TOWARDS A CLASSIFICATION SYSTEM OF SIGNIFICANT WATER RESOURCES WITH A CASE STUDY OF THE THUKELA RIVER

by

Harrison Hursiney Pienaar

Submitted in partial fulfilment of the requirements for the degree

Master of Science

in the

Department of Earth Sciences
Facility of Natural Sciences
University of the Western Cape

March 2005

Supervisor: Professor Y. Xu

DECLARATION

I declare that *Towards a classification system of significant water resources with a case study of the Thukela River* is my own work, that it has not been submitted for any degree or examination in any other tertiary institution, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

NAME: Harrison H. Pienaar

SIGNED: ……………………………………….

DATE: March 2005

ABSTRACT

Towards a classification system of significant water resources with a case study of the Thukela River

H. H. Pienaar
MSc Thesis
Department of Earth Sciences

The increasing demand for water to provide for South Africa's growing population has resulted in increasing pressure being placed on the country's limited water resources. Water developments however cannot be undertaken without considering the water resource base (quantity and quality; groundwater and surface water) and the key policy frameworks that govern its use and protection. The Department of Water Affairs and Forestry (DWAF) as the custodian of water resources in the country initiated the implementation of the National Water Act (NWA) (Act No 36 of 1998) during 1999. It has therefore the mandate to ensure that the protection, use, development, conservation, management and control of water resources be achieved in an equitable, efficient and sustainable manner, to the benefit of society at large.

The NWA prescribes that the Minister of the DWAF as soon as reasonably possible, develop a system for the classification of all significant water resources to ensure its protection and sustainable utilisation. Chapter 3 of the NWA (which was enacted in October 1999) is devoted to the comprehensive protection of the water resources. Parts 1, 2 and 3 of Chapter 3 provide a series of measures intended to achieve this protection, through both the classification of significant water resources, the determination of the Reserve and the setting of the Resource Quality Objectives (RQOs). The classification system is to be used to determine the class and RQOs of all significant water resources. The intention is that this system should establish guidelines and methods to enable this process. Procedures and methodologies for determining the Reserve were developed and refined during the period 1999 – 2004, and will continue to be used and refined into the foreseeable future.

In the absence of a formal classification system, a framework (which the NWA does not prescribe) was developed through this research study in order to guide both the **development** of a classification system and the **implementation** (the act of classifying significant water resources), hence ensuring an overarching structure within which integrated water resource management can be achieved. The main goal of this framework was to seek an appropriate balance between protecting significant water resources and at the same time promoting water resource utilisation in support of socio-economic development. This framework was executed in the preliminary determination of the Reserve for the Thukela River catchment to ensure that informed and calculated decision-making processes are followed once significant water resources are classified.

The execution of this framework in the Thukela River Catchment led to an integrated approach for considering a range of ecological categories, social and cultural importance and the economic value so as to better inform decision-making in setting the Reserve. The goal of this research study was therefore not to stop or inhibit water resources utilisation in the Thukela River Catchment but rather to make sure they are used in a sustainable manner maintaining the water quality and quantity of the resource in accordance with the class for current and future potential uses.

Important to the findings of the case study was the emphasis on the sequence and integration of classification activities to one another: The Minister sets the Reserve in accordance with the class; The Minister sets the class in accordance with the classification system. The process of developing a classification system requires an integrated approach (ecological, social, and economic) in protecting and utilizing the water resource. Adopting the development of this framework (within which a classification system of significant water resources is designed) is therefore critical and should precede the design and implementation of a classification system as such since it presents numerous challenges. This research study was therefore aimed at developing a framework for the classification of South Africa’s significant water resources. The goal of this study was achieved by means of those issues and findings reflected and experienced throughout the case study. This study was conducted through an analysis of the perspectives of key stakeholders, research institutions, consulting firms, water resource managers (through workshops, meetings and consultations), preceded by extensive literature reviews.

Key words: class, classification, classification process, classification system, ecological objective, economic objective, framework, preliminary classification, significant water resources, preliminary class, social objective, scenarios, Thukela River, Reserve, resourced directed measures, water resource management.

ACKNOWLEDGEMENTS

This research study has been conducted in collaboration with the Thukela Reserve Study (TRS) by two directorates within the Department Water Affairs and Forestry (DWAF), namely National Water Resources Planning (NWRP) and Resources Directed Measures (RDM). The author also had an opportunity of orchestrating a strategic environmental assessment (SEA) of the Usutu-Mhlathuze water management area. This SEA approach was to some extent applied and modified during the completion of the TRS in the Thukela catchment. Both aforementioned studies have been funded by the DWAF with additional funding from the Department for International Development (DFID) in support of the SEA project.

I wish to thank all those who have taken their time and trouble to share their wisdom, thoughts and opinions while writing this thesis. Among the many individuals and organisations that have been sources of information, I thank the following:

- Tlou & Matji (Pty) Ltd;
- IWR Source-to-Sea;
- Blue Science;
- CPH Water and
- Laughing Waters.

Various sections of this research study have relied on reports prepared for the DWAF and research work being conducted and facilitated by the author on the TRS and SEA respectively.

The author is particularly grateful to the DWAF for allowing use of the information from the work conducted for the TRS and the SEA. My supervisor Professor Yongxin Xu is thanked for his direction, reviews and suggestions throughout the study.

My wife and family are also thanked for their continuous support and encouragement while commissioning this research study.

Many thanks!

Harrison H. Pienaar

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABBREVIATIONS

CMAs	Catchment Management Agencies
DDG	Deputy Director-General
DEAT	Department of Environment Affairs and Tourism
DFID	Department for International Development
DG	Director-General
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Category
EWR	Ecological Water Requirements
IFR	Instream Flow Requirements
IWRM	Integrated Water Resources Management
MC	Management Class
MCDA	Multi-criteria Decision Analysis
NWA	National Water Act (Act No 36 of 1998)
NWRP	National Water Resources Planning
PES	Present Ecological State
PIP	Public Involvement Programme
P & R	Policy and Regulation
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RQOs	Resource Quality Objectives
SAM	Social Accounting Matrix
SEA	Strategic Environmental Assessment
SCI	Social and Cultural Importance
SDC	Source Directed Controls
TRS	Thukela Reserve Study
TWP	Thukela Water Project
WRC	Water Research Commission
WRYM	Water Resources Yield Model
WQOs	Water Quality Objectives

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background

Policy-makers and resource managers are facing a worldwide crisis in water resource management, but the situation is more urgent for developing countries struggling to overcome the grip of poverty. In response to these challenges, South Africa developed a ground-breaking approach to managing its water resources. The National Water Act of 1998 (Act 36 of 1998) contains three key innovations: the abolishment of private ownership permitted under the system of riparian rights; the establishment of catchment management agencies (CMAs) as the basic unit for water resource management; and the Reserve. The Reserve is one of three resource directed measures (RDM) components designed to ensure the comprehensive protection of water resources. It is worth noting the fact that the Reserve can only be determined once significant water resources are being classified by means of a classification system, according to the NWA. Provisions have been put in place though to determine preliminary Reserves (in the interim) in anticipation of the completion of a formal classification system. Crucial to the successful implementation of a formal classification system is the development of a national framework that prescribes how such a system should unfold. A proposed national framework is embedded in this thesis through a study initiated by the author, and funded by the Department of Water Affairs and Forestry (DWAF).

As a measure to both utilise and protect the integrity of South Africa's water resources, this national framework is intended to promote sustainable development. The successful implementation of this national framework will depend on long-term changes to conventional management approaches. Long-term policy reforms are complex, involving interactions between the social, political, technical and organizational dimensions, often with uncertain outcomes. These challenges can often be perceived as three major obstacles to sustainable development: willingness, capacity and understanding. Willingness refers to the political will necessary to implement changes. The knowledge and values of members within an organization influences the willingness to execute procedures and practices, enabling or hampering a new legislation. (Bainbridge *et al.*, 2000).

Given the sufficient political support within the South African context, neglecting the practicalities of implementation is a common source of policy failure (Brinkerhoff, 1996). Capacity to implement is an important determinant of policy success. Officials responsible for policy implementation usually lack sufficient resources and authority to perform all of the necessary tasks implied by a policy change (Crosby, 1996). This becomes particularly important over the long-term. Sustained reform depends upon managed implementation with direct ownership of both the process and the capacity to achieve policy goals (Brinkerhoff, 1996).

An understanding of the complexity and scale of processes required for implementation is another crucial factor determining policy success (Gallopin, 2002). Within the resource conservation literature there are many examples of regulatory measures justified by science which failed to assess the broader implications of these actions, particularly in the social, economic and political spheres (Bainbridge *et al.*, 2000; Brown, 2002). These considerations are further complicated in sustainable development policies because sustainable development assumes not only long-term changes, but a process of progressive social change (Meadowcraft, 1997). Consequently, this national framework is designed to achieve sustainable development which often demands perpetual reassessment in an atmosphere of continual uncertainty and change.

1.2 Aims and Objectives

The ultimate aim of this research is to provide a national framework to support and give overall direction to the development and successful implementation of a classification system. It is vital to state that this study will not deviate from the aims of classification as stated in the NWA; instead it will be complementing the overarching principles (sustainability, efficiency and equity) which form the foundation of the NWA.

The objectives of this research can thus be outlined as follows:

i. Outlining the underlying principles of classification;
ii. Providing key elements to be put in place when implementing classification;
iii. Identification and evaluation of the interactions between protection and development;
iv. Introduction and formulation of a risk-based assessment process; and
v. The integration of information into a generic assessment framework model to evaluate trade-offs between protection and development.

The conducting of this research is therefore deemed an absolute expedient in order to provide a planning, regulatory and management framework, which will support decisions associated with the development, utilisation and protection of a water resource. This framework should remain in place for an agreed time period prior to review to ensure consistency in a dynamic water resource management field. The foundation of this framework is a transparent, understandable and approved basis for assessing proposed impacts on water resources and deciding whether these impacts are acceptable.

1.3 Previous Studies

1.3.1 Classification within the South African context

Preliminary investigations to date within the broader South African water sector (with respect to classification) has merely focussed on the ecological integrity of ecosystem functioning. Many methods for evaluating water user and environmental requirements, in terms of water quality and quantity, are already available in a form generically applicable to the majority of South African water resources. Examples of these rules and methodologies are the South African Water Quality Guidelines (DWAF 1996, 1997) and the Assessment Guide for Quality of Domestic Water Supplies (DWAF, 1998). Mackay (2000) also produced a report on *Moving Towards Sustainability: The ecological Reserve and its role in the implementation of South Africa's Water Policy*, with another Water Research Commission (WRC) funded case study by Colvin *et al* (2002) on *Classification of groundwater under RDM: A case study for the Kammanassie-Oudtshoorn area*.

The proposed framework will act as an integrating platform for many of these assessment methodologies. The framework will therefore go beyond these generally applicable source documents, to provide an overarching structure for selecting and/or deriving appropriate resource quality objectives (RQOs) for a specific water resource, whilst taking into account specific recommendations made in previous studies i.e. Xu *et al* (2003) in a WRC funded report entitled ‘Towards the Resource Directed Measures: Groundwater Component’. It important to stress that RQOs are subject to a management class (social, ecological and economic) which is set through a stakeholder participation process for that water resource. Xu & Beekman (2003) also highlights the importance of the sustainable development of groundwater resources in their publication on *Groundwater recharge estimation in Southern Africa*. Sustainable development trends in the water sector (Southern African context) are further highlighted by Turton & Henwood (2002) in *Hydropolitics in the developing world: A Southern African Perspective*. De Witt & Reed (2003) also depicts this trend in their publication *Towards a Just South Africa: the Political economy of natural resource wealth*.

1.3.2 International trends on classification

The European Union (EU), which to date has focused primarily on water quality concerns, issued a directive in late 2000 establishing a new framework for water policy that includes a focus on river flows. A key feature of this directive is the establishment of criteria for classifying the ecological status of rivers (including other water resources) as high, good, moderate, poor, or bad, depending upon how much the river’s ecological characteristics deviate from natural or undisturbed condition. (This classification approach is similar to that used here in South Africa), with South Africa attempting to prescribe a management class focussing on ecological, economic and social relevance of the water resource in its entirety. This approach calls for a strong stakeholder engagement process especially required through the NWA once a classification system is to be published by means of government gazette (Postel and Richter, 2003).

According to the EU, member countries then to take measures to ensure that at least a “good status of both surface and groundwater is achieved” and that deterioration in the status of the water resource are prevented. Importantly, the EU directive establishes criteria for classifying the ecological status of river, including river flow and channel characteristics. In Australia and South Africa, where scientists have advanced new methods for setting environmental flow requirements, policymakers have taken great strides toward translating the concept of allocating flows for ecosystem support into actual policy and practise. Together the initiatives of these two countries are in large part responsible for the marked shifts in water resource management philosophy that are increasingly evident internationally. Because they are at different stages of economic and water resource development, these two countries and their pioneering experiences offer some useful lessons for others. Among them is the importance of establishing ecosystem-support allocations as early as possible in the course of resource development – preferably for human water use surpasses ecological limits (Postel and Richter, 2003).

With each passing year, the need for greater protection of river flows in the United States (US) became more apparent. Conflicts over the allocation of water between human needs have been intensifying across the country, from west to east and north to south. Despite widespread degradation of its river systems, the US has no overarching vision or goal to secure the flows that rivers need to support the diversity of freshwater life and to sustain ecological functions. However, in practise, the US’ engagement in water resource protection also has a focus on the quality of water resources at a watershed scale. The attention is given to areas where problems and pollutants have the most negative impact, with the protection of water resources being implemented as early as 1970, including several laws pertaining to water resource protection (Postel & Richter, 2003).

An ecological-economics framework on water allocation decision-making in Australia has also been proposed and endorsed several years ago (Van der Lee and Gill 1999). It became increasingly obvious that human activities were impacting the aquatic and riverine environments in Australia with, in some cases, severe social, economic and environmental consequences. Environmental flows have become an instrument of the Australian government policy as a mechanism through which to sustain ecological values over time. Many instream flow methodologies have been developed in the northern hemisphere where the hydrological conditions were very different from those experienced in Australia. Those methodologies therefore required adaptation to the Australian environment before application. In general, environmental flow methodologies in Australia have been developed by government agencies such as the Department of Land and Water Conservation in New South Wales and New South Wales Fisheries. The recommended ecological-economic framework approach by Van der Lee and Gill involved the development and application of a very precise procedure through which transdisciplinary (across disciplines) discussion was facilitated towards the development of the most informed foundation for strategic regional planning. Van der Lee and Gill's work led to an integrated transdisciplinary decision-making process for water allocation and the provision of environmental flows in particular was endorsed as a way of achieving sustainable economic, ecological and social outcomes for Australia's water resources (Van der Lee and Gill, 1999).

Despite the international trends described above, it is anticipated that much attention would be geared towards South Africa for implementing its sophisticated water legislation which requires integrated water resource management tools such the development and implementation of a national water resources classification system among others.

2. METHODOLOGY

2.1 Introduction

This research was conducted in collaboration with the Thukela Reserve Study (TRS) by two directorates within the Department Water Affairs and Forestry (DWAF), namely National Water Resources Planning (NWRP) and Resources Directed Measures (RDM).

The research collaboration addressed the following three aims:

- To propose a framework within which a national water resources classification system can be developed at a national scale.
- To assess the relevance and applicability of this framework approach through pilot testing in the Thukela River System.
- To make recommendations for advancing the formal development and implementation of a national water resources classification system.

Through selected interviews and internal departmental (DWAF) workshops with a number of stakeholders it was agreed that the classification system would not work unless it was established on a set of sound conceptual principles. A set of principles (which serve as the conceptual foundation) for the development and implementation of a national water resources classification system are briefly described below.

2.2 Underlying principles of classification

2.2.1 Sustainability

The concept of 'sustainability' is regarded as a central theme of the classification system. The principal reason for protection of the resource is to maintain the ecosystem integrity at a level that ensures the continued delivery of the desired ecosystem Goods and Services. The concept of limited trade-offs between costs and benefits should be a consideration in classification, for example, allowing development of one part of a resource in exchange for rehabilitation of another degraded section of the same resource (thereby adding protection value).

2.2.2 Balance and trade-offs

The classification process should produce a set of RQOs in accordance with a specific class for a water resource. A major consideration in arriving at these end points is the balance between protection and utilisation of the resource. While development can provide economic and social benefits, the associated potential impacts may compromise ecosystem integrity thus impacting the sustainable utilisation, resulting in economic and social costs. To obtain efficient allocations between resources **trade** in environmental and water rights should be encouraged.

2.2.3 National interest

Decisions about the class of a resource may produce solutions which are acceptable in a catchment context but may not be optimal when placed in a national context. Catchment-level decisions must therefore be evaluated against a national framework for classification and the need to conserve selected resources. This national framework is aimed at orchestrating a map at national level which could outline the specification for conservation and rehabilitation as well as for development. Criteria that could be used for these specifications encompass the necessity to ensure representative ecosystems while providing for development in key industrial and urban areas.

2.2.4 Transparency

The consultative requirements in the development of the classification system oblige that the system, while scientifically robust and legally defensible, must be devised in a language and a format which is accessible to the general public. Public participation in the classification process necessitates transparency throughout the decision making process. The inputs into the classification system and the results of classification must be comprehensible and meaningful, in order to allow individuals to participate meaningfully in catchment management.

2.2.5 Implementability

As there is a legislated requirement for the development and use of the classification system, the initial system created must be sufficiently practical and robust to be implemented at a catchment level by trained DWAF staff. There should be a balance between the costs of implementation and the confidence levels associated with the determination of a class. It is likely that different methods resulting in increased levels of confidence in the determination of classification will eventually evolve (e.g. low, medium and high confidence versions of the same system). It has been suggested that the most basic of these methods be used in a preliminary classification of all significant resources country-wide.

2.3 Systematic Approach

The classification system should be implemented at a catchment scale, so that all resource units are classified in a catchment during one study. The socio-economic implications of different states of the health of resources within the catchment will be integrated into this process. A systematic approach for the classification of significant water resources is depicted in the Figure 2.1. The NWA refers to the imperative of classifying the country's water resources in order to develop a framework in which social and economic development can take place under the ambit of sustainable development. This process is inherently political because of two key reasons:

- The spirit of the NWA is focussed on the core issue of redressing past inequities arising from decades of discrimination.
- The country's history of discrimination was supported by, and ultimately manifest in, a profound example of resource capture that resulted in gross maldistribution of water in society.

The interaction of these two key elements means that water resource management as envisaged by the NWA is always going to be underscored by political dynamics, motives and tensions. As such it will never be purely technical or neutral. The figure below therefore makes provision for a balanced approach (legal, scientific and community-based inputs) through a collective and transparent process in order to successfully achieve classification of water resources.

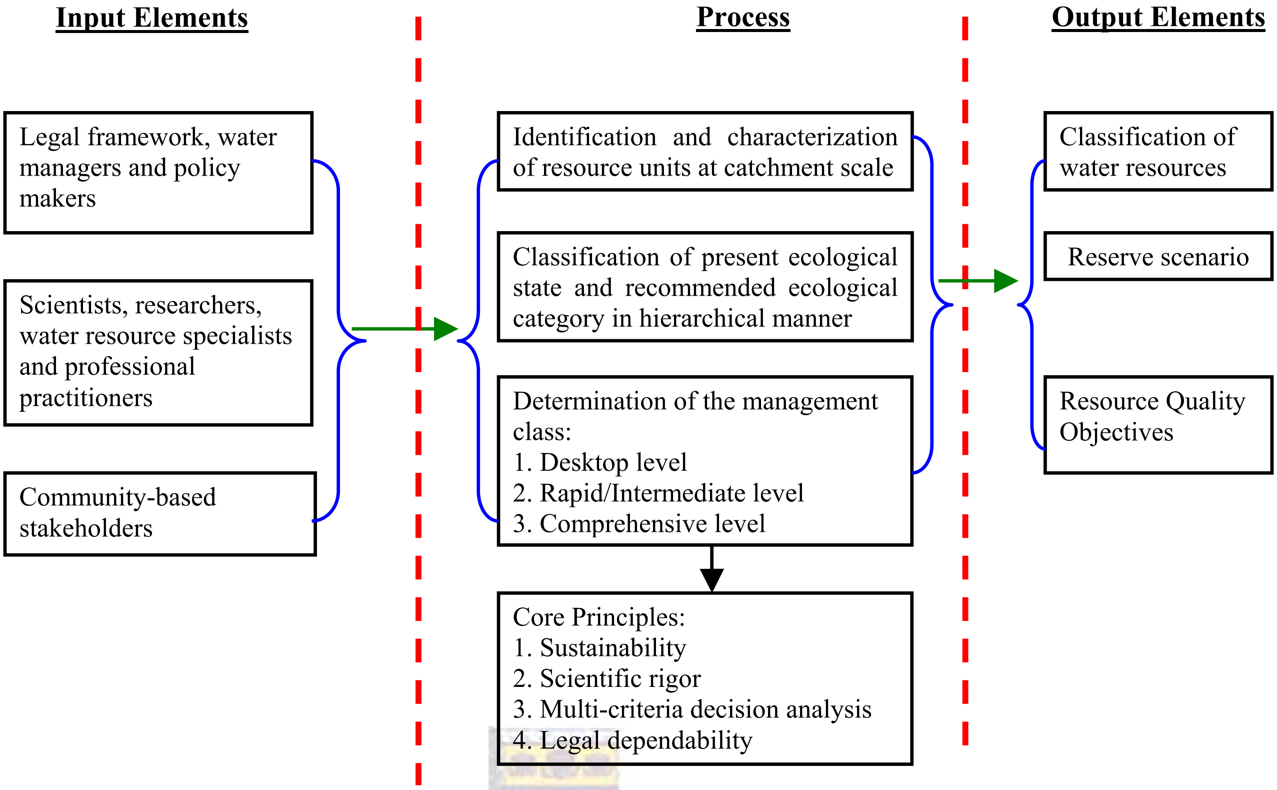

Figure 2.1 A systematic approach: System and elements.

The strategic objective of this approach illustrated above is to develop a framework for the classification of the national water resource, at levels of resolution that are appropriate, with the highest level of buy-in from the widest range of stakeholders (both internal and external to DWAF). This will mean therefore that the classification methodology should have the lowest level of contestation and the highest level of legitimacy. In order to attain the strategic objective noted above, it is necessary to make an assessment of the key elements for classification (discussed in Chapter 3), and that management strategies be developed to mitigate the risks (as presented in Chapter 4) arising from such a venture.

3. KEY ELEMENTS FOR CLASSIFICATION

3.1 <u>Introduction</u>

The classification system embodies a methodology whereby water resources (i.e. wetlands, rivers, estuaries, reservoirs, lakes and groundwater) are grouped into certain categories in terms of both water quality and quantity. The classification system also encompasses the process whereby stakeholders codify the resource in terms of both its present status and its future desired state, set in terms of the resource quality objectives (RQOs). The determination of the future desired state obliges stakeholders to take into account the social, political, economic and environmental landscape and as such the classification system needs to encompass the perceived costs and benefits associated with development versus protection.

The classification system and the setting of RQOs provides water resource managers with specific targets which must be met by addressing the impacts associated with various water use activities within a catchment. This process thus represents a useful management tool where water resource managers (through the use of a system similar to the ISO 14000 standards) could set management plans and actions in a particular catchment area. It also represents a system whereby various water users and an entire catchment system can be audited to ensure compliance.

3.2 <u>Summary of specific elements outlined in the National Water Act</u>

The classification system is the first stage in the protection process and must provide a set of guidelines and procedures for determining the different classes of the resource. Such guidelines and procedures in respect to each class may:

- Establish procedures for determining the reserve;
- Establish procedures to designed to satisfy the water quality requirements of water users without significantly impacting the natural water quality characteristics of the resource;
- Define which instream of land-based activities must be regulated or prohibited in order to protect the resource, and
- Provide for such other matters relating to the protection, use, development, conservation, management and control of water resources as the minister considers necessary.

The classification system once it is established should be used to determine the class and set the resource quality objectives for all significant water resources. In determining the resource quality objectives a **balance** must be seek between the need to protect and sustain the resource and the need to develop and use them. Once the RQOs have been determined they are binding on all authorities and institutions when exercising any power or performing any duty in accordance with the NWA. The class must be determined in terms of the prescribed classification system. The resource quality objectives are based on the class and may be related to the following:

- The Reserve;
- Instream flow;
- Water level;

- Presence and concentration of particular substances in the water;
- Characteristics and quality of the water resources and the instream and riparian habitat;
- Characteristics and distribution of aquatic biota;
- Regulation or prohibition of instream or land based activities which may affect the quantity of water or the quality of the water resource, and
- Any other characteristic.

The NWA makes provision for the preliminary determination of the class and water resource quality objectives.

3.3 Description of underlying principles against key elements

- **Sustainability**, the recognition that we are protecting the resource to ensure that it is able to sustain developments and usage in both the short and long term.
- **Balance and trade off**, the recognition that we are attempting to satisfy both protection and development. The understanding that a trade off will occur in most cases between the development and usage of the resource and the protection. An understanding how the various impacts associated with development may compromise the long term sustainability of the resource.
- **Interdependence of the hydrological cycle**, the knowledge that all components of a water resource are linked and that when looking at a classification system it must be generic enough to encompass all sections of the water cycle in terms of both protection and development.
- **Dependency**, the recognition that certain elements in the natural system are dependent on one another for survival and that a seemingly small impact in one area could have dire consequences in another.
- **Transparency,** the requirement for users to understand the inputs and outputs to a classification system thus allowing them to interact with each other on a equal basis. It should be recognised that transparency does not mean simplicity it is the ability translate scientifically complex information into understandable information that can be used to make decisions. Different groups of people should be able to analyse and understand the system from highly technical users who can dispute the guts of the system to laymen who can understand the outputs and inputs and use these as a negotiating framework.
- **Legal dependability and scientific rigor**, the understanding that not only must a system be transparent but must be based in scientific principles and techniques that make it legally defendable and as unbiased as is possible.
- **National interest**, the recognition that certain decisions made in a catchment framework may compromise some national interest goals and thus can be overridden by the Minister.
- **Scale,** the understanding that the complexity associated with different decision may vary with their conflict causing potential, information availability, aspect of the water cycle being discussed etc, This will require different techniques to be applied at different scales of decision.
- **Conflict,** the recognition that two conflicting elements are being dealt with and that they may need to be looked at different levels of complexity according to the amount of conflict a decision will create.
- **Continuum,** the recognition that in many cases we are dealing with a continuum in terms of the elements that we are quantifying and trading off. This means that the

codification of various elements is essentially arbitrary and that no fixed barriers may in reality exist. Associated with this is the principle of thresholds.

- **Thresholds,** The understanding that in certain situations thresholds can be identified that must not be crossed and that these make important break points in terms of the codification process and thus must be identified.
- **Auditable and enforceable,** the system needs to be auditable and legally enforceable to ensure that it is not abused or ignored.
- **Implementability,** the system should be practically implementable otherwise it may become redundant and unenforceable.

3.4 Critical elements from a public sector perspective when implementing classification

The institutional and transaction costs associated with making a decision in terms of grouping a resource into a specific class and setting resource quality objectives must be as low as possible in order to prevent the inhibiting of development (this interactive process is discussed in more detail in Chapter 4). Decision making processes must be transparent and legally defendable to prevent legal liability accruing to the department or the stakeholders. Methodologies used in making the decision must be scientifically rigorous to be legally defendable. The classification system must present results in a standard manner that can readily be used to communicate effectively with stakeholders participating in the process of setting the class and the RQOs. The outputs of the system must be understandable enough and rigorous enough for the effected stakeholders to understand the consequences of a decision and the tradeoffs that are taking place. The system must be practically implementable so that an effective decision can still be made despite possibilities of lack of knowledge or missing information. The scale should be at a resolution that it will enable individual water users to participate in the negotiating process and understand the consequences of each decision and action.

4. INTERACTION BETWEEN DEVELOPMENT AND PROTECTION

4.1 Introduction

Perhaps one of the most important elements that permeates the discussions about the classification system in the NWA is the concept of balance and trade-offs between protection and development. This is highlighted by the following two statements from the NWA in chapter 3 which discusses the protection of water resources:

- "The protection of water resources is fundamentally related to their use, development, conservation, management and control".
- "In determining resource quality objectives a balance must be sought between the need to protect and sustain the water resources on the one hand and the need to develop and use them on the other."

It is thus necessary to develop a framework within which the interactions between protection and development can be captured and evaluated. It is also necessary to identify that the classification system must not only consider the environmental aspects associated with protection and sustainable use but must also encompass the social and economic aspects associated with usage and development. It is thus necessary to develop a framework within which the benefits associated with development can be evaluated against the costs associated with the impacts of such developments.

Fortunately the concept of risk is embodied in both the protection and development environments. Risk assessment could thus be used as a common methodology in determining the costs and benefits associated with protection, development and usage of water resources. A large body of international and local literature is available on the well established risk assessment approaches and the approach has been advocated in recent literature (Hughes and Munster, 2000) as a feasible assessment methodology for the setting of resource quality objectives and the determination of the reserve. In the following sections the risk based approach as an assessment methodology is discussed in more detail identifying how it could be used as a framework for the development of a classification system.

4.2 Evaluating the interactions between development and protection

As mentioned earlier the principle of balance is central to the development of a classification system and the process of implementing classification in a particular catchment. It is proposed that a risk based approach be used to capture these interactions and evaluate this balance. The questions that need to be asked are thus:

- Why do we need to use a risk based approach?
- What elements need to be incorporated in the risk based assessment process that will allow the evaluation of trade-offs?
- To answer the first question there are a number of aspects that make the risk based approach a viable methodology in considering trade offs:
- Risk based assessment approaches are used by environmental scientists, developers, water managers, water resource planners, economists, sociologists, industry, agriculture and commercial industries, and although the methodologies differ, the results, terminology and understanding could be described as relatively generic and universal and thus could be incorporated into a single assessment framework.

- The complexity of the natural ecosystem means that it has varying degrees of resilience and recovery potential to the same natural and environmental hazards. In fact in many areas the natural ecosystem has adapted to the variability of both water quality and quantity in a particular area. This means that a risk based approach is one methodology which can account for the local scale variations in the resilience and recovery potential of systems (Smith, 1996).
- The outputs from a risk based assessment can easily be incorporated into an assessment matrix using tool such as multi-criteria decision analysis (MCDA) and Bayesian networks to quantify the costs and benefits associated with trade offs (Smith, 1996).
- Risk assessments have different paradigms that can operate at different levels of complexity with different input requirements. A risk assessment can be mainly qualitative in nature following a Quantal Assessment Paradigm (QAP) where expert knowledge, peoples' perceptions and peoples' experience could be captured into a broad risk assessment framework. A risk assessment could also be quantitative following a more the formal Continuous Assessment Paradigm (CAP) which follows a more comprehensive probabilistic assessment approach (Smith, 1996).
- The concept of risk management and assessment is also well established in terms of courtroom understanding which will make the entire classification process more legally defendable.
- The risk based approach encourages a scientifically rigorous (thorough) investigation of all the elements causing the impacts associated with a particular development thus bringing a degree of objectivity to any decision making process.

The second question will be dealt with in chapter 5 in more detail. The next sections will focus on defining hazard and risk in more detail prior to incorporating them into a framework which could be used to develop the classification system.

4.3 Defining hazard

Hazard may be defined as a naturally occurring, or human induced, event that has the potential to create loss (Zhou, 1995; Smith, 1996; Fairman *et al.*, 1998). The definition serves to highlight the concept that a process only becomes a hazard when it threatens to create some sort of loss (such as loss of life or damage to property) within the human environment (Smith, 1996). This is essentially an anthropocentric view of hazard and does not take into account the effect that an extreme natural event can have on an uninhabited area (Suter, 1993). The assessment of losses and the determination of the detrimental effects on future overall sustainability in uninhabited areas are extremely difficult to estimate and generally fall under the concept of ecological risk assessment (Suter, 1993). In this document the magnitude of a hazard is determined by the extent to which an event (Anthropogenic or natural) can disrupt the human and natural environment. A hazard is the combination of both the 'active' physical exposure to a natural or anthropogenic process and the 'passive' vulnerability of the human or environmental system with which it is interacting (Plate, 1996).

The physical exposure is essentially the damage-causing potential of the event and is a function of both the intensity and duration of the process. However, although processes can cause damage, most processes produce some benefit to the human or natural environment with which they interact (Smith, 1996). Rainfall, for example, is considered a benefit in that it is used in the crop growth process and it generates streamflows which feed dams which, in turn, can be used for recreation, irrigation and domestic water use. A natural process, however, becomes a hazard when it produces an event that exceeds the bounds that the environment can normally tolerate. In the case of rainfall, too much produces a flood hazard and too little a drought hazard. In Figure 4.1 the shaded area represents the tolerance limits of the variation about the average, within which the resource can be used beneficially for social and economic activities in the human environment (Plate, 1996). Hence, a process only becomes a hazard once it has exceeded a certain threshold. The magnitude by which an event exceeds a given threshold determines the damage-causing potential of such an event.

The term 'intensity' refers to the severity of a process, thus the greater the intensity the greater the damage-causing potential (e.g. rainfall at 20 $mm.h^{-1}$ is generally less damaging than at 100 $mm.h^{-1}$ over the same time period). Duration is the other variable determining the damage-causing potential of an event. The longer the exposure to an event, the greater the damage-causing potential (Zhou, 1995; Plate, 1996; Smith, 1996). The hazard intensity is determined by the peak deviation beyond the threshold (vertical scale in Figure 4.1). Hazard duration is determined by the length of time the threshold is exceeded (horizontal scale in Figure 4.1).

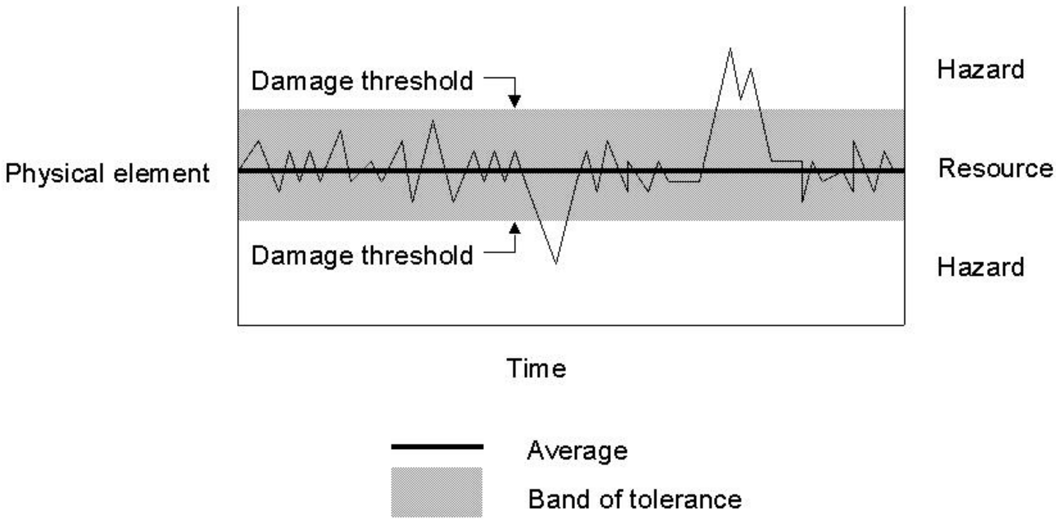

Figure 4.1 The magnitude of environmental hazard expressed as a function of the variability of physical elements and the degree of socio-economic tolerance (after Smith, 1996; Smith and Ward, 1998)

The concept of threshold also applies to the passive dimension of the vulnerability of the human or environmental system to a process. Vulnerability is the most manipulable dimension in risk management schemes and thus assumes most importance in any hazard assessment (Smith and Ward, 1998). Vulnerability is the degree to which a system or its components react to a hazardous event (Gilard, 1996). Vulnerability is a function of the resilience and reliability of a system. Resilience is the capacity of a system to absorb and recover from a hazardous event (Vogel, 1997). Reliability is the probability that the system, or component of the system, will perform its intended function for a specified period of time (Frankel, 1984; Plate, 1996).

For example, a dam is constructed to withstand a certain flood magnitude before the wall fails; the reliability is the ability of the wall to perform this task. In terms of a so-called 'assault' event (rainfall, heat, pollution, deposit) the vulnerability threshold is determined by the system absorption and redirection capacities (Vogel, 1997). The thresholds in the case of a so-called 'deprivation' event (e.g. drought, cold, leaching, and erosion) are determined by the retention and replacement capacities of the system (Smith, 1996). Hazards represent only the potential to create loss. Loss is incurred when the hazard potential is realised. It is important to understand that not all hazards produce disasters. Disaster is the extreme form of hazard realisation, causing extensive damage and sometimes loss of life or permanent loss of sustainable system functions.

4.4 Defining risk

Risk is defined as the probability of specific hazard occurrence (Smith, 1996). Hence, risk is comprised of two factors viz., the probability of occurrence and the loss caused by the associated hazard realisation (Fairman *et al*., 1998; Shamir, 1996). The two major factors that influence the risk associated with an event in an area are changes to the physical system affecting that area and changes to the vulnerability in that area (Vogel, 1997).

In Figure 4.2 several of the possibilities that give rise to increased risk are illustrated. Case A represents a scenario where the tolerance and the variability remain constant, but there is a rise in the mean value (e.g. a trend occurs due to change in land-use). In this particular case the frequency of extreme events at one end of the scale increases. Case B shows a scenario in which both the mean and the band of tolerance remain constant, but the variability increases (e.g. change in variability associated with climate change). In this particular case the frequency of damage producing events increases at both ends of the scale. In Case C the physical variable does not change, but the band of tolerance narrows, i.e. the vulnerability of the human system increases (e.g. vulnerability increases as people locate their houses closer to a river). In this particular scenario the frequency of damage-causing events increases at both ends of the scale. This pattern can also occur in a stepwise fashion where hazard event reduce the long term vulnerability of the system.

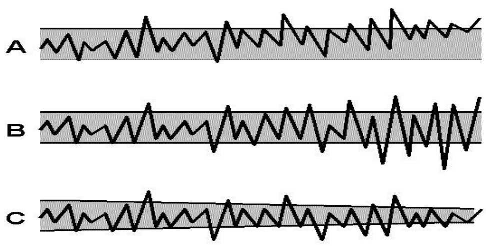

Figure 4.2 A schematic illustration in which risk changes due to variations in the physical system and socio-economic events. In all the cases risk increases over time (after Smith, 1996; Smith and Ward, 1998)

Most water uses affect the system in at least one of the 3 ways shown in Figure 4.2. Therefore in most cases of development, an increase in risk will result as a consequential occurrence. This increase in risk represents an impact onto the system and thus produces certain social, economic and physical systems consequences for other water users or the environment in a particular system which we will call costs.

5. FORMALISING A RISKED-BASED ASSESSMENT PROCESS

5.1 Introduction

From the previous discussions it is possible to see that the concept of risk can be applied to both water users and to the natural environment. A proposed conceptual framework for the evaluation of risk and developing a classification system is presented by the author in Figure 5.1. It is important to realise that this section refers to risk associated with any type of process, event or component in the water resource system. It is considered useful to separate risk analysis into two main dimensions described as requirements and impacts (Figure 5.1).

The requirements essentially represent the vulnerability dimension of the risk assessment and set the limits within which certain elements (water quality and quantity) must occur to satisfy the environmental or water user requirements in a system. It is believed that a set of functions and rules will need to be developed which can combine the water user requirements with the environmental requirements (in certain circumstances the water users may require a better quality or more quantity that the environment and visa versa, it is important to realise that the requirements from both water users and the environment are in most cases not mutually exclusive but actually complimentary). Associated with both the environmental requirements and the water user requirements are certain physical, social and economic benefits, such as income generated, jobs created, aesthetic appeal, water filtering etc. The requirements from the system thus generate associated benefits, however in the case of water users who bring a development function in many cases there are associated impacts and thus costs.

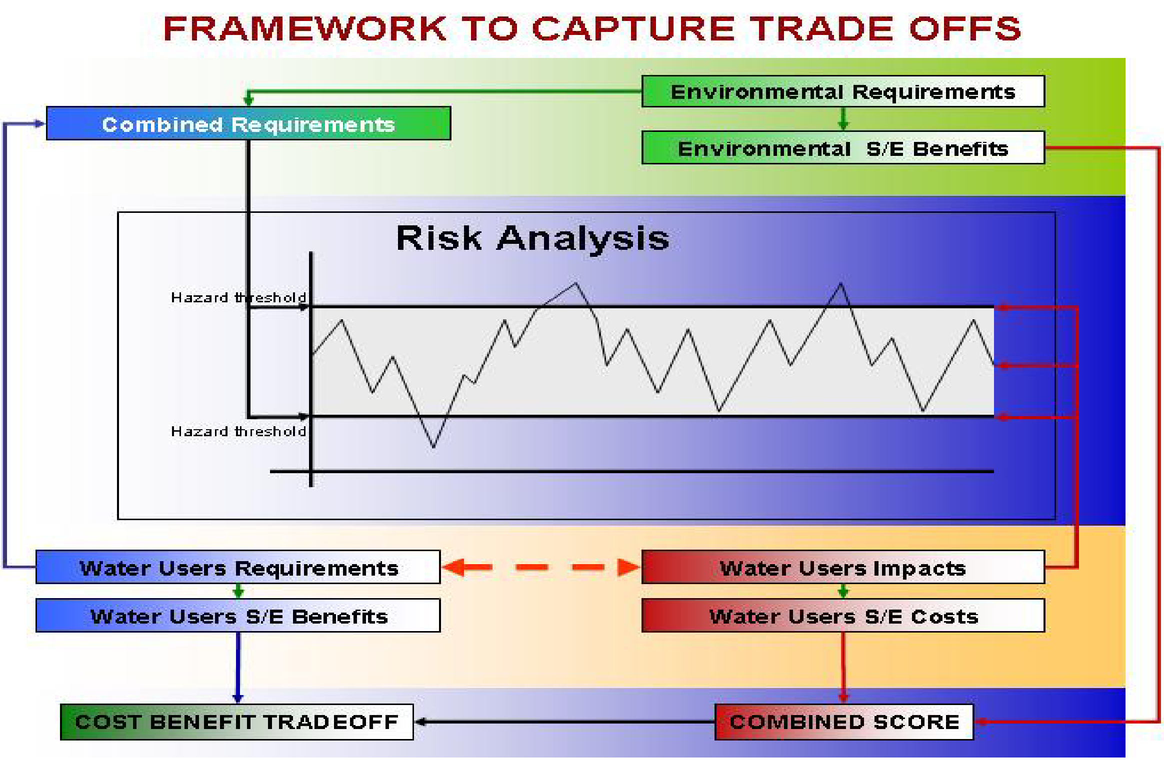

Figure 5.1 Representation of conceptual framework model for risked based assessment process.

As can be seen from Figure 5.1 it should be possible to combine the benefits generated by environmental services generated by protection with the costs associated with impacts produced by development and compare these against the benefits generated by development in a cost, benefit matrix using a MCDA or a similar tool. This will enable a relatively unbiased assessment of tradeoffs and act as a negotiating platform within which stakeholders can interact. The risk based approach could also effectively act as a basis for codifying the various elements associated with the water resource system (water quality, quantity, biota and habitat integrity) into different classes which would form the basis for the classification system and the setting of RQOs.

5.2 Defining scales and levels of assessment complexity

The levels of risk and conflict potential associated with specific decisions will vary throughout the country. Added to this the information availability and skill levels of water managers and water users vary from region to region. It is thus prudent to develop a methodological framework that is able to encompass several different levels of complexity and information availability. A risk assessment framework allows for both quantitative and qualitative information to be used thus allowing users to make justifiable decisions in the light of lack of information. MCDA (or similar methodology) is an appraisal methodology which is flexible enough to encompass different levels of information availability and compare trade-offs of the various costs and benefits associated with developmental options. The varying levels of information, skills, complexity and conflict potential within the country would suggest that it may be prudent to adopt a methodology much like the Reserve estimation process in which several levels of assessment complexity have been adopted.

It is suggested that in this preliminary exercise three levels of complexity be adopted, namely:

- Basic;
- Intermediate; and
- Comprehensive.

The classification system should be developed in such a manner as not to hamper the decision making process through lack of information. Each level of assessment complexity must be formulated in such a way that as a more complex assessment level is adopted certain key elements in terms of the class and resource quality objectives are in harmony. This will ensure that estimates in terms of resource quality objectives do not change substantially when a more complicated assessment level is instituted in a particular area. Therefore prior to embarking on any classification exercise it may be necessary to adopt a system that allows the users to codify the catchments according to what we will define as an assessment complexity matrix. It is suggested that the following assessment complexity matrix (Figure 5.2) be used to identify the conflict potential in a particular catchment area. This will enable classification participants to identify the level of classification assessment complexity that should be used in their particular catchment and thus adopt the appropriate assessment tools and methodologies and assist with the collection of the necessary supporting information and data. It is recommended that the following three axes could be used in the in the assessment complexity matrix. These and the associated sub criteria could be used to produce a final overall score which could provide a good indication of the level of assessment complexity that could practically be implemented or should be implemented in a particular area.

It is recommended that the following criteria and sub-criteria should be used to evaluate what level of assessment complexity you should use:

- Degree of conflict
  - Level of resource utilization
  - Types of users
  - Complexity of interactions the system
  - Types of supply sources
- Information availability
  - Existing data and information availability
  - What extra infrastructure can be implemented in order to develop the level of skill
  - What is the economic implications of improving data capturing network
- Institutional capability
  - What is the institutional framework in the area
  - What is the level of skills from a modelling and computer literacy level

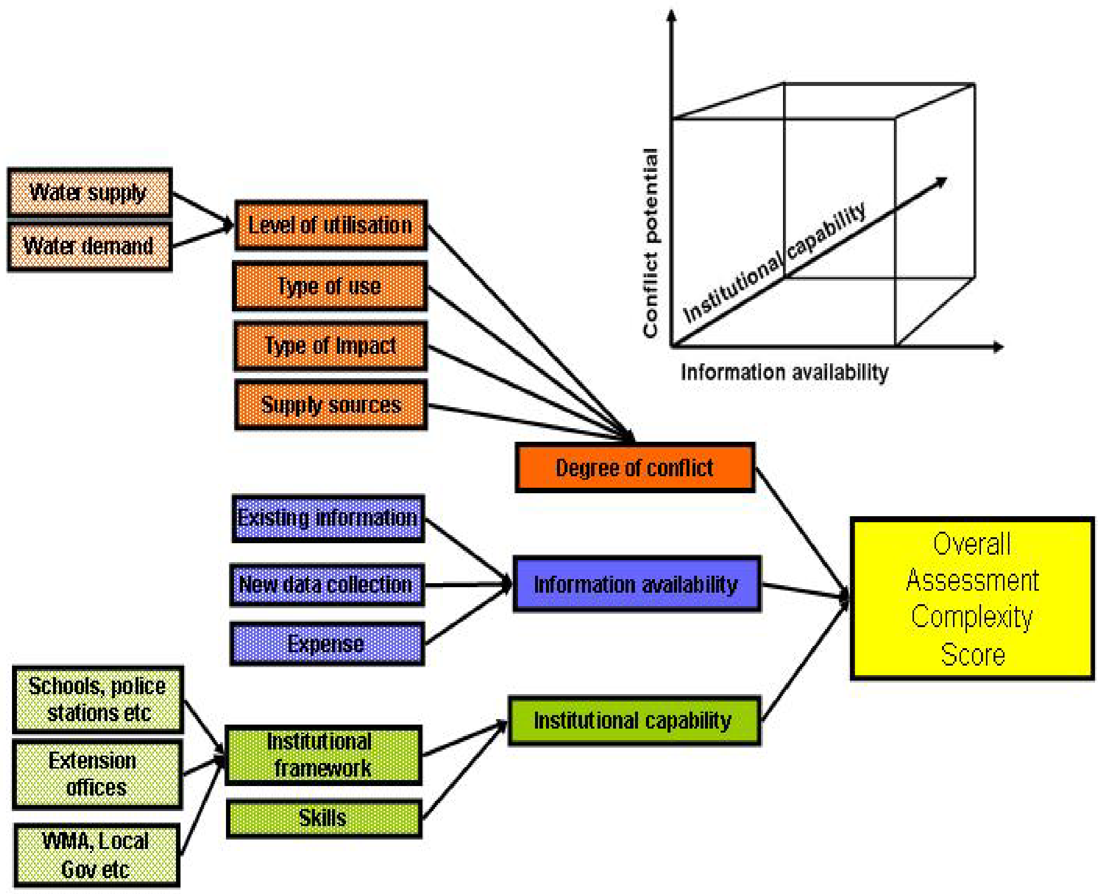

Figure 5.2 Assessment complexity model and associated decision analysis framework.

The above matrix will allow us to define the level of complexity required to make certain decisions in terms of classification. In an area where conflict potential is low and the institutional capabilities and information availability is low one would get a low score in terms of the above matrix and thus use a basic level of assessment to determine the class. If the scores became higher in any of the 3 variables depicted on the matrix then an intermediate or comprehensive level of assessment might be chosen. It also represents a useful matrix whereby a specific assessment methodology may be chosen.

The following three elements are critical to the assessment complexity and require consideration when implementing classification:

- What level of skill will be required for each level of assessment complexity?
- What spatial and temporal scale should the different levels of assessment complexity encompass?
- What level of public participation should be covered at the different levels of assessment complexity?

The following table represents the author's views on these two questions and provides recommended spatial and temporal scales associated with the various levels of assessment complexity as well as identifying the level of public participation that would probably be required in setting the class and the resource quality objectives.

Table 5.1 Public participation requirements and spatial/temporal resolution associated with the various levels of complexity.

Assessment complexity level	Complexity matrix description	Spatial and temporal scale	Skill level	Level of public participation
Desktop/Basic	**Conflict potential**: low **Information availability**: Low **Institutional capacity**: Low	**Spatial scale:** Quaternary catchment **Temporal scale:** Monthly/yearly	Water manager level	Classification system preliminary status with inputs from key stakeholders
Rapid/Intermediate	**Conflict potential**: Intermediate **Information availability:** Low/ intermediate **Institutional capacity**: Intermediate	**Spatial scale:** Sub-quaternary catchment/river reach **Temporal scale:** Daily/weekly/monthly	Water manager and some specialist scientists	A consultation process with the representatives of the water use sectors within a particular catchment
Comprehensive	**Conflict potential:** high **Information availability:** Intermediate **Institutional capacity:** high	**Spatial scale:** Quaternary catchment **Temporal scale:** Daily/Weekly	Specialist scientist team with local experts and water managers	A consultation process with the representatives of the water use sectors within a particular catchment

It should also be noted that a set of national directives be developed from both a protection and development perspective that would inform the classification process from a higher level preventing actions that may actually impact on the national stability within a specific catchment.

6. A GENERIC ASSESSMENT FRAMEWORK

6.1 Introduction

There are a number of methodologies such as MCDA developed and funded through the various research institutions (i.e. Water Research Commission studies among others), neural networking and Bayesian networks, which enable the quantification of tradeoffs. These systems can be used as a unifying framework within which data and information collected and generated can be compared in a specific subjective framework which makes assumptions and decisions transparent. These systems also enable public participation and allow for the representation of trade offs in a workshop environment.

6.1.1 The multi-criteria decision analysis (MCDA) approach

It is recommended that a modified MCDA approach be adopted which enables the quantification of both quantitative and qualitative information as well as collected and modelled information. The framework for evaluating the tradeoffs should follow those criteria depicted in Figure 5.1 of the previous chapter. However a more complex interaction matrix showing the scoring is presented in Figures 6.1, 6.2 and 6.3 below. It is extremely important to remember that costs and benefits represented in this matrix do not follow the normal cost benefit approach where an attempt is made to convert most aspects into monetary values. The costs and benefits are social, economic and environmental elements which are traded off between each other in a manner that captures the participants' perceptions on the value of the particular element to themselves. The costs and benefits of the different elements are thus essentially embodied in the weightings provided in the MCDA matrix.

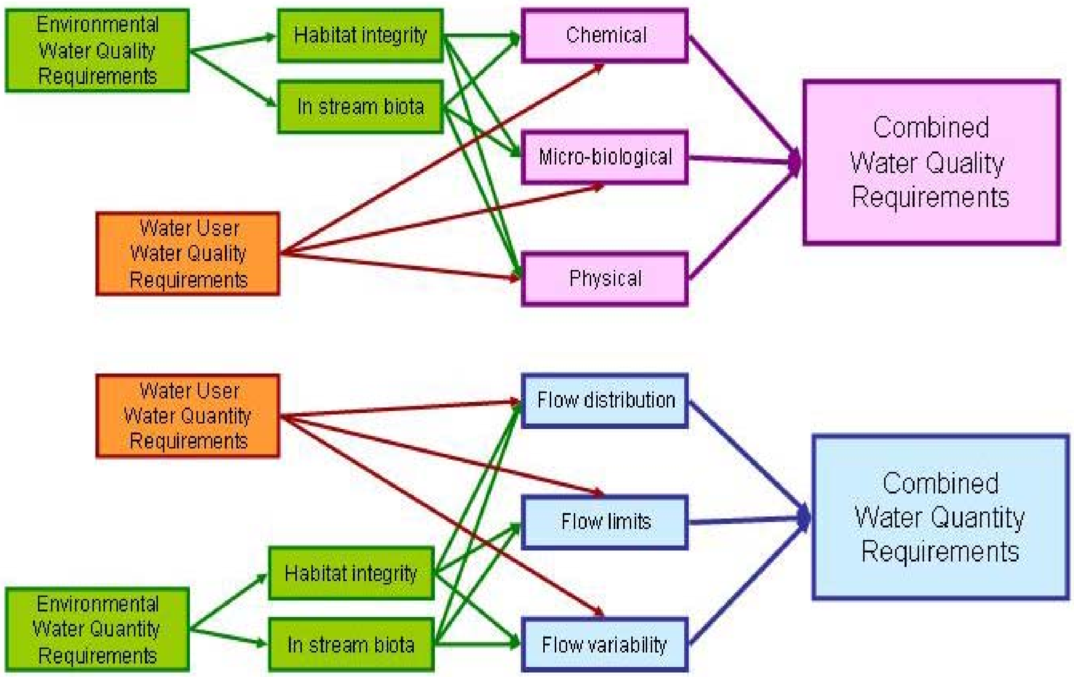

Figure 6.1 MCDA framework for the evaluation of water requirements.

6.1.2 Assessment of water user impacts

In Figure 6.1 the requirements are determined using certain source and resource directed measures but it is important to note that the ecosystem and water users in many cases are demanding specific quality and quantity of water and require certain minimum requirements to be met so as to minimise risk to both the environment and the water users. These are divided into the 3 main water quality categories and the 3 main water quantity categories. Scientific rules need to be developed to ensure that the weighting and adding up are consistent and do not allow specific quantities to become dangerous that may influence the water user and the environment.

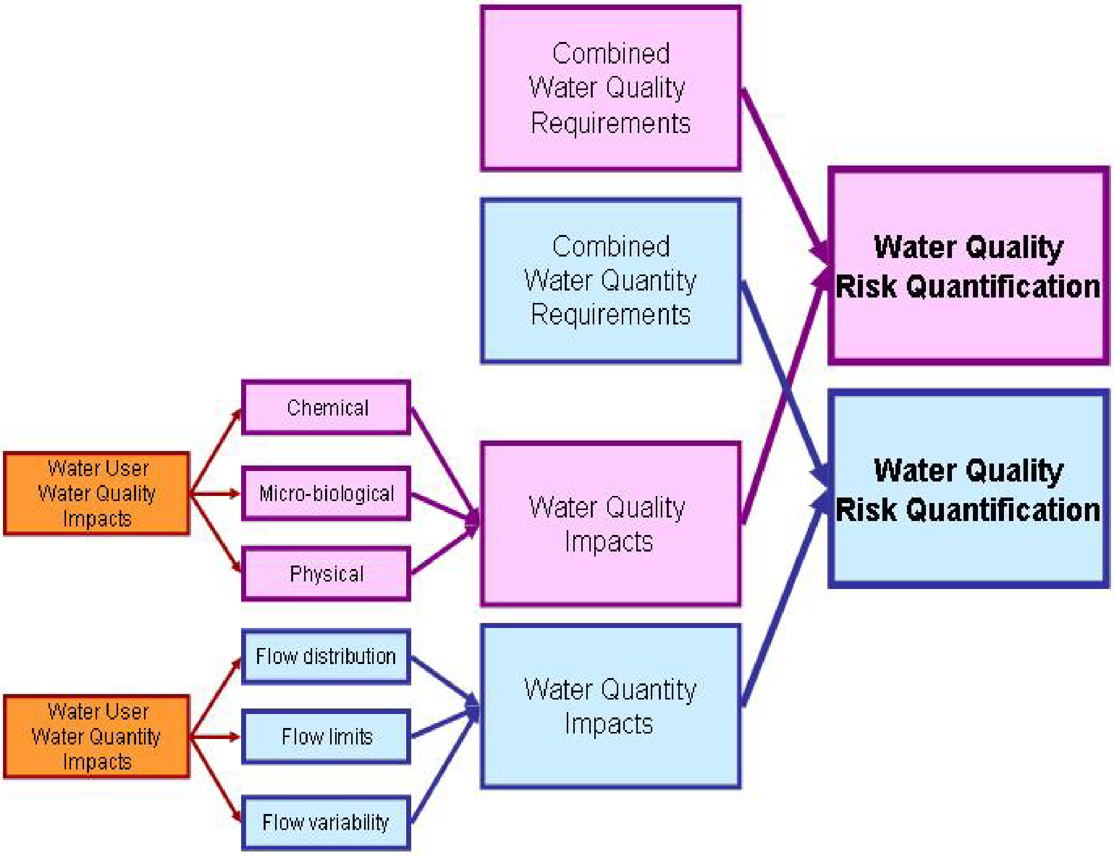

Figure 6.2 The assessment of water user impacts on the risk structures in the trade off matrix.

In Figure 6.2 a quantification of risk can be obtained from the trade off matrix; this quantification would allow the water resource manager and affected parties to identify if the risk of development is acceptable, taking into account the economic, ecological and social benefits and disadvantages.

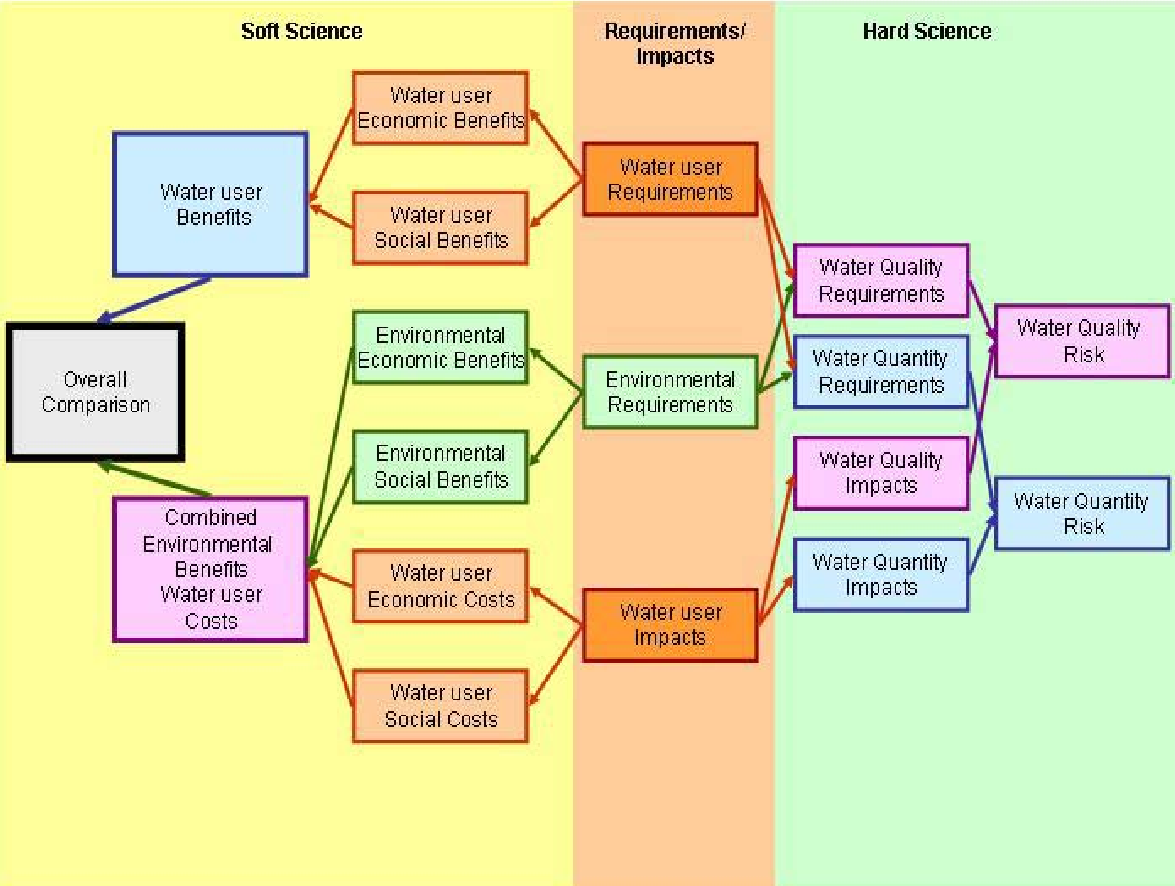

Figure 6.3 Depiction of the cost benefits trade off.

Scientifically speaking the classification system should be the first level of comparison (Figure 6.3). However, if compromises occur in this area then it is not viable to go for development options. If these factors are indeed met then a comparison should be attempted in terms of the costs and benefits.

6.1.3 The cost benefits trade-off approach

The cost and benefits should perhaps be compared as is shown in Figure 6.3. The benefits generated by protection are added to the costs associated with the impacts of development. These are then weighted against the benefits generated by development or water use. If the costs and benefits generated by protection and stopping development are greater than the benefits generated by development the development should not be allowed to progress in terms of the costs benefits.

The MCDA matrix represents a relatively good way of weighing up the different variables and allows one to capture qualitative impacts such as aesthetic appeal and social value. There are however certain elements in a particular system that represent overriding threats to a system if they are found within certain limits (these could be among others elements that are toxic such as heavy metals). In developing the MCDA framework from a risk assessment and management perspective it is important to identify the different role players who will form part of the MCDA assessment process.

6.1.4 The classification process

In Chapter 3 of this thesis the classification system was defined as the rules, guidelines and procedures for determining the different classes of the water resource. The classification process could be defined as the act of implementing the classification system by grouping the resource into specific present and future categories represented by the resource quality objectives. In Figure 6.4 a conceptual representation of the classification process is provided. The first stage (Steps 1, 2 and 3) of the classification process encompasses the defining of the Current State (1) of the resource and the definition of the Future Desired State (3) in terms of setting the Reserve and the RQOs. The process should in fact start by using the classification system (2) to define the combined current state (1.1) of the water resource (or part there of) in terms of the ecological and biophysical elements (water quality, water quantity, vegetation integrity, biodiversity etc).

A consultative process is then embarked upon whereby the classification system (2) is used, taking into account all the ecological, social and economic aspects, to define a future desired state (3). The outputs of this process will thus be the environmental and human needs reserve and a set of resource quality objectives (3). Once the future desired state has been defined through the consultative process a management strategy (4) is required to implement a solution that will enable the stakeholders to achieve the defined future state. While the Reserve and the RQOs are defined for the entire resource management actions to attain those goals will need to be set at an individual user level. It is anticipated that effect will be given to certain management actions incrementally through the licensing process. It is thus expected that an arrangement similar to that used in the ISO 14000 environmental standards could be used whereby the impact producing activities are identified and rules to modify those impacts are set and implemented over time through associated licensing conditions.

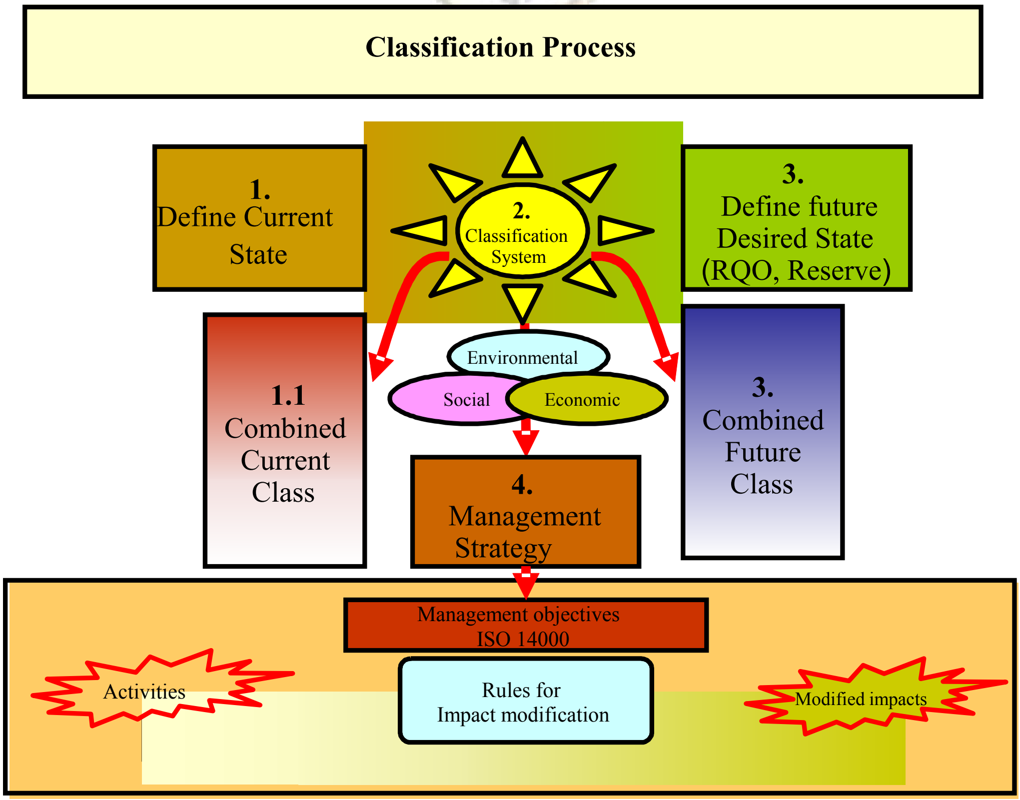

Figure 6.4 A conceptual representation of the classification process.

Two levels of compliance monitoring and auditing may be required to give effect to the class:

- Firstly, on an individual level to ensure that each user is modifying their impacts in terms of the agreed management objectives and licensing conditions, and
- Secondly, at a resource level to ensure that the management objectives are having the desired effect in moving towards the desired future state of the resource (this may not only imply a movement towards improving the quality of the resource but can also imply a movement in terms of developmental objectives which may entail greater usage and impact on the resource), which will be established by stakeholders when specifying the water allocations and licensing conditions.

Figure 6.4 represents a simplified conceptual representation of the classification process conceived at a catchment level. It is plausible that the classification process will play out at the National Water Resources Strategy level, the catchment level and at an individual licensing level. While it is possible, that the generic diagram (Figure 6.4) will not change at the different levels, the stakeholders participating at the different levels will due to the dynamic nature of stakeholder participation.

6.2 <u>Existing approach for classification under resource directed measures (RDM)</u>

In general, RDM has a six-step methodology that can be carried out at three levels to produce a rapid, intermediate or comprehensive determination of the Reserve:

i. Identification/delineation of significant water resources;
ii. Determining the ecological type;
iii. Determining the reference conditions (A)
iv. Determining the current status of the resource (A to F);
v. Determining the Ecological Management Category (EMC) (A to D) and, taking social and economic factors into consideration, the final management class (MC, A to D); and
vi. Setting the reserve in quantifiable, measurable terms, on the basis of the management class (MC).

Each level of assessment (rapid, intermediate or comprehensive) involves an increasing level of complexity of data requirements and analysis. At present, rapid and intermediate assessments produce an EMC and this is taken to be the preliminary MC of the resource. In other words the MC cannot be set at a lower class than the EMC under conditions of partial information gleaned from short-term studies. In a comprehensive Reserve determination, the MC is set on the basis of other social and economic criteria as well as the EMC, in a participative process. Whereas the methods up to the determination of EMC have been rigorously defined and tested, there is no defined method for going from EMC to a management class. Colvin (In Xu *et al* 2002) has also attempted the following 7-step approach for groundwater classification:

i. Delineate area;
ii. Delineate groundwater regions;
iii. Delineate groundwater response;
iv. Describe reference conditions and present status;
v. Describe importance and vulnerability;
vi. Delineate groundwater management units; and
vii. Set management class.

Once the management class is defined, the quality and quantity of the Reserve is described so as to maintain the physical condition of the resource (both in the case of groundwater and surface water). The next step is the allocation of the remaining water to users in a licensing process. Water allocation planning (compulsory licensing) is being carried out around the country over the next decade. This has led to a greater urgency for the classification system. Since RDM have not been developed beyond the setting of the EMC, RDM is sometimes erroneously understood as only going as far as setting the EMC. This exposes the limitations of the existing approach.

6.3 Limitations of existing approach

RDM methods have focussed on working at the scale of individual water resources such as river reaches, and are therefore limited in their capacity to make a meaningful contribution to the decision process leading to classification. Since classification has very broad scale implications, and the classification of one resource affects the next, the current scale of analysis is inadequate. RDM methods have focussed on biophysical issues, but do not provide information on socio-economic implications of alternative options (classes or scenarios within classes), both of which are required in the decision process. Moreover, these cannot be done adequately at the current scale of analysis. Furthermore, although preliminary classification of some systems has been carried out, there is no defined and publicly accepted decision process or public participation process at this stage.

6.4 Development and pilot testing of an adapted systematic approach for classification

The proposed systematic framework approach for an integrated classification system which was briefly discussed in chapter two of this thesis was applied and refined in the Thukela River Study through an iterative approach involving a stakeholder engagement process. The framework has allowed for the generation and testing of multiple options/alternatives for economic development likely to achieve utilisation objectives but still ensure adequate protection of the water resource. As such this approach resulted in the development of a set of rules for determining the influence of those upstream resource conditions on the downstream resources. A particular challenge was the identification of resilience determinants in order to avoid unplanned deviations from the intended condition class.

The ecological, social and economic implications of each of the selected scenarios were described in sufficient detail to form the basis of a decision-making process. The findings of applying this adapted approach are explored substantially in the following chapter.

7. THE THUKELA RIVER CASE STUDY

7.1 Introduction

The Dublin Statement of the International Conference on Water and the Environment indicated that "water has an economic value in all its competing uses and should be recognised as an economic good". There has been little agreement as to what this means and there is still debate around complementarity between environmental resource protection and economic development. Economic valuation has been seen to be controversial largely because its purpose and use have not been clearly conveyed to non-economists such as ecologists and water resource managers. The economic valuation of water for socio-economic benefits and the valuation of the ecological water requirements (EWR) to sustain natural functioning of the ecosystem and assist in the decision-making process aimed at balancing development and protection measures of water resources have not been done extensively in Reserve Determinations before.

The National Water Act, (Act No. 36 of 1998) is premised on the objective that "managing the quantity, quality and reliability of the nation's water resources is to achieve optimum, long term environmentally sustainable social and economic benefit for the society from their use". The objective of environmentally sustainable water use is to balance utilisation of the water resource with the protection of the very resource in such a way that the resources are not degraded beyond the level from which recovery is possible (resilience). The concept of sustainability involves linking three major points of view; economic (to achieve efficient use of the scarce resource), social (to achieve equity objectives and poverty alleviation) and ecological (to achieve resource protection for the long term use of the resource). The Reserve determination could not be conducted in isolation of an integrated water resource management because the outcome must inevitably involve multi-objective trade-offs in a multi-disciplinary and multi-participatory decision making process as required the NWA.

In order to ensure environmental sustainability, the NWA provides that only that water required to meet basic human needs and maintain environmental sustainability will be guaranteed as a right known as the Reserve. All other water uses will be subject to a system of allocation based on the beneficial use that is in the public interest. The use of water that achieves the equity objectives, social and economic objectives is in the public interest. The determination of preliminary Reserves (i.e. absence of a formal classification system) particularly at a comprehensive level of detail has not attempted to integrate ecological objectives into the social and conventional economic objectives (as required by the NWA) to facilitate decision making – mainly by valuing ecological goods and services of development and management of water resources to environmentally adjusted national accounts at the regional and macro-economic level. This aspect was recognised during the development of the scope of work for the preliminary determination of the preliminary Reserve for the Thukela River catchment. The issue was further reinforced by the absence of a framework and a system for classification of the water resources.

7.2 Overview of Thukela river catchment

A locality sketch of the Thukela River Water Management Area is given in Figure 7.1. This comprehensive Reserve Determination is in respect of the whole Thukela River Water Management Area. The management area was divided into 22 resource units and 16 IFR sites were identified on the main stem and the major tributaries from the Upper Thukela down to and including the Thukela River Mouth. There are three major storage dams in the main stem of the Thukela, i.e. Woodstock, Driel and Spioenkop Dams and four on tributaries, namely, Wagendrift Dam on the Bushmans River, Craigie Burn Dam on the Mnyamvubu River, Ntshingwayo Dam on the Ngagane River and Zaaihoek Dam on the Slang River.

Woodstock and Driel Dams supply the existing Thukela-Vaal Project transferring water to the Vaal River System via Sterkfontein Dam in the Wilge River. Water is also exported to the upper reaches of the Vaal River Supply Area from Zaaihoek Dam for use at the Majuba Power Station and for transfer to Grootdraai Dam. Spioenkop Dam is the only dam on the main Thukela River which regulates flow for downstream users. The Thukela River System also supports inter-basin transfers to the Mgeni River System through the Mooi-Mgeni Transfer Scheme and the Middeldrift Scheme taking water from the lower Thukela River to the headwaters of the Mhlathuze River Catchment. The water resources of the Thukela River system support significant economic activities both within the catchment as well as outside of the catchment. There is therefore a need to understand the implications of the Reserve in view of the socio-economic activities that are supported by abstracting water from the Thukela River for use in the catchment.

Figure 7.1 Map of study area (Source: DWAF, 2003).

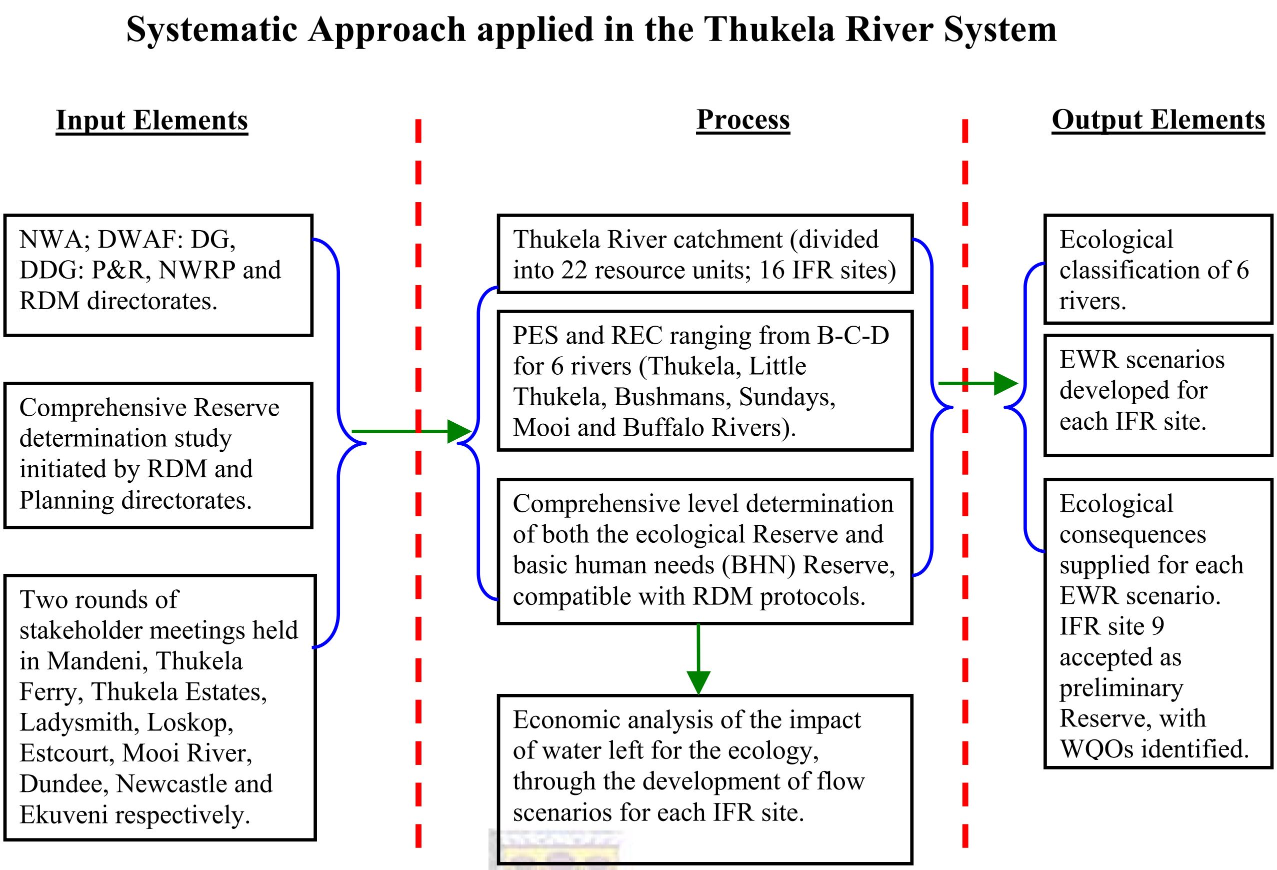

Figure 7.2 Systematic approach applied and tested in the Thukela River System.

7.2.1 Background

The need for the Thukela Water Project (TWP) Decision Support Phase was identified during the finalisation of the TWP Feasibility Study. Because of the changing environmental legislation that was taking place at the time particularly with the promulgation of the National Water Act (Act No. 36 of 1998), it became apparent that the TWP Feasibility Study would not deliver unqualified development proposals complying in all respects with this Act, and the National Environmental Management Act, 1998. This will necessitate additional investigations prior to the commissioning of Detailed Design and Project Implementation. This has led to the definition of a Decision Support Phase comprising the following modules which must be undertaken before the development proposals can be finalised and implemented if found to be necessary:

- Environmental Reserve Determination as required by the National Water Act, No. 36 of 1998. The study will enable the available transferable yield to the Vaal River System to be confirmed.
- Strategic Environmental Assessment & Environmental Impact Assessment in compliance with regulation R1183 of the Environment Conservation Act. An important milestone of this study is project authorisation by the Department of Environment Affairs and Tourism (DEAT) and will require the formulation of Environmental Management Plans (EMPs).

- Technical Optimisation of the TWP scheme configuration. This will allow design and tender stage to proceed without additional work.
- Financial and Economic update (costs, budgets and the flow of funds).
- Institutional arrangements and funding arrangements.
- Compliance with national and provincial legislation concerning physical development and changes in land use.
- A Public Involvement Programme (PIP) supporting all other modules.

Before any of the other modules could be investigated there was a need to conduct the determination of the preliminary class, resource quality objectives and the preliminary Reserve as required by section 14 and 17 of the Act. The Thukela Reserve Study was initiated in the year 2001 with a view to supporting the then imminent implementation of the Thukela Water Project (TWP). The TWP was at that stage the most likely option to be constructed to augment water supplies to the Vaal River System by 2011. It was later found that the projected growth in water requirement in the Vaal River System were not being realised as previously expected and work on preparing the TWP for implementation was slowed down accordingly. Despite this change, the Department of Water Affairs and Forestry (DWAF) decided to complete the Reserve Determination in the Thukela River Catchment. This decision was justified by the number of numerous requests that the Directorate: Resource Directed Measures was receiving from the Eastern Cluster to determine the Reserve so that various licence applications for water use by physical developments in and outside of the Thukela River catchment, including streamflow reduction activities, can be considered.

<u>7.2.2 Rationale for use of economic valuation in Reserve determinations</u>

In the absence of an approved classification system a preliminary determination of the Reserve was undertaken for the Thukela River Catchment. This determination consists of most of the elements that are likely to be contained in a classification system still to be developed and promulgated. An integrated approach for considering a range of ecological categories was adopted based on the ecological importance and sensitivity (EIS), social and cultural importance (SI) and the economic importance (i.e. value of in-river and out of river use of the resource) so as to better inform decision-making regarding the Reserve. This approach included, for the first time in Reserve determination assignments, the detailed use of scenario analysis which includes the economic analysis which is consistent with a basic principle of Integrated Water Resource Management (IWRM), i.e. consideration of all realistic alternatives to a specific proposal. This was then followed with the determination of the consequences of the various flow regimes by deriving the economic value of water provided to each economic sector as well as the water left in the river for the natural functioning of the ecosystem. The basis of this process is the ecological economics which is a new interdisciplinary field.

7.2.3 <u>Ecological economics</u>

Ecology is the study of the distribution and abundance of animals and plants. A central focus is an ecosystem, which is an interacting set of plant and animal populations (biotic) and their abiotic, non-living environment. Ecology can be said to be the study of nature's housekeeping while economics is the study of human housekeeping. Ecological economics can be said to be the study of how these two sets of housekeeping are related to one another. This is the origin of the sustainability problem. The need to ensure sustainability is the cornerstone of the Act.

The distinguishing characteristics of ecological economics are that it "treats the economic system as part of the larger system that is planet earth" (Perman et al: 1999). According to Roger Perman et al, it starts from the recognition that the economic and environmental systems are interdependent, and studies the joint economy-environment system in the light of developments in natural sciences, particularly thermodynamics and ecology over the last decade. Sustainability can be promoted by better economic accounting of the natural capital hence the need to integrate economic valuation in reserve determination to promote informed decision making of the use of the scarce water resource. This is the background of the approach and process used in the determination of the preliminary Reserve of Thukela River catchment at a comprehensive level.

7.3 <u>Process followed in economic valuation</u>

In order to evaluate the economic activities in the Thukela River catchment, the catchment was divided into seven (7) sub-catchments which were considered the most suitable units for economic evaluation.

7.3.1 Process for conventional regional economic analysis

The conventional economic analysis was conducted at sectoral / regional level. The first step of the economic analysis of the impact of the ecological water requirements for the Reserve was to determine the level of economic activity in the Thukela River catchment for the base (defined as the without EWR) scenario. This step involved identification of the entities or groupings involved in economic activities in the Thukela River catchment that use water directly and indirectly and incur costs and benefits from the use of water. The base year that was agreed upon was 2000 with the year 2015 being the planning horizon for the economic analysis. The turnover of each economic sector identified was then calculated for the Thukela River catchment. These turnover figures were then fed into the Social Accounting Matrix (SAM) structure to isolate the value added per economic grouping. The second step was the development of the water accounts. The water accounts were generated from the results of the water resources yield model (WRYM) which determined the available water to each sector for the scenario being investigated. The average volume of water available to each sector together with the sector coefficients was then used to calculate value added and the level of employment each sector would support. This was done after accounting for the ecological water requirement for each ecological category scenario that was looked at.

The third step was the use of the water accounts to determine the volume of water used by each economic grouping (e.g. irrigated agriculture, forestry, industry, mining, municipal use, etc.) at the different levels of assurance of supply for each user sector. The water accounts were then used to generate the economic value of water per m^3 of water use for each sector. These value added figures were then divided by the volume of water consumed by the sector to arrive at the so-called coefficient. Besides identification of the economic entities in the Thukela River catchment, the system was subdivided into seven (7) suitable units for economic analysis. These economic sub-systems were as follows:

- Buffalo sub-catchment. The main towns Newcastle, Utrecht and Dundee.

- Mooi sub-catchment. This sub-catchments comprises Mooi River Town,
- Bushmans sub-catchment: This sub-catchment has the main towns of Estcourt and Weenen.
- Sundays sub-catchment:
- Upper Thukela down to the confluence with the Sundays river
- Little Thukela down to the confluence with the Thukela River
- Lower Thukela down from the Sundays to the Thukela River Mouth.

The impact on economic value added and employment opportunities for each scenario for sub-systems of the Thukela were also calculated in order to improve the resolution of the economic analysis.

7.3.2 Process followed for the valuation of the water for ecology

The valuation of the ecological goods and services derived from the river system because of the ecological water left in the river was determined in economic terms. The steps followed were almost similar to the conventional economic analysis of the use of water taken out of the river to generate wealth and distribute the total wealth (i.e. economic value added) among the sectors and the individuals of society (i.e. income distribution). The first step in the ecological valuation process was the identification of the ecological goods and services that would be derived from the Thukela River including the Thukela River mouth. These were mainly the direct use value as indicated in Figure 7.3. The economic value of the goods and services derived from the water left in the river system for natural ecosystem functioning was determined for the year 2000 base scenario. In order to estimate the economic value for these goods and services, the survey was conducted to identify the number of users of the river for that particular service. The number of households dependent on the goods and services from the river in each subsystem was estimated using the 5 km buffer zone.

The approach used for determining the goods and services such as subsistence fishing, craftwork sedges, construction reeds, floodplain agriculture, was by examining market-like transactions to determine the value of the good or service, identifying the households benefiting from the ecological functions, estimating the demand curve and then calculating the value of the goods and services made available because of maintaining ecological water requirements left in the river. The process followed for the impact of illness due to water borne diseases such as bilharzia because of changes of the flow regimes of the different ecological categories were determined differently. The costs of illness estimates consisted of the cost of treatment, costs of lost production and cost for extra transportation. For treatment costs the costs for private treatment are used as the opportunity costs.

The final step was the determination of the changes in the goods and services for each scenario. This was conducted through a workshop environment where ecologists estimated the likely changes in the quantity of the goods and services. The biological and physical environment scientists then identified the potential change that each key service may undergo in the each of the three scenario clusters. The potential change was noted as a factor. For example, no change = 1, a 50% increase = 1.5, and a 20% decrease = 0.8. The current value of services was then multiplied by the factors of change identified for each

tributary in each scenario to provide an indication of the potential future value of the service, and the change in value was measured.
For example, in the Upper Thukela, scenario 8 was estimated to cause a reduction in subsistence fishing by 10%. The calculation then used looked like this:

- Future value (FV) of fishing = change factor x the current value of fishing
- FV = 0.9 x R2.7million
- FV = R2.44 million per annum
- With a reduction of R272 000 per annum

The numbers of people or households impacted was also noted to provide an idea of how many people or households may be impacted by the potential changes. For example, in the Upper Thukela some 4 800 households may be impacted by the change in subsistence fishing.

7.3.3 Limitations of the ecological economic analysis

The process followed in the valuation of the water for natural ecosystem function was not exhaustive and there were limitations due to budget constraints. The following aspects were not considered in the assessment of the ecological goods and services:

- The economic value of the transfer of water to the Vaal River Supply Area from the upper Thukela subsystem, Mooi-Mgeni transfer, the transfer from the lower Thukela subsystem to Mhlathuze catchment as well as from Nstingwedzi for power generation were not included in the analysis.

- Internalisation of the costs and benefits of using water was not conducted in the conventional economic valuation by the different economic sectors using water in the catchment.

- The focus of the valuation of the ecological goods and services was on the direct use values as presented in Figure 7.2 below. However not all the use values were considered in the valuation of the goods and services. The indirect use values were not considered in the ecological economic analysis. Flood control and damage taking place in the Thukela River system were not considered.

- The no-use values of the ecological services were not quantified. Therefore the process for determining the benefits does not include the no-use value of the services provided by the ecology. This is indicated in Figure 7.2 below.

- The study did not determine the impact on the income distribution and the people who will be significantly impacted due to changes in the value added for different scenarios.

- There was no integration done between the economic values from the conventional economic analysis and the ecological economic analysis.

- No sensitivity analysis was conducted for the different variables affecting the economic valuation.

As can be deduced from the arrow in Figure 7.2, the limited budget necessitated that the project team focused on economic values that could be quantified.

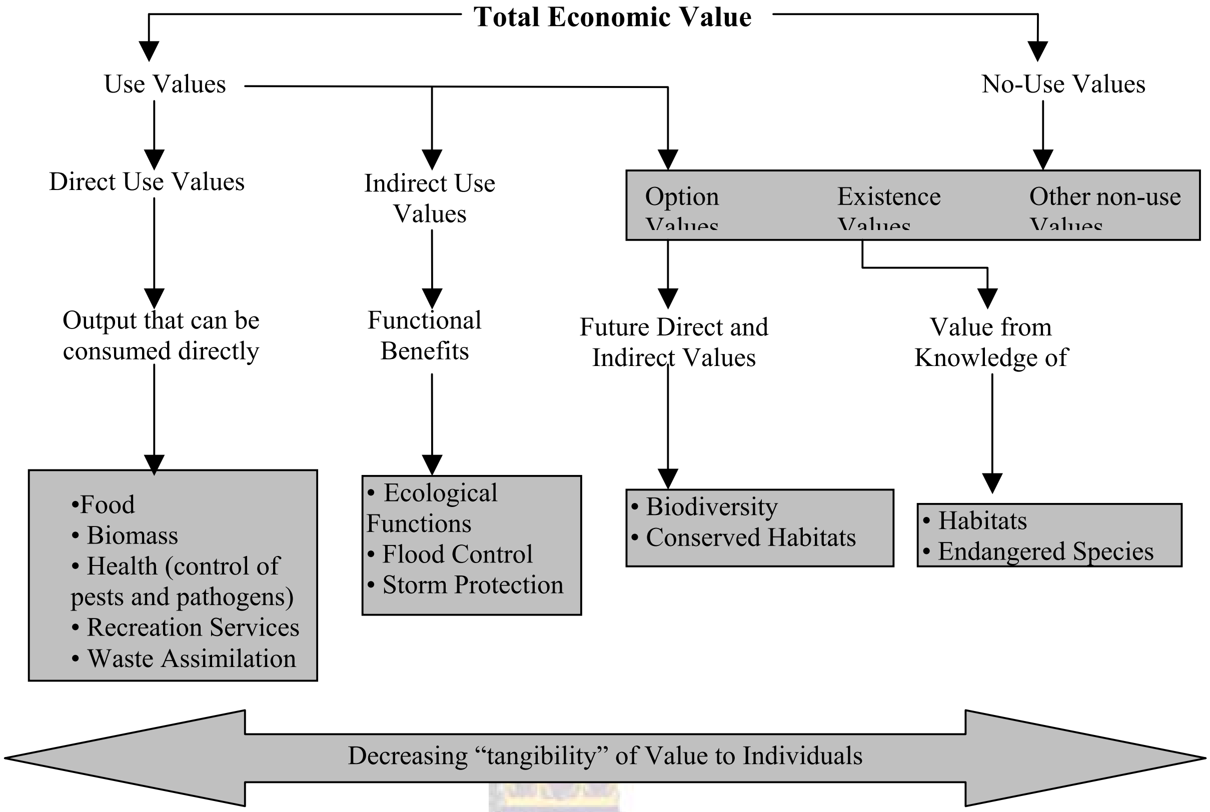

Figure 7.2: Categories of economic values attributed to the natural capital generated by the Thukela ecological assets (Source: After *Tlou et al, 2004*).

7.4 Economic valuation of the flow scenarios to meet different ecological categories

7.4.1 Development of flow scenarios

Sixteen IFR sites were identified in the Thukela River catchment. In order to conduct an economic analysis of the impact of the water left for the ecology, the Thukela Project Team designed flow scenarios for each IFR site. The ecological specialists first determined the present ecological state and the reference conditions for each of the 15 IFR sites in the Thukela River system. Through a specialist workshop process the recommended ecological category (EC) for each IFR site was determined. The flow regime for the recommended EC was known as scenario 2. Two more ecological categories were then generated, one above and the other below the recommend EC. The flow scenarios of these two more ecological categories became scenarios 1 and 3 respectively. The available water for economic use in the Thukela River catchment at 2000 level of development was derived from the water resource yield model (WRYM) using a set of the curtailment rules to maximise use of the available water after meeting the flows set for each EC.

Based on the three principle criteria against which scenarios and their elements must be tested, flow scenario 3 was found to be unrealistic because it had a major negative impact on the available water for economic use. Further refinement of flow scenarios 1 and 2 generated additional flow scenarios 4, 5, 6, 7, 8 and 9. These scenarios are described in table 7.1 below.

Table 7.1 Flow scenario description

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

Although the total number of 8 flow scenarios was designed by the ecological team, the number of scenarios that were investigated to determine the impact on the economic activities of and employment opportunities from using water abstracted from Thukela (out–of-river use) and the economic valuation of the changes in the ecological assets i.e. goods and services provided by the river (in-river use) were limited to only three. For the market economic analysis scenarios 2, 6 and 9 were chosen. The first two scenarios provided the worst case and best case for the users while the third scenario was the optimised scenario 9. For the economic valuation of the goods and services, scenarios 2/5, 8 and 9 were chosen. The impact of the other flow scenarios would fall within the range of impact provided by the scenarios chosen for the economic analysis. For the ecological goods and services, scenario 8 was investigated instead of scenario 6 because it provided the worst case scenario for the ecology where no EWR is provided at 2015 development.

7.5 Outcome of the market economic analysis

7.5.1 Changes in the economic value added for different flow scenarios

The following six (6) economic sectors directly using water from the river (out of river water use) were identified in the Thukela River catchments:

- Irrigated agriculture
- Livestock farming
- Afforestation
- Irrigated sugar cane
- Mining and heavy industries
- Urban water use (including light industries)

The contribution to the value added of each economic sector before determination of the preliminary Reserve (at 2000 prices per annum) is presented in Table 7.2 below.

Table 7.2 Economic value added before the IFR (Base scenario)

Economic sector	Value added (2000 prices) (R million per annum)	Average annual Water use (million m^3 per annum)	Value per m^3 of water used
Irrigated agriculture	200.6	285.0	0.70
Livestock farming	303.8	11.42	26.59
Afforestation	63.9	30.00	2.13
Sugar cane	5.4	5.12	1.05
Mining & Heavy industries	960.3	32.32	29.71
Urban requirements (incl. light industries)	4 182.7	20.55	203.51

(Source: DWAF, 2003).

The table indicates that the urban sector has the highest economic value followed by mining and heavy industry. Irrigated agriculture utilises the most amount of water but its contribution to the economy per m^3 of water used is the lowest at R0.7 per m^3. Table 7.3 presents the results of the analysis conducted on the impact of flow scenarios on the economic value added of the Thukela River catchment. The impact of the different scenarios on each of seven (7) subsystems was also determined.

Table 7.3 Value added for base scenario and impact of the different scenarios on the Thukela River catchments

Economic sector	Base Scenario	No IFR at 2015 development	Scenario 2	Scenario 9	Scenarios 6
	Value added (2000 prices) (R million per annum)	Value added (2000 prices) (R million per annum)	Value added (2000 prices) (R million per annum)	Value added (2000 prices) (R million per annum)	Value added (2000 prices) (R million per annum)
Irrigated agriculture	200.6	253	57.59	17.68	9.69
Livestock farming	303.8	304	0	0	0
Afforestation	63.9	89	0.55	0.03	0.03
Sugar cane	5.4	5	0.01	0.01	0.00
Mining & Heavy industries	960.3	1 165	283.97	67.95	50.96
Urban requirements (incl. light industries)	4 182.7	6608	547.73	85.96	49.39
Total value lost if scenario is implemented			889.85	171.64	110.07
Estimated value added in 2015	5 71.7	8 424.			
Estimated value added for scenario			7 534.61	8 252.83	8 314.39
Percentage impact of scenario			10.6%	2.0%	1.3%

As can be seen from the table scenario 2 whose flows were set to achieve the recommended EC has the greatest negative impact reducing the annual economic value added in 2015 from R8.4 million to R7.5 million (at 2000 prices). This result confirms that often the objectives of economic development are in conflict with the objectives of resource protection. As would be expected, scenario 6 had the least impact in terms of economic impact but carried a higher risk of the ecology being degraded beyond the threshold of recovery.

7.5 2 <u>Changes in employment opportunities for different flow scenarios</u>

Table 7.4 indicates the impact of different scenarios on the employment opportunities for each sector and the subsystem.

Table 7.4 Impact of different scenarios on the level of employment for each sector

Economic sector	No IFR at 2015 development	Scenario 2	Scenario 9	Scenarios 6
	Employment in 2015	**Job losses in 2015**	**Job losses in 2015**	**Job losses in 2015**
Irrigated agriculture	5608	1278	91	57
Livestock farming	5994	0	0	0
Afforestation	2898	49	0	1
Sugar cane	214	0	0	0
Mining & Heavy industries	6454	1949	384	288
Urban requirements (incl. light industries)	81934	9887	1255	773
Total jobs lost if scenario is implemented		13163	1730	1119
Estimated employment in 2015	103102			
Estimated employment opportunities for scenario		87446	87446	87446
Percentage impact of scenario		15%	2.0%	1.3%

The impact on employment is significant for scenario 2 and less significant for scenario 6 which leaves less water in the river. The sectors that will be significantly affected are mining and heavy industries as well as the urban sector. Although the income distribution was not calculated, the low income level is likely to be significantly impacted. This will exacerbate poverty which pervades the Thukela catchment. Therefore the scenario to be implemented has to be considered in the light of the impact on employment, income distribution, and economic value added if it is to be sustainable in the long term. Although from a regional/sectoral economic analysis indications are that the original recommended EC would have significant impact on the livelihood of the catchment, the dependence of the communities on a healthy functioning river system

7.6 Economic valuation of the goods and services

The summary of the economic valuation of the goods and services is presented in Table 7.5. While rivers supply benefits with positive values to the Thukela community, they may also supply negative externalities to the community. Rivers may host water-borne diseases, and therefore changes to these externalities can be measured by assessing the changes to the costs (rather than the benefits) that they generate for communities. In the following table the estimates in brackets (…) denote a reduction in costs and are therefore positive for communities.

Table 7.5 Impact of scenario on the of value of goods and services

Thukela River : Summary of service benefits and costs											
		Status quo	Scenario 2/5			Scenario 8			Scenario 9		
Services and dis-services	Households or individuals impacted	Total value	Value change per Hh	Total value	Total change in value	Value change per Hh	Total value	Total change in value	Value change per Hh	Total value	Total change in value
Services as benefits											
Fish*	17,194	9,136,184	(87)	7,640,728	(1,495,456)	(59)	8,116,703	(1,019,481)	(87)	7,640,728	(1,495,456)
Reeds*	6,895	496,468	1	504,312	7,844	(0)	494,631	(1,837)	1	505,047	8,579
Sedges*	15,811	1,138,397	2	1,166,122	27,725	(4)	1,075,146	(63,251)	2	1,166,122	27,725
Waste assimilation*	63,794	4,422,420	1	4,485,857	63,437	(13)	3,579,613	(842,807)	1	4,482,846	60,426
Waste dilution*	63,794	29,100,720	-	29,100,720	-	(228)	14,550,360	(14,550,360)	-	29,100,720	-
Cultivated floodplains*	15,521	3,099,718	2	3,129,481	29,762	(30)	2,641,267	(458,451)	1	3,121,277	21,558
Cynodon lawns*	15,511	41,093,549	(25)	40,700,054	(393,495)	(324)	36,073,335	(5,020,214)	(52)	40,283,788	(809,761)
Rafting	2,990	1,297,900	(1)	1,294,090	(3,810)	(86)	1,040,090	(257,810)	(1)	1,294,090	(3,810)
Canoeing	1,700	961,200	44	1,035,660	74,460	(47)	881,220	(79,980)	35	1,021,080	59,880
Swimming	116,209	79,022,093	-	79,022,093	-	(15)	77,304,226	(1,717,867)	-	79,022,093	-
Trout fishing	312	4,223,232	-	4,223,232	-	-	4,223,232	-	-	4,223,232	-
Estuary fishing	5,000	1,000,000	20	1,100,000	100,000	10	150,000	50,000	20	1,100,000	100,000
Dis-services as costs											
Biharzia treatment	107,512	15,589,199	(5)	15,065,025	(524,175)	165	33,372,398	17,783,199	0	15,610,474	21,275
Biharzia productivity loss	107,512	12,041,313	(4)	11,636,433	(404,880)	128	25,777,301	13,735,988	0	12,057,745	16,433
Pathogens treatments	35,834	796,851	(2)	721,713	(75,138)	7	1,043,497	246,646	(2)	724,894	(71,957)
Pathogens productivity loss	35,834	7,214,159	(19)	6,533,906	(680,253)	62	9,447,129	2,232,970	(18)	6,562,707	(651,451)
Cholera treatment	4,908	319,020	(3)	303,069	(15,951)	23	432,671	113,651	(3)	303,069	(15,951)
Cholera productivity loss	4,908	1,374,240	(14)	1,305,528	(68,712)	100	1,863,813	489,573	(14)	1,305,528	(68,712)
* These services benefit households while the rest (including costs) are for individuals											

As can be see from table 7.5 above the impact of scenario 8 is very significant to the households utilising the goods and services from the river. Only 15% of the annual current (base scenario of 2000) economic value is left if the reserve is not implemented at the 2015 level of economic development. Although the market economic analysis will be much higher, the impact on the low income group who depend on the river will be very significant. Implementation of scenario 2/5 will ensure the current level of economic value is at least maintained. Scenario 9 which provides the best balance between resource protection and impact on the users in the catchment is marginally lower than the base scenario of 2000 level of development. It is important to note the value of the dilution service supplied by the river.

The value estimated is for the Ngagane River, only one sub-catchment and only considering the outfalls of the mining industry. With large companies like Iscor unaccounted for, and the numerous mines in the other tributaries feeding into the Buffalo River, this value may be 2 to 3 times higher. The implication of this is that losses may increase by an additional R15m to R30million per annum in scenario 8. The impact per sub-catchment was also determined and is presented in Table 5.6. In scenario 2/5 all the disservices are reduced, with a significant reduction of costs to user communities. In scenario 9, the impacts are similar to scenario 2/5, except that there is a significant increase in costs associated with bilharzia in the lower Mooi River. In scenario 8 all the disservices are aggravated, with serious increases in costs being borne by communities. The costs of bilharzia infections to communities may increase by R30 million per annum.

Table 7.6 Summary of impact of different scenarios in the value of goods and services per subsystem

Thukela River : Summary of subcatchment benefits											
		Status quo	Scenario 2/5			Scenario 8			Scenario 9		
Sub-Catchment	Households impacted	Total value	Value change per Hh	Total value	Total change in value	Value change per Hh	Total value	Total change in value	Value change per Hh	Total value	Total change in value
Bushmans	7,160	11,007,511	6	11,047,898	40,387	43	11,313,329	305,818	6	11,047,898	40,387
Mooi	5,614	2,246,549	(275)	700,466	(1,546,083)	(1,286)	(4,975,631)	(7,222,180)	(529)	(721,717)	(2,968,266)
Sundays	4,313	5,130,685	-	5,130,685	-	(30)	5,000,919	(129,766)	-	5,130,685	-
Buffalo	14,501	56,984,855	(9)	56,858,485	(126,370)	(1,220)	39,297,942	(17,686,913)	(9)	56,858,485	(126,370)
Upper Thukela	14,190	20,004,426	(16)	19,773,345	(231,080)	(118)	18,336,906	(1,667,520)	(16)	19,773,345	(231,080)
Lower Thukela	15,582	4,356,630	132	6,420,694	2,064,064	(1,993)	(26,696,111)	(31,052,741)	132	6,420,694	2,064,064
Little Thukela	4,593	23,938,162	(45)	23,732,156	(206,006)	(143)	23,279,633	(658,529)	(49)	23,714,270	(223,893)
Thukela Estuary	5,000	11,458,310	-	11,558,310	-	20	10,559,280	100,970	-	11,558,310	-
Thukela River	**70,954**	**137,657,099**	**2.53**	**137,836,674**	**179,575**	**(840)**	**78,043,015**	**(59,614,084)**	**(0.02)**	**136,396,605**	**(1,260,494)**

In scenarios 2/5 and 9, the change in value between the status quo and scenario 2/5 is insignificant. There is an insignificant overall reduction in value of scenario 9 (just less than 1%). However, this loss has a significant impact within the Mooi, which accounts for most of the reduction in value. It must be noted that particular groups are impacted by these changes despite overall values not changing. Scenario 8 has serious negative impacts on the Thukela community. There is an overall decline in value by R54 million per annum. This scenario has very serious implications for community well-being in the Thukela catchment. The reasons for the significant changes in services are listed in Table 7.7 below.

Table 7.7 Reasons for significant changes in values of goods and services

Environmental asset	Sub catchments	Scenario	Extent Of Change	Reason For Change
Subsistence fishing	Upper and Little Thukela	2/5, 9	0.5	Reduction in water volume, with habitat loss
Subsistence fishing	Mooi	8	0.05	No flows in winter with major habitat loss
Subsistence fishing	Thukela estuary	8	1.5	Low flows result in salt water intrusion with entry of marine fish
Reed and sedge harvesting	Bushmans	8	1.5	Increase flows increase habitat available for reeds
Reed and sedge harvesting	Mooi & Little Thukela	8	0.6	Low flows result in habitat reduction for reeds and sedges
Waste assimilation	Bushmans	8	1.5	Increased flows result in greater assimilation capacity
Waste dilution	Buffalo	8	0.5	Lower flows reduces dilution capacity
Floodplain agriculture	Mooi	2/5, 8, 9	0.5	Lowering of water table in surrounding floodplain
Floodplain	Buffalo	8	0.5	Lowering of water table in

Environmental asset	Sub catchments	Scenario	Extent Of Change	Reason For Change
agriculture				surrounding floodplain
Cynodon lawns	Mooi,	2/5, 8, 9	0.5	Lowering of water table in surrounding floodplain
Canoeing	Little Thukela	8	0.5	Lower water levels with insufficient water depth
Recreation fishing	Thukela estuary	8	1.5	Low flows result in salt water intrusion with entry of marine fish
Bilharzia treatment costs and productivity loss	Lower Thukela and Mooi	8, 9	3	Increasing vector habitat, reduced dilution and many people to be potentially infected
Bilharzia treatment costs and productivity loss	Mooi	9	1.15	Increasing vector habitat, reduced dilution and many people to be potentially infected
Pathogens treatment and productivity loss	Bushmans, Upper and Lower Thukela	8	1.5 – 1.3	Decreasing flow in lower regions, with lower dilution and many people to be infected
Pathogens treatment and productivity loss	Little Thukela	8	2	Decreasing flow in lower regions, with lower dilution and many people to infected

As reflected in table 7.5, overall, the change in value between the status quo and Scenarios 2-5 is insignificant. There is also an insignificant overall reduction in value of Scenario 9. In summary Scenario 8 has a serious negative impact on the Thukela community, despite there being an improvement in the Bushmans River and Thukela estuary. This scenario has serious implications for community well being in the Thukela catchment. It should be borne in mind that although the values that are estimated are relatively low, they represent changes to communities that can least afford it, and as such, impacts are significant from a socio-economic perspective. Of note are the changes to the bilharzia and pathogen regimes. These were deemed to have changed significantly as the amount of water under Scenario 8 was greatly reduced at certain points of the river thereby exposing some communities to greater health risks. To illustrate the level of impacts of the three scenarios of communities in the Thukela, impacts on individual households was estimated for the catchment as a whole. In Scenario 2-5 and 9, the overall impact on households in the Thukela catchment is negligible. Scenario 8 shows substantial losses for communities, close to R900 loss per household per annum. This is very significant for rural households who can least afford this type of loss.

7.7 Overall outcome of economic valuation of flow scenarios

The market economic analysis represented the economic valuation of the use of water abstracted from the Thukela River using the two main parameters; economic value added and employment. The economic valuation of the goods and services derived by the ecological assets from the water left in the Thukela River system to meet the natural functioning of the ecosystem represented (although not fully) the value of the water left to meet the Reserve. These two economic valuations were incorporated with the ecological impact and are presented in Figure 7.4 below in the form of a traffic diagram to the stakeholders.

The results of the economic valuation of flow scenarios to meet different levels of resource protection as well as the impact of flow scenarios on the socio-economy of the catchment provided the choices to the stakeholders. Stakeholders were presented with these results to assist them in making informed choices of a preferred balance between resource protection and socio-economic development. Based on the economic valuation measures of stakeholder preferences for, or against, environmental change were able to be tested with the communities who are directly affected by the decision on level of resource protection.

The market economic analysis and economic valuation of the goods and services for the flow scenarios indicated that scenario 9 provided the best balance between minimising the impact on the economic value added and loss of employment with the objectives of not degrading the resource beyond the level from which recovery is possible (resilience).This scenario could not have been generated without linking ecological and economic concerns in the decision making process. The economic valuation of the ecological environment plays a key role in identifying options for efficient water resource management that facilitate environmental sustainability. The extent that some functions of the ecology cannot be valued in monetary terms (e.g. biodiversity, etc.) was recognised during the study. The final result that was presented to stakeholders was an optimised scenario, which maximised socio-economic development while minimising ecological loss to the Thukela River catchment.

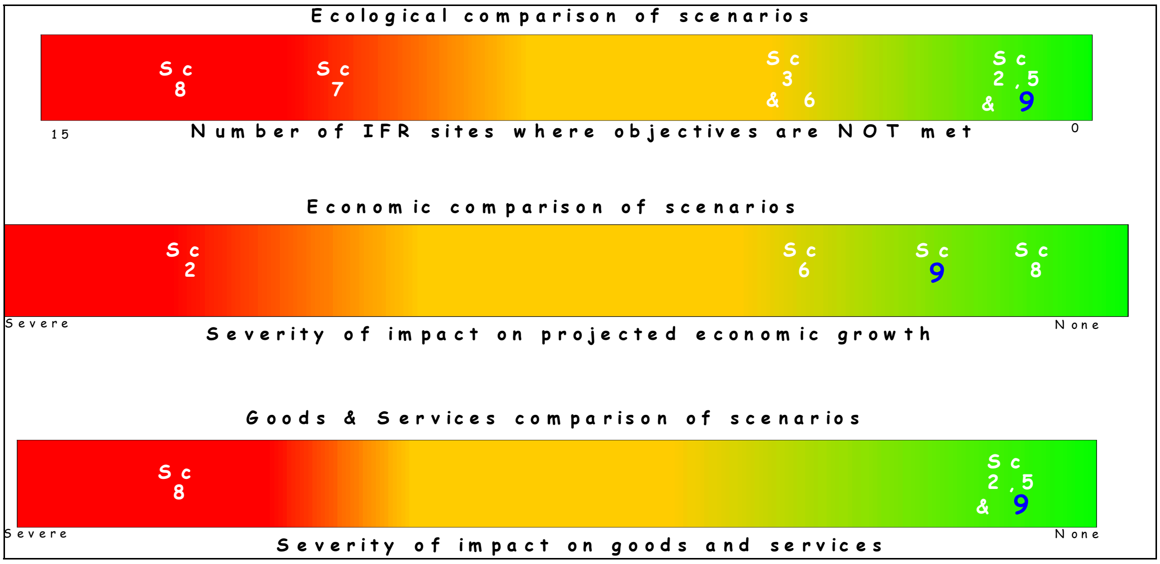

Figure 7.4 Comparison of scenario impacts across major study components

7.8 Framework for ecological-economic decision making process

Water is of critical importance for environmental sustainability. It sustains the natural functioning of the ecosystem and ensures maintenance of the resource base from which goods and services are provided for society's use. The protection of the resource base through the determination of the Reserve provides services to human society. Therefore the consequences of their degradation must be incorporated into the decision making process. The services provided by the ecosystem can be described as follows:

- The natural resource base provides essential raw materials and inputs which support human activities. In the case of Thukela River system, communities living close to the river are dependent on the river for subsistence fishing, harvesting of reeds and sedges, floodplain agriculture, etc.;
- A functioning ecosystem serves as a sink to absorb and recycle (often at little or no cost to society) the waste products of the economic activity through waster assimilation. For example water is released from Spioenkop dam for dilution of waste from Mandini due to the economic activities taking place; and
- The ecology does not only provide benefits but also costs to society. For example the waterborne diseases are disservices provided by the ecology due to the water resource supporting the natural functioning of the ecosystem.

While the water left in the river provides the ecosystem from which goods and services are derived, the need to improve the welfare of society can be achieved by utilising the water for socio-economic development. This takes water out of the ecosystem and provides waste products into the ecosystem. A trade off between protection and utilisation can be better understood by economic valuation of the ecology as well as the market economy. The implementation of the Reserve requires a consultative social framework that among other things facilitates the exchange of information between stakeholders and water resource managers in order to ensure stakeholder buy-in and long tem sustainability.

The determination of preliminary Reserve in the absence of a classification system has not been tested with stakeholders in the way that they can understand what the implications of protecting the resource to them are. Implementation of such reserves is not likely to succeed if communities are not well informed, given the choices in a manner they can understand and informed of the implications of the choices they have in the medium to long term. The scenario approach and economic valuation of water for both the environment and the economic use as conducted in the comprehensive determination of the preliminary Reserve for Thukela River system provides with first the choices available and second the implications of those choices for the long term sustainable use of the scarce resource such as water to not only stakeholders but to water resource managers (and ultimately the Minister) who have to make the final decision for balancing protection with water use. There is an increasing competition for water to ensure that the resource is protected while meeting the social and economic objectives of society. In view of the increasing need to balance resource protection with social objectives (i.e. ensure equity in water allocation, and alleviate poverty) and economic objective (i.e. to ensure wealth creation and achieve income redistribution), accounting for the environment in economic analysis plays a key bridging role in the decision making process.

The causes of environmental degradation arise from human activity. For example overexploitation of the scarce water resources can lead to irreversible ecological damage if it is not achieved balanced with socio-economic development. Determination of the Reserve in isolation of the human activities that is likely to cause ecological damage will not (are in conflict) with achieve environmental sustainability as required by the Act. In view of the increasing risk of unsustainable management of the water resource leading to environmental degradation, even the modest attempts to assess the impacts of flow scenarios on the ecological assets derived by the river by and the economic analysis of the out of river water use and ensuring a balance between protection and utilisation are well justified.

7.9 Framework for incorporating economic valuation in Reserve determinations

Water is a resource and natural capital which provides important benefits to society, both commodity benefits and environmental values. Incorporating the economic valuation of the ecology and the conventional markets provides a more holistic picture of the implications and related risks in balancing resource protection with socio-economic objectives. Reserve determination does not only involve focusing on protection of the ecological systems and preserving the resilience and dynamic ability of such systems to adapt to change. Its determination also has an impact on the other two main objectives namely social and economic objectives. Figure 7.5 below presents the framework for incorporating economic valuation in reserve determinations in order to improve the decision process on resource protection and resource utilisation. If the ecological requirements are determined in isolation of the socio-economic objectives, this will result in a non-inferior solution. The same applies for achieving socio-economic objectives. However by incorporating ecological valuation into the conventional economic valuation, the best compromise solution can be achieved. As indicated in the Thukela Reserve determination study the best compromise solution was scenario 9. Therefore a multi-objective framework in the decision process is essential to ensure sustainability.

Incorporating economic valuation in scenario planning during the reserve determination process provides stakeholders with the choices on which informed decision making can be done. This has been demonstrated in the Thukela River system Reserve determination. In order to ensure environmental sustainability, there is a need to elicit communities' preference of the level of protection that can be achieved. By providing communities with the implications of the different levels of protection through incorporating economic valuation in the decision process, ensures that there's a much better probability of the level of protection required. This approach also provides elements for classifying the resource in the absence of the classification system.

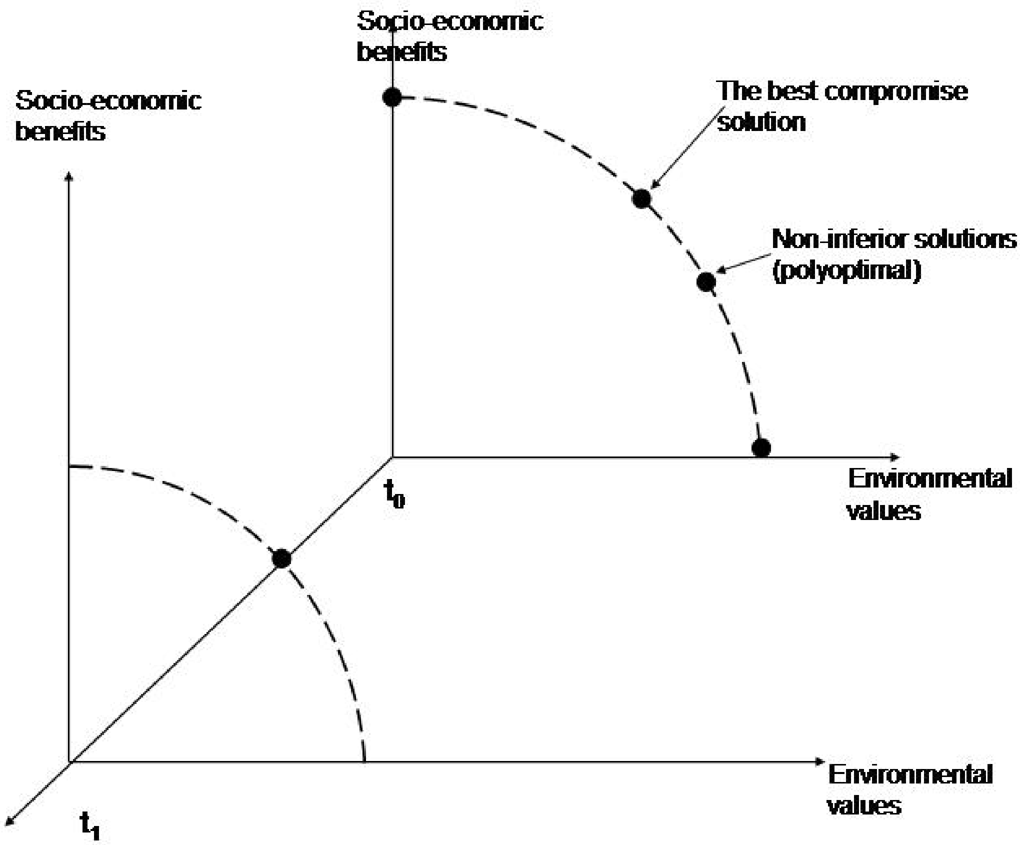

Figure 7.5 Framework for trade-off between socio-economic objective and environmental objectives

8. DISCUSSION AND CONCLUSION

The determination of a preliminary Reserve for the Thukela River catchment and the Thukela River mouth has provided a new approach to integrated water resources management, in attempting to provide a balance between water resource protection and socio-economic development to maximise the welfare of the communities in the catchment. This balance between water resource protection and socio-economic development forms the basis of the classification process once a formalised classification system has been gazetted. The aims of the research (as outlined by the author in Chapter 2 of this thesis, i.e. propose and endorse a framework approach that enhances the development and implementation of a formal classification system) have thus been achieved to a large extend; A framework approach was proposed and endorsed in the Thukela River System, which led to a more integrated approach of water resource assessment studies when determining the Reserve (i.e. taking into account the ecological, economic and social sequence of activities in the Thukela catchment). The author is confident that the recommended framework approach will result in a viable rollout of a robust classification system with its associated methodology.

However, the development of a national water resources classification system and its associated classification methodology (to assist stakeholders during the classification process) is a legal imperative, but it is also fraught with political risk. It therefore becomes important to assess that risk at various stages in the development of the classification system with a view to generating mitigation strategies. It is therefore recommended that the whole process be closely monitored, and the capacity to generate and incorporate iterative responses at critical stages in the evolution of such an assignment be strongly considered. In the absence of a formal classification system, it is further recommended by the author that this framework approach to Reserve determinations be conducted as the norm in the interim. The Reserve determination process based on this framework approach should provide information and knowledge on how ecosystems will react under various flow conditions and what the implications are for consumptive users in financial and economic terms in order for stakeholders (including DWAF) to make informed and calculated decisions. It should be noted that a more comprehensive level determination of the social assessment component for Reserve determinations be considered. As for the Thukela case study, social impacts have merely be considered in terms of resource and does not take into account external factors (i.e. increased investment and the Aids pandemic among others) that will definitely impact on the socio-economic situation in the catchment.

Integrated water resource management (IWRM) includes social, economic, and environmental factors in the planning, development, monitoring and protection of land and water resources. Hence, IWRM is not limited to addressing just physical relationships or water resource characteristics. It also includes water as an integral part of the ecosystem, a finite natural resource, and social and economic good. It is thus essential that **water quality** issues be appropriately addressed during the development of a formal classification system to properly handle the often conflicting demands of water resources, such as competition between irrigation and domestic water supply, increased degradation of water resources, variations in water quality stored behind hydraulic structures (such as dams), and increased cost of treatment. It is important to stress that classification of water resources (in determining the Reserve) is not just about the minimum water quality, water quantity, habitat and biotic integrity required for protection of the resource. Ideally, for a water resource classified with a high protection class, the Reserve would be set at a higher level, which corresponds to minimum risk and maximum caution. However, for a water resource in a lower protection class, the Reserve is set at a level which will still afford protection to the resource, but without the benefit of the buffer which is provided by caution. To assume that a “higher” Reserve necessarily means that only a greater quantity of water is allocated to protect the resource is somewhat simplistic. The assurance, or reliability of water, especially under extreme climatic conditions, is just as critical an aspect (during the classification process for determining the Reserve) as quantity and quality.

Classification of water resources, and the subsequent derivation and setting of resource quality objectives, should ideally be undertaken in a formal process of negotiation and consensus seeking among all stakeholder groups which should be represented in this process (i.e. water use sectors, industrial sectors, agricultural sectors, special interest groups, provincial and local government, as well as other government departments responsible for resource protection and development. Resource quality objectives (RQOs) for aquatic ecosystems can be derived from measurements and an understanding of ecosystems in the field and laboratory conditions, especially ecosystem responses under stress induced by changes in water quality, water quantity or habitat integrity. For recognised water users, the primary focus of RQOs is on water quality aspects. RQOs for water quality for these water users are based either on a scientific understanding of the direct physiological effects of changing water quality (e.g. effects on human health, damage to sensitive crop, toxicity to livestock, etc.), or an assessment of economic impacts (e.g. the cost of increased water treatment, or loss of productivity).

The regional differences in biological communities across South Africa must be accounted for in the national water resources classification system development. This can be done by comparing the biology of water resources to regional reference condition. As biological conditions change across the country, the reference conditions will change subsequently. In order to account for the regional differences in biological communities, and also for the differences that result from structural differences in biological habitat (either natural or caused by human activities), adherence to DWAF’s recommendation that the classification of water resources be grouped into categories and that a reference condition be developed for each category, be strongly considered (DWAF 1999). Biotic index comparisons can then be made within each category, and inappropriate biological comparisons between different classes will be avoided. Moreover, the aquatic life expectations of water bodies are tempered by realistic regional expectations; there is no attempt to set a single numeric aquatic life designated use standard for the entire country.

9. GLOSSARY

Benefits	The social, economic or environmental benefits generated by protecting the environment or associated with a particular development which may induce associated costs.
Class	This represents boundaries within which the variable you are examining falls within. When the variable examined creates a continuous gradually changing spectrum in response to other variables the definitions of classes are essentially arbitrary chosen at equal or other intervals according to the distribution. However in some cases discontinuities exist and thresholds can be determined in such cases it is possible to define class boundaries in a less arbitrary manner.
Classification process	Process of actually classifying the resource into different classes.
Classification system	A system for classifying water resources that establish the guidelines and procedures for determining different classes of water resources.
Conservation	In relation to a water resource means the efficient use and saving of water, achieved through measures such as saving devices, water efficient processes, water demand management and water rationing.
Costs	The social, economic or environmental consequences associated with a certain impact or hazard realization.
Development	Added anthropogenic interventions (more than existing utilisation) which use water and can influence the nature and characteristics of the water resource.
Ecoregion	Geographic regions of ecological similarity defined by similar climate, soil, natural vegetation, hydrology or other ecologically relevant variables.
Estuary	Means partially or fully enclosed body of water, which is open to the sea permanently or periodically; and within which the sea water can be diluted, to an extent that is measurable, with freshwater drained from land.
Framework	An interim overarching structure that allows for the testing of various principles before formally implementing a classification system.
Hazard	A naturally occurring, or human induced, event that has the potential to create loss.
Indicator	Characteristics for the environment, both abiotic and biotic, that can provide quantitative information on environmental conditions.
Instream habitat	Includes the physical structure of a watercourse and the associated vegetation in relation to the bed of the watercourse.
Integrated water resources management	Includes all the components of the water resource, i.e. surface water, groundwater, wetlands, etc. taking account quantity and quality aspects in management considerations.
National water resource strategy	Provides the framework for the protection, use, development, conservation, management and control of water resources for

	the country as a whole.
Preliminary classification	The process of temporarily classifying the resource in the absence of a formal classification system.
Preliminary class	An interim resource class that is determined until a more formal classification process is conducted.
Protection	A set of measures to ensure that the resource is maintained at a level which preserves certain environmental functions, such as water purification, thus ensuring sustainable development while conserving the cultural, ecological, and biophysical fabric of the resource.
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 extend and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas.
Reference condition	Describe the characteristics of water body segments least impaired by human activities. As such, reference conditions can be used to describe attainable biologica.
Resource quality objectives	The requirements in terms of both water quality and water quantity to maintain a resource in a specific class. This could be defined for the entire system (Resource) as well as for various users in the system.
Risk	The probability of specific hazard occurrence. Alternatively in a less scientific definition could be severity versus likelihood.
Significant resource	Any resource that is a source of supply supporting significant water users. A significant user may be considered as any user on a water resource whose use is above schedule 1 or general authorization.
Threshold effects	Result from chemicals that have a safe level (i.e. acute, subacute, or chronic human health effects).
Watercourse	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 of Gazette, declare to be a watercourse.
Water management area	Is established as 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.
Water resource	Includes a watercourse, surface water, estuary, or aquifer.
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.
Utilization	Anthropogenic interventions which through usage can influence the nature and characteristics of a water resource (Flow regime, water quality, etc) which can be detrimental to other users and the ecology.

10. REFERENCES

Bainbridge,V, S Foerster, K Pasteur, M Pimbert, G Pratt and IY Arroyo (2002). Transforming Bureaucracies: Institutionalising Participatory Approaches and Processes for Natural Resource Management: An Annotated Bibliography. London: International Institute for Environment and Development.

Brinkerhoff, DW (1996). Policy perspectives on policy change: highlighting implementation. *World Development*, 24(9), 1395-1401.

Brown, K (2002). Innovations for conservation and development. *The Geographical Journal*, 169 (1), 6-17.

Crosby, BL (1996). Policy implementation: The organizational challenge. *World Development*, 24(9), 1403-1415.

DEFRA. (2002) Guidelines for Environmental risk assessment and management. www.defra.gov.uk/environment/eramguide/02.htm

Department of Water Affairs and Forestry (DWAF) (1999). Integrated Manual Version 1.0, In *Water Resource Protection Policy Implementation, Resource Directed Measures for the Protection of Water Resources, Vol. 2*, Pretoria: DWAF.

Department of Water Affairs and Forestry (DWAF) (2002). *Natural Water Resources Strategy: Summary, Proposed 1st Edition.* Pretoria: DWAF.

Department of Water Affairs and Forestry (1999). Resource Directed Measures for Protection of Water Resources. Volume 8: Classification System for Water Resources Version 1.0, Pretoria. South Africa.

Department of Water Affairs and Forestry (1999). Resource Directed Measures for Protection of Water Resources. Volume 2: Integrated manual, Version 1.0, Pretoria. South Africa.

Department of Water Affairs and Forestry (2003). Thukela Water Project Decision Support Phase. Pretoria, South Africa.

Department of Water Affairs and Forestry, (DWAF) 1996: South African Water Quality Guidelines (second edition). Volumes 1 to 5, Department: Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry, (DWAF) 1997: South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems. Pretoria.

De Wilde, A.J. (2002) Setting class boundaries for the classification of rivers and lakes in Europe. Royal Haskoning. Netherlands.

Eekhout S., King J.M., & Wackernagel A. (1997). Classification of South African rivers, volume 1. Department of Environmental Affairs and tourism, Pretoria. South Africa.

EPA (1998). Guidelines for ecological risk assessment. EPA, Washington DC, United states of America. Federal Register 63(93):26846-26924.

Fairman, R., Mead, C.D. and William W.P. (1998). *Environmental Risk Assessment. Approaches, Experiences and Information Sources*. Office for the Official Publications of European Communities, Luxembourg.

Frankel, E.G. (1984). *Engineering Application of Systems Reliability and Risk Analysis*. Martinus Nijhoff Publishers, The Hague, Netherlands.

Gallopin,GC (2002). Planning for resilience: scenarios, surprises, and branch points, In *Panarchy: Understanding Transformation in Human and Natural Systems,* LH Gunderson and CS Holling (Eds.), pp. 361-393. Washington: Island Press.

Giddings, J, Barnthouse, L, Farrar, D, Hall, T, McKee, M, Newman, M, Reinert, K, Sebastien, B, Solomon, K, Stavola, A, Touart, L, and Wentsel, R (1998). Preliminary findings of the ecological committee on FIFRA risk assessment methods (ECOFRAM): United States of America, EPA.

Gilard, O. 1996. Flood risk management: Risk cartography for objective negotiations. Paper at 3rd IHP/IAHS Kovacs Colloquium on *Risk, Reliability, Uncertainty and Robustness of Water Resources Systems*. UNESCO, Paris, France. Mimeographed. pp 14.

Gleick, P.H., Wolff, G., Chalecki, E.L., Reyes, R. (2002), The New Economy of Water: The Risks and Benefits of Globalization and Privatization of Fresh Water. Pacific Institute for Studies in Development, Environment, and Security. 654 13th Street. Preservation Park, Oakland, California, 94612, www.pacinst.org. pp 48.

Hughes, D.A. and Munster, F. 2000. Hydrological information and techniques to support the determination of the water quantity component of the cological Reserve for rivers. WRC report TT 137/00. Water Research Commission, Pretoria.

Meadowcraft, J (1997). Planning for sustainable development: insights from the literatures of political science. *European Journal of Political Research*, 31, 427-454.

Mackay, H.M. (2000). Moving towards sustainability: The ecological Reserve and its role in the implementation of South Africa's Water Policy. Unpublished manuscript. Pretoria: Department of Water Affairs and Forestry.

National Water Act (1998). Act No 36 of 1998. Republic of South Africa Government Gazette, Vol 398, No 19182, Government Printer, Pretoria, South Africa. pp 200.

Plate, E.J. (1979). Extreme value models. In: McBean, E.A. Hipel, K.W. and Unny, T.E. (eds). *Inputs for Risk Analysis in Water Systems*. University of Waterloo, Waterloo, Ontario, Canada

Plate, E.J. (1996). *Risk Management for Hydrological Systems under Hydrological Loads*. Institute of Hydrology and Water Resource Planning, Karlsruhe University, Germany. pp 18.

Postel S. and Richter B. (2003) Rivers for life: Managing water for people and nature. Island Press, Washignton DC, USA.

Reed D. and de Wit M. (2003). Towards a just South Africa: The political economy of economic resource wealth. CSIR-Environmentek. Pretoria, South Africa.

Republic of South Africa (RSA) (1996). *Constitution of the Republic of South Africa, Act 108 of 1996*. Pretoria: Government Printers.

Rogers, K and T Sherwill (2003). The Ecological Reserve: for people or for insects and fish? *The Water Wheel,* 2(3), 9-11.

Rogers, K, D Roux and H Biggs (2000). Challenges for catchment management agencies: lessons from bureaucracies, business and resource management. *Water SA*, 26(4), 505-511.

Seetal, A.R, and Perkins J.C. (2003). Partitioning water use in South Africa. ATSE. DWAF. Pretoria, South Africa.

Shamir, U. (1996). Risk and reliability in water resources management: Theory and practice. Paper at Third IHP/IAHS Kovacs Colloquium on *Risk, Reliability, Uncertainty and Robustness of Water Resources Systems*, UNESCO, Paris, France. Mimeographed. pp 14.

Smith, K. (1996). *Environmental Hazards*. Routledge, London. United Kindom, pp 376.

Smith, K. and Ward, R.C. (1998). *Floods Physical Processes and Human Impacts.* John Wiley and Sons, West Sussex, England. pp 382.

Suter, G.W. (1993). *Ecological Risk Assessment*. Lewis Publishers, South Main Street, Chelsea, Michigan, United States of America. pp 538.

Tlou, T., Pienaar, H.H., Mullins D., Huggins, G., and Van Wyk N. (2004). Contribution of economic valuation as decision support tool in Reserve determination processes. Unpublished paper presented at the Southern African Society of Aquatic Scientist Annual Conference. Department Water Affairs and Forestry. Pretoria, South Africa.

Turton A & Henwood R. (2002). Hydropolitics in the developing world: A South African Perspective. AWIRU. University of Pretoria. Pretoria, South Africa.

Uys M., (2003). Devlopment of river rehabilitation in Australia: Lessons for South Africa. WRC Report No. KV 144/03. Water Research Commission. Pretoria, South Africa.

Van der Lee, J.J. and Gill, R.A. (1999). Water allocation decision-making in Australia: An ecological-economic perspective. Centre for Water Policy Research. University of New England, Armidale, Australia.

Vogel, C.H. (1994). (Mis)management of droughts in South Africa: past, present and future. *South African Journal of Science*, 90, 4–5.

Vogel, C.H. (1997). Vulnerability and global environmental change. *Regional Workshop on Risk Reduction in Southern Africa, Disaster Mitigation and Sustainable Livelihoods Project*. SADEP, University of the Western Cape, Cape Town, South Africa. IUCC newsletter, 3, 15-19.

Vogel, C.H. (2000). Usable science: An assessment of long-term seasonal forecasts amongst farmers in rural areas of South Africa. *South African Geographical Journal*, 82, 107-116.

Xu Y. and Beekman H.E. (2003). Groundwater recharge estimation in Southern Africa. Mills Litho, South Africa.

Xu Y., Colvin C., van Tonder G.J., Hughes S., le Maitre D., Zhang J., Mafanya T., and Braune E. (2002). Towards the Resource Directed Measures: Groundwater Component (Version 1.1). WRC Report No. 1090-2/1/03. Water Research Commission. Pretoria, South Africa.

Zampatti B. and Raadik T.A. (1997). An assessment of environmental flow requirements for Hoddles Creek. Freshwater Ecology Division, Melbourne Water Waterways and Drainage, Melbourne, Australia.

Zhou, H.M. (1995). Towards an Operational Risk Assessment in Flood Alleviation. Unpublished PhD Thesis. Technische Universiteit Delft, The Netherlands.