.
Avoid spurious precision	Most estimates are, by necessity, approximate. Do not simply paste the result in the spreadsheet, with its three decimal points, into the report: round the result appropriately. When there is substantial uncertainty, report the results as ranges.
Submit results to sanity checks	Are the results consistent with other results? Are they reasonable in light of the context? Extraordinary results are not necessarily wrong, but must be checked carefully. Extraordinary results require extraordinary proof.

Source: Natural Value, 2009; Pagiola et al., 2004.

v. Conventional economic valuation techniques[41]

Whereas the preceding valuation techniques are used to quantify the value of ecosystem services, a range of conventional economic techniques exist through which to quantify the economic benefits of a project. These techniques may be used to estimate both the direct economic costs and benefits of a project as well as the indirect net benefits (also referred to as the multiplier effect).

These include:

- The multi sector input-output (I-O) tables framework
- Social accounting matrix framework
- Direct approach
- Equilibrium models

The multi-sector input-output (I-O) tables framework

Multi-sector models can capture the economy-wide effects of a development project. The Input-Output (I-O) framework is based on the linear structure of inter-industry production linkages. The most important product of the I-O framework is what is known as "the total input requirements matrix", which is used to calculate the direct and indirect intermediate inputs' requirements per extra unit of output or VAD to be generated in any particular sector. The major problem with and limitations of the I-O framework stem from the fact that it only captures production or supply-side linkages.

The later views and research results led to the emergence of alternative approaches to analyzing growth linkages that incorporate demand and consumption feedback effects. Most of this literature was based on the use of one or another version of the social accounting matrix (SAM).

The social accounting matrix framework

This approach extends the I-O framework to include demand components of the multi-sector structure of the economic system. The consequence is larger multiplier effects as feedback and spin-offs from spending on final consumption are captured.

A SAM can be transformed into an economy-wide model by subdividing the SAM into endogenous and exogenous accounts and expressing the transactions between endogenous accounts in coefficient form, resulting in the familiar multiplier equation for the vector of endogenous variables: $y = (I - A)^{-1}x$ [42].

---

[41] Crafford et al. (2004)

[42] Abbink, G. A., Braber, M. C. and Cohen, S. I. (1995) 'A SAM-CGE Demonstration Model for Indonesia: Static and Dynamic Specifications and Experiments', International Economic Journal, 9:3, 15 - 33

A SAM is often used in South Africa. SAMs are constructed by Statistics South Africa (StatsSA) or by specialist consultancies based on StatsSA supply and use tables.

Direct approach to estimating VAD[43] multipliers

Multiplier effects can be estimated using a simplified version of a semi-I-O models' approach. Production multipliers can be derived using data on forward and backward value chains collected from surveys of the studied sectors as well as other secondary sources. Accordingly, an estimate of the total economic benefits realized throughout the forward and backward activities linked to the firm in question can be calculated.

Limitations

However, the problem with both I-O Matrixes and SAMs are that that it models the economy as a linear and static entity, where no substitution or efficiency gains from improved technology are possible. This limits the ability of the SAM to estimate the total economic benefits of:

- Very large projects which is expected to change the structure of the economy and
- Projects with multi-year time-frames.

Equilibrium models

Equilibrium models can be used to overcome these problems of linearity and substitution.

Firstly, non-linear econometric supply and demand functions can be estimated from time-series or cross-sectional data, using specialist software. A series of demand and supply models can be simultaneously solved, using either partial equilibrium analysis or the more advanced computable general equilibrium models.

Computable general equilibrium (CGE) models are widely employed by various national and international organizations (IMF, World Bank, OECD), the European Commission, research centers, and universities for economic policy analysis at the sector-level as well as the economy-wide level.

However, as the sophistication and complexity of these economy-wide models increase, they increasingly become "black boxes" (and they become more expensive), at the expense of transparency.

---

[43] Value Added VAD = Salaries + Wages + Taxes + Interest + Dividends + Profit

3B. Data Collection

After selection of the appropriate valuation techniques, the appropriate data has to be collected through which to conduct the analysis.

In some instances secondary data from prior studies and published reports may be sufficient (benefit transfer). This is especially important in the case of rapid and some intermediate studies.

For large projects, and especially projects with possible legal implications, where comprehensive assessments are required, primary data collection through surveys and similar techniques are required. In these cases it is advisable to make use of qualified statisticians and professional field workers to design and conduct the data collection experiments.

Primary data collection can be the single most costly component of a valuation study. In addition, background socio-economic data, through which to contextualise the economic problem, has to be gathered. The purpose of socio-economic background information is to provide socio-economic context to the problem being analysed. Conventional economic indicators such as Gross Domestic Product (GDP), demographic data, level of employment, poverty indicators and general description of economic infrastructure, including land use, are useful here.

The audience of valuation studies such as these are most often the decision-makers responsible for the design, investment and management of the project through its life-cycles. It is therefore important to design the valuation and its outputs such that an adequate and scientifically credible set of background data is generated to inform decision-making.

3C. Conduct valuation

Demand functions (or demand curves) are mathematical functions that have a particular ecosystem service as a dependent variable, and regulatory and or supporting ecosystem services, and other demand variables as independent variables. They are constructed using either observed behaviour or hypothetical behaviour (as described in Phase 3A above).

Qualitatively describe every demand function by dependent and independent variables. Ensure that the demand functions include:

- All relevant variables required for the particular valuation technique,
- Relevant production function variables,
- Variables required to estimate consumer surplus (if required),
- Relevant intermediate consumption ecosystem services variables.

Use statistical analysis software to develop demand functions from the data. Apply econometric techniques where required.

PHASE 4: Evaluation of trade-offs

A development project causes a set of changes in net benefits for economic goods and services and ecosystem services. This is a set of trade-offs. To evaluate the combined effect of these trade-offs, an evaluation framework is required.

A large number of such evaluation frameworks exist. These include, cost-benefit analysis (CBA), multi-criteria analysis (MCA), cost-effectiveness analysis, portfolio theory, game theory, public finance theory, behavioural decision theory, policy exercises, focus groups, simulation-gaming, and ethical and cultural prescriptive rules[44]. In literature, CBA and MCA are most commonly recommended although CBA is by far the most commonly applied.

A cost-benefit analysis (CBA) assesses the net social benefits of a scenario over time. A net present social value (NPSV) is derived, through discounting, from the flow of costs and benefits over time, and is then used to assess project options. Financial, social and environmental costs and benefits incurred by a society are measured in a CBA. This is as opposed to an investment decision, where financial returns of an individual entity are often the only concern.

CBA informs two types of decision-making (a) whether a project is worthwhile to be pursued and (b) where more than one project option is available, which of these are more beneficial. A project is worthwhile to be pursued if the net present social value is positive. The more beneficial project option has a higher net present social value.

Whereas a cost-benefit analysis (CBA) is effectively an aggregate of valuation estimates of ecological services, multi-criteria analysis (MCA) is a decision-making tool designed for facilitated solutions to complex problems. There are a number of multi-criteria techniques but the main aim of multi-criteria decision analyses is “not to discover a solution, but to construct or create a set of relations amongst actions that better inform the actors taking part in a decision process” (Salgado, 2009).

---

[44] MA 2003. Ecosystems and Human Well-being. A framework for assessment. World Resources Institute. Island Press, Washington.

From this it clear that the results of a CBA may provide data into an MCA, and that, for utilitarian-based valuation as envisaged in projects of this nature, the CBA remains the suitable evaluation framework[45].

For every scenario, in every SWR, quantify the non-ecosystem service costs and benefits that are relevant. It is possible that these costs are already quantified in a separate process.

Three approaches are applicable:

- For earlier implementation of planned augmentation: Determine the change in present cost of augmentation projects. This will be the difference in augmentation project construction cost, between each of the future scenarios and the present condition, expressed in present value terms.
- New infrastructure: Determine the present cost of new infrastructure development required. This will be the difference between each of the additional infrastructure developments costs in the future scenarios and the present condition, expressed in present value terms.
- Economic opportunity cost: Determine the change in economic activity, resulting from allocation of water to the Reserve. This would also be expressed in terms of a present value (to be consistent with the other methods) and should be calculated in terms of value added.

The analysis is applied to every scenario and compared to the baseline condition.

[45] CIC International. 2007. Framework and Manual for the evaluation of aquatic ecosystems services for the Resource Directed Measures, Water Research Commission

PART III. CASE STUDIES

This section presents case studies on the evaluation of aquatic ecosystem services for Resource Directed Measures.

Two case studies will be included in this section:

1. Rapid socio-economic assessment of the Richmond Dam on the Klein Dwars River
2. Intermediate assessment of the Gevonden Dam on the Sand River, considering two scenarios.

Case study 2 presents a hypothetical case in the Sand River Catchment.

Both case studies are for demonstration purposes only, and do not include detailed description of all assumptions, methodological steps followed and other diligence conducted.

Case study 1. Rapid socio-economic assessment of the Richmond Dam

This report presents a rapid economic assessment of the financial, social and ecological effects of the proposed 2.5 MAR Richmond Dam in the Klein Dwars River, a tributary of the Groot Dwars River, which in turn is a tributary of the Steelpoort River.

The water yielded by the proposed Richmond Dam is intended for use by the Der Brochen Platinum Mine, 100% owned by Anglo Platinum. A mining authorization was granted in April 2003. The project is currently in the conceptual design phase, and site activities are currently limited to exploration drilling and land management. An environmental scoping report has been developed.

Platinum is a major source of revenue, both for Anglo Platinum and its shareholders, as well as Government and other stakeholders. Platinum mining is therefore also large job creator. Positive financial and social effects follow from these benefits.

On the other hand, negative environmental and social effects could result from the construction of the dam.

Phase 1. Systems analysis

Project Description

The Der Brochen Platinum Project is a 50:50 joint venture between Anglo Platinum and a BEE consortium, Khumama Platinum (Pty) Ltd (Khumama), now to be absorbed into

Mvelaphanda. This project is known as the Booysendal Joint Venture and resulted from an agreement reached between the SA Government and Anglo Platinum in 2002.

Under the agreement, the Der Brochen Platinum Mine, 100% owned by Anglo Platinum, will exploit the Der Brochen, Richmond, and Helena areas. A mining authorization for these farms was granted in April 2003. The project is in the conceptual design phase, and site activities are limited to exploration drilling and land management. (Anglo Platinum Annual Report 2003[46])

It will be an underground mine in the Groot and Klein Dwars river valleys yielding proximately 400,000 tons of ore per month with an estimated life of mine of 65 years. The mine will employ a total workforce of 1,200 people at full production (Anglo 2007).

For all its activities in the so-called Eastern Limb of mining projects, Anglo Platinum requires 47.5 Ml/day of water and has secured the water from the following sources (Anglo 2007):

- 29 Ml/day from the Lebalelo Water User Association by raising of the Flag Boshielo Dam;
- 14 Ml/day from the proposed De Hoop Dam;
- 2.4 Ml/day from two small well-fields – one in the Klein Dwars River valley and one in the Groot Dwars River valley (Water Use License currently under review); and
- the balance of 2.1 Ml/day from the proposed Richmond Dam.

The annual allocation from the Richmond Dam is therefore 0.77 million m^3.

Water from the proposed Richmond Dam will provide 40% of the water requirement for the Der Brochen Project. The proposed De Hoop Dam will provide another 35% of the water requirement.

The total annual water requirement for the Der Brochen Project is therefore 1.92 million m^3.

The proposed Richmond Dam will comprise the following infrastructure components:

- construction of the dam within the Klein Dwars River on the farm Richmond, with a storage capacity of 13.5 million m^3 of water;
- a dam wall height of 31 m covering an area of 1.52 km^2 (152 ha);
- realignment of the Richmond – St Georges Road to cross over the dam embankment, joining the original road upstream of the dam;
- the construction of a pump station at the dam embankment;

[46] Available at www.angloplatinum.com

- construction of water supply pipelines across the valley to the Groot Dwars River catchment for use during mining operations;
- relocation of the existing 400 kVA and 275 kVA transmission power line on the western side of the Klein Dwars river and the low voltage transmission power line on the eastern flank; and
- relocation of an overhead telephone line (Anglo 2007).

Indirect environmental costs, such as, for instance air pollution effects, were not assessed. The project boundary was therefore defined by the aquatic ecosystem services potentially affected by the proposed dam.

Location

The dam will be located within the B41G tertiary drainage region, the Klein Dwars River, which forms part of the Olifants River Water Management Area (B4). The Klein Dwars River originates on the farm Uysedoorns and has a total catchment area of 294.3 km^2. (EcoRisk undated)

The proposed Richmond Dam, where the storage and abstraction will be located, is on the farms Richmond and St George (EcoRisk undated). The dam embankment is located on the farm Richmond at approximately 24º59'35.90" S and 30º04'44.70" E (Google Earth).

Recommended water yield

The water yield of the Richmond Dam, in million m^3/a, for the scenarios assessed by BKS (2008) were as follows:

Table 12. Modelled yield for Richmond Dam (million m^3/a) Source: BKS (2008)

Yield	No EWR	B	BC	C
Richmond Dam (2.5*MAR)	2.42	1.55	1.91	2.21

BKS (2008) concluded that the 2.5*MAR proposed Richmond Dam would reduce the average flow in the Dwars River and Steelpoort River by 9% and 0.4% respectively, but that the proposed Richmond Dam would have no effect of the supply of the EWR in both the Dwars and Steelpoort Rivers.

BKS (2008) further recommended the application of an annual allocation of 1.91 x $10^6 m^3$ releasing category BC EWR. Such allocation would not have a detrimental impact on the availability of the ecological flows in the Dwars and Steelpoort Rivers. This allocation would support approval by the authorities in terms of section 17(1)(b) of the National Water Act, 1998 (Act No. 36 of 1998) for the following uses:

- Section 21(a) – taking water from a water resource; and
- Section 21(b) – Storing of water.

This recommended water allocation of 1.91 million m^3 exceeds the stated Anglo water requirement of 0.77 million m^3 per year.

General

Anglo Platinum in its Water Use License application proposes that 65 years of constant capital flow would be secured and generated in the smaller region of Sekhukhune with spin-offs to the Greater Limpopo and Mpumalanga Provinces if full production at the Der Brochen mine could be secured.

In Sekhukhune, 73% of the population lives below the breadline. Nearly half, 43%, has no education. Only 13% of the workforce has formal employment. The average monthly per capita income per person in Sekhukhune is less than R 500, which is less than a third of the national average.

This project would therefore contribute to social upliftment and economic progress that this has in the area as identified in the Greater Sekhukhune District Municipality's Growth and Development Strategy.

The Ga Mawela community has been restored to the farm St George. A small number of members of this community (exact number unknown) reside on the St George farm. A number of sites of cultural heritage are reported to exist in the Klein Dwars Valley, and in addition, the community is reportedly planning a small subsistence agricultural development (AfricanEPA 2006).

Phase 2. Assessment of ecological change

The impact of the proposed Richmond Dam on the Ecological Water Requirements (EWRs) in the Dwars River and downstream of the confluence with the Steelpoort River was therefore assessed in a separate study, by BKS (2008), through an intermediate Reserve determination. The Reserve determination used the most recent Olifants River Water Resources Yield Model (WRYM) system, modified to include the proposed Richmond Dam (BKS 2008). The following scenarios were analysed by BKS:

- Scenario 1: Present day;
- Scenario 2: Scenario 1 plus De Hoop Dam with its EWR releases;

- Scenario 3: Scenario 2 plus a 2.5*MAR Richmond Dam with no EWR releases from Der Brochen and Richmond dams;
- Scenario 4: Scenario 2 plus a 2.5*MAR Richmond Dam with Category B EWR releases from Der Brochen and Richmond dams;
- Scenario 5: Scenario 2 plus a 2.5*MAR Richmond Dam with Category BC EWR releases from Der Brochen and Richmond dams; and
- Scenario 6: Scenario 2 plus a 2.5*MAR Richmond Dam with Category C EWR releases from Der Brochen and Richmond dams.

In addition, other ecosystem services, including social services, as defined by the Millennium Ecosystems Assessment, could potentially be negatively affected by the construction of the Richmond Dam.

Supporting and regulating services are usually valued indirectly as inputs into provisioning and cultural services. In this rapid study, we therefore only assess, qualitatively, the provisioning and cultural services, based on available published data.

This report provides a rapid assessment of the potential financial, social and environmental effects of the Richmond Dam. Rapid assessments do not have to include a full CRA, but still provide the thinking for the chains of causality between management scenarios and effects on ecosystem services.

Phase 3. Valuation

This study presents a rapid cost-benefit analysis of the direct costs and benefits of the proposed Richmond Dam (please see Table 13 below).

Table 13. Summary of the benefits and costs assessed in this study.

Direct Benefits	Direct Costs
Financial benefits to Anglo Platinum and its stakeholders (shareholders, employees and Government)	Cost of water provisioning (Construction cost of the Dam + operational cost)
	Costs of ecosystem services lost as a result of construction of the Richmond Dam.

Financial benefits yielded by the Project were estimated based on financial data reported on in audited annual reports of Anglo Platinum, data obtained from Statistics South Africa, and data obtained from the Water Use Licence Application for the Project.

The costs of water provisioning were not assessed separately, but were internalised into the assessment of the direct (net) benefits of the dam.

Indirect financial benefits of the Der Brochen Project were estimated using a multiplier analysis, relevant for Anglo Platinum.

Average analysis economic techniques were applied.

No primary data collection was done. Key data sources used for this report were:

- Draft Final Environmental Scoping Report, 2006; compiled for Anglo Platinum by EcoRisk SA
- Annual Reports of Anglo Platinum for 2005, 2006 and 2007
- Status quo and development potential report of the Ga Maweala Community for the Regional Land Claims Commissioner, 2006; compiled by AfricanEPA
- A literature review, undated; conducted by EcoRisk SA
- The Anglo Platinum Water Use Licence Application for the Richmond Dam, 2007
- A Socio-economic Baseline Study for Mototolo JV, 2007; compiled by SRK Consulting (2007)
- Determination of the impact of the proposed Richmond Dam on the Ecological Water Requirements in the Dwars and Steelpoort Rivers, 2008; compiled by BKS Consulting (2008)
- The Mpumalanga Biodiversity Conservation Plan, 2006; Mpumalanga Parks Board (Lötter and Ferrar, 2006).

Direct financial benefits

The direct financial benefits accruing from the Der Brochen Project to Anglo Platinum and its stakeholders (employees, shareholders and government) is best measured through its economic value added (VAD) and employment. VAD is the sum of salaries, wages, taxes, interest, dividends, and profit realised during a financial year and can be extracted from company annual reports.

We estimate that the value contributed directly to the national economy by the use of water from the proposed Richmond Dam by the Der Brochen project, using VAD as an indicator, would be R2,498 million per year over the 65 year life of mine project. Of this, R874 million per year would comprise employment created. Please see Table 14.

Table 14. The direct benefits of the Der Brochen Project to the national economy expressed in terms of water use from the Richmond Dam.

Der Brochen Water Use	Mega-liters / day	2.1
	Cubic meters per year	766,500
Value added value of water	R'million per year	2,498
Employment value of water	R'million per year	874

These estimates were derived as follows:

Table 15 summarises the annual VAD for Anglo Platinum for the years 2005, 2006 and 2007, expressed in 2007 prices. Anglo Platinum's total value added increased from approximately R13 billion in 2005 to nearly R28 billion in 2007 for its RSA operations. The primary source of this escalation was soaring platinum prices, translating into large increases in tax (public sector) and dividend payments.

Anglo Platinum's total water use was estimated at 55 million m^3 in 2007. This was estimated from data obtained from the Anglo Scoping Report (Please see Table 16).

Using the above data, we calculate an average VAD per m^3 water used of R3,259 and an average employment value of R1,140 per m^3 water used (please see Table 4).

Table 15. Total value added and employment created by Anglo Platinum in 2005, 2006 and 2007. Combined with the estimate of water use from Stats SA, this analysis can be extended to an estimate of VAD and employment created per cubic meter of water used by Anglo Platinum.

Anglo RSA Operations		**2007 RSA R'million**	**2006 RSA R'million**	**2005 RSA R'million**
Refined platinum production	oz	2,470,000	2,816,500	2,453,200
Value added (VAD)		27,835	21,470	13,030
	Employees	8,311	6,873	6,621
	Public Sector	6,818	1,452	703
	Interest	402	257	434
	Dividends	15,905	5,168	2,275
	Profit	-3,601	7,720	2,998
Supplier purchases		22,520	20,038	15,459
Customers (Africa)		12,207		
Estimated water use	million m3	5.6	6.4	5.6
VAD: R / m3 water		4,366	3,368	2,044
Employment: R / m3 water		1,304	1,078	1,039

Average for RSA 2005-2007 (2007 prices)	
VAD: R / m3 water	3,259
Employment: R / m3 water	1,140

Table 16. Estimate of water use per value added for all mining activities (platinum and other) in South Africa.

400,000	tons ore / month
4,800,000	tons ore / year
2.1	Ml/day water from Richmond Dam
766,500	m3 per year (from Richmond Dam)
1,916,250	m3 per year (for Der Brochen)
0.40	m3 / ton ore

Indirect financial benefits

The indirect financial benefits are estimated through the multiplier effect of Anglo Platinum in the national economy.

Table 17 estimates the multiplier effect at 1.35. This means that for every R1.00 of VAD directly generated by Anglo Platinum, an additional R0.35 are generated through their purchases of materials and services and their sales to customers in the manufacturing sector in South Africa.

We therefore estimate that the value contributed to the national economy by the use of water by the Der Brochen project, using VAD as an indicator, would be R3,365 million per year over the 65 year life of mine project. Of this, R1,170 million per year would comprise employment created. Please see Table 18.

Table 17. The multiplier financial effect of the Der Brochen project and be used to calculate the combined direct and indirect financial effects attributable to water use from the Richmond Dam.

Domestic Multiplier effect	Manufacturing sector	27.8%	
	Suppliers	6,261	
	Customers (Africa)	3,394	VAD ratio
	Indirect VAD	9,656	
	Multiplier effect	1.35	in 2007

Average for RSA 2005-2007 (2007 prices)	
VAD: R / m3 water	4,390
Employment: R / m3 water	1,536

Table 18. The combined direct and indirect benefits of the Der Brochen Project to the national economy expressed in terms of water use.

Der Brochen Water Use	Mega-liters / day	2.1
	Cubic meters per year	766,500
Value added value of water	R'million per year	3,365
Employment value of water	R'million per year	1,177

Cost of water provisioning

The cost of water provisioning is internalised into the estimation of direct financial benefits in the preceding sections.

Ecosystem services cost

Supporting and regulating services

BKS (2008) proposed Scenario 5, a 2.5 MAR dam with a 1.91 million m^3 yield, as the scenario that would maintain the BC state of the analysed river system.

In this Scenario, supporting and regulating services are highly unlikely to be negatively affected, as the EWR is maintained at a level that supports present ecological processes.

Provisioning services

Potential provisioning services affected by the construction of the dam include:

- provisioning of fresh water;
- the collection by the Ga Mawela community of wild food, fiber and biochemical and pharmaceutical products; and
- scarce of threatened genetic resources.

The construction of the dam will increase the provisioning of fresh water.

The proposed Richmond Dam will destroy approximately 152 ha of terrestrial ecosystems through inundation, of which 30 Ha is located on the farm St George. (AfricanEPA 2006) This could possibly reduce opportunities for the collection of wild food, fibre, wood and other biochemical products by the Ga Mawela community. No evidence currently exists on these services.

It is highly unlikely that the service of genetic resources will be affected. The Mpumalanga Biodiversity Conservation Plan, combined with the national land cover database, classifies the area as “highly significant but not irreplaceable” as it consists of natural vegetation: thicket and bushveld. Satellite images also indicate that much of the lands to be inundated are old, disused agricultural land. These lands are reported by AfricanEPA (2006) to be in poor state due to too frequent fires and overgrazing.

It is therefore highly likely that the Ga Mawela community may have to be compensated for possible loss of food, fiber and biochemical product provisioning services.

Provisioning	Food	No evidence of reduced opportunity to collect food, directly or indirectly
	Fresh water	Fresh water provisioning to increase – not a cost
	Wood and fibre	No evidence of reduced opportunities for wood and fibre production
	Biochemical and pharmaceutical products	No evidence of reduced opportunities for collection of natural products (biochemicals, pharmaceuticals and other natural products)
	Genetic resources	No evidence of extinction of genetic or species biodiversity

Cultural services

The AfricanEPA (2006) reports on the existence of a number of cultural services in the Klein Dwars River valley. No information is currently available on the exact nature and location of these services.

It is therefore highly likely that the Ga Mawela community may have to be compensated for possible loss cultural services.

Little evidence recreational and tourism activities are reported, other than a disused hiking trail (AfricanEPA 2006). The report also regards the area to hold little potential for new tourism activities. It is therefore highly unlikely that recreational services will be negatively affected.

Cultural	Cultural diversity	The diversity of ecosystems as it influences the diversity of cultures and the identity of specific cultures.
	Spiritual and religious values	Many religions attach spiritual and religious values to ecosystems or their components.
	Knowledge systems	Ecosystems influence the types of knowledge systems developed by different cultures (traditional and formal).
	Educational values	Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.
	Inspiration	Ecosystems provide a rich source of inspiration for such activities as art, folklore, national symbols, architecture and advertising.
	Aesthetic values	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, 'scenic drives' and the selection of housing locations.
	Social relations	Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.
	Sense of place	Many people value the 'sense of place' that is associated with recognized features of their environment, including aspects of the ecosystem
	Cultural heritage values	Many societies place high value on the maintenance of either historically important landscapes ("cultural landscapes") or culturally significant species that serve to remind us of our historic roots
	Recreation and ecotourism	No evidence of loss of recreational or tourism activity

Phase 4. Evaluate optional scenarios

From a socio-economic perspective, based on available documented evidence, the proposed Richmond Dam will be significantly beneficial. This is because of the high value addition by platinum mining and processing, resulting indirectly from water use from the dam.

Supporting and regulating aquatic ecosystem services are unlikely to be affected as the BC class of the river is maintained.

However, it is likely that subsistence provisioning and cultural services derived by the Ga Mawela community may be negatively affected. No evidence exists as to the nature and location of these services and the economic consequences of this therefore remains uncertain. An assessment of the value of these services is advised.

Table 19. Summary of economic effects resulting from the proposed Richmond Dam in terms of direct and indirect economic effects and aquatic ecosystem services.

Benefits and costs	Category	Likelihood of effect	Consequence
Direct financial benefits	Value added through Anglo Platinum operations	highly likely	R2,498 million per year
Indirect financial benefits	Value added through Anglo Platinum suppliers and customers	highly likely	R867 million per year
Supporting and regulating services	Various	unlikely	A category BC river is maintained
Provisioning ecosystem services (costs)	Food, Wood and fibre, Biochemical and pharmaceutical products	Highly likely	Not quantified, relevant for a small portion of the Ga Mawela community, Anglo Platinum possibly to compensate
	Fresh water	Highly unlikely	Water provisioning will be increased
	Genetic resources	Highly unlikely	No threatened of scarce species in the affected area
Cultural	Cultural diversity	Highly likely	Not quantified, relevant the whole Ga Mawela community, Anglo Platinum possibly to compensate
	Spiritual and religious values		
	Knowledge systems		
	Educational values		
	Inspiration		
	Aesthetic values		
	Social relations		
	Sense of place		
	Cultural heritage values		
	Recreation and ecotourism	Unlikely	R0.00

Case study 2. Comprehensive assessment of the Gevonden Dam

The National Water Act (NWA) No. 36 of 1998 stipulates that water resources should be protected and that an ecological Reserve must be determined for any water resource development. The Department of Water Affairs and Forestry (DWAF) will only consider license applications after consideration of the impact of the development on the Reserve, has been given.

The Reserve determination for the Inkomati WMA is in progress and the Ecological Water Requirements (EWRs) in the Sand River have been determined at a desktop level. This study was initiated to investigate the effect of the proposed 0.51 MAR Gevonden Dam in the Sand River, a tributary of the Sabie River, on the provision of ecosystem services.

This is a hypothetical case.

Phase 1. Systems analysis of the Sand River Catchment (SRC)

1A. Defining the boundaries of the system

i. Problem description

The Bushbuckridge municipality is considering a proposed initiative to stimulate local economic development and job creation in the Sand River Catchment (SRC) – an area that was a previous homeland under the Apartheid government and thus remained under-developed.

The proposal is the establishment of new sugarcane plantings. Sugarcane would be harvested and transported elsewhere for processing. This will create many jobs and increase wealth in the area.

Sugarcane requires ~1200 mm pa, but this area has a minimum annual precipitation (MAP) of only ~600 mm pa. Therefore an irrigation scheme is required, making provision for around 30 million m^3 water per year from the Sand River. In order to ensure this yield, and taking into consideration mean annual evaporation (MAE) which is more than double the MAP, the new dam will have a capacity of 60 million m^3.

The dam and the farm will be situated in quaternary catchment (QC) X32G which has a net MAR of 118.2 million m^3. The new dam, to be called the Gevonden dam, will have a capacity 0.51 MAR. Figure 12 shows an artist's impression of the proposed sugarcane farm and location of the proposed Gevonden dam.

Water infrastructure developed will supply water from the Gevonden dam to upstream users, therefore increasing access to and supply of water.

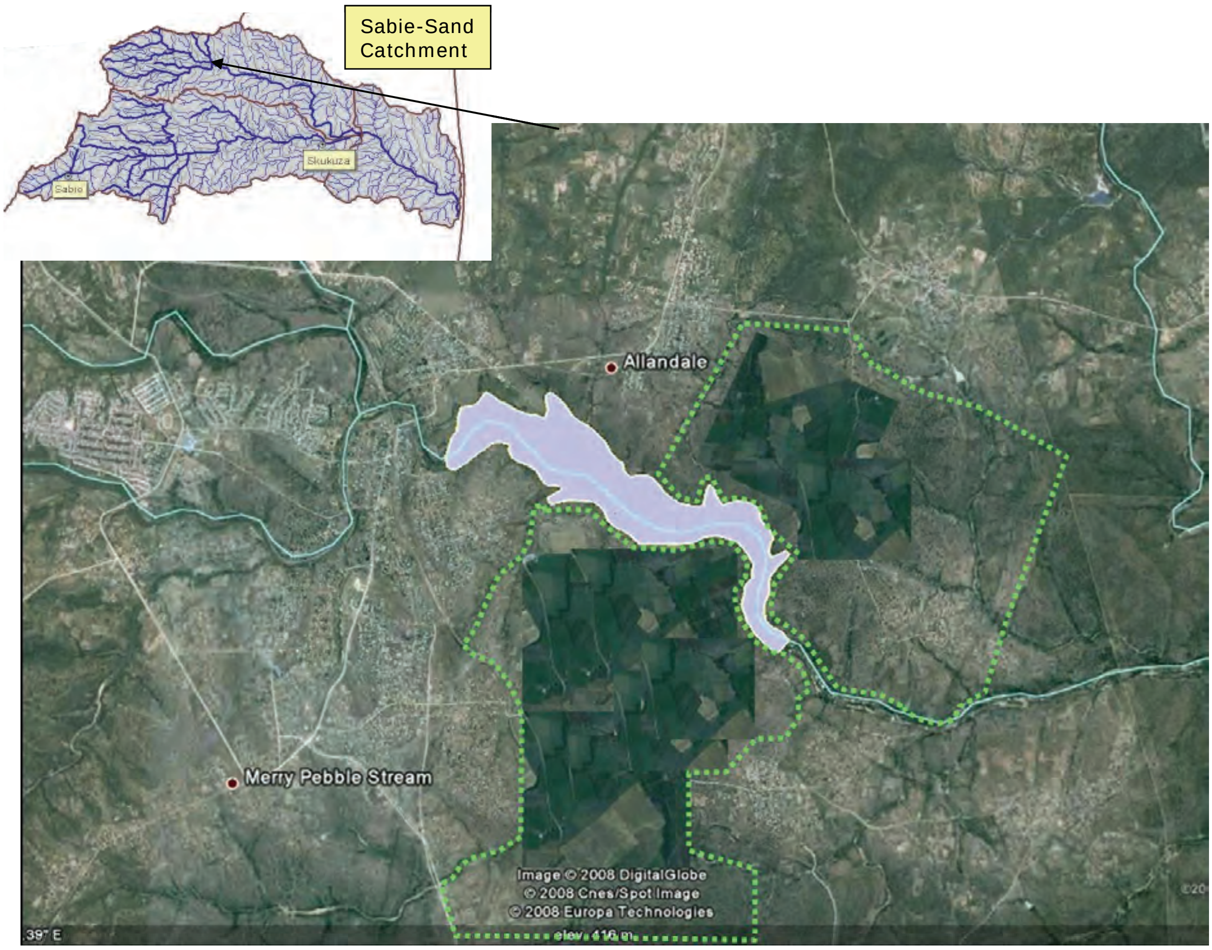


Figure 12. Artist's impression of the proposed sugarcane farm and location of the proposed Gevonden dam on the Sand river just below the confluence of the Mutlumuvi and Nwandlamuhari rivers. (Images from Pike and Schulze, 2000 and Google Earth 2009)

The proposed Gevonden Dam will be constructed in the Sand River downstream of the confluence of its two main tributaries (Mutlumuvi and Thulandiztlela) and upstream of the world famous Kruger National Park and confluence with the Sabie River. The Sand River is a tributary of the Sabie River and constitutes the quaternary catchments X32A to X32H.

A comprehensive EWR is being conducted in the Sand River, namely the Inkomati Comprehensive Reserve determination. The Inkomati EWR 9 site is situated between the proposed Gevonden Dam site and the Sand/Sabie rivers confluence. There are two EWR sites upstream of the dam and one below the confluence of the Sand and Sabie rivers.

The Reserve determination for the Sabie-Sand river catchments in Inkomati Water Management Area has been determined, although the Reserve (EWRs) still needs to be met.

A water transfer exists from Inyaka Dam in the Sabie River QC X31E into the Sand River QC X32F. There are ecologically sensitive and important ecosystems in the lower reaches of both Sabie and Sand River Catchments, namely Kruger National Park and a number of other private conservation areas.

A full and clear description of the dam development and establishment of sugarcane plantings is necessary to understand the ecosystem changes as a consequence. The construction of the Gevonden Dam and the logistics of sugarcane cultivation are detailed in this section.

b. Construction of the Gevonden Dam

There are two distinct phases of impact to the development of the Gevonden Dam and associated agricultural irrigation. Each phase poses a variety of threats to the Sand River catchment: (1) the short-term impacts of building the dam wall and filling it up combined with the clearing of land for the irrigation scheme; (2) the long-term impacts of the dam operation and the management and long term operation of the sugarcane irrigation scheme.

A clear understanding of the phases of construction is needed to consider the ecological consequences and assets affected (to be done in the CRA below). A detailed description of the phases follows.

Phase 1 is the construction and fill-in of dam (approximately 12 months) and associated preparation for irrigation scheme and water supply schemes. The construction of the Gevonden Dam will inundate an area approximately 900ha of river habitat, wetlands, riparian zones, small-scale agriculture, some infrastructure such as homesteads, roads degraded bushveld and grazing area. Environmental effects will occur over the short-term (12 months) and include the following processes with resulting effects:

a) Construction activities including blasting (resulting in dust and loose sediments), instalment of new infrastructure such as pipelines, roads (resulting in dust, soil compaction and loss of vegetation cover);
b) Land-clearing activities for sugar cane irrigation pipelines and preparation of lands (resulting in a greater area exposed to the elements, a source of sediment and short-term effects of carbon release, increased runoff and erosion);
c) River diversion – during part of Phase 1 the river is diverted to make way for dam wall construction (resulting in increased sediments, loss of riparian vegetation) but it is otherwise unhindered;
d) Dam filling – while the dam is filling environmental flows will be released but effects will include loss of migration pathway for fish and submersion of river upstream of dam wall.

Phase 2 is the long-term operation of the dam and long-term management of the schemes. In the immediate vicinity of the dam, a new wetted perimeter around the dam develops. This new wetted perimeter will have an altered ecosystem function to the original wetted perimeter area. Alien vegetation shouldn't be allowed to colonise the area (although this might be as the area will be degraded and thus more vulnerable to invasion).

In Phase 2 the sugarcane plantations will be operational. Environmental effects of this are likely to include increased nutrient loading, increased sediment load and possible erosion (Strange et al., 1999). It is possible that higher flows will persist in summer due to irrigation return flows. There might be increased daily flow fluctuations due to irrigation.

The dam will be built in such a way that operating rules to release environmental flows can be implemented. Different scenarios for environmental flow releases would have profound consequences for downstream communities.

c. Sugarcane cultivation

Sugarcane is a tropical grass that stores sucrose in its stem and is extensively cultivated in South Africa, and many other parts of the world, for the production of sugar, and potentially biofuels. Sugarcane is renowned for its capacity to convert solar energy into biomass (organic material). This exceptional efficiency is an often cited positive environmental feature of the crop. However to fulfil this considerable growth potential, the crop needs strong sunlight and sufficient water (Cheesman, 2005).

The following facts about growing sugarcane are extracted from Cheesman (2005):

- Growing period depends on local conditions but varies from 10-22 months.
- Yield ranges from 50-120 t/ha/year.
- In terms of nutrient input requirements, sugarcane requires around 14 different chemical elements for normal growth and development, of which the most important is Nitrogen (N). Potassium (K) is also heavily consumed. In relation to other major nutrients, levels of phosphorous (P) tend to increase in soils following regular fertilizer inputs partly as it is relatively immobile compared to the other nutrients, such as nitrogen which is leached from the soils more easily. In the absence of fertilizer, few arable soils can provide more than 100kg N/ha during the growing season. Nitrogen recovery by sugarcane is generally 20-50%. Because nitrogen is fairly mobile in soil solution, this poses a threat of nitrate impacts of water resources.
- Sugarcane typically ripens in the cooler and drier part of the year, and water stress enhances sucrose accumulation.
- Controlled burning is a common practice before harvest to clear dead leaves and remove the waxy coating on the case.
- Post harvesting, roots of the old crop may be ploughed out and the field replaced, or under certain conditions the old crop will remain in the field and cane will re-

grow from the old root stock (this is called ratooning, and at least two ratoon crops is typical, resulting in fields being ploughed only every 3 years at the most).

- Extraneous material from the field may be removed or remain in field as valuable mulch.

d. Time frames

The assessment of the proposed new dam began in April 2008 and will be completed by April 2009.

ii. Delineation of the entity

This case study focuses on the Sand River Catchment downstream of the proposed dam. The entity is the Sand River Catchment.

iii. Level of RDM assessment

The level of RDM assessment is intermediate to comprehensive.

iv. Metasystem

The metasystem is the Sabie-Sand River Catchment.

1B. Description of the entity

i. Historical overview

A comprehensive overview of the historical factors that have driven ecosystem change in the SRC is provided in Pollard et al. (2008).

Much of the SRC is economically very poor having been heavily affected by social and political decisions during the Apartheid years. Much of the catchment was turned into a Bantustan (former homelands for black people) and had low agricultural potential. Combined with increasing densities of people, agricultural-based livelihood has become virtually impossible. As a means of creating more jobs in the area, agricultural schemes and forestry were developed, but very few of these became viable business ventures (Pollard et al., 1998).

The social consequences of the Apartheid era in this area continue today. Migrant labour resulted in female-headed households (with men absent for the majority of the year) and reduced social capital. The quality of education at schools was poor and the livelihood security for black people was jeopardised. Water supply is ad hoc and bulk supply water infrastructure is inadequate with access to basic water supply being problematic (Pollard et al., 2008).

In the 1980s concerns were raised about declining flows and associated water quality problems, and the first proposal for environmental flows was made from the national Department of Water Affairs- albeit simplistic.

Drought and floods are major natural shocks to the system and disease influenced human settlement for many decades. Pollard et al. (2008) explain that tsetse fly, host to sleeping sickness, and malaria were both prevalent in the Lowveld and contributed to limiting human settlement. The combination of drought and rinderpest may have been responsible for the demise of tsetse fly at the turn of the century. In the 1950s, as the treatment and prophylaxis improved for malaria, the Kruger National Park remained open all year round and the area became more comfortable for habitation.

Table 20. Time line of events that have influenced that socio-ecological system of the Sand River Catchment (Pollard et al., 2008).

Pre-1860: Transmigrants – seasonal grazing land
1860: Influx of settlers and refugees
1896: Rinderpest
1897-1913: Drought
Early 1900s: Plantation forestry started
1912: Rinderpest – allowed permanent settlement; inception and growth of disenfranchisement for black people and the entry of entrenched racism and apartheid planning; Land Acts start racial segregation
>1913: Demise of tsetse fly in the Lowveld as a result of combination of rinderpest and drought
1926: KNP established
Mid-1930s: Agriculture begins to decline as the mainstay of the rural economy Apartheid laws
1940s: Rural economies becoming dependent on migrant remittances and state pensions for cash injections
1948: Racial segregation is formalised and institutionalised; autocratic and separatist policies further entrenched under Nationalist Party government
1948: The apartheid policies of the National Party government entrenched ethnic segregation through the establishment of homelands (Bantustans), through the Promotion of Bantu Self-Government Act of 1959, and a plethora of other apartheid laws. The homelands became dumping grounds for what the state regarded as 'surplus' Africans and large-scale forced removals occurred, creating overcrowded and impoverished Bantustans in which investment and development was negligible (Fischer, 1988; de Wet, 1995).
1961-1970: Major increase in population
1972: The central Lowveld was divided into piecemeal parcels of land comprising two 'self-governing states'. Gazankulu was established for the Tsonga 'tribe' and Lebowa, adjoining Gazankulu on the western side, for the Pedi people. Traditionally, the driest eastern districts that were used only for seasonal grazing and hunting due to the inhospitable summer climates (Harries, 1989; Spenceley, 2001).
1994: Democratic transition (release of Mandela, new policies).
1994: New South African government
After 1994: Bantustans were abolished and it is this area that is referred to as communal lands. The situation in the communal lands stands in stark contrast to the adjacent private conservation areas (SSW), currently owned mainly by English and Afrikaans speaking whites.

ii. Physiography and geomorphology

The SRC has an area of 1 910.02 km^2, includes QCs X32A-J, and has a river length of 125 km to the confluence with the Sabie river. The source of the Sand river lies 1800 m asl in the northern Drakensberg mountains from where it "descends 1000 m within a distance of 10 km into a semi-arid, low-lying region, colloquially known as the Lowveld. The Sand River then descends more gradually to reach an altitude below 300 m at the confluence with the Sabie River" (Pollard et al., 2008). The Sabie river below the confluence with the Sand river flows through the Kruger National Park and the main tourist camp, Skukuza, into Mozambique where it joins the Incomati river.

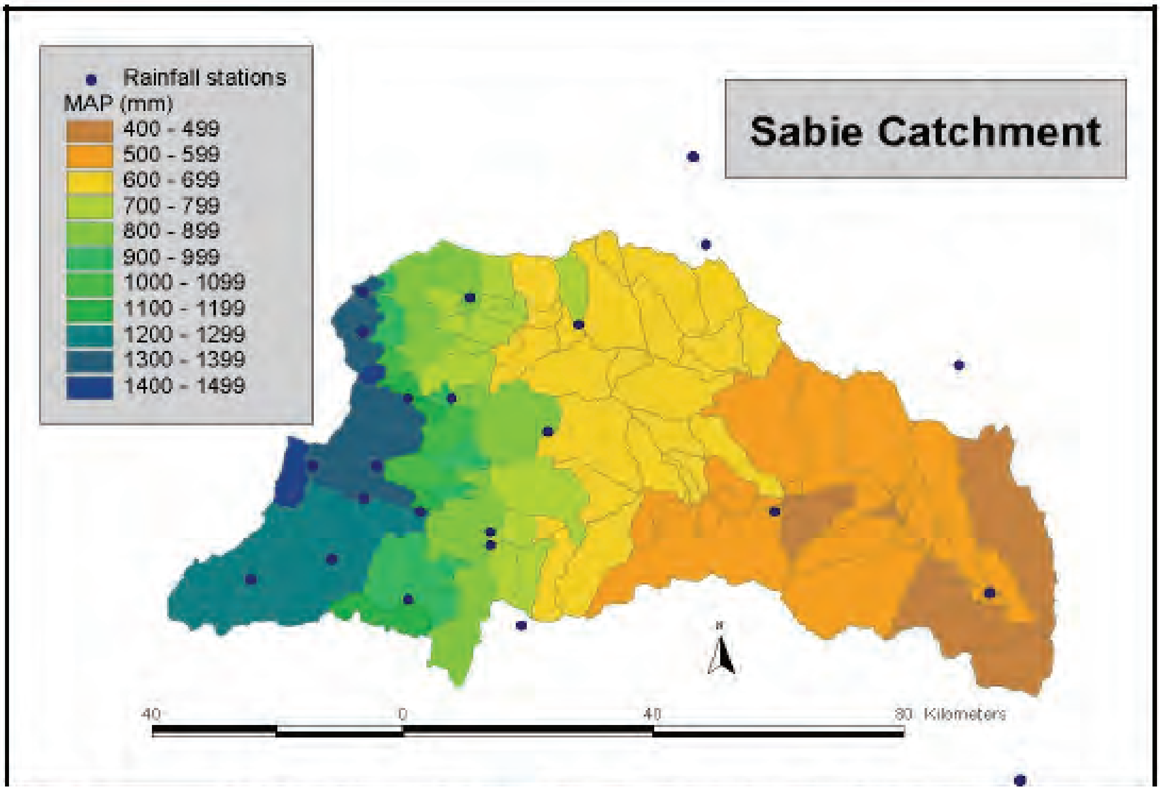
Geomorphic provinces were used to describe the geomorphological template (as per Nel et al., 2004). Geomorphic provinces "are homogenous areas of similar landforms that reflect comparable climatic, erosional and tectonic forces. They impose broad constraints on the types of drainage basins, macroreaches and channel types, and therefore physical processes and types of biota found within each of these" (Nel et al., 2004). There are two geomorphic provinces in the SRC: the Great Escarpment in the very west and Lowveld, which is predominant.

iii. Climate

The entity has a warm to hot subtropical climate, but has significant spatial variation in temperature and potential evaporation values from west to east across the entity and on a month-by-month basis. Average min-max temperatures range from 15-34°C in summer and 4-29°C in winter (Ackerman, 2000; SEF and EAT, 2007), with maximums in excess of 40°C in the low-lying eastern parts. Minimum-maximum water temperatures range between 20°C and 35°C in summer, and 10°C and 15°C in winter (Pollard et al., 2008). Rapid water temperature changes, rather than observed extremes, tend to be more critical for biota. For example, sudden reductions in temperature following hailstorms have resulted in fish kills. This will be important with respect to dam releases.

High temperatures give rise to high evaporation rates, which range from 1850-2200 mm from west to east. Mean annual precipitation (MAP) is also influenced by this altitudinal and climatic gradient. Figure 13 illustrates MAP of >1000 mm in the mountainous west, declining rapidly to <700 mm per annum in the low lying Lowveld (Pike and Schulze, 2000).

Nearly half the mean annual runoff (MAR) of the Sand River Catchment is generated in the upper escarpment area, which constitutes only 25% of the catchment (Pollard et al., 2008).



Weather Bureau Station Block 0595		
Rainfall zone	X3D	X3E
Sand River Catchments	X32C, X32F	X32G
Rainfall stations #	161	428, 579
Average rainfall	100.91 mm (±25.85)	99.62 mm (±27.86)
Rainfall data period	1920-1989	1920-1989
Mean annual runoff	50-100 mm	20-50 mm
Hydrozone	Q	R
Rainfall/runoff response	8	8
Mean annual evaporation (S-pan measurements)	X32C = 1500-1600 mm X32F = 1600-1700 mm	X32G = 1500-1600 mm

Figure 12. Sabie-Sand Catchment showing the range of mean annual precipitation (MAP), the 25 daily driver rainfall stations selected in a study by Pike & Schulze (2000), and a table detailing the rainfall data for the region (as per Midgley et al., 1994).

"Precipitation is a major driver of the ecology in the region. Inter-annual rainfall variability is high and intra-seasonal drought is common. A situation in which the monthly or annual rainfall is less than 75% of the average rainfall occurs as often as every 3.5 years in the northern portion of the catchment (Shackleton et al., 1995). There is evidence of various long-term cyclical rainfall fluctuations superimposed on the normal annual variability typical of the region. A quasi 18-year rainfall oscillation of alternating wet and dry periods of approximately nine years each has been identified in the eastern summer rainfall parts of southern Africa (Tyson, 1986). Periods characterised by higher than average rainfall were 1934-42, 1952-60, and 1971-78; drier periods were experienced from 1943-51 and 1961-1970. The 1979 period onwards has fallen within a dry period, with a 38% decrease in expected annual rainfall in the Lowveld" (Pollard et al., 2008).

Drought and floods are key natural shocks or disturbances to the system. The unprecedented floods of 2000 are the most recent example. Although the Sand River was affected, the effects were more significant and devastating in larger Sabie catchment and others such as the Olifants, the Crocodile downstream in Mozambique (Pollard et al., 2008).

iv. Geology and soils

Again, Pollard et al. (2008) provide the best description of the geology and soils of the SRC, which they describe as: “underlain by the granitic Basement Complex, with minor intrusions of gabbro. The highly weathered granite produces friable, nutrient-poor soils, while gabbro areas are typified by nutrient-rich black turf soils. The granitic geology has produced a gently undulating topography with a characteristic catenal sequence. Clay particles and bases move downslope, resulting in shallow, sandy, nutrient-poor soils on the ridgetops, and relatively deeper, clayey, nutrient-rich soils in the bottomlands. A seepline generally forms where water meets the relatively impermeable clay layer in the bottomlands and is forced to surface” (Pollard et al., 2008).

The entity has a high erodibility index of 5 (Midgley et al., 1994). Midgley et al. (1994) provide the sediment yields for quaternary catchments, where the upper SRC X32C has a sediment yield of 36 000 tonnes per annum, X32F has 24 000 tonnes per annum and X32G has sediment yield of 52 000 tonnes per annum. Sediment production in the catchment is highest in the region west of the Kruger National Park due to overgrazing and land degradation (SEF and EAT, 2007).

A “dolomitic area runs from north to south through the upper reaches of the Sand and Sabie catchments” and it is therefore expected that “runoff processes associated with karst hydrology dominate the production of streamflows in subcatchments falling within this area" (Pike and Shulze, 2000). There are two dominant soil Land Types according to the Institute for Soil, Climate and Water (ISCW) (Pike and Shulze, 2000). "For each Land Type a vast amount of information on percentages of soil series per terrain unit, soils depths, texture properties and drainage limiting properties” is obtainable from the ISCW (Pike and Schulze, 2000).

Soils for the entity are classified as moderate to deep and the majority of all catchments are sandy loam texture, with a steep relief. A small portion (20%) in the south of X32F is moderate to deep clayey loam with a steep relief (Midgley et al., 1994). Alluvial deposits are present along the lower reaches of the Sand river before it enters the Sabie River. These deposits are mainly present from where rivers descend to elevations of between 300 to 350 m.a.m.s.l. (Vegter, 2003). The whole entity was classified as Acid and intermediate intrusive (according to the Simplified Lithostratigraphic map of water bearing formations).

v. Hydrology

High variability in rainfall drives runoff and stream flow in the entity. Streamflow is considered highly variable (Pollard et al., 2008; also see Figure 14).

Table 21. Mean Annual Runoff (MAR) and Hydrological Index (HI) for Sabie and Sand River Catchments, where entity is in upper reaches of Sand River. HI is extracted from spatial layer NSBA spatial data by Nel et al. (2004)

	Mean Annual Runoff		Hydrological Index	
	Sabie River[47]	Sand River	Sabie River[48]	Sand River
Mean	36.38	8.65	2.41	6.53
Standard deviation	42.45	2.86	0.54	0.68
Min	1.54	6.25	1.75	5.59
Max	104.08	11.92	3.04	7.03

The hydrological index is "used to characterise hydrological variability, measured as a ratio of flow variability to base flow in a river" (Nel et al., 2004). The Sand River has a higher average hydrological index than the Sabie River (Table 21), with lower HI in the upper catchment indicating commonly perennial-type rivers (Figure 15), and higher HI downstream indicative of the semi-arid region of high variability. This is clearly concordant with climatic conditions and highlights the importance of the contribution to flow of the upper catchments. The larger area of high MAP in the Sabie River results in a lower hydrological index on average.

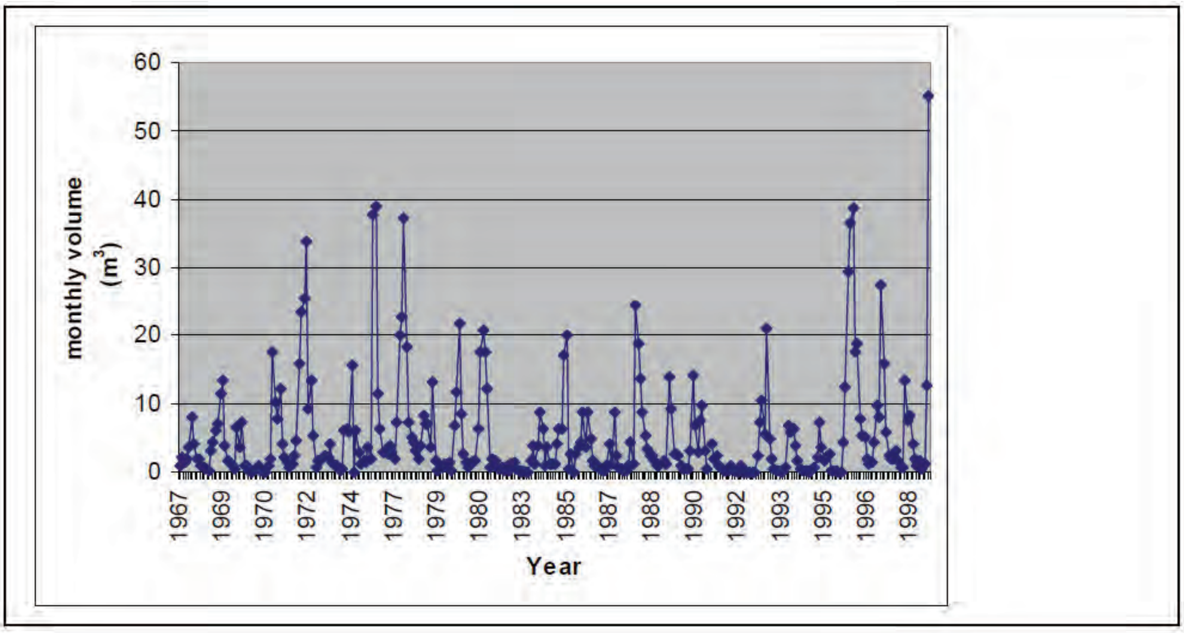


Figure 13. Graph depicting streamflow variability. Hydrological data (monthly volumes) depicts the period 1967-1998 from hydrological gauge station X3008.

[47] Mean Annual Runoff in million cubic meters as defined by the DWAF quaternary catchments.

[48] Hydrological indices were according to Hughes and Hannart (2003).

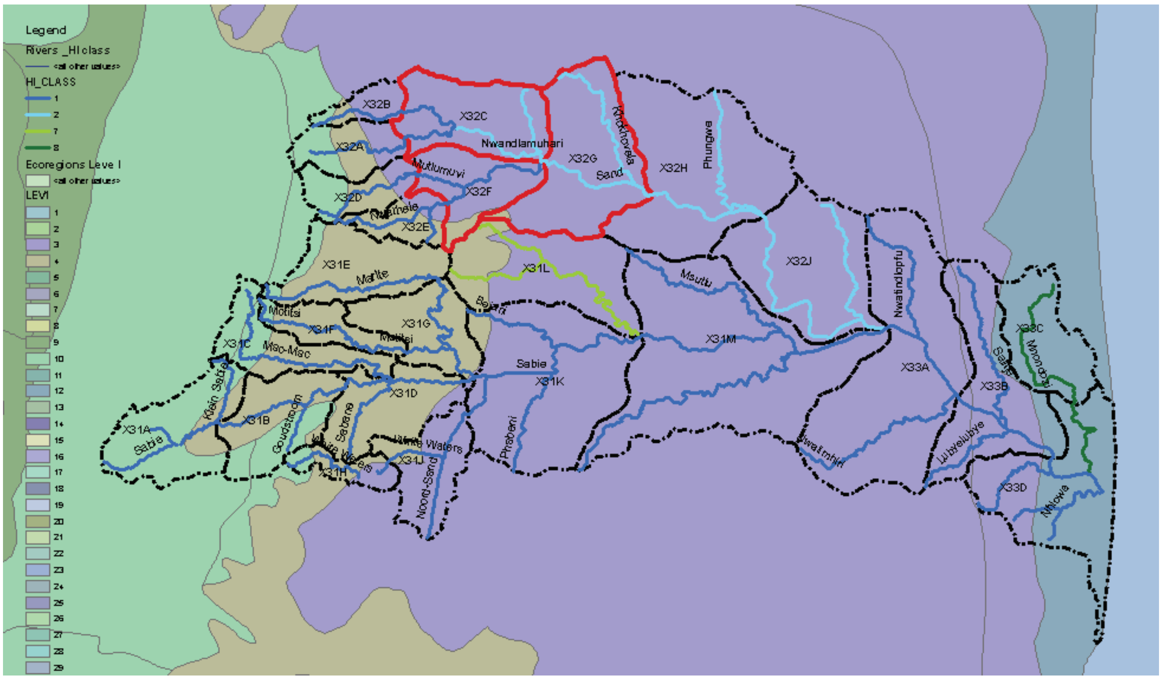


Figure 14. Index of hydrological variability (HI) and ecoregions of the Sabie and Sand River Catchment with the entity highlighted in red (Quaternary Catchment X32C, X32F and X32G).

The present ecological status (PES) of rivers within the entity (Figure 16; according to the desktop WSAM) indicate largely natural conditions in the upper reaches, where catchments are dominated by natural and plantation forests, but moderately modified in the rest of the entity. Rivers in the upper reaches of that flow from the higher altitude and higher rainfall areas are dominated by natural and plantation forests and are considered largely natural.

Concordant with the PES, the ecological importance and sensitivity categories (EISC) for rivers within the entity (Figure 17) are high in upper reaches, but moderate in much of the rest of the entity. EIS is high in the conservation areas in the lower SRC (Water for Africa, 2008b). “Ecological importance relate to aspects such as diversity, uniqueness and scarcity, whereas ecological sensitivity describes the severity of response to stressors” (DWAF 1999).

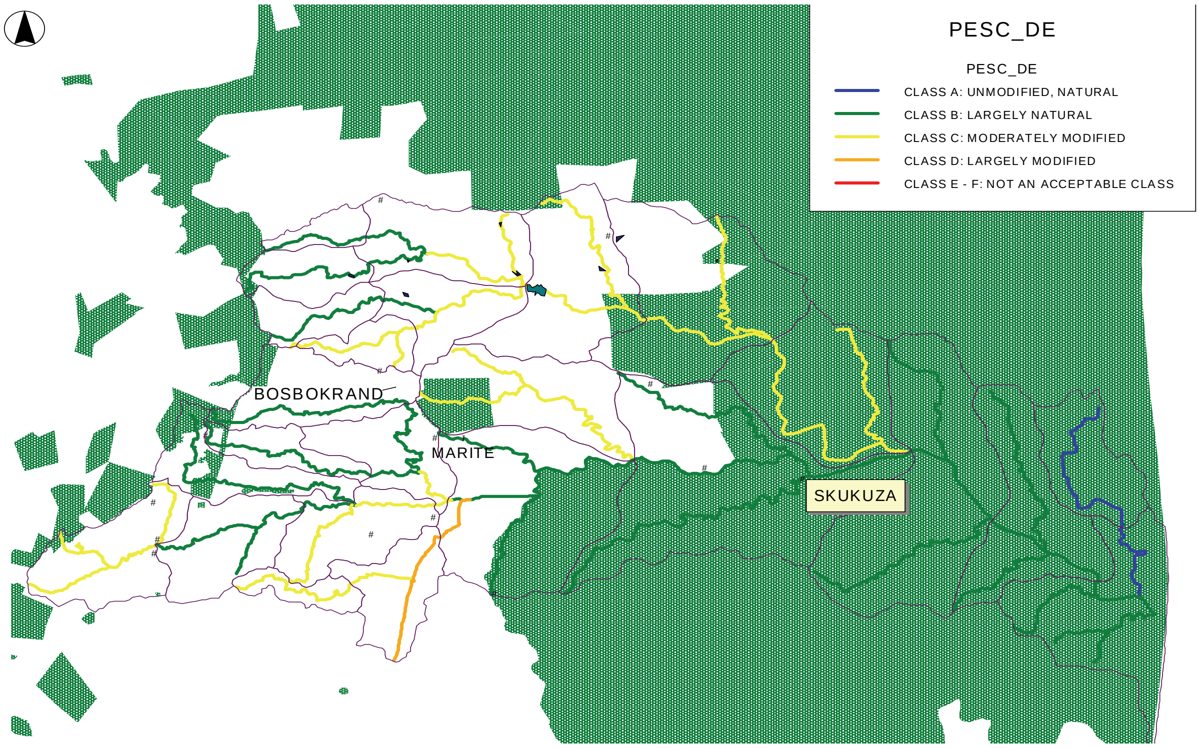


Figure 15. Present ecological status (PES) of rivers within the Sabie-Sand catchment metasystem with the overlayed conservation areas within the entity (X32C, F & G).

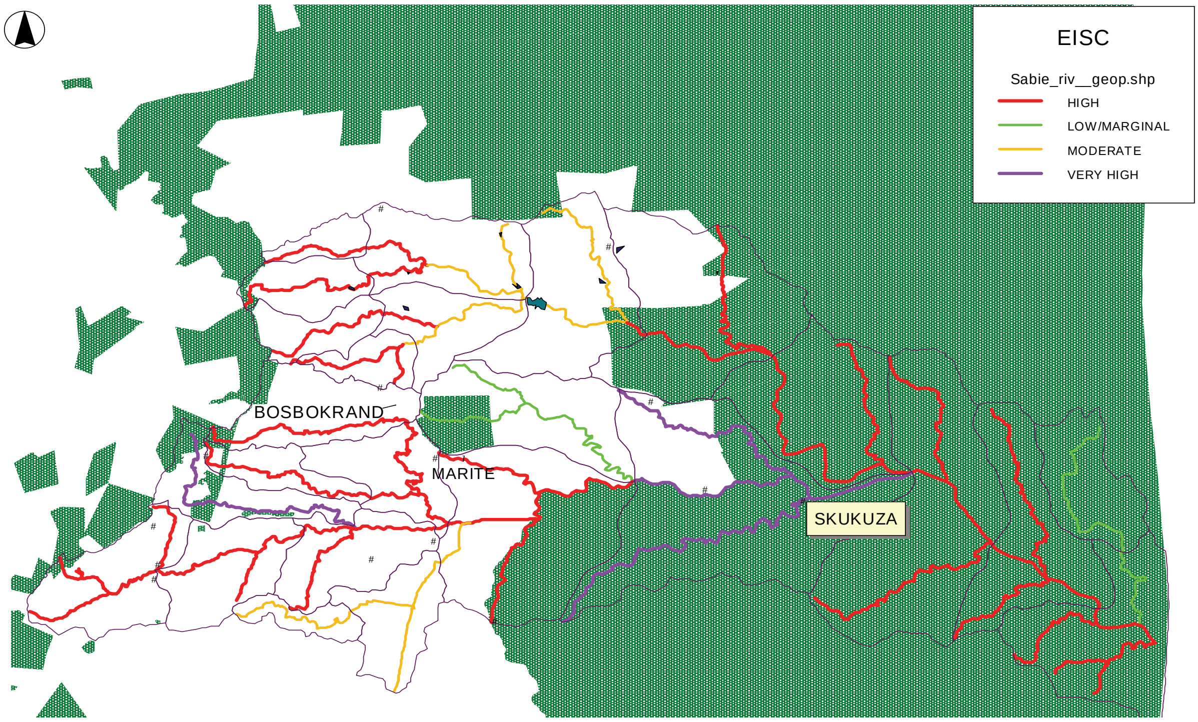


Figure 16. Ecological importance and sensitivity categories (EISC) of rivers within the Sabie-Sand catchment metasystem with the overlayed conservation areas within the entity (X32C, F & G).

vi. Geohydrology

Principle aquifer types in the SRC are extrusives, basement complex and younger granites (Colvin et al., 2007). The upper reaches of the Sand River, along the Eastern Escarpment, are effluent streams, where the ground water table is above the stream and groundwater reaches and emerges into the stream at all times. Groundwater contribution to baseflow is 10-20% and according to Colvin et al. (2007), the base flow discharge from the upper catchment, primarily groundwater (Birkhead et al., 1997), keeps this river perennial.

Away from the escarpment, the percentage contribution of groundwater to baseflow drops to 1-10%. Water-bearing alluvium is present in the lower reaches of the Sand River to a limited extent and is of local importance only (Vegter, 2003). When groundwater is recharged, it flows to near-by lower-lying areas and therefore is important to watering riparian vegetation and imperceptibly augmenting stream flow (Vegter, 2003). The riparian forests that grow in the alluvial deposits are an example of a riverine ecosystem where groundwater discharge sustains key ecosystems (Colvin et al., 2007). Characterised by relatively low rainfall, the riparian forests utilize groundwater stored in the alluvial deposits in the floodplain which are sustained by river discharge (with groundwater a major contributor from upstream) into the river bank aquifer (characteristic of an influent or intermittent stream). These riparian forests are quite sensitive to changes in groundwater levels and defined as aquifer-dependent ecosystems (ADE). “These aquifers are recharged by periodic floods and also, potentially, by lateral groundwater inflow from the adjacent areas and sub-surface flow in the active channel, fault systems and fractures associated with dykes crossed by the rivers" (Colvin et al., 2007).

Everywhere else groundwater is principally stored in fractured rock of the hard-rock formations, where the volume is limited except in localized areas of deep weathering (Vegter, 2003). Although hydrogeological data are limited in this area, data from KNP indicate that except for localized over-exploitation at a few localities, there is no indication of general lowering of groundwater levels (Vegter, 2003).

Groundwater level is >10 m below ground level over much of the basin, the total aquifer storage is between 125 and 500 mm, and the mean aquifer recharge is >60 mm in the upper catchment and 30-60 mm in the rest of the catchment. Vulnerability of aquifer dependent ecosystems (determined as a function of groundwater level, aquifer storage and aquifer recharge) in the catchment is low to just below moderate (Colvin et al., 2007).

Groundwater use as a percentage of recharge is <20%. Land cover is used as an indicator of hazard to aquifer flow regimes and this is considered low to no hazard in the SRC (Colvin et al., 2007). Based on the assessment of aquifer vulnerability and presence of hazards at a national scale, the riparian forests (aquifer-dependent ecosystems) of the SRC are assessed to be at low to medium risk (Colvin et al., 2007).

Boreholes are likely to dry-up during droughts in higher-lying areas of shallow weathering and fracturing.

vii. Water quality

Data in Table 22 is based on stream data obtained for the X32 103014 monitoring point in the X32H catchment near the border between X32G and X32H from the 12th July 1977 to the 7th of June 2006 (max n = 340).

Table 22. In-stream water quality data for X32H, adjacent to X32G, the Quaternary Catchment unit of the Entity. Data obtained from DWAF water Quality data set.

	SODIUM	POTASSIUM	CALCIUM	MAGNESIUM	PH	CONDUCTIVITY
Mean	8.885294	-2.024411	1.867647	-0.45	2.412617	16.30294
Standard Deviation	13.65833	4.981886	8.089660	6.213542	7.646675	5.342200
Minimum	-9	-9	-9	-9	-9	4.9
Maximum	44	6	27	17	8.55	45.8

	SULPHATE	FLUORIDE	PO4(P)	NH4(N)	NO3(N)	TALKALINITY
Mean	0.702941	-2.871470	-2.974961	-2.964558	-2.735058	32.40294
Standard Deviation	7.926840	4.330782	4.257254	4.264627	4.194903	30.69758
Minimum	-9	-9	-9	-9	-9	-9
Maximum	50	0.6	0.217	0.15	1.36	112

	KN	FLOW_RATE	TDS	BORON	TP	GP_READING
Mean	-9	-9	72.08235	-9	-9	-9
Standard Deviation	0	0	64.30159	0	0	0
Minimum	-9	-9	-9	-9	-9	-9
Maximum	-9	-9	257	-9	-9	-9

	SILICA	CHLORIDE	END_DEPTH	PRESERVE	NDATE	SAR
Mean	2.629705	6.597058	3.52E-05	0.464705	69055.99	-2.149679
Standard Deviation	8.406783	12.71816	0.000184	0.499487	3231.65	4.912336
Minimum	-9	-9	0	0	64476	-9
Maximum	16.3	49	0.001	1	75033	2.46

viii. Vegetation types

The majority of the entity lies within the savanna biome. Vegetation “reflects the altitudinal, temperature and rainfall gradients, as well as the soils in the basin” (Pollard et al., 2008).

The upper reaches of the SRC lie in sour afro-montane grassland (Pollard et al., 2008) but the predominant vegetation types are Legogote Sour Bushveld in the upper catchments and Granite Lowveld in the majority of the entity (Mucina and Rutherford, 2006; Figure 18).

“Woody species composition also reflects smaller-scale catenal sequences. The ridgetops are dominated by broad-leafed Combretum species, the bottomlands by fine-leafed Acacia species, and the seeplines by Terminalia species” (Pollard et al., 2008).

An important vegetation type that is closely tied to aquatic ecosystems are riparian forests, which occur in the lower reaches of the Sand River, but more predominantly along the Sabie River. Riparian forests are quite sensitive to changes in groundwater levels. "This type of vegetation is confined to the larger river systems of the lowveld, from the Limpopo to northern KwaZulu-Natal. The forests occur on alluvial deposits in the floodplain (macro-channel) of the rivers. The forests are generally characterised by large trees and include species such as *Faidherbia albida* (Ana tree), *Acacia xanthophloea* (Fever tree) *Ficus sycomorus* (Sycamore fig), *Diospyros mespiliformis* (Jackal berry), *Lonchocarpus capassa* (Appleleaf) and *Xanthoxercis zambesiaca* (Nyala tree)" (Colvin et al., 2007).

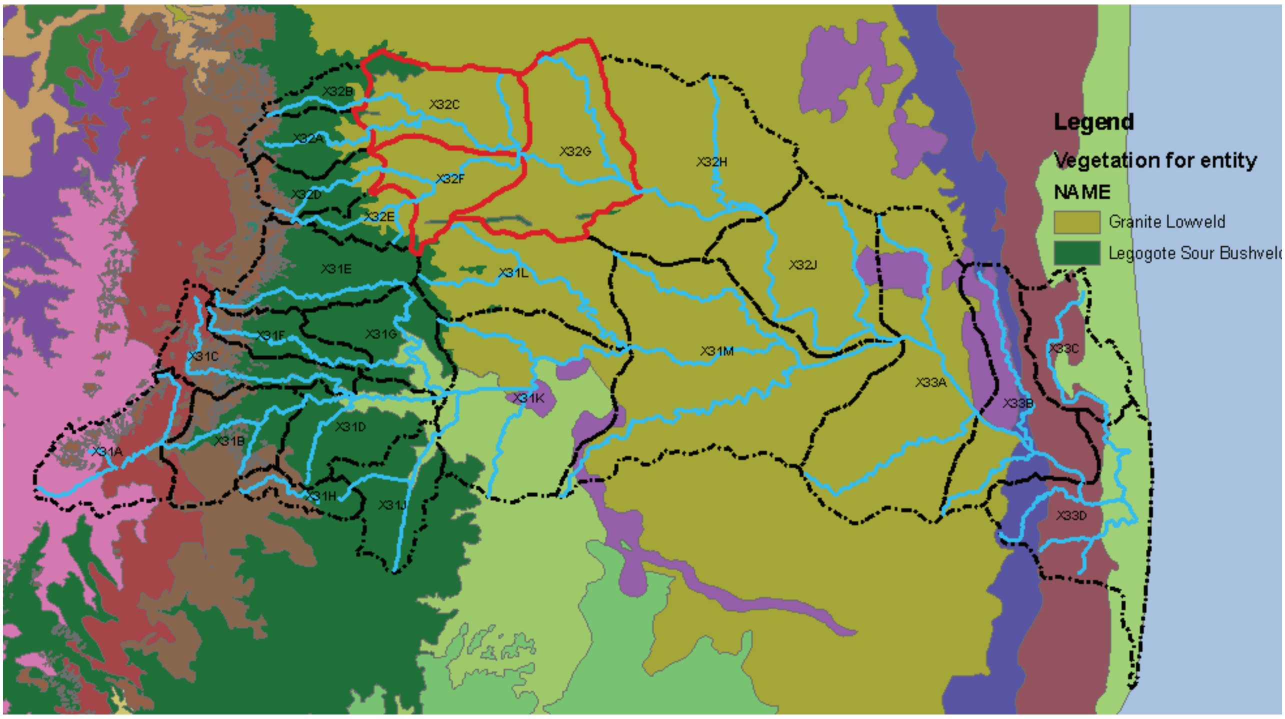


Figure 17. Vegetation types with the entity defined by quaternary catchments X32C, X32G and X32F (Mucina and Rutherford, 2006). The entity has predominantly Granite Lowveld (mustard colour) and marginally Legote Sour Bushveld (dark green).

ix. River ecoregions

The entity is found in two level I ecoregions (predominantly region 3 & marginally region 4) and two level II ecoregions (mainly regions 7 and marginally in region 4; see Table 23).

Two stretches of river were highlighted (red outlines in Figure 19) in the Mpumalanga Biodiversity Conservation Plan as mainstream rivers requiring protection as they are either vulnerable and of high biodiversity value, or they are important in linking up important sub catchment areas.

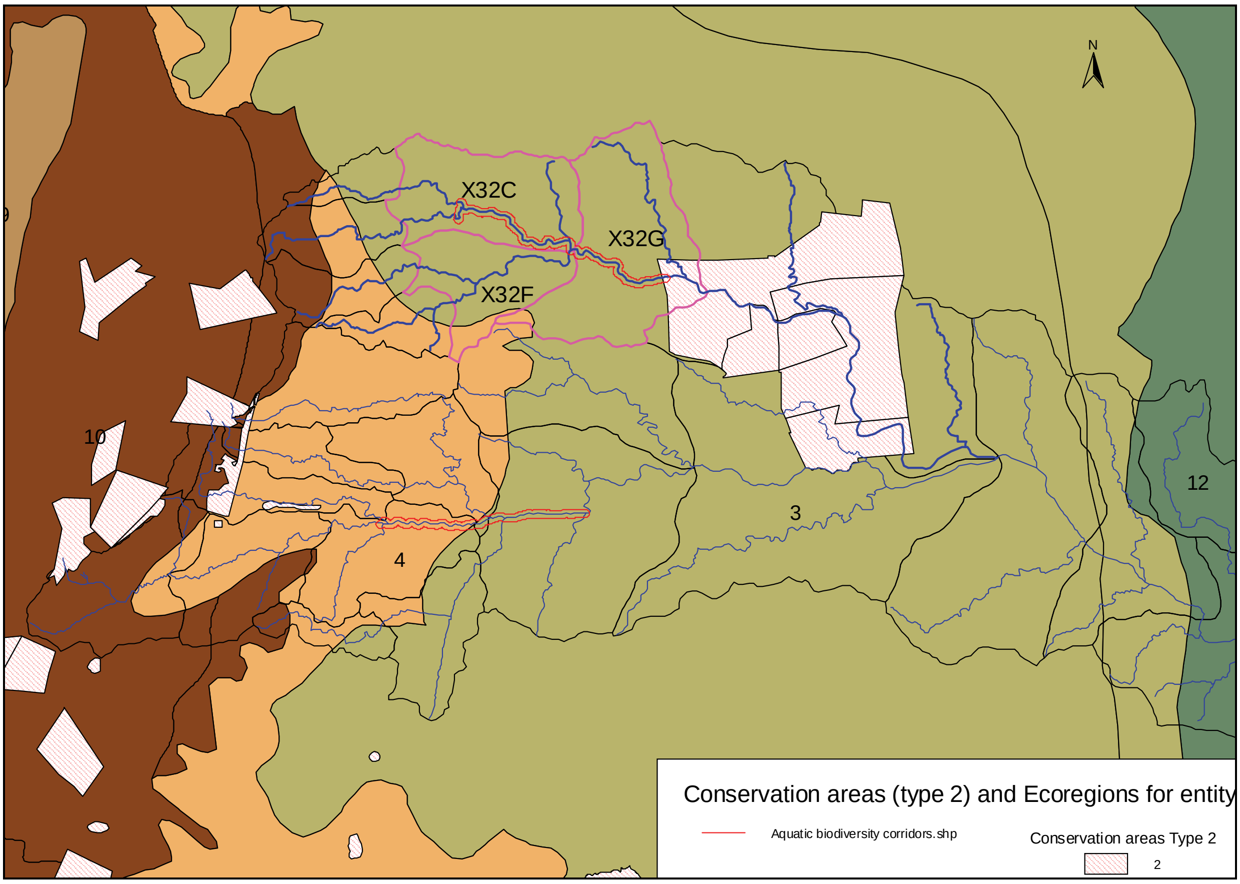


Figure 18. Ecoregions Level I and Sabie-Sand Catchments with entity (X32C, F & G) in upper regions of Sand River Catchment. The Sabie Sand Game Reserve is located at the South East edge of catchments X32G. Majority of the entity is located in Level I region 3 and marginally region 4.

x. Biodiversity assessment

A variety of conservation areas exist in the entity:

- Statutory reserves (such as Kruger National Park, Blyde River Canyon);
- Type 2 (non-statutory) game Reserves (e.g. the Sabie-Sand nature reserve); and
- Type 3 game farms.

No new areas of any conservation type have been proposed according to the Mpumalanga Biodiversity Conservation Plan.

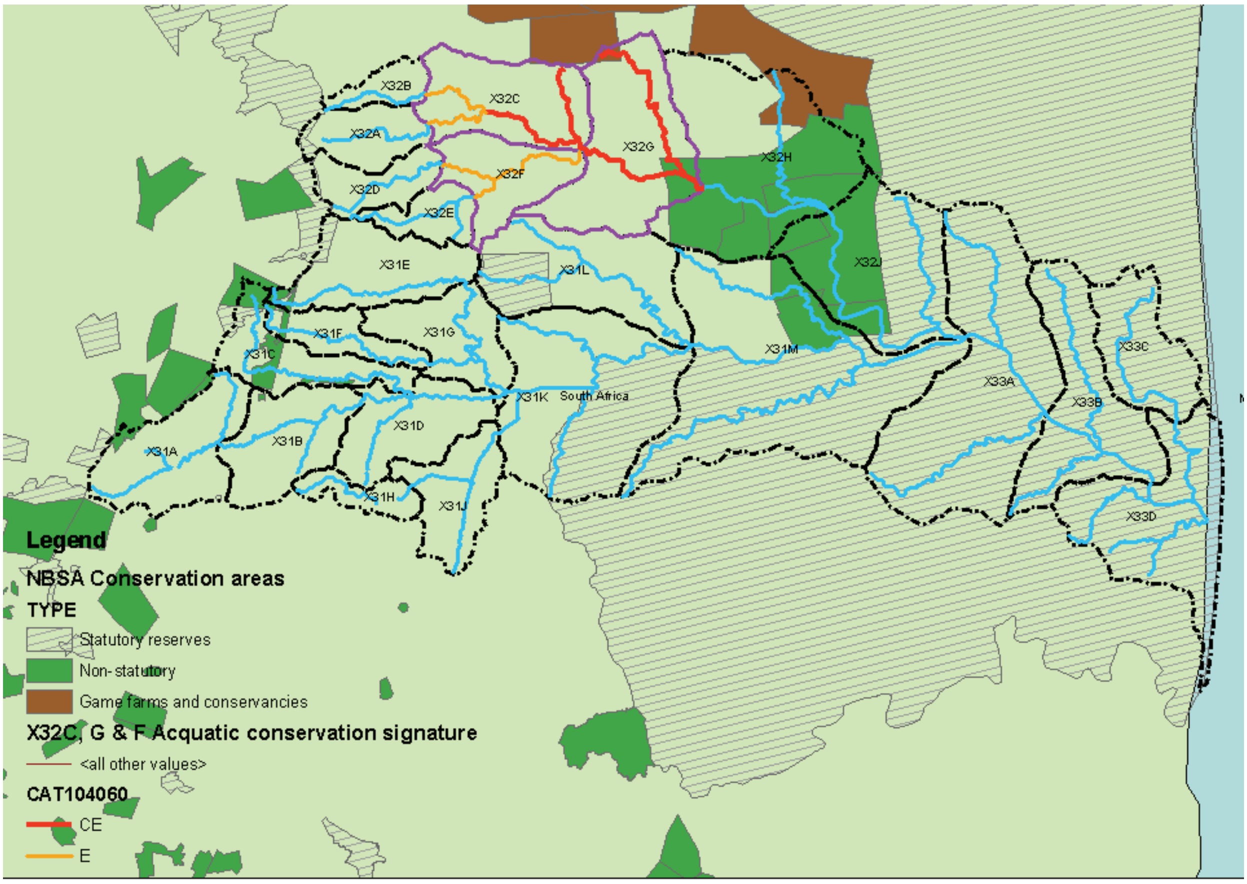


Figure 20. Conservation areas found within the metasystem (including statutory reserves, non-statutory reserves, game farms and conservancies) and the Aquatic Conservation status of rivers within the entity. Orange represents a Endangered (E) river signature, while Red represent a Critically Endangered (CE), both making up the whole entity stream (Nel et al., 2004).

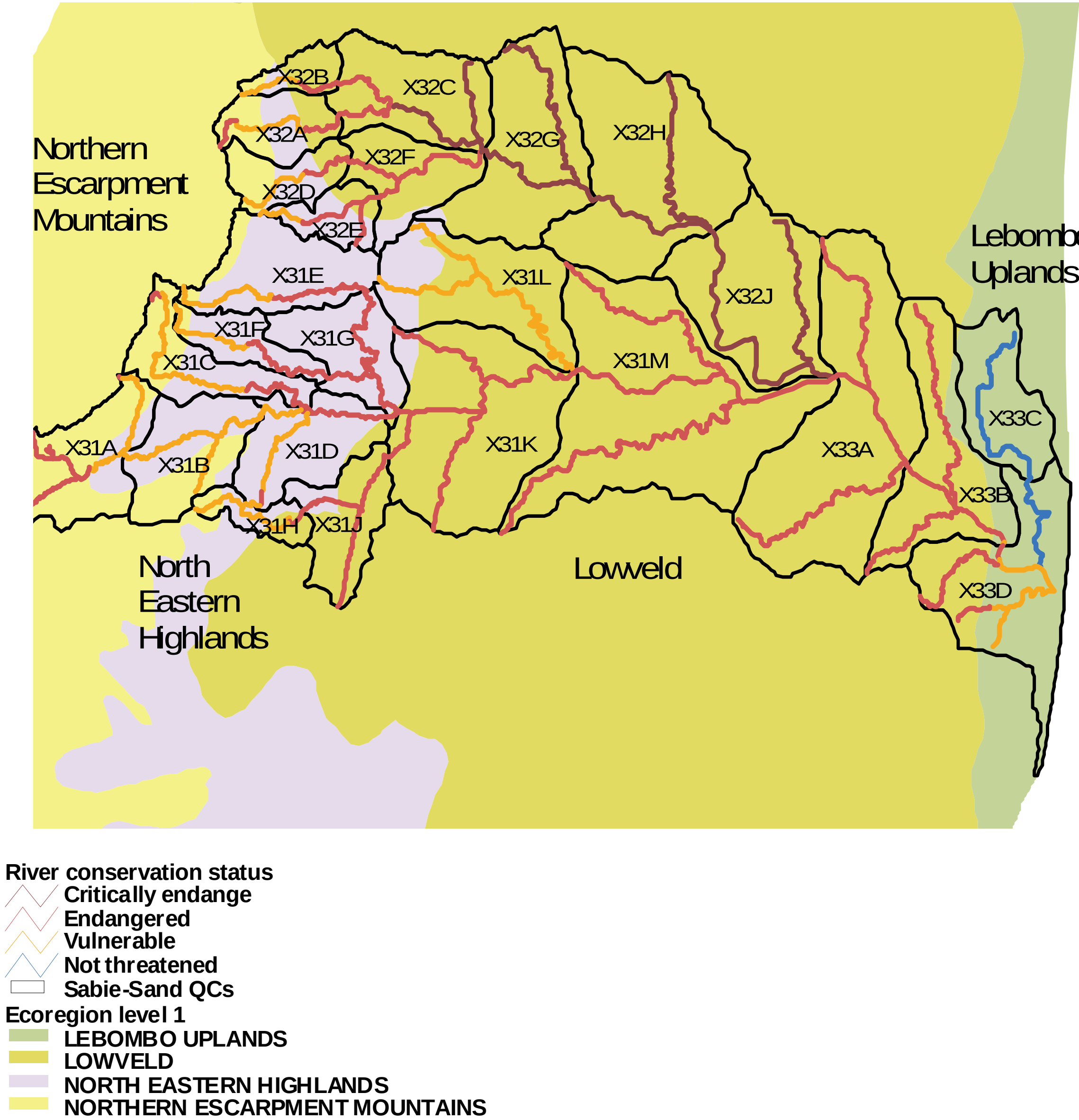


Figure 19. Conservation status of rivers in the Sabie-Sand Catchment (Nel et al., 2004)

The majority of the Sand River Catchment has a conservation status category of critically endangered according to Nel et al. (2004). "Critically endangered ecosystems have lost so much of their original natural habitat that ecosystem functioning has broken down and species associated with the ecosystem have been lost or are likely to be lost. Endangered ecosystems have lost significant amounts of their original natural habitat, so their functioning is compromised. Vulnerable ecosystems have lost some of their original natural habitat, and their functioning will be compromised if they continue to lose natural habitat. Least threatened ecosystems have lost only a small proportion of their original natural habitat, and are largely intact (although they may be degraded to varying degrees)" (Nel et al., 2004).

As explained in Nel et al. (2004), it would be beneficial to conservation and water protection policy and management perspective if these categories were aligned with water classification classes if possible. This would facilitate integrated management of these threatened water resources.

Table 23. Conservation status category associated with each river section in the entity with their signatures (based on the 120 river signatures comprising a combination of the surface codes and HI class; extracted from Nel et al. (2004) NSBA spatial layer).

Name	River signature	Conservation status category
X32C	Lowveld 1	Endangered
	Lowveld 2	Critically Endangered
X32F	Lowveld 1	Endangered
	Lowveld 2	Critically Endangered
X32G	Lowveld 2	Critically Endangered

xi. Feedback loops in the SES

Pollard et al. (2008) identify a number of feedback loops evident the Bantustans area of the entity. “Firstly, agricultural (including forestry) water abstraction coupled with clearing of land (both for agriculture and people), led to a wide-scale decrease in riverine integrity. As flows declined sedimentation increased – with effects being evident at both a catchment and local scale (van Niekerk and Heritage, 1993). This in turn jeopardized ecosystem services, water security and hence livelihood security.

The influx of people together with increasingly vulnerable livelihoods saw people moving onto increasingly marginal areas (e.g. steep slopes, wetlands, riparian zones) and sedimentation increased. Over the scale of two to three decades, environmental degradation rendered farming even less viable and livelihoods more vulnerable.

A second feedback loop existed between livelihood security and social capital. As explained, the combined effect of livelihood vulnerability, together with the demand for cheap labour for the expanding mining sector, led to the temporary migration of males who were often absent for most of the year, although this has now stabilized (Collinson et al. in press-a).

Female headed households became the norm and, as the migrant labourers established second families in their places of work, impacts were felt on family stability – or social capital – in the rural bantustans such as Bushbuckridge. Again livelihoods became more vulnerable and as they did so men, and some women, left home in search of work.”

xii. Socio-economic zones (SEZ)

The Sand River Catchment has been divided into three socio-economic zones by Pollard et al. (2008), based on socio-ecological systems thinking and in a manner consistent with WRCS.

The land use is described according to each zone.

- Zone A: The land use is dominated by plantation forestry which started in the early 1900s. Of the 11 900 ha, on three farms (known as Welgevoden, Hebron and Onwerwacht) about 50% is under pine. Wetlands in this zone comprise an important resource for local communities in that they offer land for small-scale agriculture that is more fertile and holds water for longer periods of the year.
- Zone B: A large number of people between 320,000 and 400,000 reside within Sand River Catchment, with densities varying between 176 and 300 people km (-2) in the communal land (Pollard et al., 1998) this includes a small number of Mozambican refugees which has declined from an estimated 24 000 people at the height of civil strife in that country. Uncultivated land is used for natural resource harvesting and grazing, where stocking rates are at agricultural carrying capacity (Parsons et al., 1997). The dominant landuse activities in the communal lands include small-scale cropping, state-owned commercial farming, and grazing.
- Zone C: game reserves and the Kruger National Park towards the Mozambique border. The privately-owned conservation area is run as a share-block scheme (e.g. encouraging traversing rights on each others' property).

These zones were overlayed with the wards in the Bushbuckridge Municipality (Figure 22 above) and the socio-economic description that follows is based on this Ward information. There is no ward data in Zone C as this is conservation land upon which no people are permanently settled.

Land use in the Sand River Catchment

The upper portion of the catchment is state-owned and is under commercial afforestation. The middle portion comprises the former bantustans of Gazankulu and Lebowa – is under communal tenure. The majority of the population live in this middle portion of the catchment. The lower catchment is under conservation, both state and private.

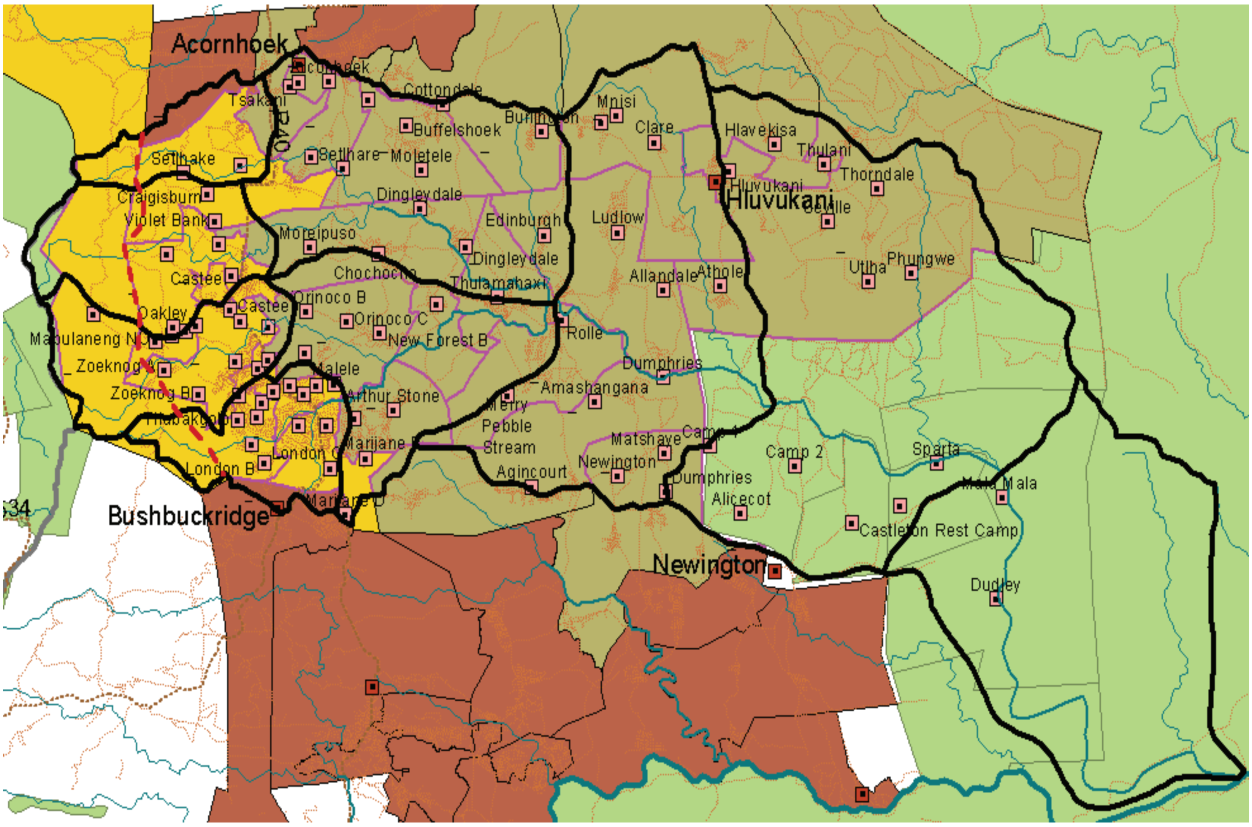


Figure 20. Wards in Bushbuckridge Municipality (pink outline) categorized by the socio-economic zone in which they fall: yellow is Zone A, khaki is Zone B and green is Zone C. Brown falls outside the entity.

The dominant landuse activities in the communal lands include small-scale cropping, state-owned commercial farming, and grazing. Uncultivated land is used for natural resource harvesting and grazing, where stocking rates are at agricultural carrying capacity (Parsons et al., 1997). The privately-owned conservation area is run as a share-block scheme (e.g. encouraging traversing rights on each others' properties). Interestingly, whilst being economically dominant, as the downstream stakeholder they are located in the most vulnerable part of the catchment in terms of water security. In general most of the entity is used as rangeland, for cattle and harvesting of fuel wood, etc. (Pollard et al., 2008). A summary of the present-day land uses is provided in Table 24.

Table 24. Land-use/land-cover in the Sand River Catchment based on (1996 land cover data) (adapted from Pollard et al., 2008)

Land use		Total (ha)	%	Sub-total per land use (ha)
RANGELANDS		80193.8	41.99	80193.8
CONSERVATION BUSHLAND		69486.6	36.38	69486.6
RESIDENTIAL:	sparse and garden plots	15391.6	8.06	18141
	dense	2750.3	1.44	
Dryland agriculture	annual	7600.4	3.98	7742
	permanent	142.6	0.07	
FORESTRY	Indigenous vegetation	5931.7	3.11	11926
	planted	5339.6	2.80	
	Unplanted	656.0	0.34	
IRRIGATED agriculture	Annual	2145.0	1.12	2538
	Permanent	438.1	0.23	
WATER BODIES		926.6	0.49	926.6
TOTAL				191002.40

Population data

SEZ 1 and 2 consist of between 90 and 100 villages and three small towns. The villages and towns are grouped into municipal wards, where, zone 1 consists of 6 wards and Zone 2 of 11 wards.

In 2001, people living in the zone 1 area were estimated to be 80 578 and those lying in the zone 2 area were 160 431. The main language in the upper catchment (SEZ1) is Sepedi (65%), with a much smaller portion of the population speak Xitsonga (20%) and Sesotho (9%) as their main language, while in the lower-lying areas Xitsonga is predominantly spoken (73%), with Sepedi (22%) and Sesotho (3%).

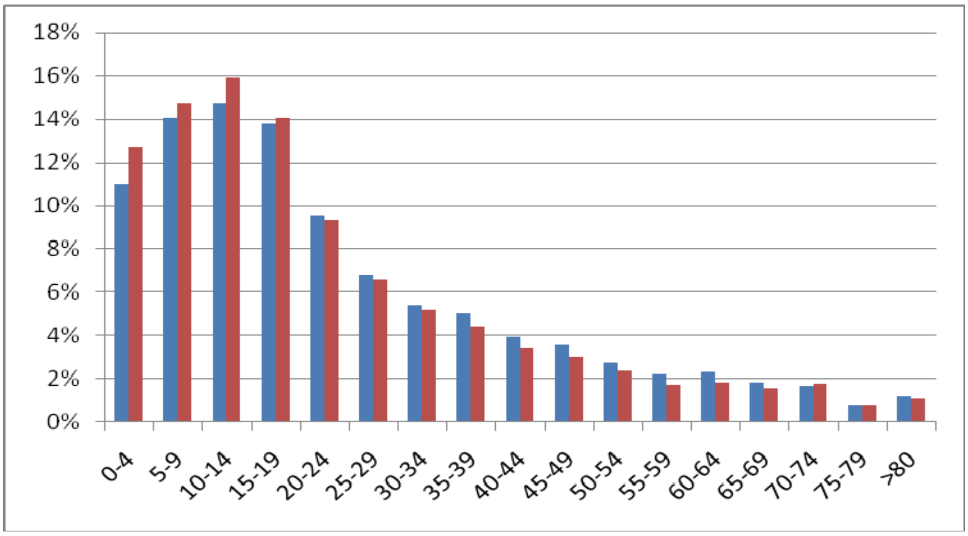


Figure 21. Age distribution in socio-economic zone 1 (blue) and 2 (red) according to Population Census data 2001

There are just over 18000 households in SEZ1 and just over 35000 in SEZ2. More than 50% of the households have fewer than 4 members (Figure 24). Female-headed households make up 57% of the households in the entity. More than 50% of the population is under 20 years of age.

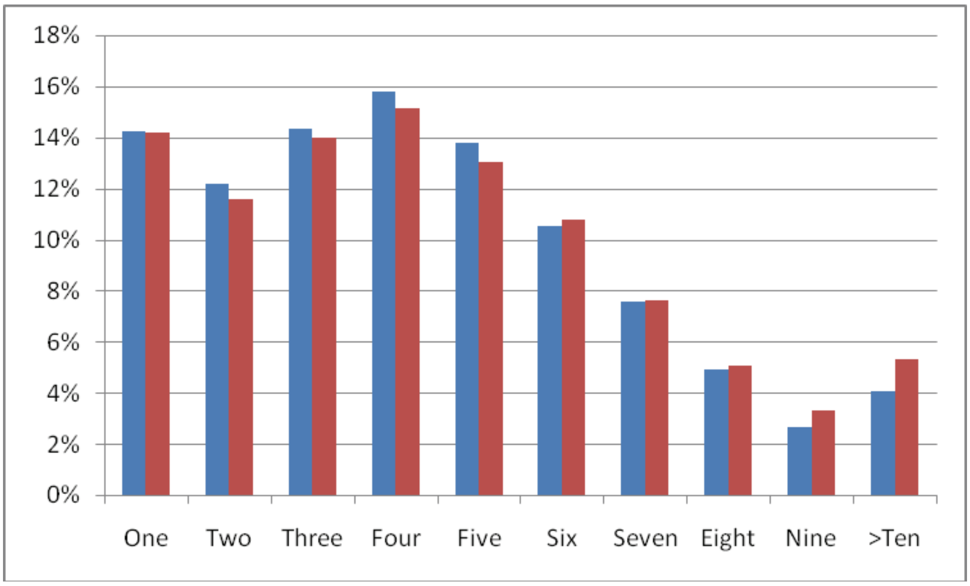


Figure 22. Distribution of household size socio-economic zones (blue) and 2 (red)

Household income categories

Only 14% of economically active people are employed. Most of the employed have occupations such as elementary occupation, technicians and associated professions, clerks, or service workers.

Table 25. Households income are divided into categories of poor and non-poor and subcategories are defined within this categories

Category	Definition	Annual household income in Rands	Zone 1	Zone 2
Poor	Very poor	No income-9 600	72%	79%
	Poor	9 601-38 400	20%	17%
Non-poor	Tolerable	38 401-76 800	5%	3%
	Comfortable	76 801-153 600	2%	1%
	Wealthy	153 600 and above	1%	0%

Poverty level for the zones is very high, with more than 70% of households earning less than R 9 600 per year. Only less than 10% of households fall under non-poor income category.

More than 40% of households registered no annual income in 2001. 72% of households have an annual income of less than R10, 000, while 92% of household annual income is less than R38, 000. Livelihoods are based on migrant income, and social welfare rather than agriculture.

Land tenure

Land under communal tenure, where the majority of the residents live, accounts for 56% of the SRC (Pollard et al., 2008). Data from the 2001 Census indicate that more than 70% of the population own and have fully paid for their land in both SEZ 1 and 2 (Figure 25).

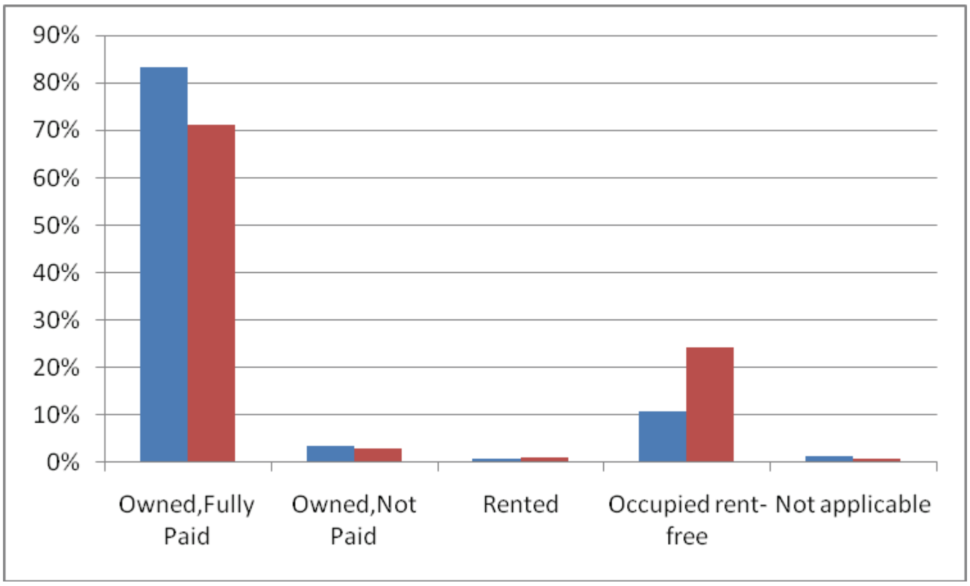


Figure 23. Land tenure in socio-economic zones 1 (blue) and zone 2 (red)

Services and infrastructure

In SEZ 1, only 14% of the households benefit from refuse removal once a week or less, while the majority (67%) use their own refuse dump or no disposal (18%). The majority of households in SEZ2 also use their own refuse dump (83%) or no disposal (16%), but no households benefit from refuse removal in 2001.

The water resources of the catchment serve an estimated population of approximately 270,000. This demand is met by a network of highly interconnected bulk water networks, drawing water from a number of off-takes both along the river and from storage dams (Pollard et al., 2008).

Fewer than 5% of households have piped water to their dwelling, but nearly 15% have piped water to their yard or within 200 m from their homes. At least 8% of households rely directly on water from rivers, streams, dams or pools for daily use, but it is likely that many more supplement piped water with water from natural water sources.

Very few households have access to flush toilets (see Figure 27) and the majority use pit latrines (WO/vent).

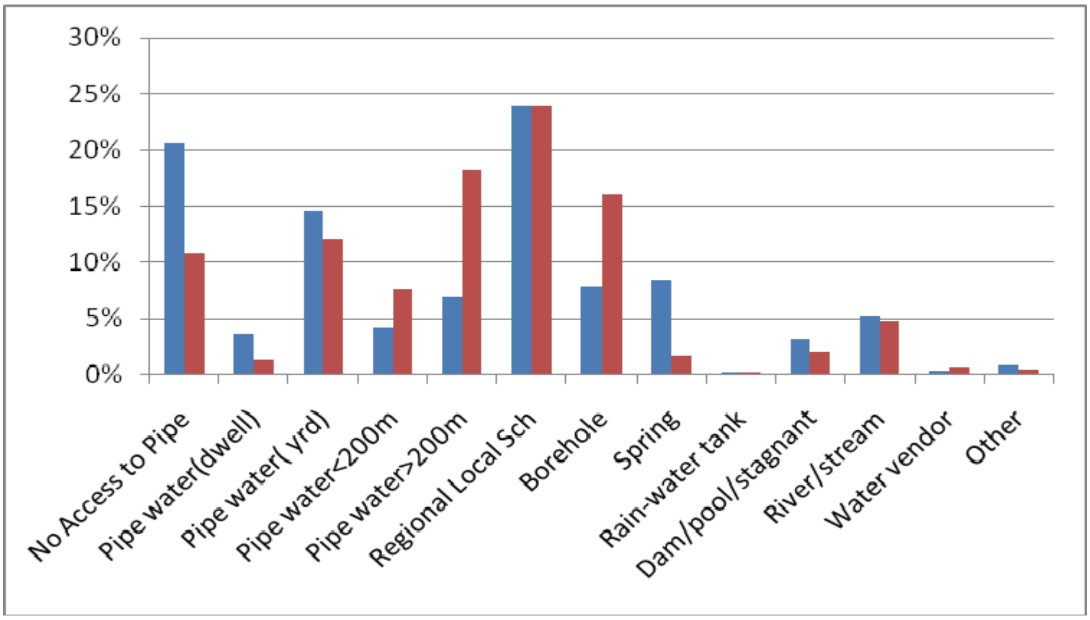


Figure 24. Basic water supply and access in socio-economic zones 1 (blue) and zone 2 (red)

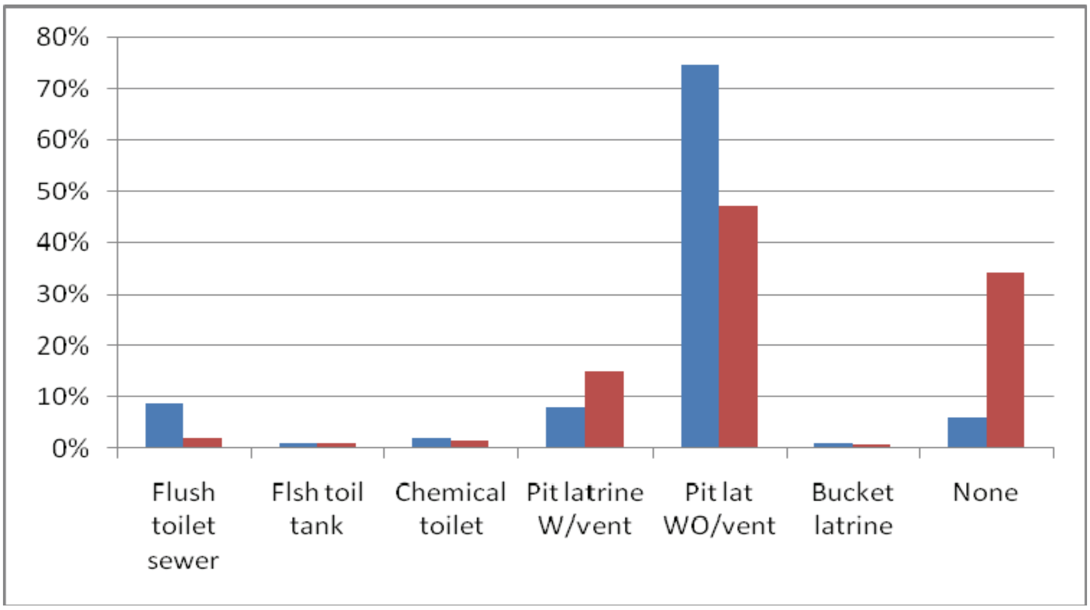


Figure 25. Basic sanitation information for socio-economic zones 1 (blue) and zone 2 (red)

Education

Of the population in SEZ 1 aged 20 or older 34% had no schooling, 16% had some primary schooling, 5% had completed primary, 26% had some secondary schooling, 12% had Grade 12 and 7% had higher education. In SEZ2, 44% had no schooling, 13% had some primary schooling, 4% had completed primary, 21% had some secondary schooling, 13% had Grade 12 and 5% had higher education.

Literacy rates are estimated at 66% but these figures are questioned (Pollard et al., 2008).

Social capital

Pollard et al. (2008) describes the social capital in the SRC, including an indication of the nature of three aspects of social capital namely, networks, norms of trust and norms of reciprocity. Their assessment suggests that there is moderate to high social capital within the poorer communities, indicating "moderate to high resilience within the poorer levels of society and that resilience decreases with affluence and at community and institutional levels". "Also, social capital appears to be higher within the family unit, decreasing away from the family. Niehaus (pers.comm. 2006) maintains that there has been a system flip with sibling networks playing a more important role that parental support in the Sand River Catchment" (Pollard et al., 2008).

Other indicators of social capital might include:

- Communication networks: In SEZ1, approximately 25% of households have access to a cellphone, while 8% have no access to a telephone of any sort. In SEZ2, approximately 21% of households have access to a cellphone, while 6% have no access to a telephone of any sort. The majority of households make use of public telephone or neighbours phones nearby.
- Female-headed households: Most households are female-headed, with most of the men, finding work outside the catchment.

Pollard et al. (2008) provide further discussion on social capital in the SRC.

Natural resources used – extent of use, % of population using them

Natural resources are under pressure, although critical to people's livelihoods. Following Pollard et al. (2008) people in the SRC continue to use communal land for grazing, and harvesting of natural resources (wood (trees), reeds, medicinal plants and fruit). This use is not sustainable.

Access to piped water and electricity has not immediately, and will not necessarily, result in a decrease in the use of natural resources. For instance although 85% in SEZ 1 and 73% in SEZ2 use electricity for lighting, wood resources are still heavily relied upon for daily use (see section above).

Human health information

There is little health information at ward level. There is relatively typical prevalence of infectious diseases (HIV, TB, Hepatitis), water-related disease (malaria, bilharzia) or illnesses (diarrhoea, cholera, typhoid) and pollution-related illnesses among the total population. Malnutrition is also prevalent in the poorer communities.

Water balance and water use by sector

Under natural conditions the SRC is not in water balance as MAP is lower than the MAE. With forestry plantation water use and water requirements for current agricultural, livestock and domestic use the Sand River already runs dry downstream in the conservation areas (SEZ 3).

“Without considering groundwater, which is under-exploited and the inter-basin transfer, there is very little surplus water available for ‘new allocations” (Pollard et al., 2008). Agricultural irrigators have experienced serious deficiencies in the past. The SRC is stressed in terms of water security. Available water is insufficient to meet demand (even before taking the ecological Reserve in account) (Pollard et al., 2008). Table 26 illustrates this.

Several large, densely populated rural areas occur in the study area. These areas receive potable water through a network of supply schemes. However, a inter-basin transfer (IBT) from Inyaka dam is needed to meet domestic use demands in rural areas and put the ecological Reserve in place. The pumping station not complete, distribution of transferred water is inadequate.

Table 26. Summary of water resources availability and demands within the Sand River catchment from Pollard et al. (2008). ER = Ecological Reserve, BHNR = Basic Human Needs Reserve.

Description		**Resource**	**Demand/ Entitlement**
Surface-water availability	Median	75,200,000	
	Lower quartile	48,830,000	
Ground-water	DWAF est.	8,000,000	
	2%recharge	30,902,127	
	5%recharge	77,255,319	
	10%recharge	154,510,637	
ER	IFR 50% probability of exceedance		38,620,800
	25 l p.c.d^{-1}		2,466,907
Domestic	100 l p.c.d^{-1}		9,867,629
Agriculture	(DWAF est.)		12,170,000
Forestry	(AWARD est.)		6,755,706
Total			**62,489,335**

1C. Describe the Integrated Units of Analysis (IUA) and Significant Water Resources (SWR)

Groundwater and rivers are the two water resources being assessed. Six integrated units of assessment (IUA; illustrated in Figure 28) are identified and the groundwater and river resources are described for each IUA.

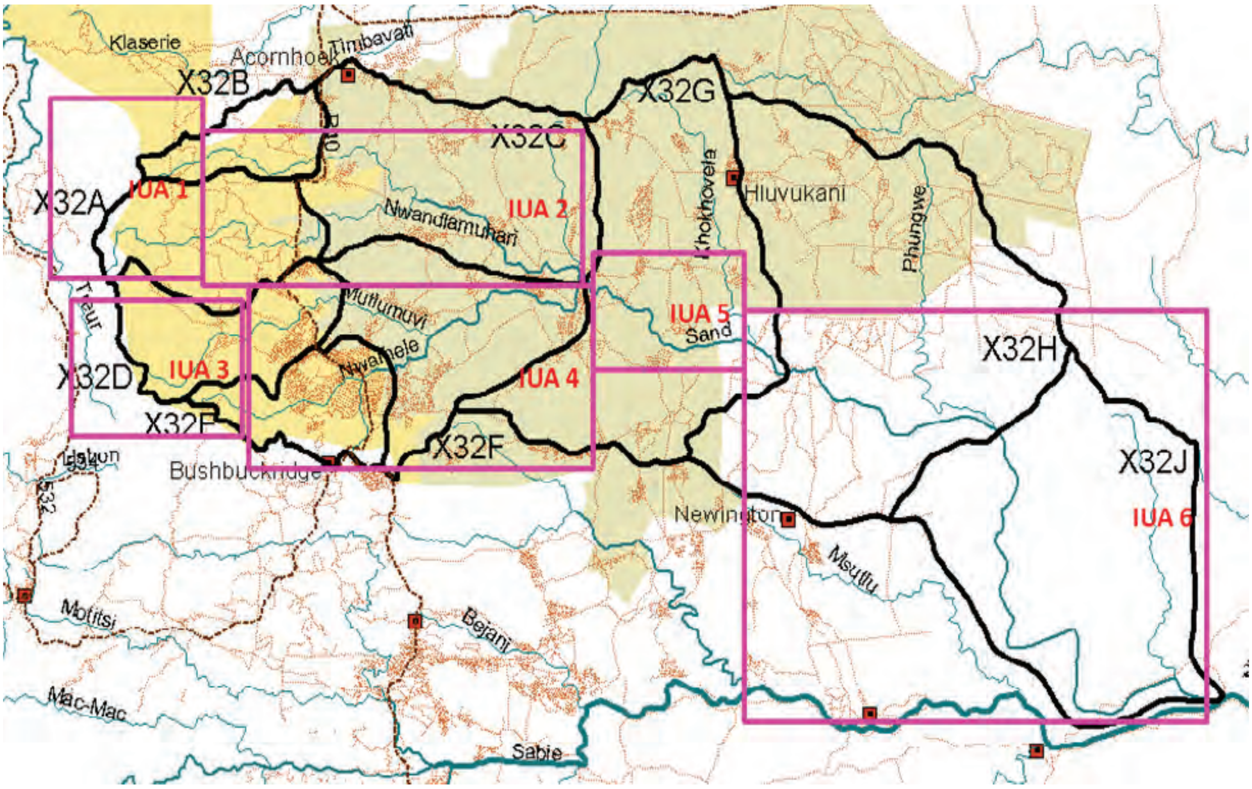


Figure 26. Map of the integrated units of analysis in the Sand River Catchment.

IUA 1 and IUA 3: Socio-economic zone A

IUA 1 and IUA 3 have very similar characteristics.

Rivers in IUA 1 and 3 are the upper reaches of the catchment. This part of the catchment receives a large proportion of the rainfall of the catchment and thus produces much of the MAR. The area has a number of wetlands. This area is important for recharge of aquifers and thus the rivers and wetlands are important for water regulation in the whole basin as much of the rest of the basin receives sporadic thunderstorm events that flush out the system fairly quickly. Maintenance of flow in rivers is important to fish.

Land use in this region is largely forestry plantations, which withdraw a substantial proportion of the potential runoff. There are programmes to remove areas of plantations and put in place stricter regulations in these sensitive upper catchments.

More than 50% of the vegetation in the upper catchment, Legogote Sour Bushveld, is transformed by other land uses and it is considered highly endangered (Ferrar and Lotter, 2007). At this level of transformation, it is assumed that a high degree of ecosystem functioning has been lost and the vegetation type needs to be properly protected and managed to ensure that it does not become critically endangered (at which stage many species may be lost) (Ferrar and Lotter, 2007). The area is recognised for its biodiversity value, the mountains have many endemic species, particularly plants and invertebrates. The very upper portion is protected area.

The human population is this area is relatively low. Most of this land is privately owned or owned by the State. A few subsistence agriculture communities rely on freshwater provisioning for their crops and livestock water demands. There are a number of small dams important to water provisioning.

This escarpment area offers a variety of cultural services. The escarpment is known for its aesthetic value and is part of a cultural route that attracts many tourists and a source of inspiration for numerous residents and visitors. It is possible that the rivers and wetlands are also having spiritual and religious value in this area. As this is an area of groundwater recharge and few ecosystems are supported by aquifers, this asset is not relevant to cultural services in this area.

IUA 2 and IUA 4: Socio-economic zone B

IUA 2 and IUA 4 have very similar characteristics.

The IUA 2 runs from the dramatic decent from the escarpment where forestry is the dominant land use, to the confluence of the Sand (Thulandziteka) and Mutlumuvi river. Being in the east of the basin this area receives more rainfall than SWR 4 and 5.
This area is old homelands area, largely dominated by the Tsonga and has high human density. Land use is mixed but dominated by small-scale agricultural activities, subsistence agriculture and small urban settlements. There are a few larger multi-party agricultural enterprises with irrigation.

Much of the land in the area is degraded, about 50% remains in bush and woodland. These degraded lands, having lower vegetation cover and poorer soil characteristics results in higher erosion rates and increased sediment contribution to rivers.

Intact wetlands and riparian zones are important to erosion regulation and water purification. Decreasing condition of these assets through poor management is a trend in this area. Consequences of increased sediment load downstream have been extensively studied.

Wetlands occur in this area and have important, well defined ecological functional roles. They have a particularly important role in the delivery of provisioning services for the poor communities in the area. The importance of wetlands to vegetable growing, cattle fodder, freshwater, edible and medicinal plants and materials for mats or construction are detailed in a number of comprehensive studies by the Association for Water and Rural Development (AWARD) as well as other authors.

The importance of wetlands to cultural services is less well defined, but it is quite likely that spiritual and religious value is delivered by wetlands and pools during initiation ceremonies.

The regulation services of wetlands (including riparian zones), such as water regulation, purification and climate regulation, are important to the delivery of provisioning and cultural services and other regulating services downstream and locally.

IUA 5: Socio-economic zone B

SWR 5 begins at the confluence of the Thulandziteka and Mutlumuvi rivers. The area is typical lowveld, with sweet lowveld bushveld the dominant vegetation, supported by shallow black, brown or red clayey soils, sandstones, granites and shales (RHP, 2001). The relief if moderate and characterised by typical undulating hills (catena sequence). Evaporation is higher than precipitation, which averages 600-700 mm per annum and falls in the form of sporadic, and patchily distributed thunderstorms usually. Large storms may result in fairly sudden 'flush' of the system, with high overland flow of water and increase in streamflow. However these storms are usually smaller and water sinks into soils, and evaporates quickly afterward. There is little recharge of groundwater.

The river is characterised by low gradient, some bedrock, pools and sandbars and a riparian zone dominated by tall trees with reeds in open areas. The river is wide, with both slow, deep flowing channel and broad chute over unfractured bedrock (RHP, 2001). Floodplains can be fairly broad in some places.

The catchment lies in the old homelands. The human population density is fairly high. Predominant use of land is for grazing cattle, and many homesteads have plots used for growing subsistence crops. As a result of the population density, an artefact of political history, and due to the natural high variability of rainfall, this area has suffered extensive degradation with resulting implications for erosion due to increased runoff and poor infiltration capacity (feedback to poor vegetation cover). The riparian zone naturally plays an important role in regulating services such as water regulation (to a small degree), erosion regulation, water purification or the formation of physical barriers for the purpose of natural hazard regulation (i.e. floods). However, because of the degraded nature of the riparian zone is in the middle reaches of the river, the delivery of these services is compromised to some extent.

The average household income is quite low and people rely on the ecosystem for additional resources such as medicinal plants, foods, and reeds. Riparian areas are extensively used for subsistence agriculture and harvesting of natural resources.
Water supply and sanitation is still a problem in this area. Although many communities have access to running water within 2 km from their home, water from rivers and streams is still extensively used to meet domestic needs. Water in the river is also critical for livestock, an important cultural asset. Currently bilharzia may be present in

some reaches of the river, exacerbated to some degree by poorer flow due to upstream abstraction.

The ecological importance and sensitivity of the river was evaluated to be moderate in the most recent Reserve determination (Water for Africa, 2008b). “Ecological importance relate to aspects such as diversity, uniqueness and scarcity, whereas ecological sensitivity describes the severity of response to stressors” (DWAF 1999). So it is interesting that is it rated moderate, as the NSBA (2004) classified this river reach as critically endangered as it represents a stretch of river that is underrepresented in protected areas and is under threat.

It is also prioritised as an important aquatic biodiversity corridor between the upper catchments of the Thulandziteka (which are considered to be irreplaceable) and the protected conservation land downstream. These corridors were identified in the Mpumalanga Biodiversity Conservation Plan (Ferrar and Lotter, 2007) for long term connectivity and biological movement, guided by the need to link important biodiversity areas and promote connectivity. This indicates that the river and its riparian habitat have important corridor function that might relate to the maintenance of species habitat for migration and dispersal.

IUA 6: Socio-economic zone C

IUA 6 includes quaternary catchments X32H and X32I. It has very similar biophysical characteristics to IUA 5. The area is typical lowveld with moderate relief characterised by typical savanna catena sequence. Temperatures and evaporation is high and mean annual precipitation averages below 600 mm, with most rainfall in the form of summer thunderstorms. The river is characterised by low gradient, some bedrock, pools and sandbars and a riparian zone dominated by tall trees with reeds in open areas. The river is wide, with both slow, deep flowing channel and broad chute over unfractured bedrock (RHP, 2001).

Riparian forests exist in the lower reaches of the river and utilize groundwater stored in the alluvial deposits in the floodplain which are sustained by river discharge (with groundwater a major contributor from upstream) into the river bank aquifer (characteristic of an influent or intermittent stream). These riparian forests are quite sensitive to changes in groundwater levels and defined as aquifer-dependent ecosystems (ADE). “These aquifers are recharged by periodic floods and also, potentially, by lateral groundwater inflow from the adjacent areas and sub-surface flow in the active channel, fault systems and fractures associated with dykes crossed by the rivers" (Colvin et al., 2007).There are no other types of wetlands other than the rivers and their riparian zones, but the river meanders down the low gradient forming large floodplains in some places.

Completely different to IUA5 though, is that the predominant land use in this SWR is managed for conservation. Much of it is privately owned land, and has been managed for wildlife for a number of decades. Tourism and nature-based recreation is the main land use purpose.

As a consequence of good land use management for conservation, riparian zones are largely intact (ecosystem functioning and ecological interactions tend towards natural). However, these lower reaches of the Sand River are susceptible to the effects of upstream water use. Altered water regime due to upstream abstraction and higher sediment loads has had effects in this downstream area. High abstraction upstream has resulted in the river running dry earlier and more regularly than natural. This has placed great pressure on riparian zones around pools and necessitated increased use of groundwater pumped to water holes in some cases and loss of wildlife in other cases (not necessarily directly due to lack of water, but may be indirectly due to increased stress, reduced resistance to disease, etc.), and negative impressions of tourists.

The value of this area in terms of regulating services such as erosion regulation and water purification is evidenced by the improvement in water quality and ecological condition at the confluence of the Sand and Sabie Rivers.

The use of natural resources for provisioning services, such as food, medicine, fiber, etc. is very limited as this is a protected conservation area with limited access. While people illegally entering the area (particularly for bushmeat, etc.) or by staff or landowners might occur, it is considered minimal.

The cultural value of this area is high because it has been protected for a long time, it has aesthetic and inspirational value, has contributed to knowledge systems and has educational value as well as recreational value. Because it is land from which people were displaced and excluded, the equity of cultural benefits received is poor.

1D. Determination of the present-day ecosystem services delivered from each SWR

The proposed Gevonden dam and sugarcane agricultural scheme will take place in IUA 5. Its impact will extend to IUA 5, but will not impact on the IUA's upstream of IUA 5. Thus, all further analysis will be limited to IUA 5 and 6.

The project will directly affect the watercourse (river). Wetlands occur in the 'SWR' but are situated on tributaries to the Sand River and will not be affected by the project.

Although there is negligible base flow produced in IUA 5 and 6, groundwater is recharged as it flows to near-by lower lying areas and is thus important to watering riparian vegetation and imperceptibly augmenting stream flow. There are no known areas of aquifer-dependent ecosystems in IUA 5 or 6. There is no estuary directly linked to the SRC.

As a consequence, only the watercourse and groundwater are considered.

Table 27 provides a summary of the description of the present-day ecosystem services delivered from each SWR within each IUA, which are detailed in the sections that follow the table. The table is populated with information where available on the type of resource use and the beneficiaries.

Table 27. List of ecosystem services in the present-day entity populated with a description of resource use (e.g. subsistence, commercial, etc.) and beneficiaries

Type of service in the category	IUA 5		IUA 6	
	Rivers	**Groundwater**	**River**	**Groundwater**
Regulating services				
Air Quality regulation	Not applicable			
Climate regulation	Not applicable			
Water regulation	Downstream beneficiaries	Not applicable	Downstream beneficiaries	Not applicable
Erosion regulation		Not applicable		Not applicable
Water purification and waste treatment				
Disease regulation	Control of incidence of bilharzia in individuals	Not applicable	Not relevant	Not applicable
Pest regulation/Biological control	Localised use	Not applicable	Not relevant	Not applicable
Pollination	Localised beneficiaries	Not applicable	Localised beneficiaries	Not applicable
Natural hazard regulation	Downstream beneficiaries	Not applicable	Downstream beneficiaries	Not applicable
Provisioning				
Food	Subsistence food crops cultivated in wetland fields, dryland fields and homestead gardens. Wetlands represent 40% of the crop production Home garden crops rely on domestic or surface water supply for irrigation Edible wild herbs and wild fruits are collected and consumed by more than 70% of households	Not applicable	Not relevant	Not applicable
Fresh water	Households collect water from natural source for drinking, washing and basic hygiene purposes Subsistence farmers water livestock at dams, rivers and springs	Some rural households in IUA5 make use of boreholes to meet domestic water requirements. In addition, those households using pipe water supplies may also be reliant on underground water as this may be the water source of the reticulated water supply system.	Livestock in the conservation area will rely on surface water for survival.	Not applicable
Wood and fibre	Households collect reeds from wetlands for weaving of mats. Reeds and thatching grass are collected for	Not applicable	Not relevant	Not applicable

	construction purposes. Common in the communal area is the use of twig brooms constructed from collection of twigs from the surrounding area. Over 80% of households rely on wood as a source of household heating and for cooking purposes.			
Biochemical and pharmaceutical products	The large majority of households in Bushbuckridge purchase medicinal plant product, but at least 10% of households in the communal area collect their own medicinal products from the surround areas.	Not applicable	Not relevant	Not applicable
Genetic resources	Not applicable			
Cultural				
Cultural diversity	Not relevant here	Not relevant here	NA – protected area	Not relevant here
Spiritual and religious values	No evidence found			
Knowledge systems (traditional and formal)	Not relevant here			
Educational values	Not relevant here		Relevant	
Inspiration	No evidence found		Recreational and tourism benefits	
Aesthetic values	Not relevant			
Social relations	Not relevant		Not relevant	
Sense of place	Not relevant		Not relevant	
Cultural heritage values	No evidence found		No evidence found	
Recreation and ecotourism	No evidence found		Ecotourism benefit from game water provided from fresh water services	

Present-day ecosystem service benefits utilised in IUA 5:

Food: Commercial farming

The largest water user is the irrigation sector (estimated as 32.3 Mm^3 in 1985). This includes irrigated plantations of citrus, coffee and mango, and small-scale irrigation (mainly field crops) (Butterworth et al., 2001). There are four schemes under irrigated annual crops (Dingleydale, New Forest/ Orinoco, Dumfries, the Allandale Small Farmers Schemes) that are operated by numerous small farmers, each cultivating a small area of between 1 to 6 ha. The total area is estimated to be 2145 ha although only some 1612 ha of this is farmed. There are an estimated 1000 farmers involved in these schemes. (Pollard et al., 2008). The upper and middle reaches of the catchment have approximately 1,500 ha land under irrigation of one form or another.

Food: irrigated home gardens

A study in the Bushbuckridge area, South Africa (Perez de Mendiguren and Mabelane, 2001) showed a high-levels of water use for economic activities in villages, with both poor and good water supplies, ranging from 23-40 l/c/d above the amount used for basic needs (21-22 l/c/d). Economic returns are relatively high, ranging from 0.01-0.02 R/l for vegetable gardens and fruit trees (the most common use of 'extra' water) to 1.2-1.6 R/l for beer brewing and ice block making (DWAF 2001).

It is common for households to have home vegetable gardens in areas of Bushbuck Ridge Municipality which have a reliable water supply. Households water these gardens using their domestic water supply. These gardens are usually only present in households with a yard connection, where the home garden is watered using hosepipes or sprinkles (Perez de Mendiguren and Mabelane, 2001). Vegetable gardens are also evident in areas where water can be easily accessed, namely next to rivers, springs or cattle dams. Irrigation of these gardens is done using a bucket (Perez de Mendiguren and Mabelane, 2001).

Home gardens are generally small, ranging between 30 and 600 m^2. Vegetable crops grown in the gardens include tomatoes, cabbage, lettuce, pepper. Field-crops such as maize, groundnuts and cassava are also cultivated. The majority of the crop is consumed, with surplus, if any, sold in local and regional markets (Perez de Mendiguren and Mabelane, 2001).

Irrigations of home gardens vary based on the water source. The Perez de Mendiguren and Mabelane (2001) study of households in villages in the Bushbuckridge area found that on average 30% of household had a home garden, with average water consumption for irrigation of between 8 and 32 litres per capita per day.

Food: wetland cropping

In the SRC, crops are grown in one of three places: wetlands fields, drylands fields or homestead gardens. In general, wetlands represent around 40% of the crop production, in both wet and dry growing seasons (Pollard et al., 2005). Most households have more than one field but wetland fields produce a wider variety of crops (especially madumbes and leguminous crops).

Crops grown make an important contribution to household livelihoods, with crops grown in wetlands including marope madumbes, maize, Greenleaf plants, beans, *Miscanthus junceus*, Morepho, bananas, sugar cane and traditional root vegetables.

Fresh Water: Domestic Water Use

In the SRC, surface water resources are heavily utilised, but groundwater has not yet been fully developed. Historically, investment in rural water supplies has focused on extensive bulk water supply systems utilising surface water resources (relying upon large dams, treatment works and distribution networks). But in many cases, the planned reticulation systems have never been completed.

Despite the vast improvements in water supply to the rural sector made by the South African government, many of the current patterns of water use are still characterised by inequality, inefficiency, and inadequacy. The poor remain marginalised, and emerging farmers and poor rural communities have limited access to water resources while water continues to be used inefficiently by an irrigation sector with few incentives to improve its water use efficiency.

Initial attempts in the SRC simply estimated domestic water needs based on population, but improved approaches will need to account for losses in distribution, and carefully consider where and how the Reserve is made available. Theoretical availability of sufficient water at one point in the catchment (e.g. in a river) will have little relevance for water supply systems that are not connected to a reticulation system to transfer bulk water around the catchment, or for settlements dependent on a groundwater supply. In addition the new allocation process must address temporal issues such as droughts (a Reserve should be utilised during droughts and re-established during wet periods), and the potential future development of groundwater for small-scale irrigation.

Domestic water supply in the SRC is provided to households from boreholes or via piped reticulation systems using surface water as the primary source (Perez de Mendiguren and Mabelane, 2001). A small percentage (6%) of households in the Bushbuck Ridge Municipality have no potable water supply and thus make direct use of rivers, streams or dams for the supply. Despite many households having access to potable water, many of these systems are unreliable and intermittent. This results, in most cases, in the households having to draw at least a portion of the daily water requirements from an unprotect source such as a storage container filled with rainwater, rivers, streams or dams.

Domestic water provided to households in the SRC should be free, due to the free basic service policy of providing indigent households at least 6kl of water per month free of charge. However, there is an informal water market which includes households paying for water collected by water vendors. This practice usually occurs during dry periods, during large function (i.e. weddings, funerals), or when no water is available in the village. Vendors usually collect water from surrounding villages (Perez de Mendiguren and Mabelane, 2001).

Domestic water demand is estimated to be 4.4 million m^3 for meeting of basic water needs (25 litre per capita per day) and an additional 9.8 million m^3 for meeting domestic needs of 100 per capita per day (Pollard and du Toit, 2005). However, when actual water use for basic needs and household productive uses are taken into account, the real water use from ‘domestic’ water supply systems may well be two to three times greater. Also, at village level domestic water needs can account for a large proportion of the yield from local aquifers, and during droughts needs may equate to a much larger share of the available resources than during normal years (Butterworth et al., 2001; Mokgope and Butterworth, 2001).

A study by Perez de Mendiguren and Mabelane (2001) in thirteen villages in the Bushbuckridge Municipality found that households were using, on average, between 21 and 22 litres per capital per day for basic needs (i.e. drinking, domestic hygiene, cooking and washing). This level of water consumption was consistent for households where the water source was outside the house. In the same study, household with internal water connections, usually in the kitchen, consumed three to four time more (85-114 litre per capita per day) than in households with an outside water source (Perez de Mendiguren and Mabelane, 2001).

44% of the population were estimated to have supplies below government minimum levels (25 l/c/d of potable water from a standpipe within 200 m of each household) (Pollard and Walker, 2000).

Some of the reasons why domestic water use represents only a small component of the overall water balance are: water resource constraints (e.g. upstream use impacting on downstream users); poorly planned infrastructure; and inadequate operation and maintenance. These factors result in actual domestic water use being much lower than needed. However, this relatively small component of the water balance is obviously of vital importance.

In the SRC most of the existing surface water resources are already utilised (Pollard et al., 1999), and any increased use for previously marginalised sectors and communities will need to be met through: groundwater development; reduced use in other sectors or areas; or transfers from outside the catchment (construction of a new dam has made basin transfers possible). Competition for scarce water resources and inappropriateness of priorities in water use have been widely recognised since the 1992 drought. Tankers had to be used as an emergency water supply to rural communities and large numbers of wildlife and livestock died, while irrigated agriculture utilised water without restriction. This crisis acted as a catalyst and stimulus for an integrated approach to water resources management to be adopted.

Freshwater: Livestock

Livestock in the communal areas of the Sand River Catchment are water from sources such as cattle dams, rivers and springs and occasionally from domestic water supply systems (Perez de Mendiguren and Mabelane, 2001). The Perez de Mendiguren and Mabelane (2001) study of village in Bushbuckridge estimated that 22% of households owned cattle with the average number of cattle per household ranging between 8-9. In the same village, 25.5% of households owned between 8 and 9 goats. This study estimated that an additional household demand of 7 litre per capita per day and 71 litres per capita per day are required to keep goats and cattle, respectively.

Wood and Fibre

Forestry (mainly exotic species such as pine) in the upper parts of the catchment is another large water user (11.3 Mm^3 in 1985).

Wood and fibres are harvested from wetland areas or riparian zones. Approximately 8% of the population use the wetlands for harvesting of reeds only and do not have fields in the wetlands, 25 % use wetlands for cropping and do not collect reeds, and 67% do both. Of the total number of people interviewed, 75% harvest reeds (Pollard et al., 2005). Participants of this harvesting are mainly women between the ages of 45 and 70, mainly from single-headed households (Pollard et al., 2005). Natural products collected include Leshago (*Schoenoplectus corymbosus*), Segaba (*Cyperus latifolius*), Sediba (Springs) and Lehlakanoka (*Phragmites mauritianus*).

Grazing: livestock

Wetland areas are particularly important to livestock during the dry season when there are little resources available elsewhere (Pollard et al., 2007).

Clay

There is limited use of clay (letsopa) from wetlands for cultural purposes.

Present-day ecosystem service benefits in IUA 6

IUA 6 falls entirely within land protected for conservation. Recreation and ecotourism are the primary benefits here.

Phase 2: Assessing ecological change

2A. Management scenarios

Only two management scenarios were considered in this case: (1) a larger irrigation scheme requires higher yield with 90% assurance resulting in lower ecological flows and likely a decrease in the ecological category to C/D; (2) smaller irrigation scheme in order to allow higher releases to improve ecological category downstream to a B.

Scenario 1. Large irrigation scheme resulting in C/D ecological category

A larger irrigation scheme is proposed, which will require a higher yield with 90% assurance. This means that under conditions of water stress, meeting the 90% assurance will place preference to irrigation and require drawdown of the dam. This scenario will require a yield of 28 Mm^3. This means that there is only a 2 Mm-3 yield available for release and that the dam will impact on drought flows, maintenance flows and some maintenance highs. This will result in a C/D ecological category downstream in terms of hydrology.

The maintenance requirement for category C/D is 21 Mm^3 (18% of 117 Mm^3 MAR), which is a 5 Mm^3 drop from the present condition. To maintain this ecological category downstream, the drought requirement is 6% MAR, maintenance low is 9% (includes 6% of drought) and maintenance high is 8.5% MAR. This scenario will have greatest effect on maintenance low and high flows.

Scenario 2. Smaller irrigation scheme resulting in B ecological category

A smaller irrigation scheme is proposed in order to allow higher releases to improve ecological category downstream. The desired downstream ecological category in terms of hydrology is a B, which requires 38.6 Mm^3 (33% of MAR). This will result in the actual yield from dam being 8-10 Mm^3 less and the available yield available for irrigation 20-22 Mm^3. To maintain this ecological category downstream the drought requirement is 6% of the MAR, maintenance low is 21% (includes 6% of drought) and the maintenance high is 11.5%. The yield of the Gevonden dam drops by 10 Mm^3 in this scenario.

Summary of scenarios to be considered

There are thus two scenarios for water resource management being considered within each IUA and for each SWR (groundwater and river). This lays the basis for the assessment of ecological change within each IUA, for each SWR, under each scenario.

- Scenario 1 (dam operations for ecological category C/D, large irrigation scheme) is assessed in Section 4.1.
- Scenario 2 (dam operations for ecological category B, smaller irrigation scheme) is assessed in Section 4.2.

Table 28. Summary of the assets (significant water resource (SWR) per integrated unit of analysis (IUA)) that are exposed to the different management scenarios

Scenarios	**IUA 5**		**IUA 6**	
SWR	**River**	**Groundwater**	**River**	**Groundwater**
Scenario 1 (degraded EC) – dam operations for ecological category C/D, large irrigation scheme	Yes	Yes	Yes	Yes
Scenario 2 (improved EC) – dam operations for ecological category B, smaller irrigation scheme	Yes	No	Yes	No

2B. Determine and describe ecological consequences of scenarios and assess risk to ecosystem services

A comparative risk assessment (CRA) will be used to assess risk to ecosystem services. To aid this assessment, the environmental effects of the proposed project are discussed briefly below within the context of what we know about the system and how the system will be managed (scenarios).

i. Environmental effects of the proposed project

Hydrological effects of a dam

A dam will result in drought and maintenance low flows being cut off. Downstream tributaries are small and therefore contribute little to drought and maintenance low flows downstream of the dam. Maintenance low flows are the flow in the river 60-70% of the time. This is the flow upon which riverine biota depend. Maintenance high flows (freshets) will probably also be affected as abstraction from the river is expected to be high and so freshets will be used to fill the dam. Maintenance high flows are regular high flow period, related to climate, that provides ecological cues for activities such as spawning, and clean rocks of algae, flush out some sediment and debris. Dams regularly result in the elimination of small floods which might have effects on fish, floodplain diversity, plants and nutrients (Richter and Thomas, 2007).

A dam may cut off Class I and II floods but Class III usually go over. Class I and II floods are important to biologists and riparian vegetation specialists, because these flood riparian vegetation far from the main channel. Large floods are also important for geomorphological processes, spread of seeds, habitat change and purge of alien invasive species. So these 1:5 and 1:10 yr events are important for flushing out the system.

The Gevonden dam will store wet-season flows for use in the dry season to supply water to the irrigated sugarcane farm during the dry season. Thus rearranging seasonal patterns of water flow.

The effects of the dam on the interaction of ground and surface water will be greatest near the dam and directly downstream from it. The dam will result in a permanent rise in the water table near the dam that may extend a considerable distance. The dam may lose water to shallow ground water, but this water will likely return to the river as base flow directly downstream from the dam (Winter et al., 1998). The effects on groundwater downstream of the dam will be as a result of the modified flow conditions and the degree to which this differs from natural.

Geomorphological effects

Transport of sediment down the Sand River will be affected. Sediment trapping of a dam commonly produces highly modified sediment transport processes downstream often resulting in modified channel and floodplain geometry, or down-cut riverbeds, representing in many cases a fundamentally different physical habitat template to support native ecosystems.

Even with the implementation of best practices to control soil erosion, increased soil erosion is inevitable as a result of the construction of the Gevonden Dam and the associated canal systems, borrow pits for fill and road construction, and general land

clearing for the reservoir area, soil compaction, irrigable areas and roads. Considering the degraded nature of much of the SRC, sediment load due to soil erosion upstream might already be higher than natural.
The likely consequences of soil erosion include: increase in suspended solids in water with water quality implications for terrestrial and aquatic life, siltation of the dam resulting in long-term reduction in its storage capacity, reduced land use potential with loss of arable soil, degradation of terrestrial and downstream aquatic habitats and degradation of the aesthetic quality of the environment (ECS, 2009).

Ecological effects

The area of the dam is 900 ha. This will result in a loss of wildlife habitat and biodiversity in the project area. However the area has been degraded and from a terrestrial perspective, is considered to be of least concern and important for general ecosystem maintenance (Lotter, 2006).

From an aquatic perspective, while no species of special concern have been identified in the area, the river is important as an ecological corridor connecting upstream catchment and aquatic ecosystems of high biodiversity importance to downstream protected areas.

Dams disrupt the longitudinal pathway so plant dispersal is reduced and plant communities become fragmented. The dispersal process is difficult to restore without removing or opening dams (Nilsson and Svedmark, 2002).

Sugarcane cultivation can have a number of effects on the ecosystem including

- alteration of infiltration and runoff characteristics of the land surface, which affects recharge to ground water, delivery of water and sediment to surface-water bodies, and evapotranspiration (Winter et al., 1998);
- loss of soil fertility (nutrient changes);
- potential salinisation or acidification of soil;
- air quality may be affected through soil emissions and pesticides, and also combustion particulates or gases if pre-harvest burning is undertaken;
- high water demands; and
- threat of eutrophication.

Figure 29 provides a schematic of the sources of environmental effects of growing sugarcane in relation to the key processes and inputs of its cultivation.

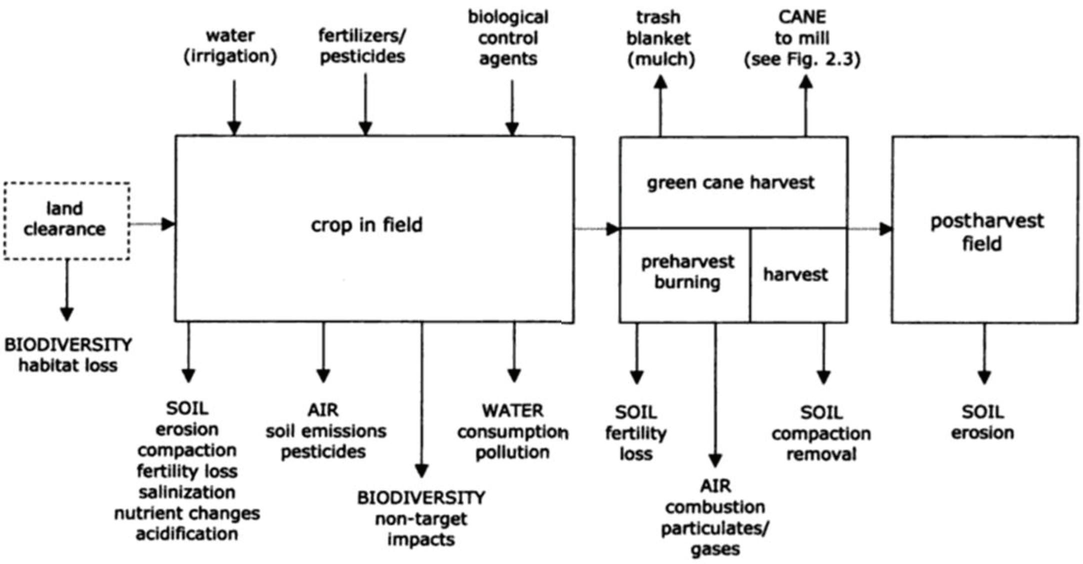


Figure 27. Sources of environmental impacts relative to key processes and inputs in the cultivation of sugarcane (from Cheesman, 2005).

Socio-economic effects

The inundation of 900 Ha for the reservoir will likely result in a range of socio-economic effects such as:

- shifting herds to other lands exacerbating already overstocked grazing lands;
- removal of land used to access resources such as firewood, construction materials (poles and thatching grass), wild foods or medicinal plants upon which many homesteads are dependent, resulting in increasing pressure on remaining land, and competition for access to resources;
- potential social conflicts between the local population and new settlers and construction staff;
- resettlement of local population, with resultant increased pressure on remaining natural resources (see above), and support services (such as clinics and schools);
- potential health hazards including risk of drowning, increased incidence of malaria and schistosomiasis (both already prevalent in the area) and possibly other communicable diseases (such as cholera and gastro-enteritis) through the introduction of waste water into the water supply;
- possible destruction of sites of cultural and religious significance; and
- possible benefits in the form of added recreational activities, fishing, development of reedbeds with their use value and possible others.

In summary:

Table 10 provides a summary of the potential negative environmental and social effects of the dam and sugarcane cultivation project. Although not discussed above, as these will be considered in the cost-benefit assessment, some of the positive effects of the project are provided.

Table 29. Summary of potential effect of dam construction and provision and development of irrigation and associated physical infrastructure (adapted from ECS, 2009)

	Negative Impacts	Positive Impacts
Physical location of the project		
Environment effects	Loss of land surface area Soil erosion Siltation and increased sedimentation Disruption of fish migration Interrupted natural drainage patterns Loss of river and riparian habitats and associated biodiversity Loss of some regulatory functions of the natural ecosystem (e.g. ecological corridors, water purification, erosion regulation) Altered water regime (particularly maintenance low and high flow (spates)	Creation of new aquatic ecosystem Green landscape in the dry season Water storage Reduction in risk of flooding Recreation Fisheries habitat
Socio-economic Impacts	Loss of traditional production and products Potential social Resettlement impacts Increased health hazards Loss of antiquities and archaeology	Employment opportunities Increased wealth Improved water supply infrastructure Increased knowledge of project area
Impacts from Irrigation Management		
Internal Impacts	Soil erosion from furrow or surface irrigation Adverse soil conditions resulting from waterlogging, excessive run-off, salinisation of soils and soil alkalisation Scouring and/or sedimentation of drainage channels over time Depletion of soil macronutrients Leaching of nutrients from soils Weed proliferation and eutrophication Polluted irrigation waters Introduction or increase in incidence of water-borne or water-related diseases Conflicts of water supply with other users	More equitable water allocation Increased potential for sugarcane production Increased potential for irrigated agriculture More land available for farming Flood control Increased food security Opportunity for improved health care
External Impacts	Deterioration of water quality below irrigation areas Contamination of local ground water	Security of water supply to downstream users and irrigators Reduction of peak floods and high flow levels

ii. Comparative risk assessment (CRA) outputs

A CRA of the ecosystem services at risk within each IUA for each SWR was undertaken using a group of specialists. The following sections provide the outputs of the CRA. They consist of an asset description (the river or groundwater per IUA) and an environmental effect description for each scenario including:

a hazard and effect description;
scope of consequence;
outcome statement;
likelihood of outcome; and
risk assessment.

IUA 5: River SWR

Asset description:
The river significant water resource in IUA 5 is characterised by low gradient, some bedrock, pools and sandbars and a riparian zone dominated by tall trees with reeds in open areas. The river is wide, with both slow, deep flowing channel and broad chute over unfractured bedrock (RHP, 2001). There are no other types of wetlands other than riparian zones, and floodplains which can be fairly broad in some places.

Scenario 1: Degraded ecological category

Environmental effect statement:

Hazard and effect description:
The construction of the Gevonden Dam will inundate a 900 ha area of river habitat and riparian zones, small-scale agriculture, some infrastructure such as homesteads, roads, degraded bushveld and grazing area. The area consists of largely degraded habitat with no known biodiversity of special concern. There will be short-term (12 months) sediment release downstream from the dam due to construction activities (including blasting, construction of new infrastructure such as pipelines, roads, etc.) and land-clearing activities for sugar cane irrigation pipelines and preparation of lands.

Both during the filling up and operation of the dam, drought flows and maintenance low flows will be released. The assurance of these environmental flows will maintain the river in its status as a perennial river. Maintenance highs (spates) will be used to fill up the dam and only 8.5% MAR will be released as maintenance highs other than when the dam is full. This will have significant consequences downstream as these influence ecosystems in a variety of ways:

- Shaping the physical character of the river channel, including pools and riffles
- Determining the size of streambed substrates (sand, gravel, cobble)
- Preventing riparian vegetation from encroaching into the channel
- Restoring normal water quality conditions after prolonged low flows, flushing away waste products and pollutants
- Aerate eggs in spawning gravels, prevent siltation

Fewer spates, will result in less disturbance and fewer habitats for invertebrates and other river-associated species. The dam itself will present a barrier for ecological interactions and processes taking place up and down the length of the river and riparian zone. This will largely affect invertebrates and seed dispersal.

Continuous irrigation of sugarcane fields will result in some return flow downstream of the dam even during very dry periods. Combined with the increased supply of nutrients from the sugarcane agriculture, this would result in threat of nitrate impacts of water resources. There would be an increase in phosphorous (P) in soils under sugarcane agriculture as a result of regular fertilizer inputs. A reduction in riparian vegetation due perhaps to the lower volumes of flow in this scenario, degradation and such, this can mean that fewer nutrients are taken up from soil and water and even higher threat of eutrophication.

Primary tillage (on average every 4 years), although better than annual crops is still unsustainable and would: increase erosion, particularly along riparian areas; reduce water retention; and alter soil communities, especially in combination with agrochemicals used on sugarcane. With regards to soil erosion, over the long term this supply of soil could make up for loss of sediment from upstream (halted by the dam) but would alter streambed substrates. Agrochemicals and increased nutrients into the system would pose particular problems for biodiversity during dry periods when water flow is lower and water is concentrated into pools. Concentration of water into pools would also pose health risks to humans, not only from build up of agrochemicals and eutrophication, but also due to exposure to water-related diseases (e.g. bilharzia, malaria already endemic in the area).

Scope of consequence:
The construction of a dam in the Sand River, establishment of an irrigated sugarcane project and management of the river SWR as ecological category C/D through appropriate environmental releases from the new dam will result in:

- 900 ha land being inundated with water
- 5000 ha land converted to sugarcane monoculture
- Increased nitrogen in water resources
- Increased phosphorous in soil under sugarcane
- Capture of sediment behind Gevonden Dam from upstream
- Increased sediment input initially with construction of dam and establishment of sugarcane fields, long term increased sediment input as a result of tillage of sugarcane fields, etc.
- A dam would cut off Class I and II floods but Class III usually go over. Class I and II floods are important because these flood riparian vegetation far from the main channel. Large floods are also important for geomorphological processes, spread of seeds, habitat change and purge of alien invasive species. So these 1:5 and 1:10 yr events are important for flushing out the system.
- To maintain a C/D hydrological category downstream, the following environmental releases will take place (as a percentage of MAR): a minimum of 6% during drought release (7.02 Mm^3), 9% maintenance low flow (10.53 Mm^3), and 8.5% maintenance high release (10 Mm^3).
- Water availability will increase overall as a result of the dam water storage and the drought flows downstream of dam, which assure the Reserve, however there

will be less water available throughout the year as less water is released from the dam.

Outcome statement:
Construction of dam and irrigation project and management of river water resources in a C/D ecological category will affect the following benefits from ecosystem services: freshwater provisioning, production of wild foods and subsistence crops along riparian zones, production of raw materials such as reeds, and wild medicinal species, spiritual and religious values, aesthetic value, recreation and ecotourism, avoidance of injury, pollution and destruction of private property and infrastructure.

Likelihood of outcome: Almost certain
Risk assessment: (L = likelihood, C = consequence, R = risk)

ES type	Beneficial ecosystem processes	Affected?	L	C	R
	weathering/erosion	Yes	Likely	Insignificant -Minor	Low-Medium
Nutrient cycling	nutrient cycling	Yes	Possible	Moderate	High
Water cycling	water cycling	No	-	-	-
	Ecological interactions and evolutionary processes	Yes	Almost certain	Moderate	High
Photosynthesis	Production	Yes	Likely	Moderate	High
Primary production	Primary production	Yes	Possible	Moderate	High
	Secondary production	Yes	Possible	Moderate	High
Soil formation	Soil formation	Yes	Almost certain	Moderate	High
Air quality regulation	Air quality regulation	Yes/No	Possible	Insignficant	Low
Climate regulation	regional and local climate regulation	No	-	-	-
Water regulation	water regulation (timing)	Yes	Almost certain	Major	Very High
Erosion regulation	erosion regulation	Yes	Possible	Minor	Medium
Water purification	Water purification (quality)	Yes	Likely	Moderate	High
	Waste assimilation	No	-	-	-
	Water provisioning (quantity)	Yes	Almost certain	Minor	Medium
Disease regulation	Avoidance of infection	Yes	Unlikely	Major	High
Pest regulation/Biological control	Biological control	Yes	Possible	Moderate	High
Pollination	Pollination	No	-	-	-
Seed dispersal	Other ecological interactions (other than pollination and biological control)	Yes	Likely	Minor	Medium
Natural hazard regulation	Formation of physical barriers	Yes	Possible	Minor	Medium
	Formation of species habitat	Yes	Possible	Minor	Medium
	Formation of pleasant scenery	No	-	-	-
	Species diversification	Yes	Unlikely	Minor	Low
	Genetic diversification	Yes	Unlikely	Minor	Low

ES type	Beneficial ecosystem processes	Affected?	L	C	R
Fresh water	Freshwater	Yes	Almost certain	Moderate	High
Food	Food	Yes	Almost certain	Moderate	High
Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	Yes	Almost certain	Moderate	High
	Energy of different types, including working animals and hydropower	Yes	Almost certain	Moderate	High
Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	Yes	Almost certain	Minor	Medium (higher see paper)
Materials: sand/pebbles, clay		Yes	Likely	Insignificant	Low
Genetic resources	Currently unknown benefits	No	-	-	-
Spiritual and religious values	Spiritual/cultural wellbeing	Yes	Possible	Moderate	Medium
Inspiration	Psychological wellbeing	Yes	Very unlikely	Moderate	Low
Knowledge systems (traditional and formal)	Knowledge	No	-	-	-
Educational values	Research and education	No	-	-	-
Aesthetic values	Aesthetic benefits	Yes	Very unlikely	Minor	Low
Sense of place	Psychological wellbeing?	No	-	-	-
Cultural heritage values	Psychological wellbeing?	No	Possible	,	,
Cultural diversity	Psychological wellbeing?	No	-	-	-
Recreational	Recreation	Yes	Possible	Minor	Medium
Ecotourism	Tourism	No	-	-	-
	Pets, garden plants	No	-	-	-
	Avoidance of injury	Yes	Possible	Minor	Medium
	Avoidance of pollution	Yes	Likely	Moderate-Major	High-Very High
	Physical exercise	No	-	-	-
	private property and infrastructure	Yes	Possible	Minor	Medium

Scenario 2: Improved ecological category

<u>Environmental effect statement:</u>

Hazard and effect description:
The construction of the Gevonden Dam will inundate a 900 ha area of river habitat and riparian zones, small-scale agriculture, some infrastructure such as homesteads, roads, etc., degraded bushveld and grazing area. The area consists of largely degraded habitat with no known biodiversity of special concern. There will be short-term (12 months) sediment release downstream from the dam due to construction activities (including blasting, construction of new infrastructure such as pipelines, roads) and land-clearing activities for sugar cane irrigation pipelines and preparation of lands.

Both during the filling up and operation of the dam, drought flows and maintenance low flows will be released. The assurance of these environmental flows will maintain the river in its status as a perennial river. Maintenance highs (spates) will be used to fill up the dam and only 11.5% MAR will be released as maintenance highs other than when the dam is full.

This will have significant consequences downstream as these influence ecosystems in a variety of ways:

- Shaping the physical character of the river channel, including pools and riffles
- Determining the size of streambed substrates (sand, gravel, cobble)
- Preventing riparian vegetation from encroaching into the channel
- Restoring normal water quality conditions after prolonged low flows, flushing away waste products and pollutants
- Aerate eggs in spawning gravels, prevent siltation

The higher percentage of MAR released as maintenance low and high flows will provide hydrological conditions closer to natural flow. The dam itself will still present a barrier for ecological interactions and processes taking place up and down the length of the river and riparian zone. This will largely affect invertebrates and seed dispersal.

Continuous irrigation of sugarcane fields will result in some return flow downstream of the dam even during very dry periods. Combined with the increased supply of nutrients from the sugarcane agriculture, this would result in threat of nitrate impacts of water resources. There would be an increase in phosphorous (P) in soils under sugarcane agriculture as a result of regular fertilizer inputs.

Primary tillage (on average every 4 years), although better than annual crops is still unsustainable and would: increase erosion, particularly along riparian areas; reduce water retention; and alter soil communities, especially in combination with agrochemicals used on sugarcane. With regards to soil erosion, over the long term this supply of soil could make up for loss of sediment from upstream (halted by the dam) but would alter streambed substrates.

Higher environmental flows in this scenario are important to flushing the system, providing better dilution and sustaining healthy channel and riparian vegetation.

Scope of consequence:

The construction of a dam in the Sand River, establishment of an irrigated sugarcane project and management of the river SWR as ecological category C/D through appropriate environmental releases from the new dam will result in:

- 900 ha land being inundated with water
- land converted to sugarcane monoculture
- Increased nitrogen in water resources
- Increased phosphorous in soil under sugarcane
- Capture of sediment behind Gevonden Dam from upstream

- Increased sediment input initially with construction of dam and establishment of sugarcane fields, long term increased sediment input as a result of tillage of sugarcane fields, etc.
- A dam would cut off Class I and II floods but Class III usually go over. Class I and II floods are important because these flood riparian vegetation far from the main channel. Large floods are also important for geomorphological processes, spread of seeds, habitat change and purge of alien invasive species. So these 1:5 and 1:10 yr events are important for flushing out the system.
- To maintain a B hydrological category downstream, the following environmental releases will take place (as a percentage of MAR): a minimum of 6% during drought release (7.02 Mm^3), 21% maintenance low flow (24.57 Mm^3), and 11.5% maintenance high release (13.5 Mm^3).
- Water availability will increase overall as a result of the dam water storage and the drought flows downstream of dam, which assure the Reserve. Higher environmental flows will result in their being less assurance of supply for sugarcane irrigation, or a smaller portion of area should be planted.

Outcome statement:
Construction of dam and irrigation project and management of river water resources in a B ecological category will still affect core ecosystem processes such as nutrient cycling, production, soil formation, weathering and erosion processes, and some ecological interactions and evolutionary processes in blocking the corridor function of the Sand River.

Regulating services of erosion regulation, water regulation (timing), and other ecological interactions will be affected. Due to the maintenance of improved environmental flows in this scenario, the effects on ecosystem benefits are minimal, other than the avoidance of pollution as a result of the sugarcane irrigation. The dam will result in long-term effects on services such as species and genetic diversification as it lies in an important corridor for ecosystem function, that do not translate easily to effects on the benefits humans receive, but rather just a lowering of resilience.

Likelihood of outcome: Almost certain

Risk assessment: (L = likelihood, C = consequence, R = risk)

ES type	Beneficial ecosystem processes	Affected ?	L	C	R
	weathering/erosion	Yes	Likely	Insignificant -Minor	Low-Medium
Nutrient cycling	nutrient cycling	Yes	Possible	Moderate	High
Water cycling	water cycling	No	-	-	-
	Ecological interactions and evolutionary processes	Yes	Almost certain	Moderate	High
Photosynthesis	Production	Yes	Likely	Moderate	High
Primary production	Primary production	Yes	Unlikely	Moderate	Medium
	Secondary production	Yes	Unlikely	Minor	Low
Soil formation	Soil formation	Yes	Almost certain	Moderate	High
Air quality regulation	Air quality regulation	No	-	-	-
Climate regulation	regional and local climate	No	-	-	-

ES type	Beneficial ecosystem processes	Affected ?	L	C	R
	regulation				
Water regulation	water regulation (timing)	Yes	Possible	Insignificant	Low
Erosion regulation	erosion regulation	Yes	Possible	Minor	Medium
Water purification	Water purification (quality)	No	-	-	-
	Waste assimilation	No	-	-	-
	Water provisioning (quantity)	Yes	-	-	-
Disease regulation	Avoidance of infection	No	-	-	-
Pest regulation/Biological control	Biological control	Yes	Unlikely	Insignificant	Low
Pollination	Pollination	No	-	-	-
Seed dispersal	Other ecological interactions (other than pollination and biological control)	Yes	Likely	Minor	Medium
Natural hazard regulation	Formation of physical barriers	No	-	-	-
	Formation of species habitat	No	-	-	-
	Formation of pleasant scenery	No	-	-	-
	Species diversification	Yes	Unlikely	Minor	Low
	Genetic diversification	Yes	Unlikely	Minor	Low
Fresh water	Freshwater	No	-	-	-
Food	Food	Yes	Very unlikely	Moderate	Low
Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	No	-	-	-
	Energy of different types, including working animals and hydropower	No	-	-	-
Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	No	-	-	-
Materials: sand/pebbles, clay		No	-	-	-
Genetic resources	Currently unknown benefits	No	-	-	-
Spiritual and religious values	Spiritual/cultural wellbeing	No	-	-	-
Inspiration	Psychological wellbeing	No	-	-	-
Knowledge systems (traditional and formal)	Knowledge	No	-	-	-
Educational values	Research and education	No	-	-	-
Aesthetic values	Aesthetic benefits	No	-	-	-
Sense of place	Psychological wellbeing?	No	-	-	-
Cultural heritage values	Psychological wellbeing?	No	-	-	-
Cultural diversity	Psychological wellbeing?	No	-	-	-
Recreational	Recreation	No	-	-	-
Ecotourism	Tourism	No	-	-	-
	Pets, garden plants	No	-	-	-
	Avoidance of injury	Yes	Unlikely	Minor	Low
	Avoidance of pollution	Yes	Possible	Moderate	High
	Physical exercise	No	-	-	-
	private property and infrastructure	Yes	Unlikely	Minor	Low

IUA 5: Groundwater SWR

Asset description:

The percentage contribution of groundwater to baseflow is very low (1-10%) and of local importance only (along the riparian zone of rivers). Elsewhere, groundwater is stored in fractured rock more than 10 m below ground level, is not considered vulnerable is currently not under threat from over-exploitation.

Scenario 1: Degraded ecological category

Environmental effect statement:

Hazard and effect description:

The dam will result in a permanent rise in the water table in the immediate vicinity of the dam. The effect on groundwater downstream of the dam is as a result of the modified flow conditions which maintain drought flows but limit the size of spates (maintenance highs) important to flowing over floodplain and recharging the wider riparian zones.

As a result of irrigation, the groundwater levels in the land under sugar cultivation may rise.

Reduced water availability downstream (explained in the River SWR for Scenario 1 above) may result in a higher dependency on groundwater during dry periods. The groundwater resources are considered generally under-exploited and would not be greatly affected.

Scope of consequence:

The effects of the dam on the interaction of ground and surface water will be greatest near the dam and directly downstream from it.

Outcome statement:

The provision of groundwater may be affected by this scenario.

Likelihood of outcome: Very unlikely

Risk assessment: (L = likelihood, C = consequence, R = risk)

ES type	**Beneficial ecosystem processes**	**Affected?**	**L**	**C**	**R**
	weathering/erosion	No	-	-	-
Nutrient cycling	nutrient cycling	No	-	-	-
Water cycling	water cycling	Yes	Very unlikely	Moderate	Low
	Ecological interactions and evolutionary processes	No	-	-	-
Photosynthesis	Production	No	-	-	-
Primary production	Primary production	No	-	-	-
	Secondary production	No	-	-	-
Soil formation	Soil formation	No	-	-	-
Air quality regulation	Air quality regulation	No	-	-	-
Climate regulation	regional and local climate regulation	No	-	-	-
Water regulation	water regulation (timing)	No	-	-	-
Erosion regulation	erosion regulation	No	-	-	-
Water purification	Water purification (quality)	No	-	-	-
	Waste assimilation	No	-	-	-
	Water provisioning (quantity)	No	-	-	-
Disease regulation	Avoidance of infection	Yes	Extremely unlikely	Moderate	Low
Pest regulation/Biological control	Biological control	No	-	-	-
Pollination	Pollination	No	-	-	-
Seed dispersal	Other ecological interactions (other than pollination and biological control)	No	-	-	-
Natural hazard regulation	Formation of physical barriers	No	-	-	-
	Formation of species habitat	No	-	-	-
	Formation of pleasant scenery	No	-	-	-
	Species diversification	No	-	-	-
	Genetic diversification	No	-	-	-

ES type	Beneficial ecosystem processes	Affected?	L	C	R
Fresh water	Freshwater	Yes	Very unlikely	Moderate	Low
Food	Food	No	-	-	-
Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	No	-	-	-
	Energy of different types, including working animals and hydropower	No	-	-	-
Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	No	-	-	-
Materials: sand/pebbles, clay		No	-	-	-
Genetic resources	Currently unknown benefits	No	-	-	-
Spiritual and religious values	Spiritual/cultural wellbeing	No	-	-	-
Inspiration	Psychological wellbeing	No	-	-	-
Knowledge systems (traditional and formal)	Knowledge	No	-	-	-
Educational values	Research and education	No	-	-	-
Aesthetic values	Aesthetic benefits	No	-	-	-
Sense of place	Psychological wellbeing?	No	-	-	-
Cultural heritage values	Psychological wellbeing?	No	-	-	-
Cultural diversity	Psychological wellbeing?	No	-	-	-
Recreational	Recreation	No	-	-	-
Ecotourism	Tourism	No	-	-	-
	Pets, garden plants	No	-	-	-
	Avoidance of injury	No	-	-	-
	Avoidance of pollution	No	-	-	-
	Physical exercise	No	-	-	-
	private property and infrastructure	No	-	-	-

Scenario 2: Improved ecological category

Environmental effect statement:

Hazard and effect description:

The dam will result in a permanent rise in the water table in the immediate vicinity of the dam. The effect on groundwater downstream of the dam is as a result of the modified flow conditions which maintain drought flows but limit the size of spates (maintenance highs) important to flowing over floodplain and recharging the wider riparian zones. Maintenance lows and high flow releases are better than in scenario 1.

As a result of irrigation, the groundwater levels in the land under sugar cultivation may rise.

Scope of consequence:

The effects of the dam on the interaction of ground and surface water will be greatest near the dam and directly downstream from it.

Likelihood of outcome: Very unlikely

Risk assessment: (L = likelihood, C = consequence, R = risk)

ES type	Beneficial ecosystem processes	Affected?	L	C	R
	weathering/erosion	No	-	-	-
Nutrient cycling	nutrient cycling	no	-	-	-
Water cycling	water cycling	Yes	Very unlikely	Moderate	Low
	Ecological interactions and evolutionary processes	no	-	-	-
Photosynthesis	Production	no	-	-	-
Primary production	Primary production	No	-	-	-

ES type	Beneficial ecosystem processes	Affected?	L	C	R
	Secondary production	No	-	-	-
Soil formation	Soil formation	no	-	-	-
Air quality regulation	Air quality regulation	no	-	-	-
Climate regulation	regional and local climate regulation	no	-	-	-
Water regulation	water regulation (timing)	no	-	-	-
Erosion regulation	erosion regulation	no	-	-	-
Water purification	Water purification (quality)	no	-	-	-
	Waste assimilation	No	-	-	-
	Water provisioning (quantity)	No	-	-	-
Disease regulation	Avoidance of infection	no	-	-	-
Pest regulation/Biological control	Biological control	no	-	-	-
Pollination	Pollination	no	-	-	-
Seed dispersal	Other ecological interactions (other than pollination and biological control)	no	-	-	-
Natural hazard regulation	Formation of physical barriers	no	-	-	-
	Formation of species habitat	No	-	-	-
	Formation of pleasant scenery	No	-	-	-
	Species diversification	No	-	-	-
	Genetic diversification	No	-	-	-
Fresh water	Freshwater	maybe			?
Food	Food	no	-	-	-
Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	no	-	-	-
	Energy of different types, including working animals and hydropower	No	-	-	-
Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	no	-	-	-
Materials: sand/pebbles, clay		no	-	-	-
Genetic resources	Currently unknown benefits	no	-	-	-
Spiritual and religious values	Spiritual/cultural wellbeing	no	-	-	-
Inspiration	Psychological wellbeing	no	-	-	-
Knowledge systems (traditional and formal)	Knowledge	no	-	-	-
Educational values	Research and education	no	-	-	-
Aesthetic values	Aesthetic benefits	no	-	-	-
Sense of place	Psychological wellbeing?	no	-	-	-
Cultural heritage values	Psychological wellbeing?	no	-	-	-
Cultural diversity	Psychological wellbeing?	no	-	-	-
Recreational	Recreation	no	-	-	-
Ecotourism	Tourism	No	-	-	-
	Pets, garden plants	No	-	-	-
	Avoidance of injury	No	-	-	-
	Avoidance of pollution	No	-	-	-
	Physical exercise	No	-	-	-
	private property and infrastructure	No	-	-	-

IUA 6: River SWR

Asset description:

The river significant water resource in IUA 6 is characterised by low gradient, some bedrock, pools and sandbars and a riparian zone dominated by tall trees with reeds in open areas. The river is wide, with both slow, deep flowing channel and broad chute over unfractured bedrock (RHP, 2001). Riparian forests exist in the lower reaches of the river and utilize groundwater stored in the alluvial deposits in the floodplain which are sustained by river discharge (with groundwater a major contributor from upstream) into the river bank aquifer (characteristic of an influent or intermittent stream). These riparian forests are quite sensitive to changes in groundwater levels and defined as aquifer-dependent ecosystems (ADE). There are no other types of wetlands other than riparian zones, and floodplains which can be fairly broad in some places.

Scenario 1: Degraded ecological category

Environmental effect statement:

Hazard and effect description:
There is already low rainfall in this region and MAR of tributaries in this IUA. The effect of altered water regulation (timing and quantity of environmental flows) in this scenario will continue to have the following environmental effects:

- Riparian vegetation encroachment into the channel;
- Altered geomorphology of the river channel (including pools and riffles) and streambed substrates with possible increased siltation of areas;
- Reduced water quality as a result of increased nutrient and agrochemical inputs from sugarcane irrigation and fewer spates to flush away waste products and pollutants;
- Altered habitats for species as a result of the above factors resulting in fewer disturbances, effects on spawning or nursery grounds (such as limited aeration of eggs in spawning grounds, other cues for spawning).

Scope of consequence:
The construction of a dam in the Sand River, establishment of an irrigated sugarcane project and management of the river SWR as ecological category C/D through appropriate environmental releases from the new dam will result in:

- Increased nitrogen in water resources;
- Increased nutrients that normally limit primary production now available, therefore primary production increases and growth of pest species such as cyanobacteria at pest proportions may occur under certain conditions (concentration of high nutrient water in pools) for short periods;
- Algal blooms are unsightly and smelly, and they may pose a threat to wildlife and, only in extreme and unlikely circumstances, to people;
- A dam would cut off Class I and II floods but Class III usually go over. Class I and II floods are important because these flood riparian vegetation far from the main channel. Large floods are also important for geomorphological processes, spread of seeds, habitat change and purge of alien invasive species. So these 1:5 and 1:10 yr events are important for flushing out the system;
- Water availability will increase overall as a result of the dam water storage and the drought flows downstream of dam, which assure the Reserve, however there will be less water available throughout the year as less water is released from the dam. Concentration of animals around more limited water resources on a more regular basis will alter the aesthetics of riparian zones in conservation areas managed for tourism over the long term;
- There are a considerable number of research and education projects in the area which may be affected by the dam and irrigation scheme and its associated effects.

Outcome statement:

Construction of dam and irrigation project and management of river water resources in a C/D ecological category will affect the following benefits from ecosystem services: freshwater provisioning, research and education, aesthetic value, ecotourism, avoidance of pollution and destruction of private property and infrastructure.

Likelihood of outcome: Almost certain

Risk assessment: (L = likelihood, C = consequence, R = risk)

ES type	**Beneficial ecosystem processes**	**Affected?**	**L**	**C**	**R**
	weathering/erosion	No	-	-	-
Nutrient cycling	nutrient cycling	Yes	Possible	Minor	Medium
Water cycling	water cycling	No	-	-	-
	Ecological interactions and evolutionary processes	No	-	-	-
Photosynthesis	Production	No	-	-	-
Primary production	Primary production	Yes	Unlikely	Moderate	Medium
	Secondary production	Yes	Extremely unlikely	Minor	Low
Soil formation	Soil formation	No	-	-	-
Air quality regulation	Air quality regulation	No	-	-	-
Climate regulation	regional and local climate regulation	No	-	-	-
Water regulation	water regulation (timing)	Yes	Almost certain	Moderate	High
Erosion regulation	erosion regulation	Yes			
Water purification	Water purification (quality)	No	-	-	-
	Waste assimilation	No	-	-	-
	Water provisioning (quantity)	Yes	Almost certain	Minor	Medium
Disease regulation	Avoidance of infection	No	-	-	-
Pest regulation/Biological control	Biological control	Yes	Possible	Minor	Medium
Pollination	Pollination	No	-	-	-
Seed dispersal	Other ecological interactions (other than pollination and biological control)	No	-	-	-
Natural hazard regulation	Formation of physical barriers	No	-	-	-
	Formation of species habitat	Yes	Possible	Minor	Medium
	Formation of pleasant scenery	No			
	Species diversification	Yes	Unlikely	Minor	Low
	Genetic diversification	Yes	Unlikely	Minor	Low
Fresh water	Freshwater	Yes	Unlikely	Moderate	Medium
Food	Food	No	-	-	-
Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	No	-	-	-
	Energy of different types, including working animals and hydropower				
Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	No	-	-	-
Materials: sand/pebbles, clay		No	-	-	-
Genetic resources	Currently unknown benefits	No	-	-	-
Spiritual and religious values	Spiritual/cultural wellbeing	No	-	-	-
Inspiration	Psychological wellbeing	No	-	-	-
Knowledge systems (traditional and formal)	Knowledge	No	-	-	-
Educational values	Research and education	Yes	Extremely	Minor	Low

ES type	Beneficial ecosystem processes	Affected?	L	C	R
			unlikely		
Aesthetic values	Aesthetic benefits	Yes	Very unlikely	Moderate	Low
Sense of place	Psychological wellbeing?	No	-	-	-
Cultural heritage values	Psychological wellbeing?	No	-	-	-
Cultural diversity	Psychological wellbeing?	No	-	-	-
Recreational	Recreation	No	-	-	-
Ecotourism	Tourism	Yes	Very unlikely	Moderate	Low
	Pets, garden plants	No	-	-	-
	Avoidance of injury	No			
	Avoidance of pollution	Yes	Possible	Minor	Medium
	Physical exercise	No			
	private property and infrastructure	Yes	Unlikely	Minor	Low

Scenario 2: Improved ecological category

Environmental effect statement:

Hazard and effect description:

Both during the filling up and operation of the dam, drought flows and maintenance low flows will be released. The assurance of these environmental flows will maintain the river in its status as a perennial river. Maintenance highs (spates) will be used to fill up the dam and only 11.5% MAR will be released as maintenance highs other than when the dam is full.

The higher percentage of MAR released as maintenance low and high flows will provide hydrological conditions closer to natural flow. The dam itself will still present a barrier for ecological interactions and processes taking place up and down the length of the river and riparian zone. This will largely affect invertebrates and seed dispersal.

Continuous irrigation of sugarcane fields will result in some return flow downstream of the dam even during very dry periods. Combined with the increased supply of nutrients from the sugarcane agriculture, this would result in threat of nitrate impacts of water resources. There would be an increase in phosphorous (P) in soils under sugarcane agriculture as a result of regular fertilizer inputs. The higher environmental flows in this scenario are important to flushing the system, providing better dilution and sustaining healthy channel and riparian vegetation.

Scope of consequence:

The construction of a dam in the Sand River, establishment of an irrigated sugarcane project and management of the river SWR as ecological category B through appropriate environmental releases from the new dam will result in:

- An increase in nutrients to the system
- A dam would cut off Class I and II floods but Class III usually go over. Class I and II floods are important because these flood riparian vegetation far from the main channel. Large floods are also important for geomorphological processes, spread of seeds, habitat change and purge of alien invasive species. So these 1:5 and 1:10 yr events are important for flushing out the system.

- To maintain a B hydrological category downstream, the following environmental releases will take place (as a percentage of MAR): a minimum of 6% during drought release (7.02 Mm^3), 21% maintenance low flow (24.57 Mm^3), and 11.5% maintenance high release (13.5 Mm^3).
- Water availability will increase overall as a result of the dam water storage and the drought flows downstream of dam, which assure the Reserve. Higher environmental flows will result in their being less assurance of supply for sugarcane irrigation, or a smaller portion of area should be planted.

Outcome statement:
Construction of dam and irrigation project and management of river water resources in a B ecological category will still affect core ecosystem processes such as nutrient cycling, production, soil formation, weathering and erosion processes, and some ecological interactions and evolutionary processes in blocking the corridor function of the Sand River.

Regulating services of erosion regulation, water regulation (timing), and other ecological interactions will be affected. Due to the maintenance of improved environmental flows in this scenario, the effects on ecosystem benefits are minimal, other than to avoidance of pollution as a result of the sugarcane irrigation. The dam will result in long-term effects on services such as species and genetic diversification as it lies in an important corridor for ecosystem function, that do not translate easily to effects on the benefits humans receive, but rather just a lowering of resilience.

Likelihood of outcome: Extremely unlikely

Risk assessment: (L = likelihood, C = consequence, R = risk)

ES type	**Beneficial ecosystem processes**	**Affected ?**	**L**	**C**	**R**
	weathering/erosion	No	-	-	-
Nutrient cycling	nutrient cycling	No	-	-	-
Water cycling	water cycling	No			
	Ecological interactions and evolutionary processes	No	-	-	-
Photosynthesis	Production	No	-	-	-
Primary production	Primary production	No	-	-	-
	Secondary production	Yes	Extremely unlikely	Moderat e	Low
Soil formation	Soil formation	No	-	-	-
Air quality regulation	Air quality regulation	No	-	-	-
Climate regulation	regional and local climate regulation	No	-	-	-
Water regulation	water regulation (timing)	Positive	-	-	-
Erosion regulation	erosion regulation	No	-	-	-
Water purification	Water purification (quality)	No	-	-	-
	Waste assimilation	No	-	-	-
	Water provisioning (quantity)	Yes			
Disease regulation	Avoidance of infection	No	-	-	-
Pest regulation/Biological control	Biological control	No	-	-	-
Pollination	Pollination	No	-	-	-
Seed dispersal	Other ecological interactions (other than pollination and biological control)	No	-	-	-
Natural hazard regulation	Formation of physical barriers	No	-	-	-
	Formation of species habitat	No	-	-	-
	Formation of pleasant scenery	No			
	Species diversification	Yes	Extremely unlikely	Minor	Low
	Genetic diversification	Yes	Extremely unlikely	Minor	Low
Fresh water	Freshwater	No	-	-	-
Food	Food	No	-	-	-
Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	No	-	-	-
	Energy of different types, including working animals and hydropower				
Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	No	-	-	-
Materials: sand/pebbles, clay		No	-	-	-
Genetic resources	Currently unknown benefits	No	-	-	-
Spiritual and religious values	Spiritual/cultural wellbeing	No	-	-	-
Inspiration	Psychological wellbeing	No	-	-	-
Knowledge systems (traditional and formal)	Knowledge	No	-	-	-
Educational values	Research and education	No	-	-	-
Aesthetic values	Aesthetic benefits	No	-	-	-
Sense of place	Psychological wellbeing?	No	-	-	-
Cultural heritage values	Psychological wellbeing?	No	-	-	-
Cultural diversity	Psychological wellbeing?	No	-	-	-
Recreational	Recreation	No	-	-	-
Ecotourism	Tourism	No	-	-	-
	Pets, garden plants	No			
	Avoidance of injury				
	Avoidance of pollution				
	Physical exercise				
	private property and infrastructure				

iii. Determination of ecosystem services at risk under each scenario

Ecosystem services at risk are summarized in table 30.

Table 30. Summary table of comparative risk assessment results for significant water resources with each integrated unit of analysis in the Sand River Catchment under two water resource management scenarios with regards to their effect on ecosystem services (as defined by the MA 2003 categorised as supporting, regulating, provisioning and cultural, and Balmford et al., 2008, where core ecosystem processes (light grey), beneficial ecosystem processes (grey) and benefits (dark grey with white text) are categorized). Risk is categorised as low, medium, high or very high.

Integrated Unit of Analysis			IUA 5				IUA 6			
Significant water resources (SWR)			Rivers		Groundwater		Rivers		Groundwater	
ES category	ES (MA, 2003)	ES (Balmford et al., 2008)	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Supporting = ecosystem functions necessary to maintain other services	Erosion regulation (over the long term)	weathering/erosion	Low-Medium	Low-Medium	-	-	-	-	-	-
	Nutrient cycling	nutrient cycling	High	High	-	-	Medium	-	-	-
	Water cycling	water cycling	-	-	Low	Low	-		-	-
		Ecological interactions and evolutionary processes	High	High	-	-	-	-	-	-
	Photosynthesis	Production	High	High	-	-	-	-	-	-
	Primary production	Primary production	High	Medium	-	-	Medium	-	-	-
		Secondary production	High	Low	-	-	Low	Low	-	-
	Soil formation	Soil formation	High	High	-	-	-	-	-	-
Regulating = benefits obtained from ecosystem processes	Air quality regulation	Air quality regulation	Low	-	-	-	-	-	-	-
	Climate regulation	regional and local climate regulation	-	-	-	-	-	-	-	-
	Water regulation	water regulation (timing)	Very High	Low	-	-	High	-	-	-
	Erosion regulation	erosion regulation	Medium	Medium	-	-		-	-	-
	Water purification	Water purification (quality)	High	-	-	-	-	-	-	-
		Waste assimilation	-	-	-	-	-	-	-	-
		Water provisioning (quantity)	Medium	-	-	-	Medium		-	-
	Disease regulation	Avoidance of infection	High	-	Low	-	-	-	-	-
	Pest regulation/Biological control	Biological control	Low	Low	-	-	Medium	-	-	-
	Pollination	Pollination	-	-	-	-	-	-	-	-
	Seed dispersal	Other ecological interactions (other than pollination and biological control)	Medium	Medium	-	-	-	-	-	-
	Natural hazard regulation	Formation of physical barriers	Low	-	-	-	-	-	-	-
		Formation of species habitat	Medium	-	-	-	Medium	-	-	-
		Formation of pleasant scenery	-	-	-	-	-	-	-	-
		Species diversification	Low	Low	-	-	Low	Low	-	-

Integrated Unit of Analysis			IUA 5				IUA 6			
Significant water resources (SWR)			Rivers		Groundwater		Rivers		Groundwater	
ES category	**ES (MA, 2003)**	**ES (Balmford et al., 2008)**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**	**Scenario 1**	**Scenario 2**
		Genetic diversification	Low	Low	-	-	Low	Low	-	-
Provisioning = products obtained from aquatic ecosystems	Fresh water	Freshwater	High	-	Low	?	Medium			
	Food	Food	High	Low	-	-	-	-	-	-
	Fibre (timber, cotton, hemp, silk, wood fuel)	Raw materials: different types	High	-	-	-	-	-	-	-
		Energy of different types, including working animals and hydropower	High	-	-	-	-	-	-	-
	Biochemical and pharmaceutical products	Synthetic, cultivated, wild species medicines	Medium	-	-	-	-	-	-	-
	Materials: sand/pebbles, clay		Low	-	-	-	-	-	-	-
	Genetic resources	Currently unknown benefits	-	-	-	-	-	-	-	-
Cultural = nonmaterial benefits obtained from aquatic ecosystems	Spiritual and religious values	Spiritual/cultural wellbeing	Low	-	-	-	-	-	-	-
	Inspiration	Psychological wellbeing	Low	-	-	-	-	-	-	-
	Knowledge systems (traditional and formal)	Knowledge	-	-	-	-	-	-	-	-
	Educational values	Research and education	-	-	-	-	Low	-	-	-
	Aesthetic values	Aesthetic benefits	Low	-	-	-	Low	-	-	-
	Sense of place	Psychological wellbeing?	-	-	-	-	-	-	-	-
	Cultural heritage values	Psychological wellbeing?	- , -	-	-	-	-	-	-	-
	Cultural diversity	Psychological wellbeing?	-	-	-	-	-	-	-	-
	Recreational	Recreation	Medium	-	-	-	-	-	-	-
	Ecotourism	Tourism	-	-	-	-	Low	-	-	-
		Pets, garden plants	-	-	-	-	-	-	-	-
		Avoidance of injury	Medium	Low	-	-	-	-	-	-
		Avoidance of pollution	High-Very High	High	-	-	Medium	-	-	-
		Physical exercise	-	-	-	-	-	-	-	-
		private property and infrastructure	Medium	Low	-	-	-	-	-	-

PHASE 3. Valuation of the Hypothetical Case

In summary of the ecosystem services to be valued, the following ecosystem service benefits identified in Phase 2 are to be valued:

- Fresh water provisioning in
  - IUA 5
  - IUA 6
- Fibre, Food and biochemical and pharmaceutical products provisioning in
  - IUA 5
  - IUA 6
- Grazing in
  - IUA 5
- Inspiration, recreation and eco-tourism in
  - IUA 6
- Human health effects in
  - IUA 5

3A. Selection of valuation techniques

Table 31 summarises the provisioning and cultural ecosystem services to be valued, their underlying regulating services, and the valuation methods followed for each. Each line in the table represents a causal chain of events affected by either Scenario 1 or Scenario 2 of the case study.

Table 31. Selection of valuation techniques for the case study.

Causal chain	Provisioning and cultural services	Underlying regulatory services * (where applicable)	Valuation methods
1	Fresh water provisioning	Water regulation Water purification Erosion regulation	Market prices Production functions
2	Fibre, Food and Biochemical and pharmaceutical products provisioning	Water regulation Erosion regulation	Market prices Production function
3	Grazing	Water regulation and habitat provisioning (after Balmford et al., 2008)	Benefit transfer from household income studies
4	Inspiration, Recreation and Eco-tourism	Water regulation Water purification Erosion regulation Seed dispersal	Market prices Travel cost method Production functions
5	Human health effects	Disease regulation	Cost of illness

* A variety of supporting services underlie (support) ecological processes and therefore the regulatory, provisioning and cultural services.

3B. Data collection

i. Background information on IUA 5

The official source of regional macro-economic indicators is Statistics South Africa (www.statssa.gov.za). The study area falls within the Bushbuckridge District Municipality of the Mpumalanga Province (since 2006) following the disestablishment of the Bohlabela District Municipality of the Limpopo Province. Various publications on the socio-economy of Limpopo and Mpumalanga are available from this website. Data relevant to the analysis of ecosystem services identified were extracted from the Limpopo Provincial Profile 2004 (http://www.statssa.gov.za/publications/Report-00-91-09/Report-00-91-092004.pdf) and are reported below.

Limpopo covers a land area of 12,391,000 ha, or 10.2% of the total land area of South Africa. In 2001, the total population of Limpopo was 5.27 million (11.8% of the South African population) of which 89.3% lived in non-urban areas. Black African people accounted for 97.2% of the population. According to the General Household Survey 2004, there were a total of 1,283,000 households in Limpopo.

Of the Limpopo households, 58.4% used wood for cooking.

Within the Bohlabela district resided 11.3% of the population of Limpopo in the settlement types as set out in Table 32 below.

Table 32. Households by type of settlement in Zone 2. This includes only IUA 5 as IUA 6 comprises protected area.

Type of settlement	# households
Sparse (10 or fewer households)	344
Tribal settlement	169,815
Farm	205
Small holding	-
Urban settlement	1,933
Informal settlement	-
Recreational	566
Industrial area	-
Institution	-
Hostel	-
Total	172,863

Of the Bohlabela Households, 89,690 (70%) used wood as a source of energy. Households in Bohlabela collecting water from natural sources were as follows (2001):

- From boreholes, 7,841
- From springs, 4,976
- From rain-water tanks, 364
- From dams/pools/stagnant water, 3,325, and
- From rivers/streams 7,898.

In 2004, Limpopo contributed 6,7% to the total Gross Domestic Product (GDP) of South Africa. Limpopo had the lowest real economic growth rate of 2.7%.

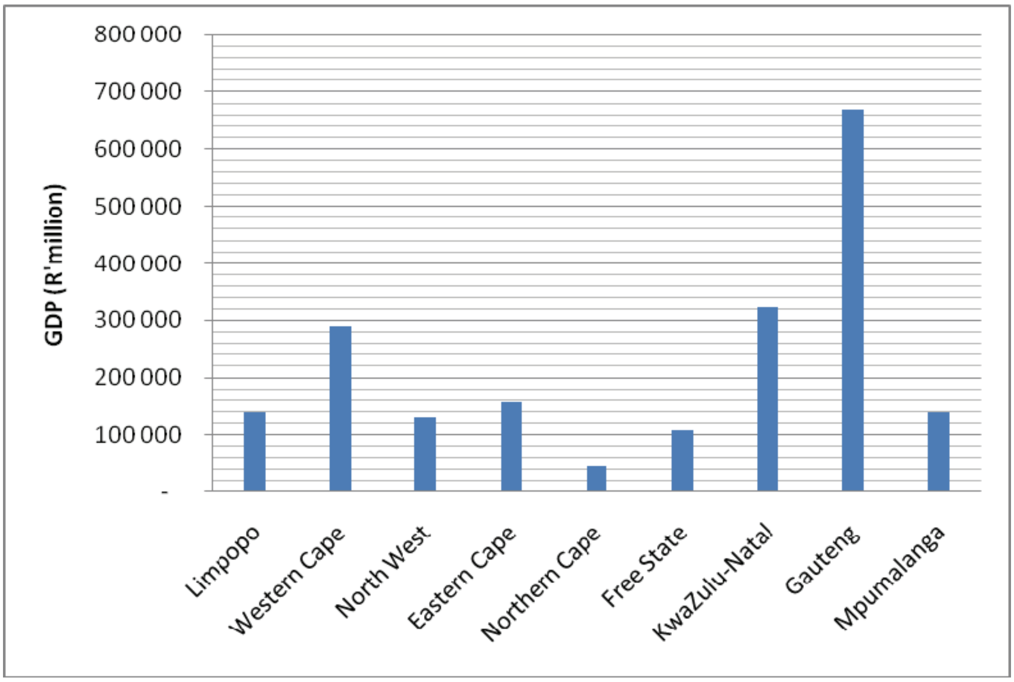


Figure 30. Comparison of the regional GDP contributions by province, to the national economy of SA.

For GDPR at current prices, mining and quarrying remained the highest contributor to the economy of Limpopo over the period 1996 to 2004, which was 21.7%. The lowest contributors were construction (1.4%), electricity, gas and water (2.8%) and agriculture, forestry and fishing (3.1%).

Table 33. GDPR and value added estimates per industry at constant 2000 prices, Limpopo, 1996-2004 (Rand million)

Industry	1996	1997	1998	1999	2000	2001	2002	2003	2004
Agriculture, forestry and fishing	1,134	1,116	1,386	1,508	1,473	1,532	1,700	1,686	1,566
Mining and quarrying	11,176	11,844	12,438	12,472	12,250	13,892	14,913	15,424	15,718
Manufacturing	2,067	2,123	2,106	2,135	2,265	2,342	2,379	2,345	2,457
Electricity, gas and water	1,542	1,619	1,646	1,596	1,688	1,616	1,677	1,948	2,030
Construction	1,189	1,190	1,125	1,058	1,191	1,190	1,325	1,144	1,224
Wholesale and retail trade; hotels and restaurants	6,342	6,486	6,611	6,989	7,482	8,003	8,065	8,187	8,453
Transport, storage and communication	3,137	3,514	3,835	4,269	4,537	5,434	6,324	6,573	6,721
Finance, real estate and business services	8,862	9,146	9,175	9,055	8,503	9,138	9,257	9,718	10,288
Personal services	2,445	2,450	2,603	2,701	2,829	2,894	2,968	3,086	3,121
General government services	8,910	10,768	11,284	11,504	11,318	11,219	11,162	11,270	11,434
Taxes less subsidies	3,122	3,526	3,627	3,546	3,419	3,714	3,865	4,005	4,202
GDPR at market prices	**51,922**	**55,779**	**57,834**	**58,832**	**58,955**	**62,975**	**65,637**	**67,389**	**69,218**

The proportion of the land used as farming area in Limpopo in 2001 was 103 million hectares, which constituted 32,8% of the farming area in the country. There were 278,000 farming operations in the province. This constituted 25.5% of the entire farming operations in South Africa. Limpopo had the second lowest number of farming units (2 915) with an asset market value of R9 720 910 million.

Of the employed, a greater percentage in Limpopo worked in the informal sector (33.5%) than in the country as a whole (22.2%). This reflects the relative lack of formal sector employment opportunities in Limpopo. The wholesale and retail trade was the largest employer in Limpopo, with 28.3%, followed by community, social and personal services with 21.3%. Agriculture, hunting, forestry and fishing accounted for 12.9% of employment. There were 112,000 people employed in the craft and related trades (12.7%).

Table 34. Employment by industry, Limpopo, September 2004

Economic sector	**N ('000)**	**%**
Agriculture, hunting, forestry and fishing	114	12,9
Mining and quarrying	61	7,0
Manufacturing	67	7,6
Electricity, gas and water supply	8	0,9
Construction	58	6,5
Wholesale and retail trade	250	28,3
Transport, storage and communication	29	3,2
Financial intermediation, insurance, real estate and business services	42	4,8
Community, social and personal services	188	21,3
Private households with employed persons	65	7,4
Total	883	**100,0**

The per capita GDP at R26,200 is significantly lower than the national average of approximately R44,400 per person per year (see Table 35).

Table 35. Mpumalanga covers 7% of SA's land area, hosts 7% of the residents of the country and contributes 7% to GDP (2007).

Province	Area		Population		Density	GDP		GDP/capita
	km²		#		#/km²	R'million		R/person
South Africa	**1,219,090**		**44,819,778**		**37**	**1,999,087**		**44,603**
Limpopo	123,910	10%	5,273,642	12%	43	138,163	7%	26,199
Western Cape	129,370	11%	4,524,335	10%	35	290,607	15%	64,232
North West	116,320	10%	3,669,349	8%	32	129,872	6%	35,394
Eastern Cape	169,580	14%	6,436,763	14%	38	155,520	8%	24,161
Northern Cape	361,830	30%	822,727	2%	2	44,159	2%	53,674
Free State	129,480	11%	2,706,775	6%	21	108,892	5%	40,229
KwaZulu-Natal	92,100	8%	9,426,017	21%	102	324,216	16%	34,396
Gauteng	17,010	1%	8,837,178	20%	520	668,926	33%	75,695
Mpumalanga	***79,490***	***7%***	***3,122,990***	***7%***	***39***	***138,732***	***7%***	***44,423***

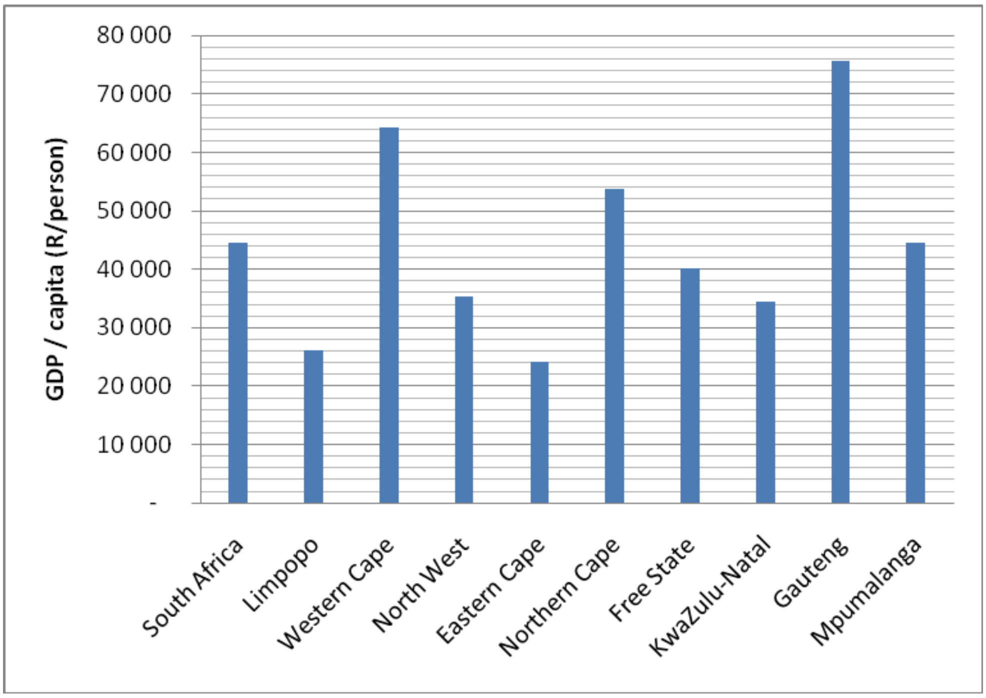


Figure 28. Comparison of the provincial GDP productivities.

ii. Background information on IUA 6

IUA 6 comprises protected areas in the form of private nature reserves. This includes the following nature reserves:

- Sabi-Sabi
- Sabi-Sand
- Mala-Mala
- Londolozi.

The tourism industry is an important contributor to economic development and growth in the Mpumalanga Province.

Data available from SA Tourism indicates as follows, for the whole Province:

- The market size for Tourism in the Categories A and B trip purposes (as defined in the Table 36 below), as measured by total direct spend by tourists in Mpumalanga in 2007, was approximately R1.5 billion.
- The single largest earner of tourism revenues in the Categories A and B are holiday trips (R786 million), followed by Business Tourism (R263 million), Shopping (R161 million), Medical (R152 million) and Religious Tourism (R139 million).
- This comprised more than 720,000 trips per year (domestic and international combined).
- Domestic tourism, measured as number of trips taken, exceeded international tourism by 3.5 times.
- International tourism spend per trip, at R4,280/trip, exceeded domestic tourism (R1,460/trip) by 2.9 times.
- The largest segment was VFR, a Category C (as defined in the Table below).

The weighted average contribution of tourism in Mpumalanga to GDP was R617 million.

Table 36. Analysis of the tourism industry in Mpumalanga. Comparison of Domestic and International Tourism by trip purpose category (Prime Africa Consultants – Internal Report).

Category	Trip purpose	Domestic			International			Total
		Tourists	Trips	Direct Spend	Tourists	Trips	Direct Spend	Direct Spend
		#	#	R'million	#	#	R'million	R'million
A	Holiday	125,000	307,000	440	n/a	80,900	346	786
	Business Tourism	43,000	106,000	165	n/a	23,000	98	263
	Sub-total	**168,000**	**413,000**	**605**	**n/a**	**103,900**	**445**	**1,049**
B	Shopping	-	-	-	n/a	37,700	161	161
	Religious	55,000	135,000	124	n/a	3,500	15	139
	Medical	5,000	13,000	91	n/a	14,400	62	152
	Sub-total	**60,000**	**148,000**	**214**	**n/a**	**55,600**	**238**	**452**
C	VFR	434,000	1,069,000	550	n/a	77,300	331	880
	Business travel	n/a	n/a	n/a	n/a	34,200	146	146
	Trade	n/a	n/a	n/a	n/a	39,000	167	167
	Sub-total	**434,000**	**1,069,000**	**550**	**n/a**	**150,500**	**644**	**4,197**
A+B	**Total**	**228,000**	**561,000**	**819**	**n/a**	**159,500**	**683**	**1,502**

3C. Conduct valuation

i. *Project benefits*

Fresh water provisioning

The key benefit from the proposed project is the delivery of additional fresh water as an input to agricultural production. The construction of the Gevonden Dam will capture mean annual runoff (MAR) and so increase the fresh water yield of the system. The paragraphs below describe the important concepts of MAR and yield (from the National Water Resources Strategy 2004).

Fresh water available from scenarios and its implication for ecological category

The Gevonden Dam would:

- In Scenario 1:
  - Make 28 million m^3 per year of fresh water available to the irrigation of sugar-cane;
  - Make 2 million m^3 per year of fresh water available to the ecological Reserve, which results in an ecological category C/D.
- In Scenario 2:
  - Make 20 million m^3 per year of fresh water available to the irrigation of sugar-cane;
  - Make 10 million m^3 per year of fresh water available to the ecological Reserve, which results in an ecological category B.

User sector		Water requirement/impact on yield/streamflow reduction (SFR) (Mm-3/yr)				
		Sabie River sub-catchment	Sand River sub-catchment	IU5&IU6		
				Current	Scenario 1	Scenario 2
		million m^3	million m^3	million m^3		
Irrigation	current	54	11	0	0	0
	new				28	20
Urban		13	9	3	3	3
Rural		2	2	1	1	1
Industrial and mining		Negligible	0	0	0	0
Afforestation		34	3	0	0	0
Water requirements	local requirements	103	25	4	32	24
	transfer out	8	0	0	0	0
	Total	111	25	4	32	24
Gevonden Dam	additional yield			0	30	30
Available water	local yield	149	20	4	6	-2
	transfer in	0	8	0	0	0
	total	149	28	4	36	28
Gross surface water resource		293	15	8.5	8.5	8.5
-ER*		-127	-3	-4	-2	-10
-Invasive alien plants		-24	-3	-1	-1	-1
Net surface water resource		142	9	3.5	5.5	-2.5
Groundwater		2	1	0.5	0.5	0.5
Return flows		5	10	0	0	0
Yield Balance		**38**	**3**	**0**	**4**	**4**

*Ecological category				C	C/D	B

Sources: Inkomati ISP and SPATSIM modelling

Figure 29. Water requirements, available water, ecological Reserve and the yield balance for the Sabie River, the Sand River and IUAs 5 and 6 for the three scenarios studied.

Sugarcane farming economics

The additional fresh water will be used for sugarcane irrigation.

The water allocation for irrigation agriculture in the study area is 8,000 m^3/ha/annum (DWAF, 2002a). This means that:

- For Scenario 1, 3,500 ha will be established under sugarcane, and
- For Scenario 2, 2,500 ha will be established under sugarcane.

Sugarcane in Mpumalanga is typically grown on a 6-year, multiple ratoon rotation, yields 78.9 tons/ha/a of cane (at 12.3 tons/ha/a sucrose) and sold for R1,702/ton (recoverable value) in 2008 (South African Sugar Association).

The growers will comprise emerging small farmers, contracted to the sugarcane value adding facility. The average farm size of these growers will be 6.8 hectares with the smallest farm recorded ranging between 3.7 hectares and the largest 30 hectares (Sartorius, 2002).

The value of irrigation water

The value of the irrigation water resulting from the project may be calculated as the product of the administered tariff of water and the volume of water delivered by the project. The administered tariff of irrigation water in the study area is expected to be 1.50 cents/m^3 water (Statistics SA), and therefore the value of the water yielded by the dam would be R0.45 million per year (1.50 cents/m^3 x 30 million m^3.)

The contribution of this to GDP is 35.2% (Statistics SA Supply and Use Table 2002) or R0.16 million.

However, this is an inadequate measure of the value of water. The value of water is better measured through its input in creating a viable economic development project, through, the proposed sugarcane irrigation project.

Water as an input to a viable project

Irrigation water from the Gevonden Dam is a key enabling input into the successful establishment of the sugarcane irrigation scheme. Tables 37 and 38 below simulates the cash flows for each of the two Scenarios under conditions that will enable a project with an internal rate of return at a low hurdle rate of 8%. These cash flows were estimated using market and farm budget data sourced from the South African Sugar Association and own sources. Capital investment requirements and depreciation were factored into annualized transport and overhead costs.

The additional production income generated as a result of the project is therefore (from year 3 onwards, R57.7 million per year in Scenario 1, and R41.2 million in Scenario 2.

The value added component of sugarcane farming is 60.3% (Olbrich et al., 2002). Therefore the contributions of the project to GDP under these two scenarios are:

- For Scenario 1 = R34.8 million per year
- For Scenario 2 = R24.9 million per year.

These values include the value of employment opportunities generated.

These values represent the direct benefits to the local, regional and national economy.

Without the fresh water yield contributed by the Gevonden Dam, these benefits would not be possible.

Beyond the direct benefits of the project estimated here, the project, in both scenarios, would also have indirect benefits to the macro economy. These are discussed in the following section.

Table 37. Cash flow simulation for the irrigation project under Scenario 1

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Sugarcane Yield	tons	0	138,121	276,243	276,243	276,243	276,243	276,243	276,243	276,243	276,243
Production Income	R'million	-	28.8	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7
Cost of Production											
Fertiliser	R'million	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
Chemicals	R'million	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Fuel	R'million	0.3	1.66	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32
Transport	R'million	0.6	3.08	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17
Gross Profit	R'million	-10.9	14.1	38.2	38.2	38.2	38.2	38.2	38.2	38.2	38.2
				66%	66%	66%	66%	66%	66%	66%	66%
Overhead costs											
Labour	R'million	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
Maintenance	R'million	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Administration	R'million	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Electricity & Water	R'million	1.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Other	R'million	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Net Profit		-38.6	-14.3	9.8	9.8	9.8	9.8	9.8	9.8	9.8	9.8
				16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%
Internal Rate of Return		**8.00%**									

Table 38. Cash flow simulation for the irrigation project under Scenario 2

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Yield	tons	0	98,658	197,316	197,316	197,316	197,316	197,316	197,316	197,316	197,316
Production	R'million	-	20.6	41.2	41.2	41.2	41.2	41.2	41.2	41.2	41.2
Cost of Production											
Fertiliser	R'million	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Chemicals	R'million	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Fuel	R'million	0.2	1.19	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
Transport	R'million	0.4	2.20	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41
Gross Profit	R'million	-7.8	10.1	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3
				66%	66%	66%	66%	66%	66%	66%	66%
Overhead costs											
Labour	R'million	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Maintenance	R'million	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Administration	R'million	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Electricity & Water	R'million	1.1	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Other	R'million	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Net Profit		-27.6	-10.2	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
				16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%

Internal Rate of Return 8.00%

Indirect benefits of the sugarcane irrigation project

The indirect benefits of the project result from the transactions of the project with its customers (forward linkages in the sugar value chain) and suppliers (backward linkages in the sugar value chain).

The indirect benefit of the project may be measured through its multiplier effect which reports the ratio of total direct and indirect benefits to that of the direct benefits.

These benefits can be estimated using an Input-Output matrix or Social Accounting Matrix. These modelling tools are however, often not available for a specific area and are expensive to construct. In the absence of such tools, value chain analysis may be conducted using primary or secondary data sources.

The sugar value chain starts with the production of irrigated sugar cane, grown on a six-year rotation. The cane is converted, through a milling process, to raw sugar. The raw sugar is refined for use in direct consumption and/or in the food and beverage industry. By-products from the sugar milling process are the molasses and the fibrous bagasse. Molasses and bagasse are converted to animal feed by feed processing industries, while bagasse is also converted to paperboard and other composite board products. High value alcohol products are other by-products from the process. The irrigated sugar value chain has been described and analysed in Olbrich et al. (2002). Figure 33 shows the sugarcane value chain. The highlighted industries comprised more than 80% of value addition in the chain and these, together with the backward linkages, were selected for value chain analyses in K5/1048.

The total GDP multiplier for production only, from literature, varies between 1.28-1.61, while the total economy multiplier, from the Social Accounting Matrix, is approximately 3.46 (see Table 39 below).

Olbrich et al. (2002) estimated the production multiplier for sugarcane in Mpumalanga to be 1.36. This means that, for every R1 of GDP produced by the irrigation project, another R0.36 of GDP is produced in the rest of the production economy only. The social multiplier of 3.46 implies that, for every R1 of GDP produced by the irrigation project, another R2.46 of GDP is produced in the rest of the economy. Similarly, employment multipliers may be calculated.

It is therefore clear that the proposed irrigation project holds significant direct economic benefits for the local and regional economy of Mpumalanga. The project would also be expected to produce very significant indirect benefits through its multiplier effects.

It is furthermore clear that, the larger the project, the larger the economic benefit. This analysis would therefore favour Scenario 1.

However, Scenario 1 comes at the cost of an ecological category C/D river in IUA 5 and 6, as opposed to an ecological category B river in Scenario 2. The question is now what benefits may be gained from the improved river category in Scenario 2 and whether this changes the decision to accept an improved ecological category (preliminary Management Class at this stage) at the cost of a smaller irrigation project.

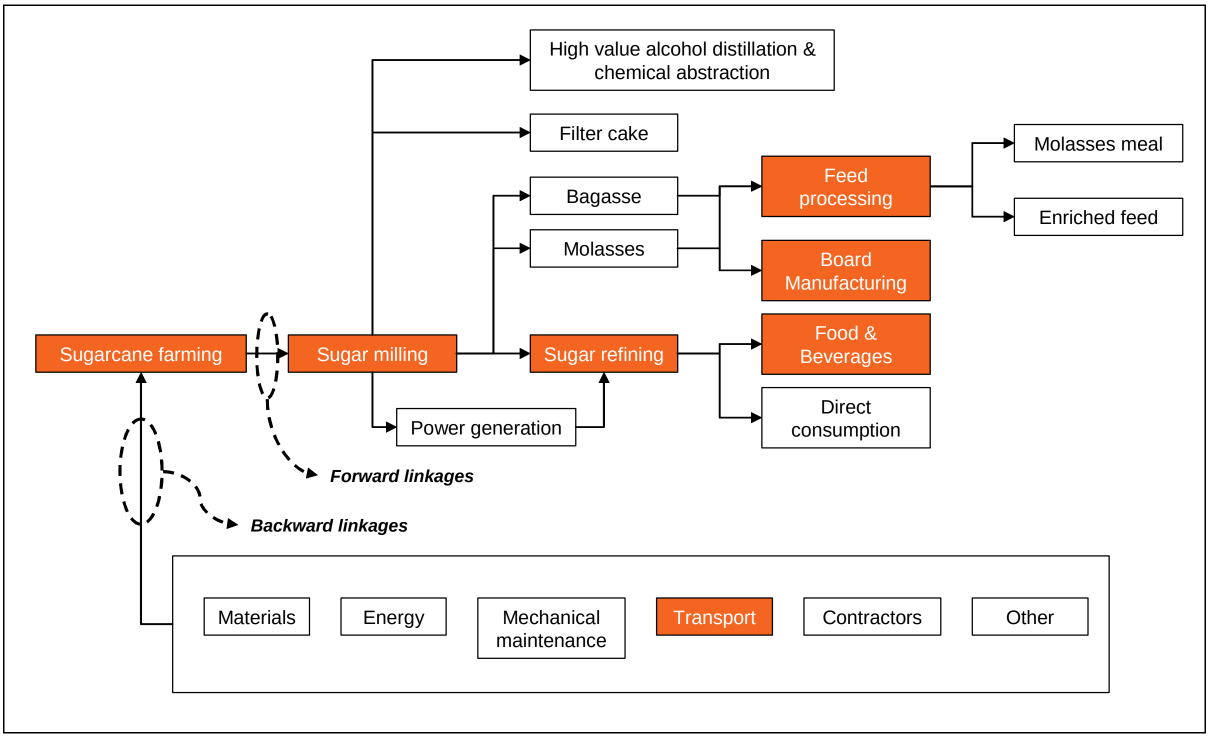


Figure 30. The irrigated sugarcane value chain

Table 39. Estimates of agricultural multipliers in South Africa. The total GDP multiplier for production only varies between 1.28-1.61, while the total economy multiplier, from the Social Accounting Matrix, is approximately 3.46.

Study/Source	Agriculture	Sugarcane	Citrus fruit	Sub-tropical fruit	Forestry	Sugar refining	Food processing	Wood products	Pulp and Paper
Production multipliers									
I-O Based	*1.49-2.13*	*1.28-1.61*	*1.625*	*1.33-1.50*	*1.42-2.15*	*1.21-2.43*	*1.26-2.73*	*1.52-2.17*	*1.5-2.09*
1988 RSA I-O Tables	1.49	NA	NA	NA	NA	1.21	1.26	1.52	1.5
1993 RSA I-O Tables	2.127	NA	NA	NA	NA	2.434	2.731	2.171	2.03
1995 RSA I-O Tables	1.846	1.611	NA	1.381	2.148	2.013	2.155	2.007	2.089
1996 RSA I-O Tables	1.822	1.423	1.625	1.331	1.524	2.262	2.337	1.94	2.08
Kirsten and van Zyl (1990)	1.863	NA	NA	NA	NA	NA	NA	NA	NA
Hassan (1998)	1.870	1.28	NA	1.500	1.42		NA	NA	NA
SAM Based									
1988 RSA SAM[1]	2.48	NA	NA	NA	NA	NA	3.39	3.18	3.04
Total SAM multipliers	*4.39-5.54*	*3.46*	NA	*NA*	*NA*	*5.06*	*5.44*	*5.38*	*5.24*
1988 RSA SAM[1]	4.39	NA	NA	NA	NA	5.06	5.44	5.38	5.24
Hassan (1998)	5.540	3.46	NA	5.84	NA	NA	NA	NA	NA
Other studies									
Woodhouse and Hassan (1999)	1.81	1.61	2.11	1.63	1.85	NA	NA	NA	NA
International Average[2]	1.26-2.88				1.12-1.61		1.33-1.98	1.42	1.53
Africa average[2]	1.48-2.88						1.33-1.98		
Asia average[2]	1.64-1.82								

Sources: The 1988 and 1993 I-O and SAM tables are produced by Statistics South Africa (SSA, 1989 and 1995). The 1995 I-O table is compiled by WEFA (1995). The 1996 I-O tables have been compiled by Conningarth (1998b).
From Townsend and McDonald (1998)
Olbrich et al. (2002)

Table 40. Total value added in sugarcane in R/ton cane and R/m3 water (Mpumalanga 1998 prices)

	Sugar Farming
Direct VAD in sector (R/ton cane)	**75.90**
Other backward sectors	26.95
Total VAD multipliers (R/R VAD in sector)	**1.36**
Total VAD in chain (R/ton cane)	102.85
Total VAD multiplier (R/R)	1.36
Water use in primary sector (m^3/ton cane)	82.2
Total VAD in R/m^3 water in primary sector	**1.3**
Total VAD for industry in R/ton cane	814.701
Total VAD for industry in R/m^3 primary	9.91

Source: Olbrich et al. (2002)

Table 41. Total Employment in Sugar (full-time jobs in man-days (MD) per ton cane and per m^3 water (Mpumalanga, 1998)

	Sugar Farming
Direct VAD in sector (R/ton cane)	75.9
Direct employment in sector (MD/ton cane)	1.03
Other backward sectors	0.43
Total employment multipliers (MD/MD) in sector	1.42
Total employment in chain (MD/ton cane)	1.46
Total employment multiplier (MD/MD)	1.42
Water use in primary sector (m^3/ton cane)	82.2
Total employment in MD/m^3 water in primary	0.018
Total employment for industry in MD/ton cane	19.355
Total employment for industry in MD/m^3 primary	0.2355

Source: Olbrich et al. (2002)

ii. Other Fresh water effects resulting from the development project

There are a number of beneficiaries of fresh water in IUA 5 and 6, additional to the new sugarcane farmers proposed by the case study project. These include:

- Subsistence cattle farmers watering their cattle
- Households collecting water from natural sources
- The eco-tourism sector in IUA 6 who benefits from the game water service provided by fresh water.

Households collecting water from natural sources

Many households in the study area still rely on the collection of water from the Sand River for household use. The availability of water for these uses will not be affected negatively in either Scenario, and is not further assessed.

Subsistence livestock farmers

Fresh water is an input into the production of livestock products by rural households in the study area. It is however, not the only factor of production. Other key factors of production include the carrying capacity of the land, or quantity and quality of grazing available (which in turn varies with climatic conditions), and the level of income of the household.

Provision of grazing is a separate ecosystem service discussed below. Therefore the evaluation of Scenarios 1 and 2 on livestock is addressed below.

Eco-tourism

Eco-tourism activities in IUA 6 rely on fresh water provided by the Sand River for game watering purposes. The availability of water for these uses will not be affected negatively in either Scenario, and is not further assessed. However, the reduced runoff expected under Scenario 1, coupled with non-point source pollution resulting from the sugarcane farming may detrimentally affect the water purification services of the system. A precedent for this exists in the Olifants River. Elevated levels of water pollution in the form of nutrients may lead to algal blooms and the formation of cyanobacteria, which in turn increases the risk of livestock mortality. Insufficient evidence currently exists through which to predict and value this risk. However, it remains a consideration in the evaluation.

iii. Fuel, fibre, food, small scale agriculture and biochemical and pharmaceutical products

A large body of evidence exists on the use of natural resources by rural households to support their livelihoods. This data may be used to estimate the value of changes in the supply of a variety of provisioning services, resulting from the proposed Scenarios.

In both Scenarios, the inundation of approximately 900 hectares of wetlands, rangeland and subsistence farming area will result in a substantial loss in provisioning services.

Table 42 summarises this.

Table 42. A variety of products provided as provisioning ecosystem services will reduce in output as a result of inundation of 900ha of land that is currently wetland area, or used as subsistence agriculture or rangeland. The total value of these changes in output, for both Scenarios 1 and 2, are approximately R2.63 million per year.

Products provided by the ecosystem (provisioning services)	Unit	Unit per hectare	Shadow price (Rand per unit)	Scenario 1 Change in value resulting from inundation in IUA 5 (Rand per year)	Scenario 2 Change in value resulting from inundation in IUA 5 (Rand per year)
Fuelwood	kg	4800	R 0.34	R 482,400	R 506,520
Poles	item	0	R 1.98	R 0	R 0
Fences and pens	item	0	R 0.11	R 0	R 0
Wood for tools	item	0.33	R 8.25	R 817	R 858
Edible herbs	kg	0	R 34.21	R 0	R 0
Edible fruit	kg	150	R 5.28	R 237,600	R 249,480
Thatch grass	bundles	1500	R 2.80	R 1,260,000	R 1,323,000
Weaving reeds	bundles	600	R 12.00	R 648,000	R 756,000
Construction reeds	bundles			R 0	R 0
Twig brooms	item		R 4.65	R 0	R 0
Agriculture (fields)	kg	2438	R 1.29	R 1,572,188	R 1,619,353
Total	R/year			R 4,201,004	R 4,455,211

Total area affected by inundation		ha
Wetland		90
Waterbody		10
Subsistance agriculture		500
Rangeland		300

Total riparian area affected downstream of dam	ha
Wetland	15

* Shackelton et al. 2001

** Twine et al., 2003

[2] Dovie et. al., 2004 - study site Thorndale village in Limpopo

[3] Dovie et. al., 2005 - Data in US$ thus 6.14exchange rate used, study site Thorndale village in Limpopo

[4] Shackleton, 1996

iv. Grazing

Nearly a third of households in the study area own livestock, in the form of goats and cattle (Shackleton, 2000). These households produce a range of goods and services from their livestock including draught power, transport, milk, manure, dung as a sealant, dung for burning, butchery products, hides and cash income (from sales and hiring out of draught power). In addition, ownership of larger livestock stock is an important asset in creating household wealth beyond these goods and services. A larger herd of livestock provides security during adverse economic conditions and has a cultural value during the negotiation of lobola payments (Shackleton et al., 2001).

Key inputs (or factors) in the production of livestock are household income (the ability to afford livestock), sufficient grazing and sufficient livestock watering capacity.

Riparian wetlands in the study area provide grazing for cattle during periods of severe drought (Pollard et al., 2007). Riparian wetlands forage is higher than that of the surrounding area.

The accurate analysis of the production of livestock requires a production function based on locally observed data over a number of drought cycles. In the absence of such a function, the analysis proceeds as follows:

- In both Scenarios 1 and 2 the Gevonden Dam would increase the assurance of livestock watering supply in the vicinity of the dam;
- However, the carrying capacity of the land, as influenced by climatic factors and human settlement factors, would remain a constraint to stocking numbers;
- 105 and 90 ha of wetlands respectively in Scenarios 1 and 2, providing a grazing service would be inundated by the Gevonden Dam;
- Assuming an average carrying capacity of 0.88 livestock units (LSU) per hectare, and a 75% higher carrying capacity for wetland grazing areas, and an average ownership of 3.3 LSU per household;
- The household income in the study area will reduce by approximately R0.51 million per year in Scenario 1 and R0.43 million per year in Scenario 2.

Table 43. **Estimate of the effect of dam construction on grazing by livestock.**

	Unit	Scenario 1	Source:
Carrying capacity (average)	LSU/ha	0.88	Shackleton 2000
Increased carrying capacity of wetlands		75%	Pollard 2007
Carrying capacity (wetland)	LSU/ha	1.63	calculated
Average LSU ownership per household	LSU/household	3.3	Shackleton 2000
Household revenue from cattle	R/year (2008)	9,781	Shackleton 2000
Estimate of winter grazing area lost	ha	105	
Reduction in large stock due to reduced carrying capacity	LSU	171.15	calculated
Reduction in household income in the study area	R/year (2008)	507,273	calculated

	Unit	Scenario 2	Source:
Carrying capacity (average)	LSU/ha	0.88	Shackleton 2000
Increased carrying capacity of wetlands		75%	Pollard 2007
Carrying capacity (wetland)	LSU/ha	1.63	calculated
Average LSU ownership per household	LSU/household	3.3	Shackleton 2000
Household revenue from cattle	R/year (2008)	9,781	Shackleton 2000
Estimate of winter grazing area lost	ha	90	
Reduction in large stock due to reduced carrying capacity	LSU	146.70	calculated
Reduction in household income in the study area	R/year (2008)	434,805	calculated

v. Inspiration, recreation and eco-tourism

The value of a number of the cultural ecosystem services, including inspiration, recreation and eco-tourism, are revealed in the behaviour of visitors to the protected areas in IUA 6.

These visitors include:

- local residents living less than 50km from the protected areas and visit the areas for recreation purposes;
- South African tourists; and
- International tourists.

The travel cost method was used to estimate the effects of Scenario 1 and 2 on recreation and tourism expenditure.

A ten-minute questionnaire was designed to gather data from a randomised sample of 200 visitors to the Kruger National Park. The study was done on a Saturday in February 2008 when a variety of day-visitors, and over-night visitors from South Africa and other countries were present.

The questionnaire gathered data for two purposes:

- Socio-economic data for the development of a travel cost function;
- Riparian feature data for the development of a river importance index which scores the importance of the riparian attributes of river habitat for tourism.

The analysis proceeded as follows:

- The questionnaire data was used to develop a travel cost function (Table 26);

- The travel cost function was converted to a demand function relating tourism expenditure to the number of days spent in the Kruger National Park;
- The effect of Scenario 1 on the river importance index score was modelled, and introduced as a shock to the demand function;
- The change in demand was calculated through calculus integration.

Table 44. The travel cost function for tourist visitors to the Kruger National Park (KNP). This function was applied to all visitors to the protected areas in IUA 6. The dependent variable is the logarithm of the number of days spent per year in the KNP. The independent variables are the logarithms of the annual travel costs (TC = travel costs; OC = other costs); the river index score and the age of the visitor.

Dependent Variable: LNVISIT2
Method: Least Square
Date: 05/27/09
Sample: 1 126
Included observations: 118

	Coefficient	Std. Error	t-Statistic	Prob.
LNTC	-00.000738	0.059948	-0.012314	0.9902
LNOC	-0.23774	0.040482	-5.872733	0
RIVER_INDEX_KS	0.004516	0.005437	0.830737	0.4079
AGE	0.131106	0.044123	2.971391	0.0036
C	2.224653	0.551157	4.036336	0.0001
Error				
R_squared	0.29914	Mean dependent var		1.069295
Adjusted R-squared	0.274331	S.D. dependent var		0.74852
S.E. of regression	0.637636	Akaike info criterion		1.97935
Sum squared resid	45.94346	Schwarz criterion		2.096752
Log likelihood	-111.7816	Hannan-Quinn criterion		2.027018
F-statistic	12.05764	Durbin-Watson stat		2.096699
Prob(F-statistic)	0			

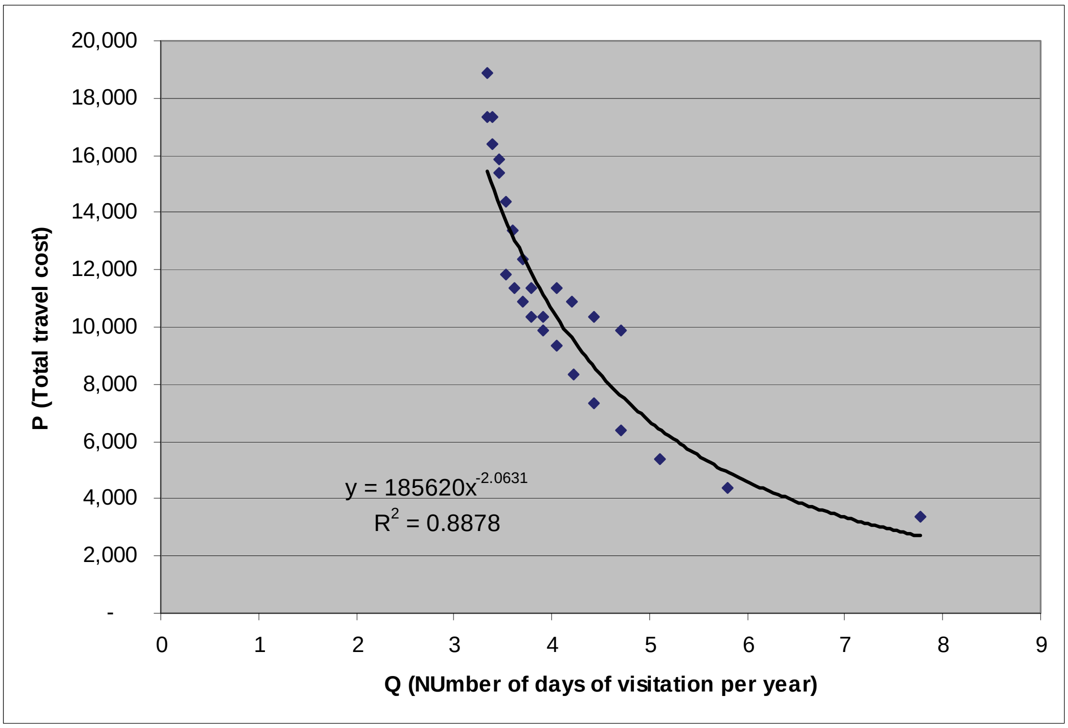


Figure 31. **The demand curve for tourism in the Kruger National Park.**

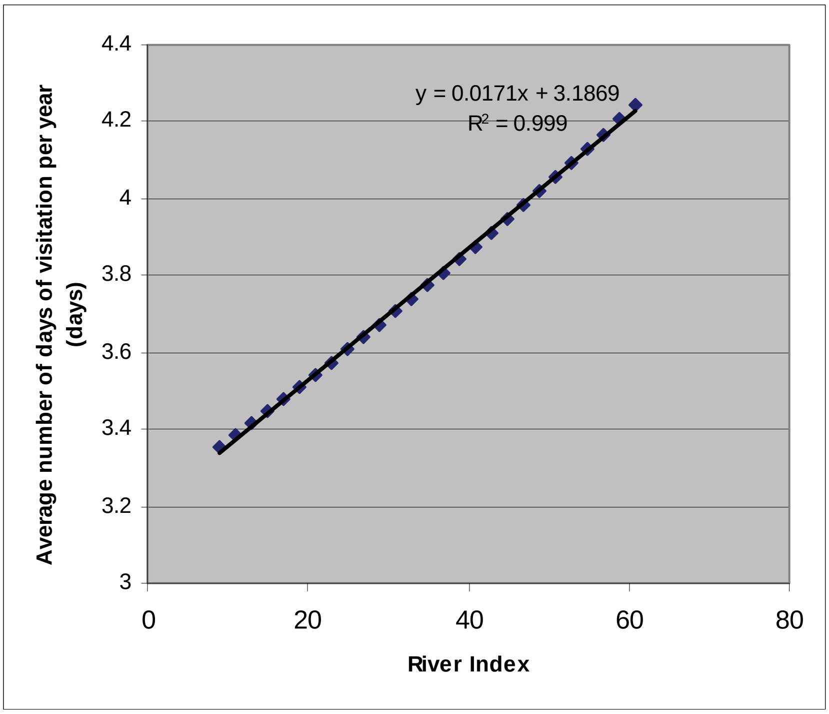


Figure 32. **The relationship between the River Index and the quantity of days spent by tourist, per year, in the KNP. This function is a partial production function.**

The rare tree, Breonadia spp. (matumi), occurs in the riparian zone in the lower reaches of the Sand River within the protected areas. These trees are charismatic in nature and provide a unique landscape feature in the protected areas. In addition, it is used by the Kruger National Park as an important indicator species of river state. Changes in the regulating services, especially erosion regulation and water regulation, resulting from a reduced stream flow under Scenario 1, would decrease the riparian zone and put the habitat of this species at risk. For demonstration purposes, we used the assumption that a 13% reduction in tall forest cover, i.e. Breonadia spp, would result from Scenario 1, but that Scenario 2 would hold no detrimental effect.

Table 44. Summary of the effect of Scenario 1 on Gross Domestic Product (GDP), resulting from a loss of tall forest cover, with an associated reduction in tourist visitation.

		Source
Reduced demand for tourism as a result of a decreas in River Index score	61	Calculated from the demand curve using Calculus integration
Estimated number of visitors to IUA 6	1,400,000	SANParks Annual Report 2008
Reduction in total annual value of tourism resulting from Scenario 1	85,474,074	calculated
The Consumer Surplus component of the above amount	24,343,528	calculated
Reduction in total annual revenue from tourism resulting from Scenario 1	24,219,051	calculated
Reduction in total annual GDP contribution from tourism resulting from Scenario 1	9,929,811	caculated

vi. Human health

It may be anticipated that in Scenario 1, the reach of river downstream of the Gevonden Dan will be exposed to prolonged period of no flow or very low flow. This will result in stagnant pools which would create a favourable habitat for Bilharzia.

Relatively little information exists on the health costs of Bilharzia, as compared to diseases such as Malaria and Cholera. Bilharzia, a parasitic infestation, results from washing, bathing or paddling in water harbouring snails shedding this parasite. Listed as a chronic disease, most people with bilharzia are asymptomatic and thus go undiagnosed. Chronic bilharzia can however, cause liver failure, renal failure and secondary bacterial infection. It may also affect the reproductive health of women with resultant infertility (Dept. of Health, 2003).

Whereas the treatment of Bilharzia is relatively inexpensive (between 1-5 tables of praziquantel at a cost of R0.77 per 500 mg tablet (2003 cost)), it is the reduction in productivity and link to HIV-AIDS that is of concern (Dept. of Health, 2003). People who are infected with bilharzia have an increased risk of becoming infected with HIV (Fincham and Dhansay, 2006). Bilharzia and HIV/AIDS are co-endemic in parts of five provinces: Eastern Cape, KwaZulu-Natal, Limpopo, Mpumalanga and North West (Fincham and Dhansay, 2006).

Insufficient data exists to value the effect of this. If the problem is deemed sufficient large, a specialist health risk assessment has to be commissioned.

PHASE 4. Evaluating trade-offs

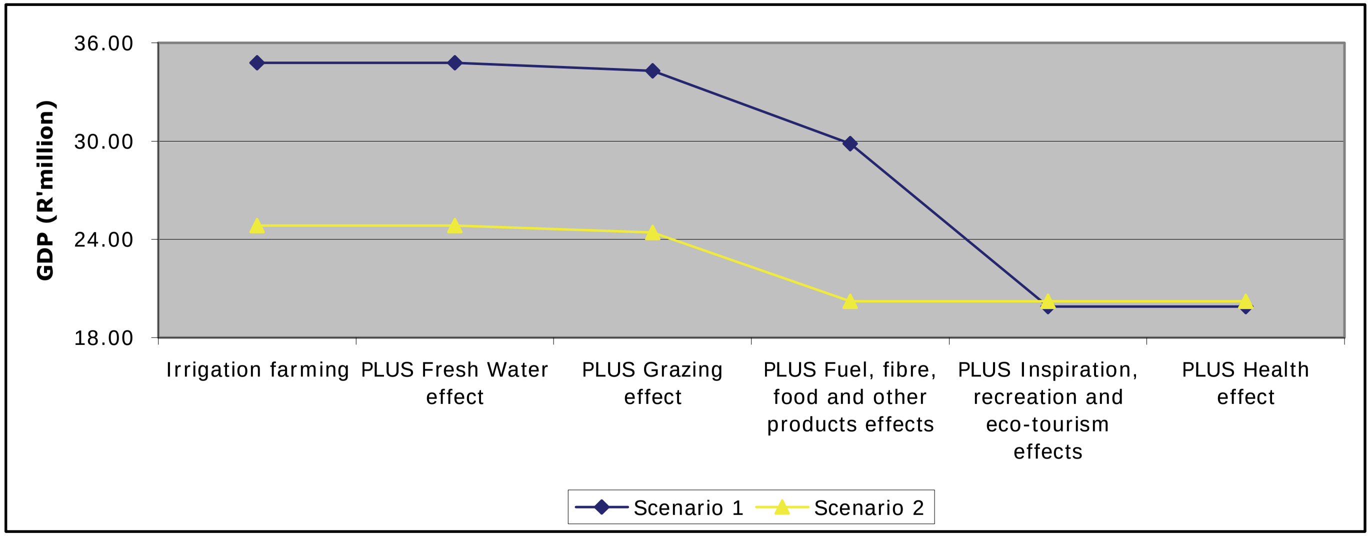
The analysis conducted is summarised in the Table below.

Without consideration of the value of ecosystem services lost, Scenario 1 is clearly the favoured option. However, after adding the full cost of ecosystem services, Scenario 2 becomes the more favoured option.

For project scenarios with different time frames, the net benefits of the project have to be captured per year over the actual lifespan of the project and valued as the net present social value through discounting. In this case study this analysis was not required.

The higher risk levels in scenario 1 overall are indicative of greater risk to the ecosystem and likelihood of negatively affecting the ecosystem and the benefits that ecosystem services provide. Considering the high level of dependence of people on the river, and the importance of the Kruger National Park (KNP) downstream and the ecological sensitivity of the river in KNP, scenario 1 seems undesirable. If the sugarcane is only viable at 90% assurance and higher hectare area, then the project is not worth the potential cost. But if it is viable at smaller area (assured in scenario 2) then under specific management regulations and proper implementation of monitoring and adaptive management, then that is a recommendable option.

	Irrigation farming	PLUS Fresh Water effect	PLUS Grazing effect	PLUS Fuel, fibre, food and other products effects	PLUS Inspiration, recreation and eco-tourism effects	PLUS Health effect
Valuation results (GDP effect in R'million per year)						
Scenario 1	34.79	-	-0.51	-4.45	-9.93	-
Scenario 2	24.85	-	-0.43	-4.20	-	-
Cumulative analysis (GDP effect in R'million per year)						
Scenario 1	34.79	34.79	34.28	29.83	19.90	19.90
Scenario 2	24.85	24.85	24.42	20.22	20.22	20.22
Qualitative considerations						
Scenario 1		Increased risk of algal bloom leading to cyanobateria toxicification				Increased risk of Bilharzia infections leading to elevated health costs
Scenario 2						



References

Ackerman, P.B.I. 2000. Zoning for Inyaka Dam for Recreation, Development and Nature Conservation. Department of Water Affairs and Forestry, Pretoria.

AfricanEPA. 2006. Status quo and development potential report of the Ga Maweala Community for the Regional Land Claims Commissioner, 2006; compiled by AfricanEPA

Anglo. 2006. Draft Final Environmental Scoping Report, 2006; compiled for Anglo Platinum by EcoRisk SA

Anglo. 2007. The Anglo Platinum Water Use Licence Application for the Richmond Dam, 2007

Australian/New Zealand Standard. 2004. Risk Management. AS/NZS 4360:2004. Jointly published by Standards Australia International Ltd, GPO Box 5420, Sydney, NSW 2001 and Standards New Zealand, Private Bag 2439, Wellington 6020

Aylward, B. and E.B. Barbier. 1992. Valuing environmental functions in developing countries. Biodiversity and Conservation 1: 34-50

Balmford, A., A.S.L. Rodrigues, M. Walpole, P. ten Brink, M. Kettunen, L. Braat and R. de Groot. 2008. The Economics of Biodiversity and Ecosystems: Scoping the Science. Cambridge, UK: European Commission (contract: ENV/070307/2007/486089/ETU/B2)

Birkhead, A.L., B.W. Olbrich, C.S. James and K.H. Rogers. 1997. Developing an integrated approach to predicting the water use of riparian vegetation. Report No. 474/1/97, Water Research Commission, Pretoria.

BKS. 2008. Determination of the impact of the proposed Richmond Dam on the Ecological Water Requirements in the Dwars and Steelpoort Rivers, 2008; compiled by BKS Consulting

Blignaut, J.N. and A. Lumby. 2004. Economic valuation. In Blignaut, J.N. and De Wit, M.P. (Eds). Sustainable Options: Economic development lessons from applied environmental and resource economics in South Africa. Cape Town: UCT Press.

Bockstael, N.E., A.M. Freeman, R.J. Kopp, P.R. Portney and V.K. Smith. 2000. On Measuring Economic Values for Nature. Environmental, Science and Technology 34: 1384 -1389.

Boyd, J. and S. Banzhaf. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63 (2-3), 616-626.

Brown, C., C. Pemberton, A. Birkhead, A. Bok, C. Boucher, E. Dollar, W. Harding, W. Kamish, J. King, B. Paxton and S. Ractliffe. 2006. In support of water-resource planning – highlighting key management issues using DRIFT: A case study. Water SA 32(2): 181-192

Brown, C.A., J. Ewart-Smith, J. Conrad, N. Rossouw, E.S.J. Dollar and C.R. Nicolson. 2007: The development of the water resource classification system (WRCS). Volume 2. Ecological, hydrological and water quality guidelines for the 7-step classification procedure. CSIR Report No. CSIR/NRE/WR/ER/2006/0187B/C. Department of Water Affairs and Forestry, Pretoria, 134pp.

Butterworth, J., Y.V. Malla Reddy and C. Batchelor. 2001. Addressing water needs of the poor in watershed management. Paper prepared for the 27th WEDC Conference, People and systems for water, sanitation and health, Lusaka, Zambia, 20-24 August 2001.

CEBC (Centre for Evidence-Based Conservation). 2006. Available at http://www.cebc.bangor.ac.uk/

Cheesman, O. 2005. Environmental impacts of sugar production: the cultivation and processing of sugarcane and sugar beet. CABI publishers, 255 pages. Available at http://books.google.co.za/books?id=rchW4QutXqwC&dq=Environmental+impacts+of+sugar+production:+the+cultivation+and+processing+of+sugarcane+and+sugar+beet&printsec=frontcover&source=bl&ots=vop6N09W-H&sig=8YenssQdEHNjcAFL8wDDbU6RIaM&hl=en&ei=g5HkScWJBYONkAWOkcTUCw&sa=X&oi=book_result&ct=result&resnum=1 (accessed 8 April 2009)

CIC. 2007. A comparative cost-benefit analysis of development options in the Port of Durban. Client confidential document.

CIC. 2009a. A comparative cost-benefit analysis of development options in the Port of Richards Bay. Client confidential document.

CIC. 2009b. ERE evaluation of the ecosystem services of the Saldanha Bay and Langebaan Lagoon marine system. Client confidential document.

Claasen, M., W.F. Strydom, K. Murray and S. Jooste. 2001. Ecological Risk Assessment Guidelines. WRC Report No. TT 151/01

Colvin, C., D. le Maitre, I. Saayman and S. Hughes. 2007. Aquifer Dependent Ecosystems in Key Hydrogeological Typesettings in South Africa. WRC Report No TT 301/07, July 2007, pp 89.

Costanza, R. 2006. Nature: ecosystems without commodifying them. Nature 443:749-749.

Costanza, R. 2008. Ecosystem services: Multiple classification systems are needed (Letter to the Editor). Biological Conservation

Costanza, R., R. D'Arge, R.S. de Groot, S. Farber, M. Grasso, M.B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260.

Crafford, J.G., R.M. Hassan, N.A. King, M.C. Damon, M.P De Wit, S. Bekker, B.M. Rapholo and B.W. Olbrich. 2004. An analysis of the social, economic and environmental direct and indirect costs and benefits of water use in irrigated agriculture and forestry. Water Research Commission. WRC Report N. 1048/1/04.

Daily, G.C. 1997: Introduction: What are ecosystem services? In: Nature's Services: Societal Dependence on Natural Ecosystems, G.C. Daily (ed.), Island Press, Washington, DC, 1-10.

De Groot, R. S., M. A. Wilson and R. M. J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41:393-408.

DEFRA (Department for Environment, Food and Rural Affairs). 2007. An introductory guide to valuing ecosystem services. Defra Publications, London, UK. 65 pages

Department of Health. 2003. Regular treatment of school-going children for soil-transmitted helminth infections and bilharzia: policy and implementation guidelines. Pretoria: Government printers

Diaz, S., J. Fargione, F. Stuart Chapin III and D. Tilman. 2006. Biodiversity loss threatens human well-being. PLoS Biol 4(8): e277. DOI: 10.1371/journal.pbio.0040277

Dollar, E.S.J., C.A.Brown, J.K. Turpie, A.R. Joubert, C.R. Nicolson and S.M. Manyaka. 2007: The development of the Water Resource Classification System (WRCS). Volume 1. Overview and 7-step classification procedure. CSIR Report No. CSIR/NRE/WR/ER/2006/0187A/C. Department of Water Affairs and Forestry, Pretoria, 74pp.

Dovie, D.B.K., E.T.F. Witkowshi and C.M. Shackleton. 2004. The fuelwood crisis in southern Africa – relating fuelwood use to livelihoods in a rural village. GeoJournal 60: 123-133.

Dovie, D.B.K., E.T.F. Witkowshi and C.M. Shackleton. 2005. Monetary valuation of livelihoods for understanding the composition and complexity of rural households. Agriculture and Human Values 22: 87-103.

DWAF (Department of Water Affairs and Forestry). 1996. South African Water Quality Guidelines

(second edition). Volumes 1-8. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). 1999. Resource Directed Measures for Protection of Water Resources. Volume 2: Integrated Manual, Version 1.0. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). 2001. Guidelines on the establishment and management of catchment forums: in support of integrated water resources management. Integrated water resources management, Sub-Series No. MS6.2, Department of Water Affairs and Forestry, Pretoria.

DWAF (Department of Water Affairs and Forestry). 2003. Water Quality Management Series, Sub-Series No. MS 8.3. A Guide to conduct Water Quality Catchment Assessment Studies: In support of the Water Quality Management Component of a Catchment Management Strategy. Edition. Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry). 2004. National Water Resources Strategy. Department of Water Affairs and Forestry, Pretoria, South Africa. www.dwaf.gov.za/Documents/Policies/NWRS/Default.htm

DWAF (Department of Water Affairs and Forestry). 2006. A draft position paper on the development of a national water resource classification system (WRCS): Draft discussion document. Department: Water Affairs and Forestry, Pretoria, 24pp. www.dwaf.gov.za/rdm/documents/WRCS19May06v7.pdf

DWAF (Department of Water Affairs and Forestry). 2007a. The development of the Water Resource Classification System (WRCS). Department of Water Affairs and Forestry, Pretoria, South Africa. www.dwaf.gov.za/rdm/documents/waterresourcedocs.asp

DWAF (Department of Water Affairs and Forestry). 2007b. Guidelines for the Development of Catchment Management Strategies: Towards equity, efficiency and sustainability in water resources management. By S.R. Pollard, D. du Toit, Y. Reddy and T. Tlou. Department of Water Affairs and Forestry, Pretoria, South Africa. www.dwaf.gov.za/Documents/Other/CMA/CMSFeb07/CMSFeb07Ed1Ch1.pdf

DWAF (Department of Water Affairs and Forestry). 2007c. Manual for the assessment of a Wetland Index of Habitat Integrity for South African floodplain and channelled valley bottom wetland types by M. Rountree (ed); C.P. Todd, C. J. Kleynhans, A. L. Batchelor, M. D. Louw, D. Kotze, D. Walters, S. Schroeder, P. Illgner, M. Uys. and G.C. Marneweck. Report no. N/0000/00/WEI/0407. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

DWAF (Undated). Guide to the National Water Act. Department of Water Affairs and Forestry, Pretoria

DWAF (Department of Water Affairs and Forestry) and WRC (Water Research Commission). 1996. The philosophy and practice of integrated catchment management: implications for water resource management in South Africa. WRC Report No TT 81/96. WRC, Pretoria, 139 pp.

EcoRisk undated: A literature review, undated; conducted by EcoRisk SA

ECS (Environmental Centre for Swaziland). 2009. The Lower Usutu Smallholder Irrigation Project. Available at http://www.ecs.co.sz/projects_lowerusutu.htm (accessed on 8th April 2009)

Ferrar, A.A. and M.C. Lötter. 2007. Mpumalanga Biodiversity Conservation Plan Handbook. Mpumalanga Tourism and Parks Agency, Nelspruit.

Fincham, J. and A. Dhansay. 2006. Worms in SA's children. MRC policy brief – no. 2, April, 2006. Online. Available: www.mrc.ac.za (26 May 2009)

Fisher, B., K. Turner, M. Zylstra, R. Brouwer, R. de Groot, S. Farber, P. Ferraro, R. Green, D. Hadley, J. Harlow, P. Jefferiss, C. Kirkby, P. Morling, S. Mowatt, R. Naidoo, J. Paavola, B. Strassburg, D. Yu and A. Balmford. 2008. Ecosystem services and economic theory: integration for policy-relevant research. Ecological Applications 18(8): 2050-2067

Fisher, B., R.K. Turner and P. Morling. 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68: 643-653

Hassan, R.M. 2007. Personal communication. Professor in Economics, University of Pretoria, Pretoria, South Africa.

Hein, L., K. van Koppen, R.S. de Groot and E.C. van Ierland. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57:209-228.

Hughes, D.A. 2005. SPATSIM, an integrating framework for ecological Reserve Determination and implementation. WRC Report No: TT 245/04, March 2005, Pretoria, South Africa

Hughes, D.A. and P. Hannart. 2003. A desktop model used to provide an initial estimate of the ecological instream flow requirements of rivers in South Africa. Journal of Hydrology 270:167-81.

IPCC (Intergovernmental Panel on Climate Change). 2007. Working Group II Contribution to the Intergovernmental Panel on Climate Change. Fourth Assessment Report. Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Summary for Policymakers. http://www.ipcc.ch/

Iversen, T.M., B.L. Madsen and J. Bøgestrand. 2000. River conservation in the European Community, including Scandinavia. In: Global Perspectives on River Conservation: Science Policy and Practice, Edited by P.J. Boon, B.R. Davies and G.E. Petts, John Wiley & Sons Ltd.

King, D.M. 1997. Comparing ecosystem services and values: with illustrations for performing Habitat Equivalency Analysis. Ph.D. thesis, University of Maryland, Center for Environmental and Estuarine Studies

King, J and D. Louw. 1998. Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. Journal of Aquatic Ecosystem Health and Management, 1: 109-124.

King, J., C. Brown and H. Sabet. 2003. A scenario-based holistic approach to environmental flow assessments for regulated rivers. Rivers Research and Application, in press.

Kleynhans, C.J. and M.D. Louw. 2007. Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No.

Kleynhans, C.J., C. Thirion and J. Moolman. 2005: A Level I River Ecoregion classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Kothuri, S. 2002. Knowledge in Organizations: Definition, Creation, and Harvesting. Harvard School of Education. Available on http://gseweb.harvard.edu/~t656_web/Spring_2002_students/kothuri_smita_knowledge_in_orgs.htm (accessed 27 June 2008)

Kruger, F. J., G. Forsyth, L.M. Kruger, K. Slater, D.C. Le Maitre, and J. Matshate. 2006. Classification of veldfire risk in South Africa for the administration of the legislation regarding fire management. In: Viegas, D. X. (ed.), Proceedings of Fifth International Conference on Forest Fire Research, Sintra, Portugal.

Kruger, F.J. and M.J. Wilkinson 2006. Disaster Risk Assessment and Guidelines for the Amathole District Municipality. Client Confidential report – CIC International.

Lemly, A.D. 1997. Risk Assessment as an Environmental Management Tool: Considerations for Freshwater Wetlands. Environmental Management 21(3): 343-358.

Likens, G. 1992. An ecosystem approach: its use and abuse. Excellence in ecology, Book 3. Oldendorf/Luhe, Germany: Ecology Institute.

Loomis, J. 1995. Public Trust Doctrine Produces Water for Mono Lake: The State of California's Water Resources Control Board Decision #1631. Journal of Soil and Water Conservation, pp. 270-271.

Lötter, M.C. and A.A. Ferrar. 2006. Mpumalanga Biodiversity Conservation Plan map. Mpumalanga Parks Board, Nelspruit

Lötter. M.C. 2006. Mpumalanga Biodiversity Conservation Plan CD-Rom. Mpumalanga Tourism and Parks Board, Nelspruit.

Louw, M.D. and D.A. Hughes. 2002. Prepared for the Department of Water Affairs and Forestry, South Africa. Resource Directed Measures for Protection of Water Resources: River Ecosystems – Revision of a quantity component.

MA (Millennium Ecosystem Assessment). 2003. Ecosystems and Human Well-being. A framework for assessment. World Resources Institute. Island Press, Washington.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being. Volume 1 – Current state and trends. World Resources Institute. Island Press, Washington.

MA (Millennium Ecosystem Assessment). 2007. Overview of the Millennium Ecosystem Assessment. http://www.millenniumassessment.org/en/About.aspx 16 May 2007

McCauley, D. 2006. Selling out on nature. Nature 443: 26-27.

Midgley, D.C., W.V. Pitman and B.J. Middleton. 1994. Surface water resources of South Africa 1990: user’s manual. Report 298/1/94, Water Research Commission, Pretoria.

Mokgope, K. and J.A. Butterworth. 2001. Rural water supply and productive uses: a rapid survey in the Sand River Catchment. WHiRL working paper 4, NRI, UK (can be accessed at http://www.nri.org/WSS-IWRM/reports.htm)

Mooney, H. and P. Ehrlich. 1997. Ecosystem services: a fragmentary history. In: Daily, G.C. (Ed.), Nature's Services. Island Press, Washington DC, pp. 11-19.

Mucina, L. and M.C. Rutherford (eds.) 2006. The vegetation of South Africa , Lesotho and Swaziland . South African National Biodiversity Institute, Pretoria, South Africa.

Natural Value 2008. International review of valuation techniques and their applicability, pros, cons and data requirements. Final report prepared for City of Cape Town, September.

Natural Value. 2009. Methodology to value the natural and environmental resources of the City of Cape Town. Draft report prepared for City of Cape Town, March.

Nel, J., G. Maree, D. Roux, J. Moolman, N. Kleynhans, M. Silberbauer and A. Driver. 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 2: River Component. CSIR Report Number ENV-S-I-2004-063. Council for Scientific and Industrial Research, Stellenbosch.

Nilsson, C. and M. Svedmark. 2002. Basic Principles and Ecological Consequences of Changing Water Regimes: Riparian Plant Communities. Environmental Management 30(4): 468-480

Norberg, J. 1999: Linking Nature's services to ecosystems: some general ecological concepts. Ecological Economics, 29(2): 183-202.

Noss, R. F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4(4): 355-364.

NWA. 1998. National Water Act No 36 of 1998, Republic of South Africa

O'Laughlin, J. 2005. Conceptual model for comparative ecological risk assessment of wildfire effects on fish, with and without hazardous fuel treatment. Forest Ecology and Management 211: 59-72

Olbrich B W, R.M. Hassan and J.G. Crafford 2002. An analysis of the social, economic, and environmental direct and indirect costs and benefits of water use in the irrigated agriculture and forestry: a case study of the Crocodile River catchment, Mpumalanga province. Report to the Water Research Commission (WRC report no: k5/1048/0/1) Environmentek, CSIR, Pretoria.

Pagiola, S., K. von Ritter and J. Bishop. 2004. Assessing the Economic Value of Ecosystem Conservation. The World Bank Environment Department, Environment Department Paper No.101.

Palmer, C.G., W.J. Muller, A.K. Gordon, P.A. Scherman, H.D. Davies-Coleman, L. Pakhomova and E. de Kock. 2004. The development of a toxicity database using freshwater macroinvertebrates, and its application to the protection of South African water resources. South African Journal of Science 10: 643-650.

Parsons, D. A., C. M. Shackleton and R. J. Scholes. 1997. Changes in herbaceus layer condition under contrasting land use systems in the semi-arid lowveld, South Africa. Journal of Arid Environments 37:319-329.

Parsons, R. and J. Wentzel. 2007. Groundwater Resource Directed Measures Manual. Water Research Commission. WRC Report No TT 299/07.

Pearce, D. 2007. Do we really care about biodiversity? Environmental and Resource Economics 37:313-333.

Perez de Mendiguren, J.C. and M. Mabelane. 2001 Economics of productive uses for domestic water in rural areas: A case study from Bushbuckridge, South Africa, Acornhoek, South Africa: Association for Water and Rural Development (AWARD). 112p.

Perrings, C. 2006. Ecological Economics after the Millennium Assessment. International Journal of Ecological Economics and Statistics (IJEES), 6(F06): 8-22

Perrings, C. 2007. Personal communication. Professor in Economics, State University of Arizona, Arizona US.

Peterson, R. and A.G. Hulting. 2004. A comparative ecological risk assessment for herbicides used on spring wheat: the effect of glyphosate when used within a glyphosate-tolerant wheat system. Weed Science 52: 834-844.

Pike, A. and R. Schulze. 2000. Development of a distributed hydrological modelling system to assist in managing the ecological Reserve to the sabie river system within the Kruger National Park. Report to the Water Research Commission, Report no. WRC k5/884

Pollard, S. and P. Walker 2000. Catchment management and water supply and sanitation in the Sand River Catchment, South Africa: description and issues. WHIRL Project Working Paper 1 (draft). NRI, Chatham, UK.

Pollard, S. R., and D. du. Toit. 2005. Harmonising policy and practice: Governance, integrated development planning and capacity development for natural resource management in the Sand river Catchment and Bohlabela Municipal District. CARE South-Africa Lesotho.

Pollard, S., H. Biggs and D. du Toit. 2008. Towards a Socio-Ecological Systems View of the Sand River Catchment, South Africa: An exploratory Resilience Analysis. Submitted to the Water Research Commission PROJECT: K8/591

Pollard, S., D. Kotze and G. Ferrari. 2007. Valuation of the livelihood benefits of structural rehabilitation interventions in the Manalana wetland, Craigieburn village, Mpumalanga Province. Jointly published by Association for Water and Rural Development and University of KwaZulu-Natal. Contribution to WRC Wetlands Project, Pretoria, South Africa.

Pollard, S., D. Kotze, W. William, T. Cousins, J. Monareng, K. King and G. Jewitt. 2005. Linking water and livelihoods: The development of an integrated wetland rehabilitation plan in the communal areas of the Sand River Catchment as a test case. AWARD On behalf of the Save the Sand Programme.

Pollard, S.R., J.C. Perez de Mendiguren, A. Joubert, C.M. Shackelton, P. Walker, T. Poulter and M. White. 1999. Feasibility Study: The Development of a Proposal for a Catchment Plan for the Sand River Catchment. Report submitted to DWAF, AWARD, Acornhoek.

Prime Africa Consultants. 2008. Water Research Commission 1644 – Literature Survey.

Resilience Alliance. 2007a. Assessing Resilience in social-ecological systems: A workbook for scientists. Version 1.1 Draft for testing and evaluation. Resilience Alliance report available at www.resalliance.org (last accessed 4 April 2009).

Resilience Alliance. 2007b. Assessing and managing resilience in social-ecological systems: A practitioners workbook. Version 1.0 June 2007. Resilience Alliance report available at www.resalliance.org (last accessed 4 April 2009).

RHP (River Health Programme). 2001. State of the Rivers Report: Crocodile, Sabie-Sand and Olifants River Systems. WRC Report No. TT 147/01, March 2001.

Richter, B. D. and G. A. Thomas. 2007. Restoring environmental flows by modifying dam operations. Ecology and Society 12(1): 12. [online] URL: http://www.ecologyandsociety.org/vol12/iss1/art12/

Rogers, K. 2007. Personal communication. University of Witwatersrand.

Rouget, M., B. Reyers, Z. Jonas, P. Desmet, A. Driver, K. Maze, B. Egoh, R.M. Cowling, L. Mucina and M.C. Rutherford. 2004. South African National Spatial Biodiversity Assessment 2004: Technical Report. Volume 1: Terrestrial Component. South African National Biodiversity Institute, Pretoria.

Rowntree, K.M. and R.A. Wadeson. 1999. A hierarchical geomorphological model for the classification of selected South African rivers. Report 497/1/99, Water Research Commission, Pretoria.

Sachs, J.D. and W.V. Reid. 2006. Environment — investments toward sustainable development. Science 312: 1002.

Salgado, P.P et al. 2009. Participative multi-criteria analysis for the evaluation of water governance alternatives. A case in the Costa del Sol (Malaga). Ecologocal Economics Volume 68, Issue 4.

Scrieciu, S.S. 2007. The inherent dangers of using computable general equilibrium models as a single integrated modelling framework for sustainability impact assessment. A critical note on Bohringer and Loschel (2006). Ecological Economics, 678-684.

SEF (Strategic Environmental Focus (Pty) Ltd) and EAT (Ecotourism Afrika Trust). 2007. Resource Management Plan for Inyaka Dam. Report compiled for DWAF, Final draft February 2007, Pretoria.

Shackleton, C. E., J. J. Stadler, K. A. Jeenes, S. R. Pollard and J. S. S. Gear. 1995. Adaptive strategies of the poor in arid and semi-arid lands: In search of sustainable livelihoods: A case study of the Bushbuckridge district, Eastern Transvaal, South Africa. Wits Rural Facility, University of the Witswatersrand, Acornhoek, South Africa.

Shackleton, C.M. 1996. Potential stimulation of local rural economies by harvesting secondary products: a case study of the central Transvaal lowveld, South Africa. Ambio, 25: 33-38.

Shackleton, C.M. 2000. Comparison of plant diversity in protected and communal lands in the Bushbuckridge lowveld savanna, South Africa. Biological Conservation 94: 273-285.

Shackleton, C.M., S.E., Shackleton and B. Cousins. 2001. The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal area in South Africa. Development Southern Africa 18: 581-604.

SRK Consulting. 2007. A Socio-economic Baseline Study for Mototolo JV, 2007; compiled by SRK Consulting

Strange, E. M., K. D. Fausch and A. P. Covich. 1999. Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin. Environmental Management Vol. 24, No. 1, pp. 39-54

Sukhdev, P. 2008. The economics of ecosystems and biodiversity: an interim report. Welzel and Hardt, Wesseling, Germany. 64 pp

Turner, R. K., J. C. J. M. van den Bergh, T. Soderqvist, A. Barendregt, J. van der Straaten, E. Maltby and E. C. van Ierland. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35:7-23.

Turpie, J.K., E.S.J., Dollar, J., Goldin, W., Mullins, S., Mallory, N., Joubert, A.R. Rossouw and C.R. Nicolson. 2007: The development of the water resource classification system (WRCS). Volume 3. Socio-economic guidelines for the 7-step classification procedure. CSIR Report No. CSIR/NRE/WR/ER/2006/0187C/C. Department of Water Affairs and Forestry, Pretoria, 113pp.

Twine, W., D. Moshe, T. Netshiluvhu and V. Suphungu. 2003. Consumption and direct-use values of savanna bio-resources used by rural household in Mametja, a semi-arid area of Limpopo province, South Africa. South African Journal of Science 99: 467-473.

Tyson, P. D. 1986. Climatic Change and Variability in Southern Africa. Oxford University Press, Cape Town, 220 pp.

US NAS (United States National Academy of Sciences). 2004. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. Committee on Assessing and Valuing the the Services of Aquatic and Related Terrestrial Ecosystems, National Research Council. 290 pages. ISBN: 978-0-309-09318-7. Available at http://books.nap.edu/catalog.php?record_id=11139

van Dam, R., R. Bartolo and P. Bayliss. 2006. Ecological risk assessments of key threats to Australia's tropical rivers: Overview, proposed framework and methodologies for the Tropical Rivers Inventory and Assessment Project. Internal Report 517, June, Supervising Scientist, Darwin. Unpublished paper.

van Niekerk, A. W. and G. L. Heritage. 1993. Geomorphology of the Sabie river: overview and classification. 2/93, Centre for Water in the Environment, University of the Witswatersrand, Johannesburg.

Vegter, J.R. 2003. Hydrogeology of groundwater Region 19: Lowveld. Water Research Commission Report No. TT 208/03

Walker, B. and D. Salt. 2006. Resilience thinking: sustaining ecosystems and people in a changing world. Island Press, Washington D.C.

Wallace, K. J. 2007. Classification of ecosystem services: problems and solutions. Biological Conservation 139:235-246.

Water for Africa. 2008a. Comprehensive Reserve determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Resource Unit Delineation. Prepared for Department of Water Affairs and Forestry, South Africa. Report no. 26/8/3/10/12/006

Water for Africa. 2008b. Comprehensive Reserve Determination study for selected water resources (rivers, groundwater and wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Desktop EcoClassification report (final). DWAF Report No. 26/8/3/10/12/002

Wilson, L.T. and C. Frappaolo. 1999. Implicit Knowledge Management: The New Frontier of Corporate Capability. Knowledge Harvesting, Inc. Available at http://www.knowledgeharvesting.com/documents/ImplicitKM.pdf (accessed on 27 June 2008).

Winter, T.C., J.W. Harvey, O. Lehn Franke and W. M. AlleyGround. 1998. Water and Surface Water A Single Resource. U.S. Geological Survey Circular: 1139. Available at http://pubs.usgs.gov/circ/circ1139/pdf/ (last accessed 15 April 2009).

Annexure 1. Policy field analysis: What are Resource Directed Measures?

1.1 Introduction

This chapter is an analysis of elements of public policy and statutory law in South Africa that affect the design of the Framework and Manual for the evaluation of services from aquatic ecosystems for the Resource Directed Measures (RDM) for the management of water in the country.

This is to facilitate:

- terminology that is consistent with terminology in policy and the statutory law
- development of an evaluation system that is compliant with these requirements and
- alignment with systems arising from the water, biodiversity and other relevant sectors, which will support efficient benefits transfer in future.

The analysis focuses on the National Water Act, the National Water Resource Strategy and the draft Water Resources Classification System. The analysis further provides an initial road map to the requirements to which authorities acting in terms of the National Water Act No. 36 of 1998 (as well as by implication other relevant instruments of South African policy, such as the National Environmental Management: Biodiversity Act No. 10 of 2004) must apply their minds when considering the environmental and socio-economic trade-offs arising from water management.

The account in this report emphasises surface water resources, but the approach encompasses groundwater management.

Overall, this chapter:

- itemises the provisions in the National Water Act relevant to the evaluation of services from aquatic ecosystems for the Resource Directed Measures
- provides interpretations
- reviews the contents of the National Water Resource Strategy and documents on Resource-Directed Measures in this context
- indicates which allied policy instruments may play a role in such evaluations and with which a conceptual and analytical bridge will be needed
- thus giving the SA policy-relevant framework for the evaluation.

1.2 Key relevant provisions in NWA

Interpretation of RDMs and their implementation are determined by the following in the NWA:

- Definitions and interpretation
- CHAPTER 2: WATER MANAGEMENT STRATEGIES
  - Part 1: National water resource strategy
  - Part 2: Catchment management strategies
- CHAPTER 3: PROTECTION OF WATER RESOURCES
  - Part 2: Classification of water resources and resource quality objectives
  - Part 3: The Reserve
- CHAPTER 4: USE OF WATER

These are discussed below.

1.2.1. Definitions and interpretation

Following are key terms, as stated in the Act:

- **water resource** includes a watercourse, surface water, estuary, or aquifer; a **watercourse** includes:
  (a) a river or spring
  (b) a natural channel in which water flows regularly or intermittently;
  (c) a wetland, lake or dam into which, or from which, water flows; and
  (d) any collection of water which the Minister may declare to be a watercourse,
  and a reference to a watercourse includes, where relevant, its bed and banks;

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

- **wetland** means land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.

The Act does not define the term aquatic ecosystem. Under law, the common meaning must then apply. The Oxford English Dictionary defines aquatic as “of or relating to water.”

From this, for this project, **aquatic ecosystems** means **water resources including riparian habitats** in terms of the NWA.

"**Reserve**" means the quantity and quality of water required:

(a) to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act, 1997 (Act No. 108 of 1997), for people who are now or who will, in the reasonably near future, be:

(i) relying upon;

(ii) taking water from; or

(iii) being supplied from, the relevant water resource; and

(b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource.

"**Resource quality**" means the quality of all the aspects of a water resource including:

(a) the quantity, pattern, timing, water level and assurance of instream flow;

(b) the water quality, including the physical, chemical and biological characteristics of the water;

(c) the character and condition of the instream and riparian habitat; and

(d) the characteristics, condition and distribution of the aquatic biota.

The Act does not define the term "management class", nor does the National Water Resource Strategy (see below), but this term clearly refers to the "class of water resource" as stipulated in Chapter 3, Part 2 of the Act.

The Act defines in Section 13(1) (b) the term "resource quality objectives" (see below).

The Act does not define "resource directed measures" though Chapter 3 in its preamble (see also below) refers to measures for the protection of water resources, as follows: "...Parts 1, 2 and 3 of this Chapter lay down a series of measures which are together intended to ensure the comprehensive protection of all water resources. These measures are to be developed progressively within the contexts of the national water resource strategy and the catchment management strategies provided for in Chapter 2. Parts 4 and 5 deal with measures to prevent the pollution of water resources and measures to remedy the effects of pollution of water resources" (note however, that this text is not part of the law).

The National Water Resource Strategy does define Resource Directed Measures (see below) in terms reflecting the provisions in the Act.

1.2.2. NWA Chapter 2: water management strategies

a. Part 1: The requirement for a National Water Resources Strategy

The Act requires the formulation of a national water resource strategy (NWRS), to provide for at least:

- the requirements of the Reserve and identify, where appropriate, water resources from which particular requirements must be met;
- international rights and obligations;
- actions to be taken to meet projected future water needs; and
- water use of strategic importance; and as well, to
- establish water management areas and determine their boundaries;
- contain estimates of present and future water requirements;
- state the total quantity of water available within each water management area;
- state the objectives in respect of water quality to be achieved through the classification system for water resources provided for in this Act.

Government published the first National Water Resource Strategy in September 2005, and established it by notice in the Government Gazette. As such it is now part of statutory law, though it contains no enforceable provisions.

b. Part 2: Water management strategies

Chapter 2 determines that each catchment management agency (CMA) will develop a Catchment Management Strategy which must:

- take into account the class of water resources and resource quality objectives …, the requirements of the Reserve and, where applicable, international obligations (see 2.2.3 below)
- not be in conflict with the national water resource strategy
- set out the strategies, objectives, plans, guidelines and procedures of the catchment management agency for the protection, use, development, conservation, management and control of water resources within its water management area;
- contain water allocation plans … which must set out principles for allocating water, taking into account the factors mentioned in section 27(1);
- take account of any relevant national or regional plans prepared in terms of any other law.

1.2.3. NWA Chapter 3: protection of water resources

c. Part 1: Classification system for water resources

The Act determines that the Minister must, as soon as is reasonably practicable, then prescribe (by regulation) a system for classifying water resources.

It continues: the system "... may

(a) establish guidelines and procedures for determining different classes of water resources;

(b) in respect of each class of water resource –

(i) establish procedures for determining the Reserve;

(ii) establish procedures which are designed to satisfy the water quality requirements of water users as far as is reasonably possible, without significantly altering the natural water quality characteristics of the resource;

(iii) set out water uses for instream or land-based activities which activities must be regulated or prohibited in order to protect the water resource; and

(c) provide for such other matters relating to the protection, use, development, conservation, management and control of water resources, as the Minister considers necessary.

This is the first stage in the protection process.

d. Resource quality objectives

Chapter 3 provides that Minister must determine for all or part of every significant water resource not only a class but also resource quality objectives based on the class.

The objectives "... may relate to:

(a) the Reserve;

(b) the instream flow;

(c) the water level;

(d) the presence and concentration of particular substances in the water;

(e) the characteristics and quality of the water resource and the instream and riparian habitat;

(f) the characteristics and distribution of aquatic biota;

(g) the regulation or prohibition of instream or land-based activities which may affect the quantity of water in or quality of the water resource; and

(h) any other characteristic, of the water resource in question."

The Act does not define "significant water resource", so the phrase takes its ordinary meaning.

This Chapter directly links resource classification, aquatic ecosystems, and water resources management.

1.2.4. NWA Chapter 4: use of water

The Act defines water use to include, among other things:

- taking water from a water resource
- impeding or diverting the flow of water in a watercourse
- altering the bed, banks, course or characteristics of a watercourse and
- using water for recreational purposes.

It provides for licensing of use, including compulsory licensing such as in the case where water used must be re-allocated.

The Act stipulates considerations for issue of general authorisations and licenses, thus binding the decision-maker to apply his or her mind to certain things. These are often in the nature of considering trade-offs that arise from the decision, and the costs and benefits of allocating a use. The considerations include that the responsible authority must consider among other things:

- efficient and beneficial use of water in the public interest; and
- the socio-economic impact;
- of the water use or uses if authorised;
- of the failure to authorise the water use or uses; and
- the likely effect of the water use to be authorised on the water resource and other water users;
- the class and the resource quality objectives of the water resource;
- investments already made and to be made by the water user in respect of the water use in question.

1.3 The National Water Resource Strategy and the strategies for water resources management

1.3.1. Integrated Water Resources Management

The National Water Resource Strategy (NWRS) adopts an approach to water resources management called integrated water resources management (IWRM). It defines IWRM as "... a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. IWRM therefore aims to strike a balance between the use of resources for livelihoods and conservation of the resource to sustain its functions for future generations, and promotes social equity, environmental sustainability and economic efficiency. Because the resource cannot be considered separately from the people who use and manage it, a balanced mix of technological and social approaches must be used to achieve integrated management."

The NWRS continues: "To give effect to the interrelated objectives of sustainability and equity an approach to managing water resources has been adopted that introduces measures to protect water resources by setting objectives for the desired condition of resources, and putting measures in place to control water use to limit impacts to acceptable levels.

"The approach comprises two complementary strategies as follows –

- **Resource-Directed Measures:** These measures focus on the quality of the water resource itself. Resource quality reflects the overall health or condition of the water resource, and is a measure of its ecological status. Resource quality includes water quantity and water quality, the character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota. Resource quality objectives will be defined for each significant water resource to describe its quality at the desired level of protection.
- **Source-Directed Controls:** These measures contribute to defining the limits and constraints that must be imposed on the use of water resources to achieve the desired level of protection. They are primarily designed to control water use activities at the source of impact, through tools such as standards and the situation-specific conditions that are included in water use authorisations. Source-directed controls are the essential link between the protection of water resources and the regulation of their use."

"Coherent and integrated approaches to balancing the protection and use of water resources will therefore require the collective application of resource-directed measures and source-directed controls in respect of water quantity and quality, as well as the biological and physical dimensions of the resource."

There is an important hiatus in the Strategy here. Although it defines IWRM to include "...the coordinated development and management of water, land and related resources ...", the scope of RDMs does not extend to the catchment area of the water resource. The OED defines catchment area as the area from which rainfall flows into a river, lake, or reservoir". However, there is an inextricable linkage between RDMs and the catchment area, which may affect the design of approaches to evaluation of RDMs trade-offs.

"The National Water Resource Strategy (NWRS) and Resource Directed Measures (RDM) place specific constraints on the development of catchment management strategies and plans. The NWRS was given further impetus through the development of Internal

Strategic Perspective (ISP) documents for the 19 water management areas. These documents present more detail on the Department's strategic perspective on how it wishes to protect, allocate usage, develop, conserve, manage and control water resource in the WMAs until the functions have been delegated to Catchment Management Agencies (CMAs)" (DWAF 2003).

1.4 The draft position paper on the development of a national water resource classification system (WRCS)

The Department of Water Affairs and Forestry has issued for comment a draft position paper on the development of a national water resource classification system (WRCS) (DWAF 2007a). This draft includes a set of guidelines and procedures for determining the desired characteristics of a water resource. Each different set of desired characteristics is to be represented by a Management Class (MC)

The MC outlines those attributes that the custodian (DWAF) and society would require of each water resource.

The WRCS is to follow these principles:

- Principle 1: Balance and trade-off for optimal use
- Principle 2: Sustainability
- Principle 3: National interest and consistency
- Principle 4: Transparency
- Principle 5: Implementability
- Principle 6: Interdependency of the hydrological cycle
- Principle 7: Legally defensible and scientifically robust
- Principle 8: Management scales
- Principle 9: Auditable and enforceable
- Principle 10: Lowest level of contestation and the highest level of legitimacy
- Principle 11: Utilisation of existing tools, data and information.

The MC for a given resource should balance protection of the resource with its utilisation in line with societal norms and values. Utilisation of the resource provides economic and social benefits; it also has the potential, however, to compromise ecosystem integrity, which has economic and social costs. The draft thus recognizes that this balance will require trade-offs in any resource-management decision.

The WRCS should therefore clearly outline the implications of different MCs to facilitate informed decision-making about trade-offs. Evaluation is thus required.

Principle 2: Sustainability is directly relevant here. In the draft, it is "… recognised that there is a sustainability baseline (or threshold) that if crossed, could result in the non-delivery of the goods, services and attributes necessary for economic growth, poverty alleviation and the redress of historical inequality. As there is a degree of uncertainty as to the exact position of this baseline, and as the risks exceeding the limits of sustainability are considerable, the precautionary principle will be applied."

The draft proposes a 7-step resource classification procedure, as follows (this summary includes the sub-steps relevant to evaluation)

Step 1: Delineate IUAs, describe the status quo of the water resources:-

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

a. Select the ecosystem values to be considered: ecological and economic data;
b. etc.;

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, etc.
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:

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

a. yield model for the Ecologically Sustainable Base Configuration scenario; b, c
d. Value the changes in aquatic ecosystems and water yield; etc,

Step 6: Evaluate the scenarios with stakeholders

Step 7: Gazette the class configuration

In addition, the draft proposes certain requirement for the guidelines, as follows:

- a manual of guideline(s) and procedure(s) for implementing the WRCS
- a Geographical Information System (GIS) database and
- a hybrid Cost-Benefit-Analysis/Multiple-Criteria-Decision-Analysis decision-support tool.

Further, the WRCS manual is to include protocol(s), checklists or procedures for systematic approaches to:

1) describing the ecological and biophysical implications of different scenarios
2) describing the groundwater implications of different scenarios
3) describing the social implications of different scenarios
4) predicting changes in economic value from implications of different scenarios ensure that the appropriate economic, social and ecological criteria are considered in the Classification Process
5) generating class scenarios
6) aggregation and presentation of economic, social and ecological data at a catchment level for alternate scenarios
7) integrated decision-analysis tool
8) identifying stakeholders for a catchment
9) stakeholder consultation process
10) a template for information on the economic, social and ecological implications of different scenarios for a decision on a MC.

By scenarios is meant the optional or alternate sets of trade-off options for the integrated water resources management available for a given significant water resource.

The Framework and Manual deriving from the present project should link with this procedure as follows:

- specify the methodology for the first step (and especially, provide for effective and efficient benefits transfer)
- provide the necessary methodology and information for the second step
- provide the framework for the sixth step
- generate the cost-benefit analysis for the seventh step
- contain the elements needed to support steps 8, 9 and 10.

1.5 Legislation that links with the NWA

In general in South Africa (and in part because of the Constitutional requirement for cooperative governance), the new policies and statutes are prescriptive regarding Constitutional rights and the measures needed to achieve these, but enabling with regard to implementation: detailed measures are not in the Acts, but their provisions allow for prescribed, detailed regulation, or frameworks that are also to be prescribed, but which guide government in its decisions. These latter frameworks may guide, but they have force in law and would determine decisions in terms of administrative justice, which must stand the test of the courts.

The NWA, with its requirements for the National Water Resource Strategy and subordinate catchment management strategies, is a good example. However, there are several others, including the National Environmental Management: Biodiversity Act

(NEMBA), which may be the most important in the context of water resources management.

Chapter 3 in NEMBA provides for the formulation of the national biodiversity framework, and bioregional plans, these to be subordinate to the framework. These instruments contain or convey substantial biodiversity and ecosystems information, both terrestrial and aquatic, which has the potential for improvement and adaptation to support the management of water resources. And NEMBA links directly to RDMS through the National Policy on the Conservation and Sustainable Use of South Africa's Biodiversity. For example, this policy commits government to, "develop a programme to rehabilitate degraded ecosystems of national concern. This programme will: identify key sites for restoration, based upon biological and socio-economic criteria, and ... develop and implement rehabilitation plans for identified sites [and] link remedial action to the provision of jobs, skills and opportunities for the poor and disadvantaged wherever possible and appropriate" (policy objective 1.5).

The value of such frameworks lies in their potential to convey information relevant to benefits transfer, and the system as a whole as required by the Constitution has the prospect of minimising redundancy in information and decisions.

Annexure 2. The Millennium Ecosystem Assessment scheme of categories for ecosystem services

What are ecosystem services?

The MA classification system accommodates the framework of total economic values (TEV) of the environment (i.e. use, non-use and option and bequest values as used in many other studies to date), but supersedes TEV. It provides the analytic linkage between ecosystem function and human well being.

Table 46 provides a description of the ecosystem services according to the MA scheme.

Table 45. The Millennium Ecosystem Assessment scheme of categories for ecosystem services. Derived from Millennium Ecosystem Assessment 2005a, 2005b. The concept of biodiversity as defined by Noss (1990) is followed here

Category of ecosystem services	**Types of services in the category**	**Description**
Supporting	Soil formation	Sediment retention and the accumulation of organic matter underpin other services
	Photosynthesis	Photosynthesis
	Primary production	Rate of biomass produced by an ecosystem
	Nutrient cycling	The process of the storage, recycling, processing and acquisition of nutrients, which underpins all other ecosystem services
	Water cycling	Affects climate, chemistry and biology and is fundamental to the delivery of all ecosystem services
Regulating	Air Quality regulation	Ecosystems both contribute and extract chemicals from the atmosphere that influence many aspects of air quality.
	Climate regulation	Ecosystems influence climate both locally and globally. At a local scale, changes in land cover can affect both temperature and precipitation. At a global scale, ecosystems play an important role in the carbon cycle by either sequestering or emitting greenhouse gases.
	Water regulation	The timing and magnitude of runoff and flooding can be strongly influenced by changes in land cover, including in particular alterations that change the water storage potential of the system such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
	Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.
	Water purification and waste treatment	Ecosystems can be a source of impurities in freshwater but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems
	Disease regulation	Changes in ecosystems can directly change the abundance of human pathogens such as cholera and can alter the abundance of disease vectors such as mosquitoes.
	Pest regulation/Biological control	Ecosystem changes affect the prevalence of crop and livestock pests and diseases.
	Pollination	Ecosystems that support pollinators are important often

Category of ecosystem services	Types of services in the category	Description
		important to the success of economies and genetic diversity. Refers to animal-assisted pollination, done by bees, rather than wind pollination
	Detoxification	Biological processes are involved in the sequestration or detoxification of various chemical wastes introduced into the environment.
	Natural hazard regulation	Such as storm protection, the presence of coastal ecosystems such as mangroves and coral reefs can dramatically reduce the damage caused by hurricanes or large waves.
Provisioning	Food	Provision of food from crops, livestock, marine and freshwater capture fisheries, aquaculture or wild plant and animal food products
	Fresh water	Ecosystems provide storage and retention of water for domestic, industrial, and agricultural use
	Wood and fibre	Direct benefits from wood for timber and pulp, biomass energy (fuel wood and charcoal consumption) and from the production of agricultural fibres such as cotton, silk and hemp
	Biochemical and pharmaceutical products	Ecosystems provide natural products that have been used for biochemicals and pharmaceuticals and other natural products (such as cosmetics, personal care, bioremediation, biomonitoring and ecological restoration.
	Genetic resources	The exploration of biodiversity for new products and industries, such as medicine, genes for plant pathogen resistance or ornamentals. Conserving genetic diversity maintains the potential to yield larger future benefits and ensures options for adapting to changing environments.
Cultural	Cultural diversity	The diversity of ecosystems is one factor influencing the diversity of cultures and the identity of specific cultures.
	Spiritual and religious values	Many religions attach spiritual and religious values to ecosystems or their components.
	Knowledge systems (traditional and formal)	Ecosystems influence the types of knowledge systems developed by different cultures.
	Educational values	Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.
	Inspiration	Ecosystems provide a rich source of inspiration for such activities as art, folklore, national symbols, architecture and advertising.
	Aesthetic values	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, 'scenic drives' and the selection of housing locations.
	Social relations	Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.
	Sense of place	Many people value the 'sense of place' that is associated with recognized features of their environment, including aspects of the ecosystem
	Cultural heritage values	Many societies place high value on the maintenance of either historically important landscapes ("cultural landscapes") or culturally significant species that serve to remind us of our

Category of ecosystem services	Types of services in the category	Description
		historic roots
	Recreation and ecotourism	People often choose the location for spending their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area

Annexure 3. Total Economic Valuation

TEV is one of the most widely used economic valuation methodologies used by resource economists today. It is used as a framework to incorporate complex and interrelated interactions between the environment and the associated value flows (Natural Value 2009).

Although there is no universally accepted framework for TEV, the methodology generally takes into account both the use and non use values individuals and society gain or lose from marginal changes in ecosystem services (DEFRA 2007).

Use and non-use values are defined below and are taken from DEFRA (2007).

Use values include direct use, indirect use and option value and are defined briefly below:

- **Direct use:** where individuals make actual or planned use of an ecosystem service
- **Indirect use:** where individuals benefit from ecosystem services supported by a resource rather than directly using it.
- **Option value:** the value that people place on having the option to use a resource in the future even if they are not current users.

Non-use value (also known as passive use) is derived simply from the knowledge that the natural environment is maintained. There are three main components:

- **Bequest value:** where individuals attach value from the fact that the ecosystem resource will be passed on to future generations.
- **Altruistic value:** where individuals attach values to the availability of the ecosystem resource to others in the current generation.
- **Existence value:** derived from the existence of an ecosystem resource, even though an individual has no actual or planned use of it.

GLOSSARY

ADAPTIVE CAPACITY/ADAPTABILITY: "the capacity to adapt and to shape change. Adaptability is the capacity of actors in a system to influence resilience. In a social-ecological system, this amounts to the capacity of humans to manage resilience" (Resilience Alliance, 2007a).

AQUATIC ECOSYSTEMS: not defined by the National Water Act (Act No. 36 of 1998), but defined elsewhere as the abiotic (physical and chemical) and biotic components, habitats and ecological processes contained within rivers and their riparian zones and reservoirs, lakes, wetlands and their fringing vegetation (Parsons and Wentsel, 2007).

AQUIFER: a geological formation (strata or group of interconnected strata), which has structures or textures that are capable of holding and/or conducting groundwater through them and of yielding useable quantities of groundwater to borehole(s) and/or springs (a supply rate of 0.1 ℓ/s is considered a usable quantity) (National Water Act No. 36 of 1998; Parsons and Wentsel, 2007).

BASEFLOW: sustained low flow in a river during dry or fair weather conditions, but not necessarily all contributed by groundwater; includes contributions from delayed interflow and groundwater discharge (Parsons and Wentsel, 2007).

BENEFITS: are defined as "the thing that has direct impact on human welfare" (Fisher et al., 2009). In other words, benefits are generated by ecosystem services, but typically in combination with other forms of capital input such as human activity and hard work, human knowledge, and/or built infrastructure.

BENEFICIARY: Individuals or groups of individuals who benefit from a particular activity or asset.

CATCHMENT: the area from which any rainfall will drain into the watercourse, contributing to the runoff at a particular point in a river system; synonymous with the term river basin (National Water Act No. 36 of 1998).

CLASS vs. CATEGORY: In line with the Parsons and Wentzel (2007), the terms 'class' is reserved to mean the management class of a water resource, while to avoid confusion the term 'category' is used to for all grouping of water resources (i.e. water resource 'categories' and Reserve categories) prior to public participation (Step 6 in the WRCS).

CONSUMPTION:

INTERMEDIATE – : intermediate consumption is an economic term which refers to the use of goods and services as inputs in production processes, including raw materials, services and various other operating expenses.

FINAL – : final consumption refers to the use of goods and services by final consumers, at the end of a value chain, usually households.

COMPARATIVE RISK ASSESSMENT: The risk assessment method described in this report.

COST-BENEFIT ANALYSIS: An economic methodology used to compare the cost and benefits of various project and or policy scenarios.

DESIRED CONDITION: An awkward term that often raises questions – but refers to the way society (in general or a particular group) regards the ecological condition of the water resource with respect to the its fitness-for-use status for particular uses. Different segments of society may disagree on what the desired state depending on what they think the function of the water resource should be. Public participation is often important to the determination of the desired state.

DISCOUNTING: Converting of a future monetary value to its equivalent present day value, through dividing by an appropriate discount rate.

ECOCLASSIFICATION: "the term used for the Ecological Classification process – refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers relative the natural or close to the natural reference condition. The purpose of the EcoClassification process is to gain insights and understanding into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river" (Kleynhans and Louw, 2007)

ECOLOGICAL WATER REQUIREMENT (EWR): As defined in the NWA, the water required for functioning of aquatic ecosystem processes in a particular ecological category.

ECOREGION: "EcoRegions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources, and are designed to serve as a spatial framework for the research, assessment, management and monitoring of ecosystems and ecosystem components. Several levels or scales of EcoRegions can be delineated (e.g.: Level I low resolution/detail; Level III high resolution and detail). In South Africa, EcoRegions form the basis of the River Health monitoring assessments. For more information go to: www.dwaf.gov.za/iwqs/gis_data/ecoregions/get-ecoregions.htm" (DWAF 2007).

ECOSPECS: short for 'ecological specifications' are equivalent to ecological water resource quality guidelines. They can be a numerical or descriptive objective that will sometimes designate a change in the ecological condition of a water resource (Palmer et al., 2004). Also see 'userspec'.

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 its capacity to provide a variety of goods and services" (Iversen et al., 2000).

ECOSYSTEM: The term ecosystem refers to "any spatially explicit unit of the earth that includes all of the organisms, along with all of the components of their abiotic environment within its boundaries" [this widely used general definition of an ecosystem is from Likens (1992)]. Ecosystems exist and can be characterised and analysed at microscopic or global scales; however, they interact in important ways across many different geographic scales. This fact makes it difficult to assess of compare the services or values of ecosystems without considering their specific landscape contexts." (King, 1997).

ECOSYSTEM ASSET: A biotic or abiotic component of an ecosystem that plays an important role in the functioning of the ecosystem

ECOSYSTEM ATTRIBUTES: Some literature has referred to ecosystem services as ecosystem attributes. Rogers (2007) has developed a protocol for determining the desired state of an ecosystem(s) under management. A key aspect of this protocol is the definition of vital attributes of the system, and is in fact the environmental assets of the system. The draft WRCS also refers to ecosystem attributes (DWAF 2007), but apply this term to designate a certain set of ecosystem services, rather than ecosystem assets. This definition may cause confusion. A term originating from Aylward and Barbier (1992) and used in the WRCS

ECOSYSTEM FEATURES: "the site-specific characteristics of an ecosystem (e.g. soil, ground cover, hydrology)" that establish an ecosystem's "capacity to support various forms of life and perform various biophysical processes" (King, 1997).

ECOSYSTEM FUNCTIONING: "the biophysical processes that actually take place within an ecosystem" and "can be characterised apart from any human context (e.g. fish and waterfowl habitat, cycling carbon, trapping nutrients)" (King, 1997).

ECOSYSTEM GOODS: Refers to the physical components (tangible products) of ecosystems that are directly used by humans, such as food, water, timber, fibre, medicinal plants and such. The concept of ecosystem services includes ecosystem goods – they are not mutually exclusive.

ECOSYSTEM GOODS, SERVICES AND ATTRIBUTES (EGSA): A term used in Aylward and Barbier (1992) and adopted in the draft Water Resource Classification System (Turpie et al., 2007) to link biodiversity, ecosystem services and the Total Economic Value (TEV) framework. This terminology has become redundant under the MA framework.

ECOSYSTEM HEALTH: "A measure of the stability and sustainability of ecosystem functioning or ecosystem services that depends on an ecosystem being active and maintaining its organization, autonomy, and resilience over time. Ecosystem health contributes to human wellbeing through sustainable ecosystem services and conditions for human health." (MA, 2003).

ECOSYSTEM INTEGRITY/HEALTH CONCEPTS: According to Kleynhans and Louw (2007), the "conceptual attributes that comprise ecosystem health (i.e. if this is present the system will be healthy) are summarized by Costanza (1992): homeostasis (tendency of biological systems to maintain a state of equilibrium); absence of disease; diversity or complexity; stability or resilience; vigour or scope for growth; and balance between system components.

ECOSYSTEM SERVICES: are broadly defined in the Millennium Ecosystem Assessment as "the benefits people obtain from ecosystems" but are more accurately described as the aspects of ecosystems utilized (actively or passively) to produce human well-being (Fisher et al., 2008). This means that they are (1) ecological phenomena (including ecosystem organization or structure as well as ecosystem process and/or functions) that are (2) consumed/utilized by society either directly or indirectly (Fisher et al., 2009).

EFFLUENT STREAM: a stream which is fed directly by the surrounding groundwater: the piezometric level is above the stream surface and discharge to the surface feeds the stream (McGraw-Hill, 1978). Also called a gaining stream (Winter et al., 1999).

ESTUARY: means a partially or fully enclosed body of water (a) which is open to the sea permanently or periodically; and (b) within which the sea water can be diluted, to an extent that is measurable, with fresh water drained from land (National Water Act No. 36 of 1998).

EVALUATION (vs. VALUATION): Please see the definition of VALUATION below.

FRAMEWORK: A hypothetical description of a complex entity or process (Princeton.edu)

GROUNDWATER BODY: a rock or group of rocks comprising saturated earth material (Parsons and Wentsel, 2007).

GROUNDWATER CONTRIBUTION TO BASEFLOW OR RIVER FLOW: that groundwater that discharges into effluent streams and sustains baseflow (Parsons and Wentsel, 2007).

GROUNDWATER DEPENDENT ECOSYSTEM: an ecosystem – or component of an ecosystem – that would be significantly altered by a change in the chemistry, volume and / or temporal distribution of its groundwater supply (Parsons and Wentsel, 2007).

GROUNDWATER MANAGEMENT UNIT: an area of a catchment that requires consistent management actions to maintain the desired level of use or protection of groundwater; delineation is based on management considerations rather than geohydrological criteria (Parsons and Wentsel, 2007).

GROUNDWATER REGION: a broad geohydrological grouping by Vegter (2001) based on dominant aquifer type (primary, secondary), lithostratigraphy, physiography and climate; groundwater regions have been identified (Parsons and Wentsel, 2007).

GROUNDWATER RESOURCE UNIT: a groundwater body that has been delineated or grouped into a single significant water resource based on one or more characteristics that are similar across that unit; also referred to as a groundwater unit (Parsons and Wentsel, 2007).

GROUNDWATER RESOURCE: all groundwater available for beneficial use, including man, aquatic ecosystems and the greater environment.

GROUNDWATER: water found in the subsurface in the saturated zone below the water table or piezometric surface, i.e. the water table marks the upper surface of groundwater systems (Parsons and Wentsel, 2007).

INSTREAM FLOW REQUIREMENT (IFR): are the water requirements of aquatic ecosystems. Methodologies such as the Building Block Methodology (BBM) are used for assessing IFR relying on several field surveys by a multi-disciplinary group of scientists, including experts in hydrology, hydraulics, geomorphology, fish and invertebrate ecology (DWAF 1999). IFR is required at the planning stage for any major developments such as dams and inter-basin transfers.

INTEGRATED UNIT OF ANALYSIS (IUA): a term was put forward in the draft Water Resource Classification System (WRCS) as a broader-scale unit of assessment for evaluating the socio-economic implications of different catchment configuration scenarios and to report on the ecological category at a sub-catchment scale. The determination of an IUA is a combination of socio-economic zones and the watershed boundaries, within which ecological information is provided at a finer scale (Brown et al., 2007)

INTERESTED AND AFFECTED PARTIES (I&APs): are “a particular group of persons who have an interest in, or are affected by, a particular intervention” (DWAF 2007a).

PAYMENTS FOR ECOSYSTEM SERVICES (PES): A fledgling financial instrument intended to internalise environmental externalities.

PRESENT ECOLOGICAL STATUS (PES): refers to the present ecological health or integrity of the various biophysical attributes of the aquatic ecosystem in question compared to the natural or close to natural reference condition. It is expressed in terms of various components namely, drivers (physico-chemical, geomorphology, hydrology) and biological responses (fish, riparian vegetation and aquatic invertebrates), as well as an integrated state, the EcoStatus (Kleynhans and Louw, 2007).

PRODUCTION FUNCTION: A mathematical unction relating production input variables (factors of production) to output.

RDM SPECIALISTS: refer to the multi-disciplinary group of scientists involved in the ecological Reserve determination and/or the Classification process. They include experts in hydrology, hydraulics, geomorphology, water quality, vegetation, fish and invertebrate ecology.

REFERENCE CONDITION: An important component in the EcoClassification process describing “the condition of the site, river reach or delineation prior to anthropogenic change and is formulated for each component considered in EcoStatus determination (fish, aquatic invertebrates, riparian vegetation, water quality, geomorphology and hydrology)” (Kleynhans and Louw, 2007).

REGIME AND REGIME-SHIFT: “Used in the sense of system dynamics (Scheffer and Carpenter (2003), A regime is the set of states that define a domain of attraction. In a regime the system has the same essential structure, function, feedbacks and, therefore, identity (Walker et al., 2004). A regime shift occurs when a system crosses a threshold into an alternate domain of attraction. “Regime” here does not mean a political regime, though there may well be occasions when the two meanings are the same” (Resilience Alliance, 2007b).

RESERVE ASSESSMENT UNIT (RAU): is an assessment unit that is even smaller than a Resource Unit (which usually align with catchment boundaries). For example if a change in land use within a resource unit warrants a different RDM assessment (e.g. river flows from degraded land area into a large protected area). In this case the RAU does not always align with catchment boundaries.

RESERVE: the quantity and quality of water required to supply the basic needs of the people to be supplied with water from that resource, and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of water resources (Parsons and Wentsel, 2007).

RESILIENCE: “the ability of a system to absorb shocks, to avoid crossing a threshold into an alternate and possibly irreversible new state, and to regenerate after disturbance” (Resilience Alliance, 2007a).

RESOURCE QUALITY OBJECTIVES: Resource quality objectives provide numerical and/or descriptive statements about the biological, chemical and physical attributes that characterise a resource for the level of protection defined by its class. Thus resource quality objectives might describe, among other things, the quantity, pattern and timing of instream flow; water quality; the character and condition of riparian habitat, and the characteristics and condition of the aquatic biota. Resource quality objectives must take account of user requirements and the class of the resource (NWRS; DWAF 2004).

RESOURCE QUALITY: the quality of all aspects of a water resource including (a) the quality, pattern, timing, water level and assurance of instream flow, (b) the water quality, including the physical, chemical and biological characteristics of water, (c) the characteristic and condition of the instream and riparian habitat, and (d) the characteristics, condition and distribution of aquatic biota (National Water Act No. 36 of 1998).

RESOURCE UNITS: areas of similar physical or ecological properties that are grouped or typed to simplify the Reserve determination process (Parsons and Wentsel, 2007). In more recent Reserve Determination studies, resource units have been prefixed with ‘natural’, ‘management’ or termed a Reserve Assessment Unit. These distinctions in the delineation of the catchment recognise that resource units are determined based on aggregations or considerations of different ecological, social and economic data.

RIPARIAN HABITAT: "includes the physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas" (National Water Act No. 36 of 1998).

RIPARIAN SYSTEM: an area of land directly adjacent to a river, stream, wetland, estuary or other surface water body that is in the transition zone, between high and low water marks and also above high water where vegetation is influenced by elevated water tables or flooding (Nilsson & Svedmark, 2002, Parsons and Wentsel, 2007).

RIVER: is a "linear fluvial, eroded landforms which carry channelized flow on a permanent, seasonal or ephemeral/episodic basis. The river channel flows within a confined valley (gorges) or within an incised macro-channel. The “river” includes both the active channel (the portion which carries the water) as well as the riparian zone" (DWAF 2007); generally larger than a stream, but often used interchangeably.

ROLE PLAYERS: are those “who by virtue of their identity, influence decisions” (DWAF 2007a). This is a broad group, including stakeholders, the public and interested & affected parties.

SIGNIFICANT WATER RESOURCES: used but not defined by the National Water Act (Act 36 of 1998); relates to the size of the water resource rather than its importance; a resource is deemed to be significant if it is large enough to warrant its own Reserve determination.

SOCIO-ECOLOGICAL SYSTEM (SES) – “an integrated system of ecosystems and human society with reciprocal feedback and interdependence. The concept emphasizes the ‘humans-in-nature’ perspective” (Resilience Alliance, 2007a).

STAKEHOLDERS: are “those parties that are directly affected by decisions and outcomes of a decision” (DWAF 2007a). Hein et al. (2006) provide a definition of stakeholders suitable for ecosystem valuation, "any group or individual who can affect or is affected by the ecosystem’s services".

SURFACE WATER: "bodies of water, snow or ice on or above the surface of the earth (such as lakes, streams, ponds, wetlands, etc.)" (Parsons and Wentsel, 2007).

SUSTAINABILITY: The Millennium Ecosystem Assessment (2003) uses the term 'sustainability', and 'sustainable management', to refer to the "goal of ensuring that a wide range of services from a particular ecosystem is sustained" (MA, 2003).

RIVER NODE: as defined in the draft Water Resource Classification System (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 " (WRCS report 2)

THRESHOLD OF POTENTIAL CONCERN: An ecological indicator of ecosystem health.

USERSPECS: short for user specifications articulate user needs. Userspecs are combined with ecospecs to become the resource quality objectives (RQOs; which in turn define the associated management classes). For instance, sometimes users will have more sensitive requirements for flow or water quality than the aquatic ecosystem. In such a case, "if the userspec will not impair the ecosystem's condition, then the userspec becomes the RQO" (Palmer et al., 2004).

VALUATION (vs. EVALUATION): The economic quantification of the level of benefits provided by an economic good or service or ecosystem service. EVALUATION refers to the comparative analysis of a variety of (valued) management scenarios.

VALUATION TECHNIQUE: A particular technique through which an ecosystem service, or other good or service may be valued.

VALUATION METHODOLOGY: A combination of valuation techniques and frameworks used to value a management scenario.

WATER COURSE: a river or spring; a natural channel in which water flows regularly or intermittently; a wetland, lake or dam into which, or from which, water flows; and any collection of water that the Minister of Water Affairs and Forestry may, by notice in the Government Gazette, declare to be a water course and a reference to a watercourse includes, where relevant, its bed and banks (National Water Act No. 36 of 1998).

WATER MANAGEMENT AREA: is an area established as a management unit in the national water resource strategy within which a catchment management agency will conduct the protection, use, development, conservation, management and control of water resources (National Water Act No. 36 of 1998).

"WATER RESOURCE CLASSIFICATION SYSTEM: ""is a set of guidelines and procedures required by the National Water Act (No. 36 of 1998) for determining the desired characteristics of a water resource, and is represented by a Management Class (MC). The MC outlines those attributes that the custodian [Department: Water Affairs and Forestry (DWAF)] and society require of different water resources"" (DWAF 2006)."

WATER RESOURCE: includes a water course, surface water, estuary or aquifer National Water Act No. 36 of 1998).