WATER RESOURCE PROTECTION AND ASSESSMENT POLICY IMPLEMENTATION PROCESS

Resource directed measures for protection of water resource:

Methodology for the Determination of the Ecological Water Requirements for Estuaries

(referred to as preliminary Ecological Reserve)

Department of Water Affairs and Forestry
South Africa

Version 2

May 2004

WATER RESOURCE PROTECTION AND ASSESSMENT POLICY IMPLEMENTATION PROCESS

Resource directed measures for protection of water resource:

Methodology for the Determination of the Ecological Water Requirements for Estuaries

Department: Water Affairs and Forestry
South Africa

Version 2

May 2004

Published by

The Department of Water Affairs and Forestry,
Private Bag X313
Pretoria
Republic of South Africa

Tel: (012) 336 7500/ +27 12 336 7500
Fax: (012) 323 0321/ +27 12 323 0321

This report should be cited as:

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF) (2008) Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria.

(this document includes amendments reflecting changes made to the methods between 2004 and 2008 during ecological water requirement studies and changes made do not represent any material deviation from the procedures followed in the earlier documents)

Senior authors:

Ms Susan Taljaard, CSIR, Stellenbosch
Prof Janine Adams, Dept of Botany, Nelson Mandela Metropolitan University, Port Elizabeth
Dr Jane Turpie, Anchor Environmental Consultants, Cape Town
Ms Lara van Niekerk, CSIR, Stellenbosch
Ms Nicolette Demetriades, Marine and Estuarine Research, Durban

Contributing authors:

Prof Guy Bate, Private Consultant, Pietermaritzberg
Prof Digby Cyrus, CRUZ, University of Zululand
Mr Piet Huizinga, Private Consultant, Stellenbosch
Mr Steve Lamberth, MCM, Department of Environmental Affairs and Tourism
Ms Barbara Weston, Department of Water Affairs and Forestry

CSIR Report No: CSIR/NRE/CO/ER/2009/0069/A

APPROVAL

TITLE:	Water resource protection and assessment policy implementation process. Resource directed measures for protection of water resource: Methodology for the Determination of the Ecological Water Requirements for Estuaries
SENIOR AUTHORS:	Ms Susan Taljaard, Prof Janine Adams, Dr Jane Turpie, Ms L van Niekerk and Ms Nicolette Demetriades
CONTRIBUTION AUTHORS:	Prof Guy Bate, Prof Digby Cyrus, Mr Piet Huizinga, Mr Steve Lamberth, and Ms Barbara Weston
EDITOR:	Ms Barbara Weston
MAIN CONSULTANT:	Ms Susan Taljaard, CSIR, Stellenbosch
REPORT STATUS:	Final
FILE NO.:	26/8/3/5
FORMAT:	This document is available in MS Word format
WEBSITE:	www.dwaf.gov.za
VERSION:	2
DATE:	May 2004

Approved for CSIR, Stellenbosch:

S. Taljaard

Ms S Taljaard

Approved for the Department of Water Affairs and Forestry by:

Ms B Weston
Chief Directorate: Resource Directed Measures

ACKNOWLEDGEMENTS

The follow persons are thanked for their contribution through workshops:

Dr Koos Reddering

Prof Tris Wooldridge

Mr Pat Morant

Dr Vladimir Smakhtin

Prof Anthony Forbes

Dr Anton Bok

Mr Ricky Taylor

Mr Laurie Barwell

Prof Arthur Dye

Dr Andrew Bath

Mr Geoff Cowan

Dr Steve Mitchell

Dr Dirk van Driel

Mr Niel Van Wyk

Mr Charel Bruwer

Dr Heather MacKay

Dr Allison Joubert

Mr Ralton Maree

Dr Alan Boyd

Dr Tommy Bornman

Dr David Walker

Dr Brian Colloty

ABBREVIATIONS

BAS	Best Attainable State
CRUZ	Costal Research Unit, University of Zululand
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EFR	Estuarine Flow Requirement
EIA	Environmental Impact Assessment
EWR	Ecological Water Requirements
IFR	In-stream Flow Requirement
NMMU	Nelson Mandela Metropolitan University
PES	Present Ecological Status
RDM	Resource Directed Measures
RQO	Resource Quality Objective

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

The Water Law Principles of 1996 clearly set the direction of the future of water resources management. The twin threads of sustainability and equity run through the Principles, the National Water Policy of 1997 and the National Water Act (Act 36 of 1998). *The key to balancing sustainability and equity lies in the provisions for the Reserve, and in our ability to quantify a Reserve, as well as to manage water uses so as to meet the Reserve.*

The move to integrated management of water resources, on an ecosystem basis, requires the introduction of a new set of tools for resource management, tools that are flexible, protective and can take account of extreme differences within South Africa, both in socio-economic conditions, and in natural variability of aquatic ecosystems.

The move to resource management has been a gradual one over the last ten years, driven by need, as South Africa approached the limits of new development of water resources and was forced to begin a shift to careful management of existing available resources. To support this change, new tools and new ways of making decisions have been under development within the Department of Water Affairs and Forestry (DWAF) and within other agencies responsible for natural resource management.

In response to requirements for environmental impact assessment, and as a result of the Department's commitment to follow the Integrated Environmental Management procedure in planning and implementation of major water resources developments, a considerable amount of effort within the South African scientific community was focused on finding ways to assess the water requirements of aquatic ecosystems (Instream Flow Requirements [IFR] and Estuarine Flow Requirements [EFR])

Therefore when the drafting of water legislation began in 1997, a selection of tools was already available which were in line with the new thinking arising from the Water Law Principles and the National Water Policy. The tools had not, at that time, been specifically tailored to fit the legislation (since the legislation itself had yet to be developed in detail), but it was clear that existing scientific approaches and procedures had the potential to serve as the foundation for a new suite of policy and regulatory tools for implementation of policy and legislation.

It was recognised that implementation of the new Water Act should be carried out in a "phased and progressive manner". The new definition of water use required a much broader approach than in the past; the provisions for ecosystem protection required new skills and capacity, and the introduction of catchment management agencies required a new institutional structure.

- Three critical phases that determined and guided the development of policy and regulatory tools are:

- The period leading up to "day 1" which required that only the most essential procedures be in place on the day on which the Act comes into effect.

- The transitional phase, a three to five-year period of transition from "day 1", during which special transitional tools and procedures might be required, in an environment which would allow pilot testing and refinement of tools and development of the full suite of tools needed to implement the Act.

- Full-scale implementation in selected areas or catchments around the country, a phase covering the five to ten year time frame after the Act comes into effect.

Until the classification and Reserve determination procedures have been prescribed, all Reserve determinations (rapid, intermediate or comprehensive) are considered to be preliminary (referred to as the preliminary determination of Ecological Water Requirements). Phases 1 and 2 of the Resource Directed Measures (RDM) project (which began in August 1997) have focused almost entirely on the development of tools for the determination of ecological water requirements at the intermediate and rapid levels, since this is the most urgent short-term priority.

1.2 Levels of Assessment

Four different levels of assessment of the Ecological Water Requirements have been identified:

- Desktop estimate (to obtain a low confidence value for the reserve of a water resource for use in the Water situation assessment model) (Not applicable to estuaries)
- Rapid determination
- Intermediate determination
- Comprehensive determination.

Criteria for the selection of the appropriate level of RDM determination include (DWAF, 1999):

- Degree to which the catchment is already utilised
- Sensitivity and importance of a catchment, and
- Potential impact of proposed water use.

An indication of the potential applications of the different levels is given below:

LEVEL	***INTENDED USE***
Desktop estimate	*For use in National Water Resources Strategy as part of planning processes only.*
Rapid determination	*Individual licensing for small impacts in unstressed catchments of low importance & sensitivity; compulsory licensing "holding action" (Barbara)*
Intermediate determination	*Individual licensing in relatively unstressed catchments*
Comprehensive determination	*All compulsory licensing. In individual licensing, for large impacts in any catchment. Small or large impacts in very important and/or sensitive catchments.*

NOTE:

- ***It is assumed that the preliminary Ecological Water Requirements determined at the rapid level will NOT be used to allocate licenses that will affect the magnitudes of the 1:5 year floods and above. In principle, floods and sediments are therefore not specifically addressed as part of a rapid level study. Caution should therefore be taken in using rapid level determination for deciding on medium size dam development in small catchments as this might well affect the floods reaching the estuary. Similarly, rapid level determinations should not be used for licensing of discharges to estuaries (e.g. wastewater).***

- ***It is assumed that the preliminary Ecological Water Requirements determined at the intermediate level will NOT be used to allocate licenses that will affect the magnitudes of the 1:5 year floods and above. In principle, floods and sediments are therefore not specifically addressed as part of an intermediate level study. Intermediate level determinations may be sufficient to use for licensing of discharges to estuaries (e.g. wastewater).***

1.3 Generic Procedures

In 1999 the DWAF developed a generic 7-step procedure to determine Resource Directed Measures for water resources (Figure 1.1). However, these procedures revealed some short comings which included:

- The steps, provided only in the context of the Ecological Water Requirement determination process, did not necessarily fit into the overall procedures required for Reserve determination (from definition to implementation) which included other Resource Directed Measures as well as Source Directed Measures amongst others.

- The procedure made reference to Management Classes which was incorrect as it should make reference to the Ecological Categories. The Management Class forms part of the classification process. This led to some confusion regarding the links between the Reserve, the ecological component of the Management Class and the classification process itself.

- The procedure has to be contextualised within the broader process that illustrates how it links to operation and implementation. Without these links, credibility of the recommended processes comes into question.

- Steps 6b and 7 were problematic as they could not directly follow on from step 6a as indicated by Figure 1.1. Resource Quality Objectives (RQO) and monitoring are linked to the final determined Management Class which comprises a separate process.

- The process does not cater for a range of Ecological Water Requirement Scenarios to be assessed. It also does not include any evaluation of other suggested scenarios which could achieve the same objectives as a recommended Ecological Water Requirement Scenario while meeting more of the user's requirements (e.g. yield and operational scenarios).

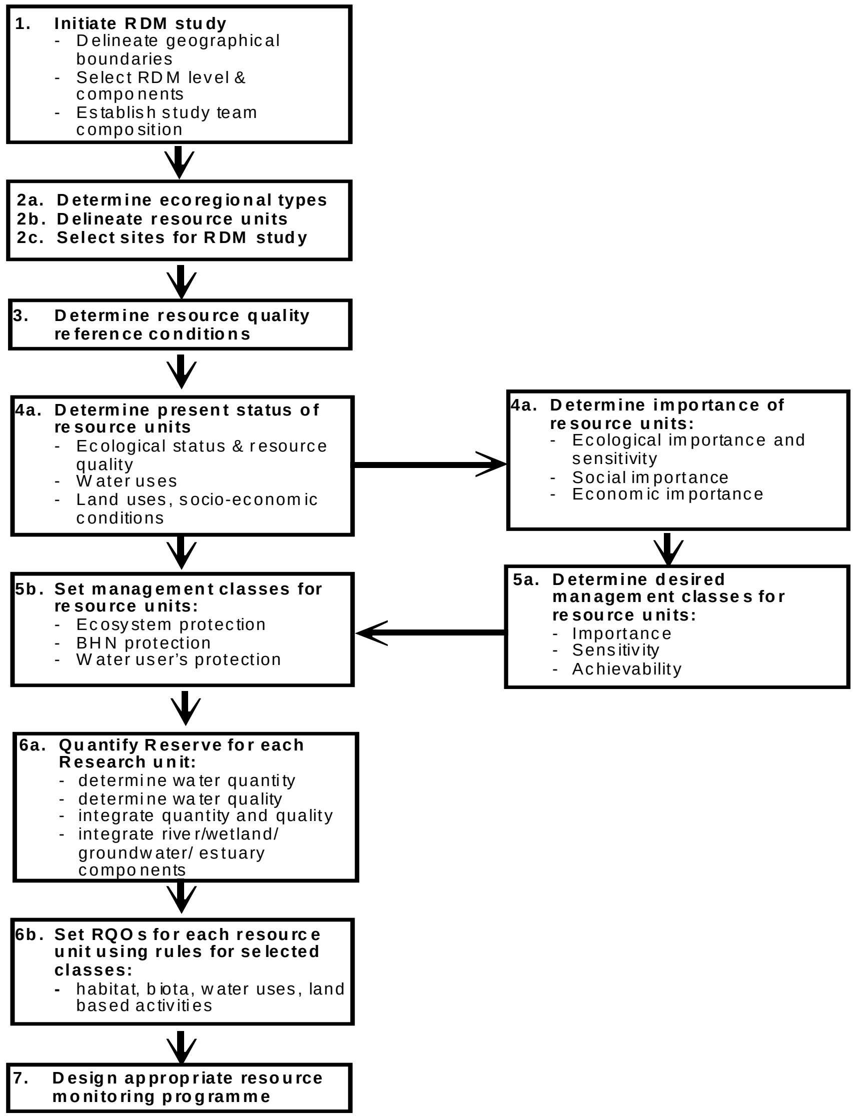


Figure 1.1: Initial Generic RDM Procedure (DWAF 1999)

As a result a revised generic procedure were put forward, which showed the process for the determination of the Ecological Water Requirement in context of the larger process, e.g. showing possible links to issues such as the stakeholder process, classification, implementation and operation (Figure 1.2). These possible links must be seen only as suggested ways to integrate the Reserve determination process. It must be noted that all the steps that formed part of the initial generic procedures still form part of the revised process.

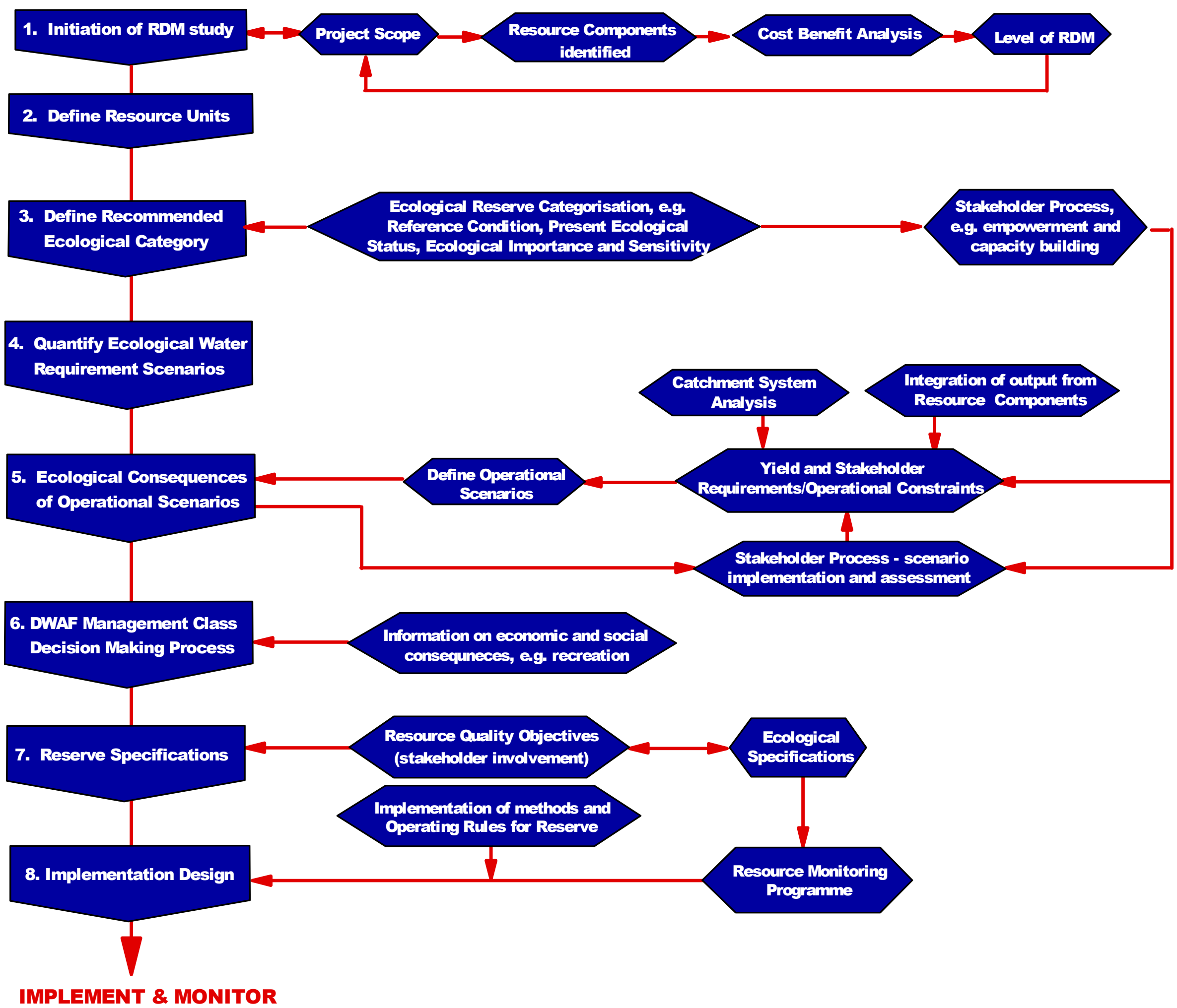


Figure 1.2: Revised Generic Procedures for the determination of Resource Directed Measures

1.4 Context within EIA and Water Use Authorisation Process

The Determination of Ecological Water Requirements (and the Reserve), in context of the Environmental Impact Assessment (EIA) Process (as stipulated in the EIA Regulations under the Environmental Conservation Act 73 of 1989) and Water Use Authorisation process (as required for water uses classified under section 21 of the National Water Act 36 of 1998) are schematically illustrated in Figure 1.3 (DEAT, 1998; RSA DWAF, 2000). Resource Directed Measures, i.e. Management Class (and associated Ecological Class), as well as the Resource Quality Objectives (which incorporate Ecological Specifications) of a water resources provides the objectives against which potential impacts need to be assessed.

NOTE:

The determination of preliminary Ecological Water Requirements DOES NOT provide the Management Class or Resource Quality Objectives. It only provides a recommended Ecological Category, the recommended Ecological Flow Requirement Scenario, as well as Ecological Specifications for the recommended Ecological Category.

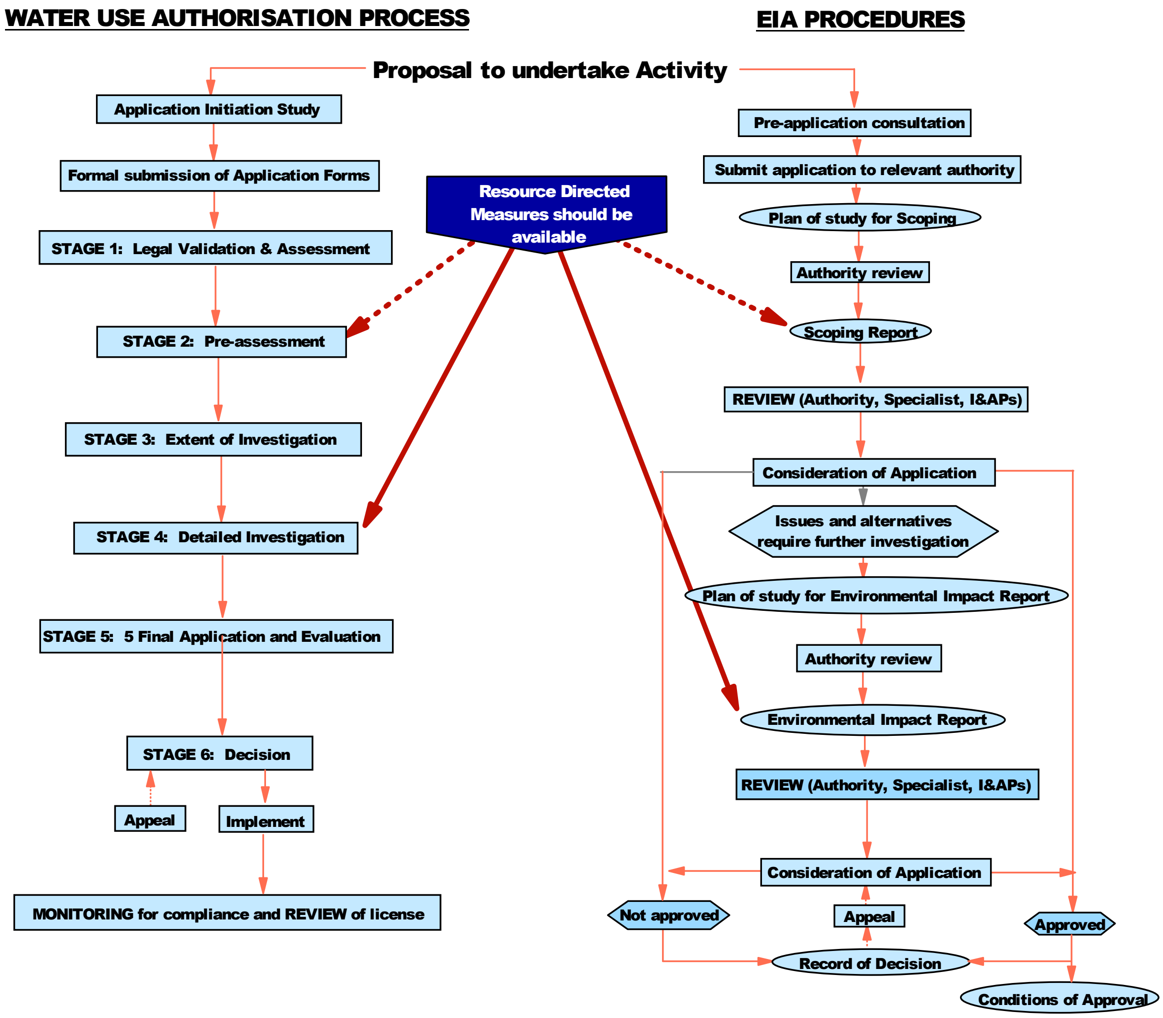


Figure 1.3: The Determination of Resource Directed Measures in context of the EIA Process and Water Use Authorisation process (under section 21 of the National Water Act)

1.5 Overview of Documentation linked to Ecological Water Requirement for Estuaries

The method development process for estuaries commenced in 1999 and was initially derived from the methodologies that were previously used in the determination of estuarine freshwater requirement (EFR) studies (see Appendix A).

Since then a limited number of studies have been conducted on estuaries to determine preliminary Ecological Water Requirements:

- ***Rapid level***. Mdloti (2002), Mhlanga (2003), Tsitsikamma (2003), Orange (2003), Tongati (2006), Siyaya (2007), St Lucia (2004), Seekoei (2006), Keurbooms (2008), Goukamma (2008) and Swartvlei (2008) estuaries

- ***Intermediate level***. Nahoon (2000), Mtata (2000) Breede (2004), Thukela (2004), Tongati (2007), Mdloti (2007), Sout (2007), Matjies (2007), Great Brak (2008) and Knysna (2008) estuaries

- ***Comprehensive level***. Olifants (2006) and Kromme estuaries (2006)

This Version 2 of the method includes the learning gained from the above studies presented in the revised generic procedure format as illustrated in Chapter 1. Methods are provided for the determination of the preliminary Ecological Water Requirements at rapid, intermediate and comprehensive levels. There is currently no desktop assessment method for estuaries. For rivers, the DWAF uses a desktop model where medium to high confidence IFR results were used to identify environmental water requirement trends in different hydrological regions. These results are of low confidence and, as no EFR results were used to calibrate the model, they are NOT applicable to estuaries.

This document containing the methods for the determination of the preliminary Ecological Water Requirements for Estuaries is structured as follows:

Chapter 1: General Introduction (to Determination of Resource Directed Measures)
Chapter 2: Overview on Estuaries
Chapter 3: Methods for Determination of Ecological Water Requirements (including comprehensive, intermediate and rapid levels)

Appendix A: Previous Estuarine Flow Requirement (EFR) Methodology
Appendix B: Integration with River Methods
Appendix C: Detailed documentation on Estuarine Health Index
Appendix D: Detailed documentation of Estuarine Importance rating
Appendix E: Templates to be completed by Specialists in the determination of the preliminary Ecological Water Requirement process.

2. OVERVIEW ON ESTUARIES

2.1 Definition of an Estuary

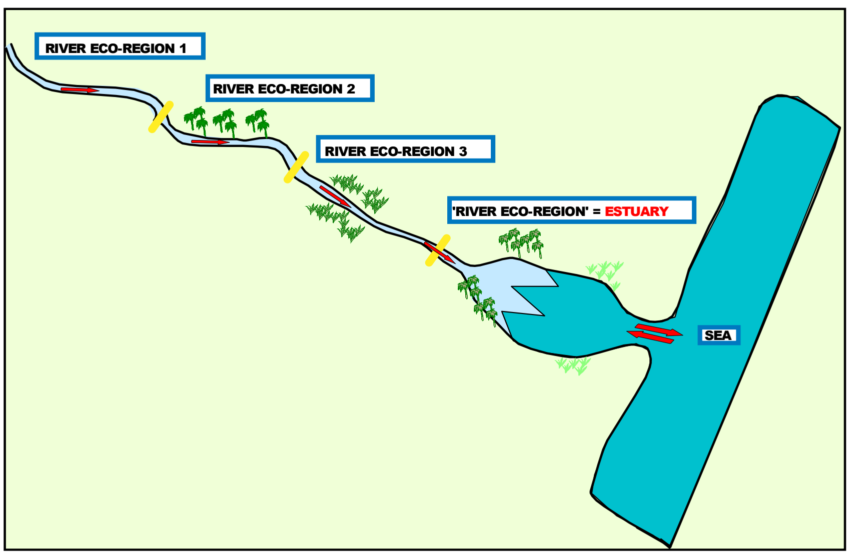
According to the National Water Act (No. 36 of 1998) an estuary is defined as a partially or fully enclosed water body-

- that is open to the sea permanently or periodically, and
- within which the seawater can be diluted, to an extent that is measurable, with freshwater drained from land.

2.2 Complexity of Estuaries

In estuaries, river inflow patterns show strong correlation with important hydrodynamic and sediment characteristics, such as state of the mouth, amplitude of tidal variation, water circulation patterns and sediment deposition/erosion. However, the relationships between these characteristics and river inflow are generally complicated to interpret, owing to the influence of the sea, i.e. state of the tide and associated seawater intrusion. The manner in which these characteristics are influenced by river flows is often not the result of a single flow event, but rather that of characteristic flow patterns occurring over weeks or months. In estuaries there is also a much larger buffer or delay-effect between river inflow patterns and their effect on abiotic parameters than in rivers.

Marked differences exist between the chemistry (or water quality) of river water and seawater, particularly in terms of system variables (e.g. salinity, temperatures, oxygen levels, pH and suspended solids) and nutrients (e.g. nitrate, ammonium, phosphate). As a result, river inflow patterns also have a strong influence on water quality characteristics of estuaries. The water quality characteristics along the length of the estuary, at any point in time, are dependent on the extent of marine or freshwater influence at that point. This, in turn, is primarily determined by the quantity of river water entering the estuary during that period, and also by the state of the tide. Longitudinal salinity distribution profiles are typically used as primary indicators of water quality.



An estuary functions as an 'eco-region' within the larger catchment

The strong longitudinal gradient of abiotic characteristics in estuaries also results in a strong longitudinal variability in biotic composition and functioning.

The complexities highlighted above shows that estuaries require a much more holistic and process-orientated approach for determination of the preliminary Ecological Water Requirements.

It is also important to recognise that each estuary is unique and different from any other estuary. For example two estuaries could occur adjacent to one another but completely different processes could be responsible for maintaining an open mouth due to differences in local coastal conditions e.g. rocky headlands, steep beaches.

2.4 Types of Estuaries

According to Whitfield (1992), there are about 250 estuaries in South Africa which fall within the definition of an estuary. A classification system has been developed for South African estuaries, based primarily on broad physical features of estuaries (Whitfield, 1992). The classification system is primarily based on broad physical features of estuaries. These include:

- ***Temporarily open/closed estuaries:*** Sand bars often form in the mouths of these estuaries blocking off connection with the sea. Sand bars form as a result of a combination of low river flow conditions and longshore sand movement on the adjacent coast. Flooding is frequently the cause of mouth opening, which also results in large amounts of sediment removal. However, infilling from marine and fluvial sediment can be rapid. Hypersaline conditions occur in these estuaries during times of drought. Tidal and riverine inputs control the water temperature in these systems when the mouth is open, but is independent of them when the mouth is closed. Marine, estuarine and freshwater life forms are all found in these systems, depending on the state of the mouth. About 75 % of South Africa's estuaries fall within this category with examples including the Great Brak and Mhlanga estuaries.

Great Brak Estuary, a temporality open/closed estuary

- ***Estuarine bay:*** Water area exceeds 1 200 ha. Bays (e.g. Knysna) are permanently linked to the sea and the salinity within them reflects this. Hypersaline conditions are not common and water temperatures are strongly influenced by the sea. Marine and estuarine organisms dominate these systems and extensive wetland/mangrove swamps occur.

Knysna Estuary, an estuarine bay

- ***Permanently open estuaries:*** Vertical and horizontal salinity gradients are present and are modified by the river flow, tidal range and mouth condition. Wetlands (salt marshes), as well as submerged macrophyte beds are common and the fauna is predominantly marine and estuarine. Hypersaline conditions in the upper reaches can occur during times of severe drought. Water temperatures in this estuary type are controlled by the sea during normal conditions and by river input during flood conditions. Examples of permanently open estuaries are the Berg and Olifants estuaries.

Great Berg River Estuary, a permanently open system

- ***River mouths:*** Riverine influences dominate the physical processes in these estuaries. Oligohaline conditions are often found. The mouth is generally permanently open but the tidal prism is small and strong riverine outflow prevents marine intrusion. During strong flood conditions the outflow of these mouths can influence the sea salinity for many kilometres. Heavy silt loads are frequent in these estuaries often resulting in shallow mouths (<2m). Water temperatures are strongly influenced by river inflow although the sea can influence bottom waters. Examples of river mouths are the Orange and Thukela estuaries.

Thukela Estuary, a system classified as a river mouth

- ***Estuarine lakes:*** Water area exceeds 1 200 ha. These are usually drowned river valleys filled in by reworked sediments and separated from the sea by vegetated sand dune systems. The dune can result in complete separation of the lake from the sea that then results in a loss of estuarine characteristics and the system can be referred to as a coastal lake. Estuarine lakes can be either permanently or temporarily linked to the sea and salinity within them is highly variable. Freshwater input, evaporation and the magnitude of the marine connection are the main causes of this large salinity fluctuation. The tidal prism is small and marine and river input have little influence on water temperatures, which are directly related to solar heating and radiation. Estuarine, marine and freshwater organisms all occur depending on the salinity condition of the system. St Lucia and Kosi Bay are examples of an estuarine lake.

Kosi Bay, an estuarine lake

The different classes of estuaries and their distribution in the three biogeographical regions (Figure 2.1) are given in Table 2.1

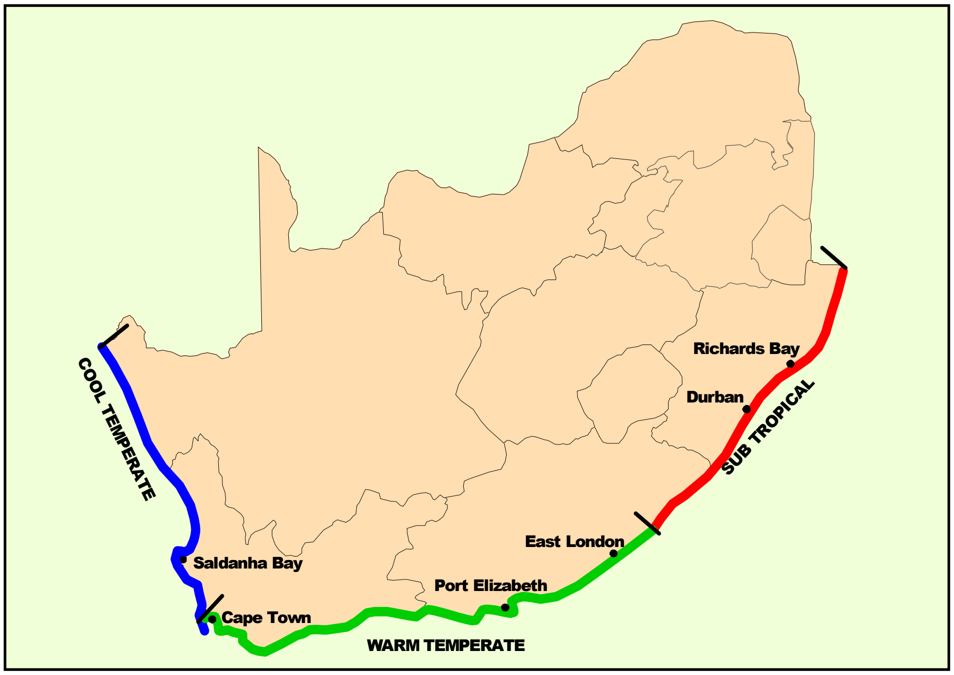


Figure 2.1: Biogeographical regions along the South African Coast

TABLE 2. 1: Distribution of estuary types in the three biogeographical regions of South Africa (Whitfield, 1992)

ESTUARY TYPE	*BIOGEOGRAPHICAL REGION*		
	COOL TEMPERATE	*WARM TEMPERATE*	*SUBTROPICAL*
Estuarine bay	*0*	*1*	*3*
Permanently open estuary	*2*	*29*	*16*
Estuarine lake	*0*	*4*	*4*
Temporarily open/closed estuary	*5*	*86*	*94*
Modified or canalised estuary	*1*	*2*	*0*
River mouth	*2*	*6*	*4*

Although the above provide a rough classification system for estuaries, there are still large differences in abiotic and biotic characteristics and processes amongst estuaries within a similar category and/or biogeographical region, for example in terms of natural mean annual run-off, size of the estuary, wave action in the mouth, biogeochemical characteristics of the adjacent marine environment and catchments and biotic composition. It therefore is important to recognise that each estuary is unique and different from any other estuary.

2.5 Sensitivity of Estuaries to Reductions and Changes in River Flows

In principle, all estuaries are sensitive to reductions and changes in river inflow. However, there are certain parameters (primarily physical parameters) that would indicate whether an estuary is particularly sensitive to modifications in this regard. Based on current understanding of estuaries, the following are important indicators that could be used towards establishing the extent to which estuaries would be sensitive to modification in inflows:

- ***Frequency of mouth closure (mostly applicable to temporarily open/closed systems).*** The sensitivity of an estuary mouth to closure can roughly be correlated to the river inflow, particularly during low flow periods, required to keep the mouth open. For many estuaries, especially the smaller ones, the most important factor in keeping the mouth open is river flow, and particularly base flows. In addition to river flow there are also other factors and/or a combination of thereof, that may contribute to an estuary's sensitivity to mouth closure such as:

  - ***Size of the estuary***. In general, larger estuaries are less sensitive to mouth closure than smaller estuaries, because of greater tidal flows through the mouth, e.g. Breede and Kromme. At breaching larger estuaries also tend to scour deeper mouths due to higher outflows, which generally take longer to close, e.g. Bot and Klein. However, when the mouth of a large estuary closes, a substantial amount of water is required to first fill up the estuary before breaching can occur and as a result more river flow is needed to ensure breaching in large estuaries compared to smaller estuaries. Small estuaries are very sensitive to flow reduction as this is the main force keeping the mouth open, once flow decrease below a certain volume the system will close, and remain closed, until such time as flow increase enough to cause a mouth breaching.

  - ***Availability of sediment***. In general, the larger the amount of sediment available in the adjacent marine environment, the greater the sensitivity to mouth closure, e.g. most estuaries a long the KwaZulu-Natal coastline. In estuaries were there is not a large amount of sediment available, for example on a rocky coastline or where longshore transport is further offshore, e.g. Nahoon, the system would be less sensitive to flow reductions.

  - ***Wave action in the mouth***. Wave action is the most important contributing cause of mouth closure in estuaries. In general, the stronger the wave action in the mouth the greater the sensitivity to mouth closure. In turn, the following factors may again influence the wave conditions in the mouth:

    Protection of the mouth. This refers to situations where the mouth is protected against wave action by, for example a headland. As a result such systems are usually less sensitive to mouth closure. For example, although similar in size and MAR, the Mkazana estuary stays open at much lower river inflows than the Mngazi as its mouth is protected form direct wave action.

    Beach slope. A steep beach slope normally means that high-energy wave action occurs on the beach at the mouth, resulting in higher suspended sediment load. This type of beach slope is characteristic of the KwaZulu-Natal coastline. The beach slope can also vary from winter to summer due to winter storms. Generally the steeper the slope of a beach, the higher the suspended sediment load in the mouth area, therefore the greater the sensitivity to mouth closure. A mild beach slope means that less energetic wave action occurs at the mouth and a mild beach slope therefore provides a special type of protection against wave action.

Taking the above into account, the degree of sensitivity of a temporarily open/closed estuaries mouth to reduction in flow can broadly be categorized as follows:

SENSITIVITY	***RIVER INFLOWS***
High sensitivity to closure	*< 2 -10 m^3/s are likely to result in closure*
Medium sensitivity to closure	*0.5 m^3/s - 2.0 m^3/s are likely to result in closure*
Low sensitivity to closure	*< 0.5 m^3/s are likely to result in closure*

Although mouth closure is normally only factored in during the analyses of temporarily open/closed estuaries, it should be noted that even some permanently open estuaries can close relatively easily if the flows are reduced for example the Keurbooms Estuary near Plettenberg Bay.

- ***Volume of mean annual runoff (MAR)***. As a first estimate, the volume of the natural MAR that an estuary receives is probably the most important parameter in judging overall sensitivity to reduced river inflows. It is, however, important to realize that it is not only the amount of river inflow that is important, but also the variability of flows. In general (although there are many exceptions), it can be assumed that the larger the natural MAR of an estuary, the less sensitive it might be to reduced river inflow. Care should be taken in applying this guideline as the local bathymetry of an estuary can cause exceptions. For example the Keurbooms Estuary has a MAR of ~177 Mm^3/a, but is extremely sensitive to flow reductions due to extensive sediment availability and large ripple forms in its mouth area.

  Sensitivity to reduced river flows versus natural MAR volumes can roughly be categorized as follows:

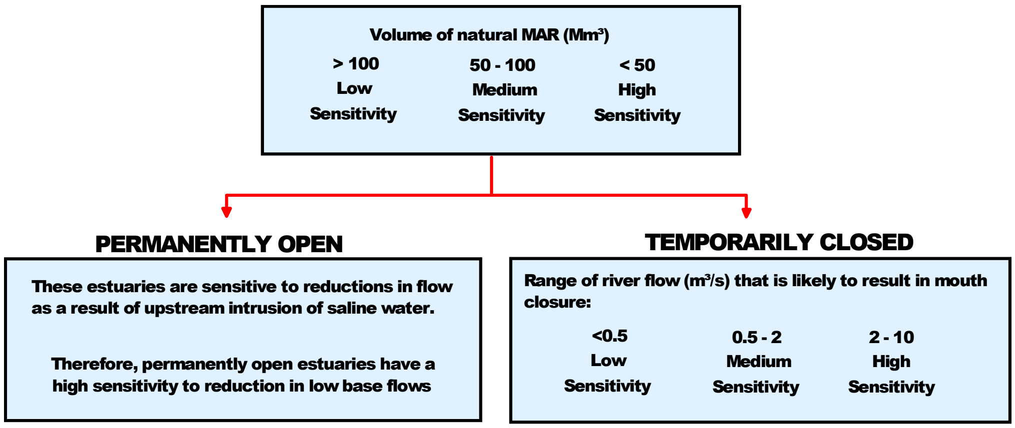
SENSITIVITY TO REDUCED RIVER FLOWS	***NATURAL MAR***
Low sensitivity	*> 100 Mm^3/a (large estuaries)*
Medium sensitivity	*50 Mm^3/a < MAR > 100 Mm^3/a (medium - small estuaries)*
Higher sensitivity	*< 50 Mm^3/a (smaller estuaries).*

- ***Extent of Saline intrusion (especially relevant to permanently open systems)***. If an estuary is permanently open to the sea, the most important effect of reduced seasonal base flows or extended duration of low flows is an increase in the upstream intrusion of saline water. The variation in salinity distribution gradients in estuaries and the sensitivity to estuaries in this regard, is very difficult to quantify. In general if an estuary is permanently open, its sensitivity to <u>reduction in seasonal base flows during the low flow period</u> is assumed to be <u>very high</u> and, therefore a reduction in river inflow during the low flow period should not be considered. Permanently open estuaries are often less sensitive to reductions in higher flows, e.g. >50 – 100m^3/s.

NOTE:

It is important to note, that although the above-mentioned parameters are mainly influenced by seasonal base flows, <u>floods</u> play an important role in the long-term equilibrium of an estuary. Floods are therefore needed for the scouring of accumulated marine and catchment sediment from the system, deepening the mouth and the resetting of the salinity regime in estuaries.

A first estimate for determining the sensitivity of an estuary to reduction in inflow can be determined as follows:



NOTE: SENSITIVITY VERSUS IMPORTANCE

Unlike for rivers, where importance and sensitivity often equates to each other, the reverse often holds for estuaries, in that systems of average to low importance can be extremely sensitive to flow reduction.

The reason for this is that more than 70% of South Africa's estuaries close periodically to the sea. Most of these temporarily open/closed estuaries have a natural MAR of less than 100 Mm^3/a (e.g. small estuaries along the Eastern Cape coast such as the Xora and Mngazi estuaries), with a large number having an MAR of even less than 50 Mm^3/a (e.g. small South coast estuaries such as Groot [East] and Klipdrift estuaries). As stated before, these medium to small size estuaries rely on river runoff to keep their mouths open, as tidal flows in such small systems contribute negligibly to total outflow through the mouth, thus they are highly sensitive to reduction in runoff.

These smaller temporarily open/closed systems generally support less species due to their smaller size and also the fact that a number of estuarine associated species prefer open mouth conditions. These smaller systems are therefore considered to be of a lower biodiversity importance, than their permanently open counterparts (Turpie et al. 2002, Lamberth and Turpie 2003). However, the importance evaluation system does not currently take into account the collective, regional importance of the large number of smaller systems found along the Kwazulu-Natal, South and Eastern Cape Coast and still needs to be investigated.

Therefore, for estuaries there is no direct relationship between importance and sensitivity to flow reduction. In general estuary size is a good indicator of importance, and this also makes the estuaries more robust to changes in inflow. However, generalisations cannot be made in this regards without more detailed investigations, as there are many exceptions to the rule such as explained earlier with the Keurbooms Estuary.

2.6 Economic Value of Estuaries

Freshwater inflows into estuaries affect their functioning, and thus also the provision of goods and services that are utilized by society or that could potentially be utilized in future. The definition of the estuary Reserve will thus have economic consequences. In the final determination of the estuary management class, these economic consequences, along with ecological and social impacts, will be weighed up against the benefits that might be obtained by the allocation of freshwater resources to alternative uses. The methodology for inclusion of these economic consequences is still under development. Some of the goods and services that are provided by South African estuaries are listed in Table 2.2 (Costanza *et al.,* 1997; Mander *et al.* 2001; Mander, 2001, Van Niekerk and Taljaard, 2003). The total economic value of estuaries includes these direct and indirect use values as well as other values such as option and existence value.

TABLE 2.2: Goods and Services provided by South African estuaries

GOODS AND SERVICES	***EXAMPLES…***
Biological Control	*Maintaining the balance/diversity of plants/ animals*
Refugia/Migratory Corridors	*Fish and crustacean nurseries and roosts for residential and migratory bird species*
Sediment supply	*Outputs of sediments which contribute to beaches, sand bars and sand banks*
Erosion control	*Soil retention by estuary vegetation, and by capturing soil in reed beds and mangroves*
Soil formation	*Accumulation of sediment and organic material on floodplains and in mangroves, beach replenishment*
Nutrient supply and cycling	*Nutrient supply, nitrogen fixation and nutrient cycling through food chains*
Genetic Resources	*Genes for mariculture, ornamental and fibre-producing species*
Disturbance regulation	*Flood control, drought recovery and refuges from natural and human induced catastrophic events (e.g. oil spills)*
Living resources for food (or resale)	*Line fishing, harvesting of inter-tidal invertebrates, beach and seine netting*
Raw material for subsistence use (e.g. building material)	*Harvesting of craftwork and house-building materials*
Nature appreciation	*Providing access to estuaries and associated wildlife for viewing and walking*
Scenic views	*Resort, residential houses, housing complexes and offices with scenic views, increasing value of properties with seaviews*
Culture	*Aesthetic, educational, research, spiritual, intrinsic and scientific values of estuary ecosystems*
Sports fishing	*Estuary flyfishing, estuary and inshore conventional fishing*
Water sports	*Water sports: swimming, sailing, canoeing, skiing and kayaking*
Waste treatment	*Breaking down of waste and detoxifying pollution.*
Water supply and regulation	*Fresh water supply to marine environment and water for mariculture*
Mariculture (e.g. oysters, bait, etc.)	*Production (natural and cultivated) of fish, crustaceans and worms*
Commercial food production	*Fishing (not allowed in South African estuaries)*
Raw material for commercial use	*Diamond and titanium mining, sand winning and salt production*
Transport services	*Ports, harbours, marinas and skiboat launching sites*

3. METHODS FOR DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS

3.1 Procedures and Human Resources

The determination of the preliminary Ecological Water Requirements for estuaries forms part of the generic eight step procedure for the determinations of the Resource Directed Measures as described in Chapter 1. The determination of the preliminary Ecological Water Requirements can be conducted on different levels, namely:

- Comprehensive level
- Intermediate level
- Rapid level.

The main difference between an intermediate and comprehensive level determination is the level of confidence (intermediate = medium; comprehensive = medium/high), which in turn is determined by the extent of data available or to be acquired. A rapid level determination, on the other hand is usually of low confidence and typically does not include additional data collection, i.e. it primarily relies on available data and expert knowledge. Baseline data requirements for each of these are discussed in Chapter 3.2.

Procedures for the intermediate and comprehensive determination of the preliminary Ecological Water Requirement for estuaries in the context of the larger process are illustrated in Figure 3.1.

Note that although the initiation of an RDM study (Step 1) is not within the domain of the preliminary Ecological Water Requirement determination process, it is recommended that qualified estuarine specialists be consulted at the inception stage of any RDM study to provide a conceptual framework of the anticipated estuarine biophysical processes and interactions that needs to be considered.

The human resources required to conduct an intermediate or comprehensive level determination of the preliminary Ecological Water Requirements for estuaries are illustrated in Figure 3.2. An intermediate level determination can be conducted within 1 to 2 years (need to capture limited data on seasonal variability), while a comprehensive level determination can take between 2 and 3 years (need to capture more detailed data sets on seasonal variability).

Procedures for the determination of the preliminary Ecological Water Requirement for estuaries at the rapid level, in the context of the larger process, are illustrated in Figure 3.3.

NOTE:

Although the rapid method does not require the preparation of a detailed Resource Monitoring Programme, key baseline data requirements, that would be required to improve the confidence of the preliminary Ecological Water Requirements, should be provided. In this regard, the recommended data requirements in the methods for the intermediate and comprehensive level determinations need to be consulted (refer to Chapter 3.2).

The human resources required to conduct a rapid level determination of the preliminary Ecological Water Requirements is provided in Figure 3.4. A rapid level study is typically conducted within 2 to 3 months.

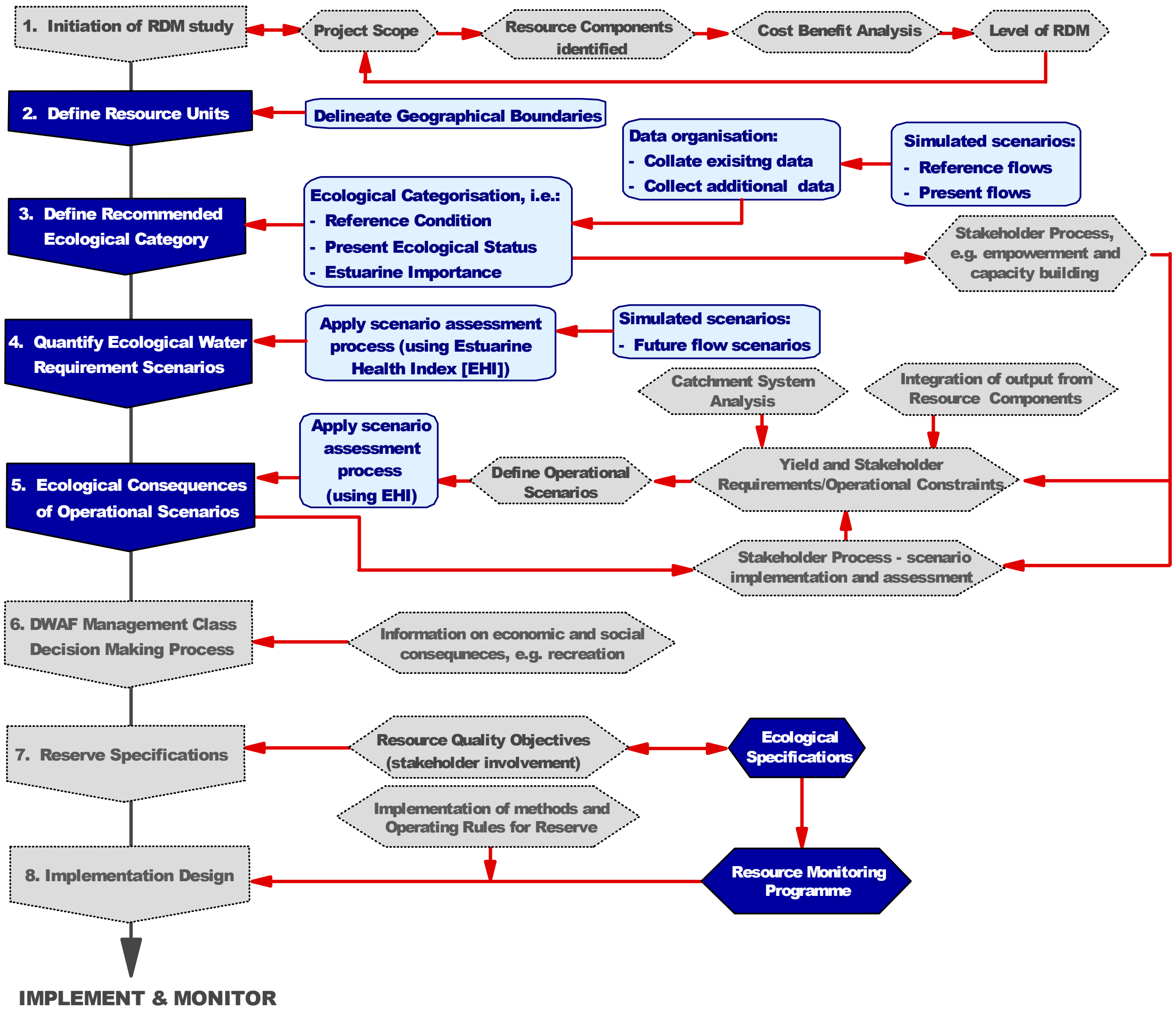


Figure 3.1: ***Procedures for determination of the preliminary Ecological Water Requirements for estuaries at the intermediate and comprehensive levels, in context of the broader RDM process (components not addressed as part of the Ecological process is indicated by non-solid line boxes)***

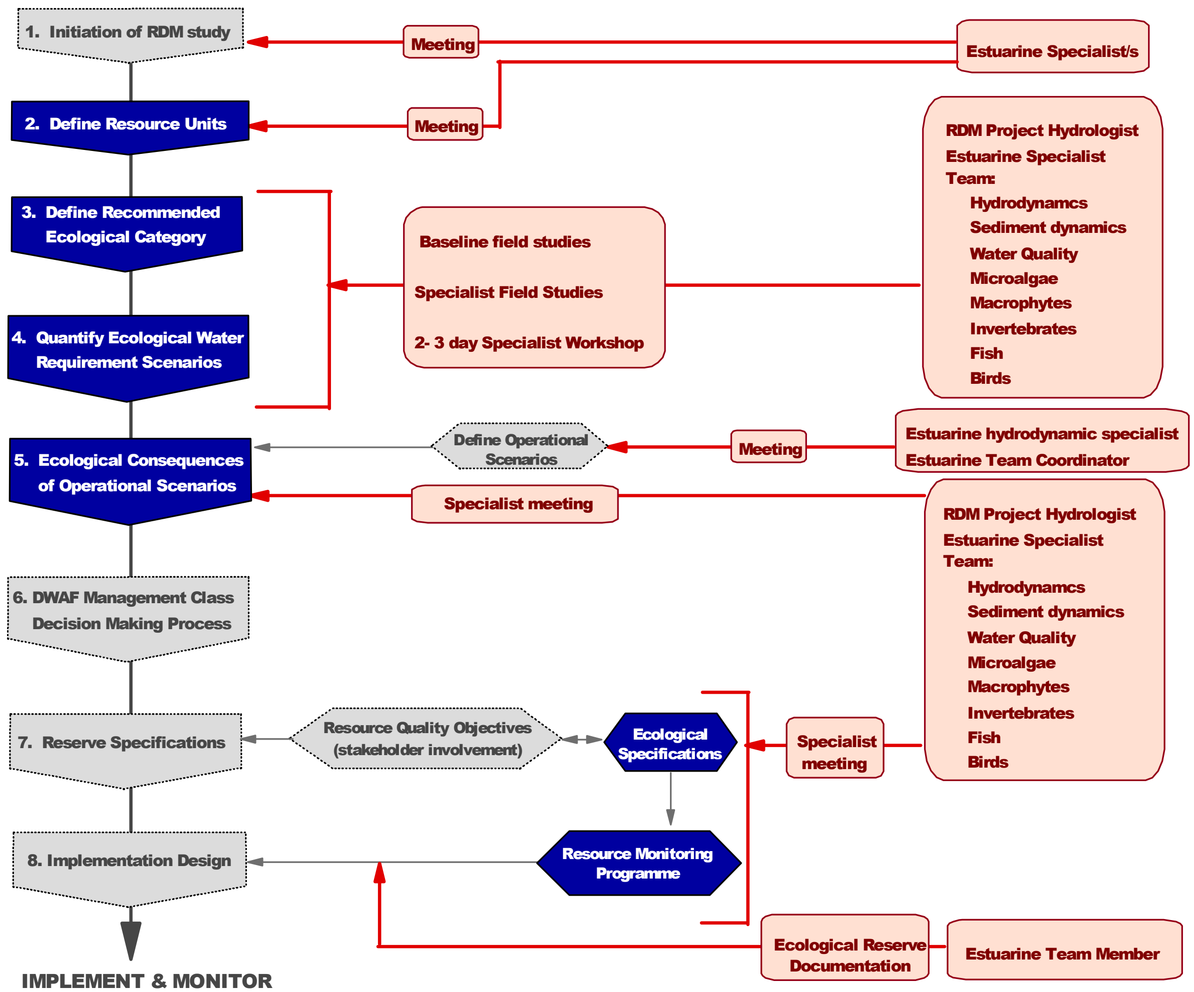


Figure 3.2: Indication of human resource requirements for the determination of preliminary Ecological Water Requirements for estuaries at the intermediate and comprehensive levels on estuaries

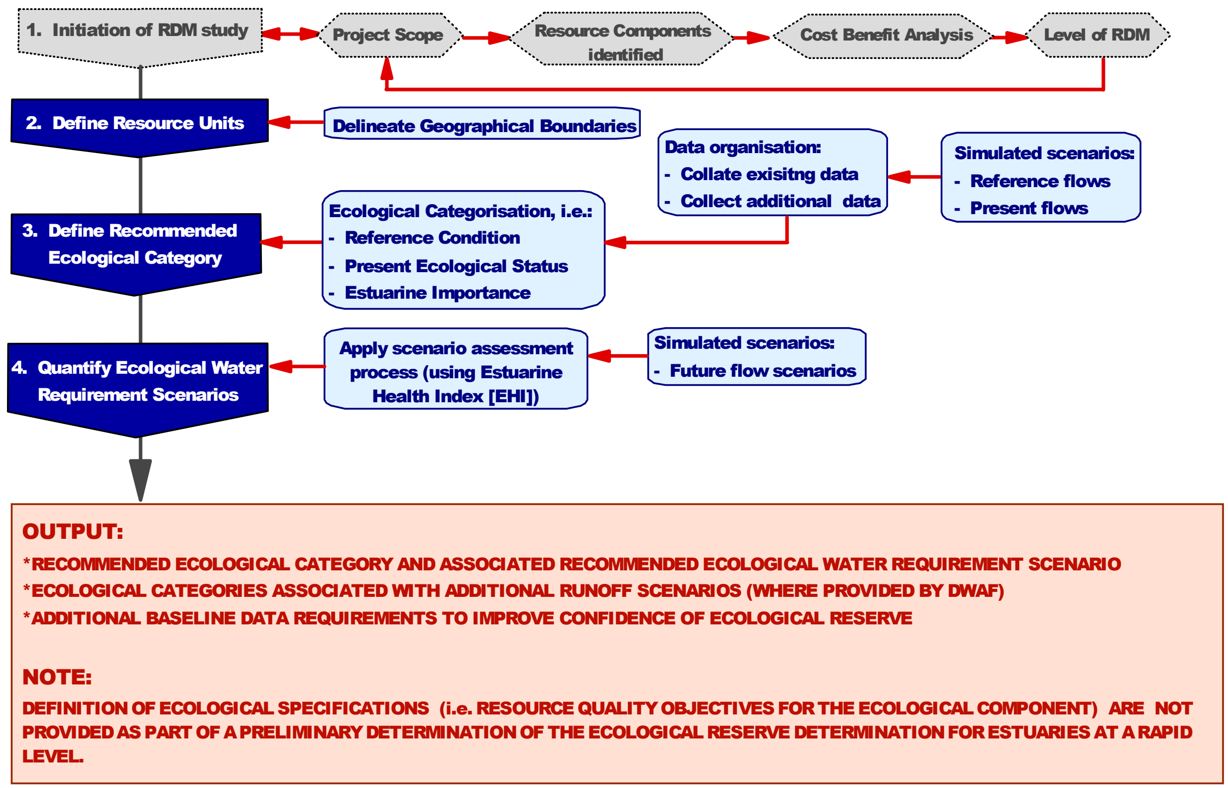


Figure 3.3: ***Procedures for the determination of preliminary Ecological Water Requirements on estuaries at the rapid level in context of the broader RDM process (components not addressed as part of the Ecological Reserve determination process are indicated by non-solid line boxes)***

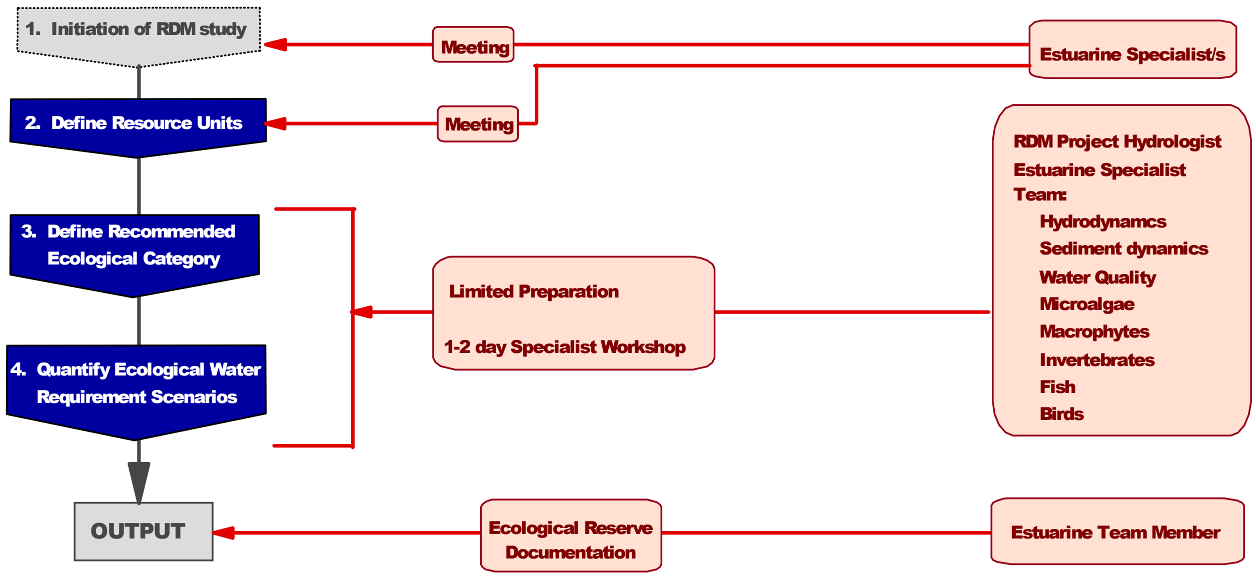


Figure 3.4: ***Indication of human resource requirements for the determination of the preliminary Ecological Water Requirements on estuaries at the rapid level***

3.2 Baseline Data Requirements

NOTE:

- ***Determination of the preliminary Ecological Water Requirements at the rapid level is usually based on available data. However, simulated runoff scenarios must be provided (see Chapter 3.2.1) even for a rapid level determination.***

- ***Where specialists are not familiar with the case study, it is strongly recommended that a site visit be planned, coinciding with the Specialist workshop.***

- ***Before any additional data are acquired on a particular system it is necessary to undertake a desktop assessment to determine the availability and suitability of existing data sets to meet the data requirements of an Ecological Water Requirement study. For any particular estuary, the extent and availability of data and information therefore depends on:***

  - ***Data available from previous research projects conducted in the estuary***
  - ***Short-term data records collected during, for example Ecological Water Requirement studies for estuaries (EFR's) or EIA studies involving the estuary.***

- ***Due to the complex nature of estuarine processes, and the limited availability of detailed data and information, it would be expected that the time required and the intensity of data collection for the preliminary determination of Ecological Water Requirements could be greater for estuaries than it is for rivers.***

- ***If additional field data are required (refer to Tables 3.1 to 3.5) the abiotic and biotic data must be collected during the same field exercise to enable the linkage of the abiotic characteristics with the biotic responses.***

- ***To allow for easier comparison, reference to stations in the specialist reports need to be standardised to 'Distance from mouth' rather than each specialist using their own station name or number.***

- ***Unlike the case for many of South Africa's rivers, there have been very few long-term monitoring programmes conducted on a national scale on South African estuaries. Programmes that do exist include:***

  - ***Gauging stations (measuring river inflow) installed upstream at some estuaries (managed by DWAF)***
  - ***Continuous water level recorders installed at some estuaries (managed by DWAF)***
  - ***Topographic surveys of estuary mouths (since 1985) and of upstream cross sections (since 1996) conducted every 2-3 years on a selection of Cape estuaries (earlier project of the CSIR, commissioned by DEAT)***
  - ***Fish data (species composition in different estuaries based on number and biomass) was collected on numerous South African estuaries (project of the CSIR (Durban), commissioned by DEAT).***
  - ***Botanical information on approximately 65% of South African estuaries is available: Water Research Commission Project K5/814***
  - ***Coordinated Waterbird Counts (CWAC) programme of the University of Cape Town.***

3.2.1 Simulated runoff scenarios

The method for the determination of the preliminary Ecological Water Requirements for estuaries uses a 'top down' approach, i.e. simulated runoff scenarios are used to derive the Ecological Categories and Ecological Water Requirement Scenarios.

For determination of the recommended Ecological Category simulated runoff scenarios for the **Present State** and the **Reference Condition** are required. Scenarios are typically simulated over a 50-70 year period and are presented as average monthly flows that represent inflows at the head of the estuary.

For determination of the Ecological Water Requirement Scenario **additional simulated runoff scenarios** are also required, preferably derived as follows:

- Simulated run-off scenarios representative of the Ecological Water Requirements for different Ecological Categories of the river reach just upstream of the estuary (e.g. Category B, C and D) (this will facilitate integration between the river and estuarine components)

- Simulated run-off scenarios for proposed future resource developments, provided by the Directorate: Planning of the DWAF

In the absence of the above, a series of hypothetical, runoff scenarios (e.g. 75%, 50% and 25% of natural MAR) could be used.

It is important that an attempt be made to select additional or future runoff scenarios that are representative of as large as possible range of Ecological Categories for the estuary. Preliminary judgement is therefore required from the hydrodynamic specialist, based on the expected response of the system to changes in flow. However, this can only be confirmed at the specialist workshop where the biological responses are properly evaluated.

The runoff scenarios need to be provided in the following format (runoff given in m^3/s):

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
1927	*1.97*	*7.90*	*2.79*	*1.09*	*0.49*	*13.20*	*3.46*	*0.00*	*49.57*	*10.97*	*21.10*	*27.42*
1928	*8.83*	*48.60*	*17.27*	*2.47*	*0.94*	*5.13*	*6.94*	*8.24*	*15.41*	*76.96*	*71.26*	*21.82*
1929	*9.39*	*3.98*	*7.66*	*4.46*	*31.13*	*18.52*	*4.14*	*2.67*	*2.05*	*6.46*	*35.94*	*56.80*
1930	*23.77*	*7.37*	*3.82*	*3.43*	*1.53*	*5.29*	*69.77*	*40.06*	*9.50*	*59.89*	*103.97*	*44.60*
1931	*65.64*	*17.58*	*34.48*	*11.63*	*32.69*	*4.28*	*0.87*	*11.75*	*21.45*	*32.98*	*21.88*	*141.31*
1932	*50.58*	*7.70*	*4.31*	*1.81*	*1.08*	*1.11*	*0.64*	*2.47*	*55.89*	*100.96*	*68.18*	*26.16*
1933	*11.30*	*9.68*	*4.27*	*4.97*	*3.68*	*3.96*	*1.12*	*1.25*	*8.81*	*20.18*	*41.55*	*42.20*
…..												
…..												

The confidence in the accuracy of these simulations must be provided since they form the basis for the quantification of the preliminary Ecological Water Requirements. Simulations should be carried out as a collaborative effort amongst the DWAF planning directorate, a hydrologist (with experience in generation of such scenarios) and an estuarine hydrodynamic specialist (to stipulate specific output requirements). In this regard WR90 or data are often unable to simulate (low) base flows at the level of accuracy that is required to make sensible predictions for estuaries, even on a rapid level.

3.2.2 Abiotic and biotic data

In terms of other abiotic and biotic data, a rapid level determination generally relies on available information. It is therefore important that a desktop assessment of available information on the different abiotic and biotic components is conducted prior to the workshop. In particular, available information on rare and endangered species, species with limited populations and habitat diversity is required.

In estuaries, the data requirements for abiotic (or driving) components, i.e. hydrology, hydrodynamics, sediment dynamics and water quality, are strongly interlinked. Generic data requirements for an intermediate, as well as a comprehensive level determination of the preliminary Ecological Water Requirements for estuaries are provided in Tables 3.1a-d, respectively.

Data requirements on estuarine microalgae and macrophytes for an intermediate, as well as a comprehensive level determination of the Ecological Water Requirements are listed in Table 3.1e and Table 3.1f, respectively.

Data requirements on invertebrates, fish and birds for an intermediate, as well as a comprehensive level determination of the preliminary Ecological Water Requirements are listed in Table 3.1g, 3.1h and 3.1i, respectively. From a temporal point of view it must be noted that faunal components should ideally be sampled over at least a one-year period, preferably on a quarterly basis for meaningful results to be obtained. However, if only two seasons (e.g. low and high flow season) can be sampled some first order estimates would have to be obtained. If only one season is sampled, then it should be the season of greatest diversity and abundance.

Data on water quality and hydrodynamics along the length of the estuary are measured as part of the abiotic data acquisition programme (Table 3.1a). Therefore, to ensure that data collection is as cost effective as possible, floral and fauna surveys should preferably be conducted simultaneously with relevant abiotic data collection exercises.

Resource Monitoring Procedures, for application in the ecological water requirements of estuaries are discussed in greater detail in Taljaard *et al.* (2003).

TABLE 3.1a: Data requirements on <u>hydrology</u> for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

DATA	***Simulated runoff data***	***To estimate seasonal variability in river flow patterns (the accuracy and confidence limits of the simulations must be indicated).***
	Flood hydrographs	
SAMPLING PROCEDURE	*Simulated runoff data: Data to be simulated for Reference Condition, Present State and a range of future run-off scenarios covering a range of flow reductions from present to worst case.* *Flood hydrographs: To be simulated for the 1:1 to 1:200 year floods for Reference Condition, Present State and a range of future run-off scenarios (usually only required on comprehensive level).*	
SPATIAL	*Simulated river runoff: Representative of inflow at head of estuary* *Flood hydrographs: Representative of flow at head of estuary*	
TEMPORAL	**INTERMEDIATE LEVEL**	**COMPREHENSIVE LEVEL**
	Simulated river runoff: Simulated over a 50-80 year period, provided as average monthly flows (daily flows may at times be required) *Flood hydrographs: Usually not required for intermediate level, but reduction in floods should be estimated based on expert opinion (hydrologist)*	*Simulated river runoff: Similar to intermediate level* *Flood hydrographs: Provided as hourly flows over the flood period*

TABLE 3.1b: Data requirements on <u>sediment dynamics</u> for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

DATA	***Sediment grabs***	***It may not be possible to acquire these data sets in the short term, but long term monitoring programmes to collect such data must be considered if the dynamic sediment processes in estuaries are to be better understood.***
	Sediment cores	
	Bathymetric/topographical surveys	***These measurements are required to establish a baseline data set of the topography, particularly if numerical hydrodynamic modelling is to be used in estimating Reference Condition and the implication of future scenarios (typically data older than 3 years should not be used, as well as data collected prior to a major flood).*** ***The data can also be used to calculate the volume of the estuary and give an indication of flushing times.***
	Sediment load at head of estuary	

<table>
<tr><td rowspan="1">SAMPLING PROCEDURE</td><td colspan="2">Sediment grabs: Grab samples should be collected using a Van Veen or a Zabalocki-type Eckman grab (to characterize recent sediment movement) for particle size analyses.
Sediment cores: Core samples should be collected using a corer (for historical sediment characterization)
Bathymetric/topographical surveys: Surveys should be conducted using Differential Global Positioning System (D-GPS) and echo-sounding to monitor berm height, mouth sediment dynamics and cross section profiles upstream of the mouth.
Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition)</td></tr>
<tr><td>SPATIAL</td><td colspan="2">Sediment grab samples: Along entire estuary at 500 to 1 000 m intervals
Sediment cores: Intervals similar to cross-section profiles (see below) where considered appropriate by sediment specialist
Bathymetric/topographical surveys: Mouth region – Intensive (10 to 50 m interval depending on the size of the estuary and variability in bathymetry); Upstream cross-section profiles along entire estuary at 500 m to 1000 m intervals.
Sediment load at head of estuary</td></tr>
<tr><td rowspan="2">TEMPORAL</td><td>INTERMEDIATE LEVEL</td><td>COMPREHENSIVE LEVEL</td></tr>
<tr><td>Sediment grabs, Sediment cores, Bathymetric/topographical surveys and Sediment load at head of estuary: Available data (usually these measurements are not required as part of intermediate level determination).</td><td>Sediment grabs: Seasonal sampling (spring, summer, autumn and winter) for one year.
Sediment cores: Once-off
Bathymetric/topographical surveys: Will depend on the time scale of dominant sedimentation/erosion processes in an estuary varying between 1 and 5 year intervals, with a minimum record of about 15 years. Alternatively, numerical models can be used to simulate longer-term processes.
Sediment load at head of estuary: Daily for a minimum 5 years</td></tr>
</table>

IMPORTANT NOTES: SEDIMENT DYNAMICS

- *It is assumed that the DWAF will not use the intermediate level determination to allocate water to users that will affect the larger floods, i.e. 1:5 years and bigger. For this reason the data requirements specified for the intermediate level DO NOT include data to estimate sediment scour/erosion (which usually needs to be collected over several years). This will however, need to be specified for the comprehensive determination*
- *Suitable sediment data records cannot be acquired in the short term. Therefore, if sediment processes in estuaries are to be better understood and quantified, long-term programmes will have to be implemented. In this regard it is recommended that the DWAF implement such monitoring activities timeously in South African estuaries, particularly those earmarked for substantial water abstraction in future.*
- *The disturbance of the sediment erosion/deposition equilibrium in an estuary can lead either to siltation, resulting in the estuary becoming shallower, or it can lead to the erosion of important sediment habitats. Under natural conditions many estuaries were probably in a state of long-term equilibrium of sedimentation and erosion. However, this equilibrium can be disturbed because of changes in run-off, especially if the occurrences and magnitudes of major floods are changed.*
- *Floods and, in some cases, high seasonal flows can influence the sediment erosion/deposition equilibrium. Floods can alter important features within an estuary, such as the bathymetry (e.g. channel depth or the size of intertidal areas) and sediment composition (e.g. sand or mud).*

TABLE 3.1c: Data requirements on hydrodynamics for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

DATA	***Continuous flow recording of river inflow***	***These data are crucial for correlating river flow to the state of the mouth (as reflected by water level recordings), particularly in temporarily open/closed estuaries. The dataset duration required will depend on, for example, the frequency of mouth closure in the particular estuary.***
	Continuous water level recordings	***To obtain long-term records of variations in tidal levels and mouth conditions***
	Daily mouth observations	***To obtain long-term records of variations in mouth conditions***
	Water levels along estuary	***These should preferably occur during an above average spring and neap tide. These are critical requirements for permanently open estuaries were numerical modelling are use to predict change in the salinity profile.***
	Wave conditions	***This information is used to correlate mouth closure with possible storms at sea (as reflected by the direction and amplitude of the waves).***
	Aerial photographs	***Aerial photography surveys specifications are: It should be done annually, at a scale 1:5 000 or 1:10 000, preferably in a digital format. The photographs should full colour and vertical (not oblique because that distorts observations). The photographs should be up to the head of the estuarine systems.*** ***Aerial photographs can provide a first estimate in terms of the dynamic of an estuary mouth, for example, to derive the effect of wave action on the mouth dynamics, in particular, the extent to which the mouth is exposed to direct wave action, and to determine the width of the breaker zone (indicative of the beach slope).***
SAMPLING PROCEDURES	*Continuous flow recording of river inflow: A flow gauging station should be installed to measure river inflow.* *Continuous water level recordings: A continuous water level recorder should be installed at the mouth of the estuary.* *Daily mouth observations: Where possible, daily mouth observations should be logged in temporarily open/ closed estuaries and particularly in systems with the semi-closed mouth phase. The time at which the observation was made and the state of the tide must also be recorded, ideally at low tide.* *Water levels along estuary: Where an Ecological Water Requirement study requires numerical modelling, water levels recordings must also be collected along the length of the estuary, either using continuous water level recorders or water level gauging poles and manual observations.* *Wave conditions: Available data should be accessed, but no measurements are specified as part of a baseline monitoring.* *Aerial photographs: Full colour geo-referenced rectified aerial photographs 1: 5 000 scale covering the entire estuary based on the geographical boundary at low tide in summer i.e. similar to those for macrophyte surveys. Must include the breaker zone near the mouth.*	

SPATIAL	*Continuous flow gauging: Head of estuary* *Continuous water level recording: Mouth area* *Daily Mouth observations: Mouth* *Water levels along estuary: 2-6 stations along estuary* *Aerial photographs: Entire estuary, particularly the mouth area.*	
TEMPORAL	**INTERMEDIATE LEVEL**	**COMPREHENSIVE LEVEL**
	Continuous flow gauging: Minimum of 5 years depending on mouth closure *Water level recordings and mouth observations: Minimum of 5 years depending on rate of mouth closure* *Water levels along estuary: Manually/digital recorded over one spring tidal cycle and one neap tidal cycle or continuous recordings over two weeks.* *Wave conditions: Available data* *Aerial photographs: Available data*	*Continuous flow gauging: 5-15 years depending on mouth closure* *Water level recordings at mouth and mouth observations: 5-15 years depending on mouth closure* *Water levels along estuary: Similar to intermediate level* *Wave conditions: Similar to intermediate level* *Aerial photographs: Available data, but needs to include one recent photograph representative of present condition.)*

IMPORTANT NOTES: HYDRODYNAMICS

- *Continuous water level recordings are currently not available for most estuaries. As a result such information will have to be based on limited visual observations of tidal variation (i.e. over at least 2 tidal cycles), but with much lower confidence. It is therefore strongly recommended that water level recorders be installed, even for the intermediate phase, and especially since 5-15 years of data are required for the comprehensive determination of the Ecological Water Requirements. In requesting continuous flow, the request is not for gauging weirs to be constructed at the top of each estuary as such, but rather that flows be monitored in appropriate ways that will not disturb migration of aquatic biota.*
- *Continuous flow recordings (gauging station) of river inflow at the head of estuaries and continuous water level recording at estuary mouths (and mouth observations) require longer-term data sets and it is therefore necessary to start such baseline monitoring programmes well in advance (at least 5 years) of a Ecological Water Requirement determination study. In this regard it is recommended that the DWAF implement such monitoring activities timeously in South African estuaries, particularly those earmarked for substantial water abstraction in future.*

TABLE 3.1d: Data requirements on water (and sediment) quality for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

DATA	***Water quality of river inflow***	***To prevent duplicate sampling, these data must be obtained from the water resource unit just upstream of the estuary.***
	Water quality of the near-shore marine waters	***At present these parameters are not measured on a routine basis along the SA coast, as is the case for some rivers. Because the seawater quality may show strong seasonal variability, particularly along the SA West coast, a short term monitoring programme (e.g. 6 week period) may not necessarily be representative. In the short term, data on near-shore seawater quality therefore need to be derived from available data sources, including the South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment (DWAF, 1995), until such time as routine water quality monitoring programmes are implemented along the SA coast.***
	Water quality in estuary (salinity and temperature)	***These measurements, together with the river inflow data (must be collected simultaneously) are used to estimate the correlation between salinity/temperature distribution patterns along the length of the estuary and river flow. Where only a limited amount of fieldwork is possible, this could best be achieved by measuring the two 'extremes' i.e. end of low flow season and the peak of high flow season.***
	Water quality in estuary (other system variables and nutrients)	***The water quality field exercise must coincide with the salinity/temperature profiling. In this way a limited water quality data set (which is usually very expensive to acquire) can be used to derive water quality characteristics under different tidal conditions, using salinity data, expert opinion or appropriate assessment tools, e.g. numerical models***
	Effluent discharges	***Where effluent discharges occur into the estuary, i.e. below the head of the estuary, these have to be sampled as well.***
	Toxic substances	***To establish the spatial distribution and extent of toxic pollutant distribution in the estuary.***
SAMPLING PROCEDURE	*Water quality of river inflow: System variables (pH, DO, turbidity, suspended solids, TDS and temperature), nutrients (inorganic nitrogen [nitrite, nitrate and ammonia], reactive phosphate and silicate) and toxic substances (where relevant) should be measured. Particulate organic matter, although not measured on a regular basis by DWAF should be provided if available.*	
	Water quality of the near-shore marine waters: Obtained form available literature.	
	Water quality in estuary: The following samples should be collected: • *Salinity and temperature profiles (also required for hydrodynamics)* • *System variables (pH, DO, turbidity, suspended solids)* • *Inorganic nutrients (nitrate/nitrite, ammonia, reactive phosphate, total phosphorus and reactive silicate)* • *Particulate and dissolved organic nutrients (to be included if considered important for a particular system).* *Salinity and temperature data must be collected at 0.5 m depth intervals, while other water quality parameters are collected in surface and bottom waters. At stations deeper than 10 m, a sample at an intermediate depth may also be required (site specific decision).*	
	Effluent discharges: In addition to flow rate, other parameters to be monitored will depend on the composition of the effluent.	
	Toxic substances: Where relevant (e.g. in estuary receiving runoff from urban and industrial areas and contaminated agricultural runoff), sediment samples should be collected and analyzed for toxic substances (i.e. trace metals, petroleum hydrocarbons, herbicides and pesticides). To assist with the interpretation of results, samples should also be analysed for sediment grain size distribution and organic content.	

<table>
<tr><td rowspan="1">SPATIAL</td><td colspan="2">A sampling station is defined as a location at a specific 'distance from the mouth' that can be sampled at different depth intervals and which is defined by GPS positioning data.

Water quality of river inflow: Head of estuary

Water quality in estuary: Small estuaries (< 5 km long) - Stations distributed geographically along the entire estuary with a minimum of 5 sites. Make sure that all the salinity regimes are covered.

Larger estuaries (> 5 km long) - Stations distributed geographically along the entire estuary at fixed intervals. A rough estimate for setting the distance between stations is to divide the length of the estuary by 10 (i.e. if an estuary is 30 km long, the distance between stations should be about 3 km). Typically a representative number of stations for longer estuaries are between 10 and 15. Make sure that all the salinity regimes are covered.

In systems with large cross sectional areas, sampling stations should also be selected along cross sections. During each sampling survey, water quality samples must also be taken in the river and in the near-shore marine waters (i.e. the water sources).

Effluent discharges: At end of pipe just before entering the estuary.

Toxic substances: A grid of sediment sampling stations to be selected across estuary, specifically targeting depositional areas (characterized by finer sediment grain sizes and/or higher organic content).</td></tr>
<tr><td rowspan="2">TEMPORAL</td><td>INTERMEDIATE LEVEL</td><td>COMPREHENSIVE LEVEL</td></tr>
<tr><td>Water quality of river inflow: At least monthly, minimum of 5-year data record.

Water quality in estuaries: Once during a low flow and a high flow season. For temporarily open/closed systems, a stable closed phase must be sampled as well as a stable open phase. Sampling should coincide with microalgae surveys and the invertebrate surveys in year 1.

Effluent discharges: Should be licensed under the National Water Act where operators are required to monitoring effluent volume and composition. Spatial scale, e.g. daily or weekly will depend on the variability in effluent composition overtime.

Toxic substances: Once, preferably during the low flow season.</td><td>Water quality of river inflow: At least monthly, minimum of 5-15 year data record.

Water quality in estuary: Similar to intermediate level except that sampling should be conducted seasonally, (i.e. during spring, summer, autumn and winter) with river inflow being representative of a particular season covering the different abiotic states. In systems where the semi-closed phase or overwash is important, these states need to be sampled. These phases are dynamic and require 3 sub-surveys.

Sampling should coincide with the microalgae surveys and invertebrate surveys in year 1.

Effluent discharges: Similar to intermediate level.

Toxic substances: Similar to intermediate level.</td></tr>
</table>

IMPORTANT NOTES: WATER QUALITY

- *The analytical techniques used in the processing of marine and estuarine water quality samples vary greatly form those used in the analysis of fresh water samples. It is therefore crucial that the analyses of water quality samples be conducted by an accredited marine analytical laboratory.*
- *It is strongly recommended that both the low flow and high flow seasons be sampled to obtain the two 'endpoints'. This, in turn, will improve confidence in deriving intermediate conditions (i.e. the in between months), using for example numerical models. If, however, it is only possible to do one survey, this should be done at the end of the low flow season, particularly for permanently open estuaries.*
- *Estuaries receive water from two sources, i.e. the river and sea, each with distinctively different water quality characteristics, particularly in terms of system variables and nutrients. In turn, the water quality characteristics along the length of an estuary depends on the extent of the influences of each of these sources (governed by hydrodynamic processes), as well as*

IMPORTANT NOTES: WATER QUALITY

biochemical processes (e.g. organic degradation, eutrophication) taking place at that point within the estuary. The influence of biochemical processes is particularly evident in parts of an estuary where residence time of water becomes longer, often observed along the middle reaches of an estuary during the low flow season. It is therefore also crucial that water samples in the two sources, i.e. river and sea.

- *River water quality requires longer-term data sets and it is therefore necessary to start such baseline monitoring programmes well in advance (at least 5 years). For example, monitoring points at the head of estuaries could be included in the water quality monitoring programme of the DWAF.*
- *At present water quality of near-shore waters is not measured on a routine basis along the SA coast, as is the case for some rivers. Because the seawater quality may show strong seasonal variability, particularly along the SA West coast, a short term monitoring survey may not necessarily be representative. In the short term, data on near-shore seawater quality therefore needs to be derived from available data sources, including the South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment (DWAF, 1995), until such time as routine water quality monitoring programmes are implemented along the SA coast.*
- *For toxic substances (e.g. trace metals and hydrocarbons) it is considered more appropriate to sample environmental components which tend to <u>integrate or accumulate change over time</u>, such as sediments. These surveys need, however, not be done in ALL estuaries, only in systems where river water quality or human activities along the banks of the estuary suggest possible contamination (e.g. industrial effluents or storm water run-off from large urban developments).*
- *For long-term monitoring programmes, water and sediment quality data are particularly important for interpretation of specific biological responses and, therefore must be collected by the relevant biotic components as indicated during their sampling surveys.*
- *Malfunctioning septic tanks, situated in close proximity to the banks of estuaries, may have an influence on water quality in the estuary. However, unlike point source discharges, e.g. effluents from wastewater treatment works, it is often difficult to quantify the inputs from such diffuse sources. Even so, where septic tanks are known to be a problem or potential problem in a particular estuary, inputs need to be taken into account in the water quality assessments.*

TABLE 3.1e: Data requirements on microalgae for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

DATA	***Phytoplankton***	***Phytoplankton biomass is an index of eutrophication while changes in the dominant phytoplankton groups indicate changes in response to water quality and quantity. A study of this nature is particularly important in large permanently open estuaries where phytoplankton are important primary producers. Measurements for different flow conditions are required to establish natural variability.***
	Benthic microalgae	***Benthic microalgae are important primary producers in shallow estuaries or those with large intertidal areas. Epipelic diatom composition can indicate changes in water quality. Measurements for different flow and mouth conditions are required to establish natural variability.***
SAMPLING PROCEDURE	*Phytoplankton: To estimate phytoplankton biomass, collect duplicate samples for chlorophyll a at the surface and 0.5 m depth intervals. Use a spectrophotometer for sample analysis before and after acidification. Do cell counts (at 400 x magnification) on dominant phytoplankton species to establish species distribution and composition, i.e. green algae, flagellates, dinoflagellates, diatoms and blue-green algae. .*	
	Benthic microalgae: Collect intertidal and subtidal benthic samples for chlorophyll a (biomass) analysis. Collect 5 samples at each station. Analyse samples using a recognised technique, e.g. HPLC. *Record the relative abundance of dominant algal groups, i.e. green algae, dinoflagellates, diatoms and blue-green algae and identify the dominant species.* *At each station also measure:* • *Water salinity and inorganic nutrients* • *Sediment particle size distribution and organic content* • *Light penetration PAR or Secchi depth.*	
SPATIAL	*A sampling station is defined as a location at a specific 'distance from the mouth' that can be sampled at different depth intervals (e.g. in the case of phytoplankton).* *As a guideline, the number of stations in a small estuary (< 5 km long) should not be less than 5, distributed along the entire length of the estuary, covering the different salinity zones.* *For larger estuaries (> 5 km long), 10 to 15 stations selected geographically along the entire length of the estuary, covering the different salinity zones, can be used as the guideline. Stations should preferably be set at fixed intervals. A rough estimate for setting the distance between stations is to divide the length of the estuary by 10 (i.e. if an estuary is 30 km long, the distance between stations should be about 3 km).* *Salinity zones in estuaries typically include:* • *Fresh (representative of river)* • *0 – 10 ppt* • *10 – 20 ppt* • *20 – 35 ppt*	

	INTERMEDIATE LEVEL	COMPREHENSIVE LEVEL
TEMPORAL	*Once during a low flow and a high flow season. For temporarily open/closed systems, a stable closed phase must be sampled as well as a stable open phase.* *Sampling should also coincide with the water quality survey and the invertebrate surveys in year 1.*	*Similar to intermediate level except that sampling should be conducted (i.e. during spring, summer, autumn and winter) with river inflow being representative of a particular season covering the different abiotic states.* *In systems where the semi-closed phase or overwash is important, these states need to be sampled. These phases are dynamic and would need to be sampled on 3 occasions.* *Sampling should coincide with the water quality survey and the invertebrate surveys in year 1.*

IMPORTANT NOTES: MICROALGAE

- *Water (salinity, temperature, other physico-chemical properties and inorganic nutrients) measurements need to be collected during the microalgae surveys. Combining water and sediment quality surveys on a particular estuary with the microalgae survey does this most cost-effectively.*
- *The temporal scale of the microalgae sampling needs to match that of the invertebrates (zooplankton) to link the response patterns of these biotic components as best as possible.*

TABLE 3.1f: Data requirements on macrophytes for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

<table>
<tr><td rowspan="3">DATA</td><td>Aerial photographs</td><td>To map the distribution of the different plant community types and to calculate the area covered by different plant community types (habitat types – see notes below). Aerial photographs can be used to monitor habitat change from reference to present day, e.g. reed encroachment.</td></tr>
<tr><td>Number of plant community types</td><td>This information is required to determine the regional and national botanical importance of an estuary, and to set the ecological category.</td></tr>
<tr><td>Permanent transects</td><td>These measurements are used to relate changes in the flora to changes in salinity, water level, flooding and sedimentation. From these data the sensitivity of the flora to changes in freshwater input can be determined and Reference Condition can be estimated. These transects are only necessary in estuaries with salt marsh areas greater than 2 ha.</td></tr>
<tr><td>SAMPLING PROCEDURE</td><td colspan="2">The following information needs to be captured from recent and any available historical aerial photographs and ortho-photographs covering the entire estuary as defined by the geographical boundaries:
• Number of different habitats (plant community types)
• Area covered by each plant habitat
• Historical change in area covered by plant habitat
• Extent of anthropogenic impacts (agriculture, flood plain development)

Field data need to be collected for ground truthing of aerial photographs:
• Number of different plant habitats (plant community types)
• Area covered by each plant habitat
• Species list for each plant habitat
• Extent of anthropogenic impacts such as grazing, trampling, alien vegetation, boating, bait digging

Permanent transects (sampling stations) need to be set up for long term monitoring of changes in plant habitats:
• Transects set up along an elevation gradient
• Record percentage cover of each plant species in duplicate quadrats (1 m^2) along transects

Along each transect (minimum of 4) the following data need to be collected:
• Elevation profile and water level
• Water column salinity and turbidity
• Sediment salinity, moisture content and sediment composition

In large supratidal salt marsh areas, boreholes are required to measure depth to water table and ground water salinity.</td></tr>
<tr><td>SPATIAL</td><td colspan="2">A sampling station is defined as a transect across the estuary (at a specific 'distance from the mouth'), with a number of quadrats arranged along the transect.

Aerial photos: The entire estuary needs to be covered, as defined by the geographical boundaries.

Transects and quadrats: As a guide the larger estuarine plant habitats in a system (e.g. salt marsh) representative of the lower (2 transects) and middle (2 transects) reaches should be covered. Other plant habitats, particularly those sensitive to changes in freshwater inflow, could also be monitored.</td></tr>
</table>

	INTERMEDIATE LEVEL	COMPREHENSIVE LEVEL
TEMPORAL	*Once-off survey during summer. For temporarily open/closed systems preferably during the open phase.*	*For permanently open systems, once during high flow and once during low flow* *For temporarily open/closed estuaries one survey needs to be conducted in a stable closed phase and one in a stable open phase.*

IMPORTANT NOTES: MACROPHYTES

- *There are nine different habitat types recognised for estuaries*, i.e.:*

HABITAT TYPE	*INDICATOR SPECIES*
Open surface water area	*Indicates available habitat for phytoplankton*
Intertidal sand and mudflats	*Indicates available habitat for intertidal benthic microalgae*
Submerged macrophyte beds	*Zostera capensis (eelgrass), Ruppia cirrhosa, Potamogeton pectinatus*
Macroalgae	*Ulva spp., Enteromorpha spp., Caulerpa filiformis*
Intertidal salt marsh	*Spartina maritima, Sarcocornia perennis, Triglochin spp,*
Supratidal salt marsh	*Sarcocornia pillansii, Sporobolus virginicus*
Reeds and sedges	*Phragmites australis, Schoenoplectus littoralis*
Mangroves	*Avicennia marina, Rhizophora mucronata, Bruguiera gymnorrhiza*
Swamp forest	*Barringtonia racemosa, Hibiscus tiliaceus*

- *These include the microalgal habitats as the area covered by each habitat is used to calculate the overall botanical importance of an estuary.*

- *Available information on the flora of South African estuaries includes Begg's (1984) early surveys in KwaZulu-Natal and the CSIR's surveys of Cape estuaries. Ward and Steinke (1982) documented the distribution of mangroves. Colloty et. al. (2001) have compiled a database on all available botanical information on South African estuaries. Colloty et al. (2001) completed a survey of Transkei and Ciskei estuaries and baseline information is now available for approximately 65 % of South African estuaries.*

TABLE 3.1g: Data requirements on invertebrates for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

<table>
<tr><td rowspan="3">DATA</td><td>Zooplankton</td><td>To estimate biomass distribution and key species of the zooplankton.</td></tr>
<tr><td>Benthic invertebrates</td><td>To estimate biomass distribution and key species of the benthic invertebrates. The richness of benthos determines the importance of the area for each species.</td></tr>
<tr><td>Macrocrustaceans</td><td>To estimate biomass distribution and species of the macrocrustaceans.</td></tr>
<tr><td rowspan="2">SAMPLING PROCEDURE</td><td colspan="2">Zooplankton: Collect quantitative samples using a flow meter <u>after dark</u>, preferably during neap tides (mid to high tide) because currents are less strong and zooplankton will be more active in water column. Sampling to be done at mid- water level, i.e. not surface. Alternatively, use a benthic D-net to do a transect across the estuary at different station. Daytime midwater and suprabenthic samples at three stations using a WP-2 (90 mm mesh) and a hyperbenthic D-Net sledge (200 mm mesh) respectively.

Two net trawls (WP 2 – 200 micron mesh), giving replicates (i.e. two samples) at each station. The net should be pulled for 3 minutes per station (10-12 m^3 of water) at 0.l5 knots diagonally across the estuary.

Record species and abundance (density per volume) in each trawl and average results for station.

At each station phytoplankton samples (i.e. water column sample) and benthic microalgae samples need to be collected for chlorophyll a analyses.</td></tr>
<tr><td colspan="2">Benthic invertebrates: Collect (subtidal) samples using a Van Veen or Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using a core sampler of minimum 150 mm diameter and 250 mm depth, with 5 replicates at each site along the transect. Put one grab/core sample in a bucket and fill with in situ water. Add a drop of formalin and stir vigorously. Pour off supernatant through a 500 micron sieve. Repeat this process 5 times (minimum). Pour remainder from bucket through a 1 mm sieve. Check form invertebrates on sieve. Repeat with four other grab and core samples.

For intertidal benthic invertebrates which are not well quantified by core sampling (e.g. mud prawns, sand prawns, some crabs), use a combination of pump sampling and counting hole densities of each species(in quadrats of minimum area 0.25m^2, with 5 replicates at each station).

The following need to be recorded at each site:
• Identify fauna to lowest taxon
• Record animal density and species abundance (animals per m^2).
• Record the presence of Zostera

At each station, sediment samples need to be collected for particle size distribution (250 ml) and organic content (250 ml). Analyze using standard techniques.

Macrocrustaceans: Quantitative sampling for macrocrustaceans should be conducted during neap tides (mid to high tide), at the same stations used for zooplankton. Use a benthic sled (80 cm x 80 cm, 500 micron mesh) with flow meter to collect sample and tow for about 30 meters diagonally across the estuary. Take 2 samples at each station. Set 2 prawn/crab traps per station overnight (more applicable to sub-tropical areas).

Use <u>appropriate</u> gear to sample shoreline (e.g. marginal vegetation) for size class distribution of dominant organisms in those areas.

Identify fauna to lowest taxon. Record number of species and determine densities.</td></tr>
</table>

<table>
<tr><td rowspan="1">SPATIAL</td><td colspan="2">A sampling station is defined as a specific location in the estuary (at a specific 'distance from the mouth') from where a number of replicates are collected.

Sampling stations must be representative of the salinity zones characteristic of a particular estuary, which typically include (these zone should be indicated on a map):
• Fresh (representative of river)
• 0 – 10 ppt
• 10 – 20 ppt
• 20 – 35 ppt

Within each salinity zone representative habitats need to be sampled such as:
• Submerged macrophytes (e.g. Zostera beds)
• Soft sediments (sand/muddy sand/fine mud), hard (rocky areas) and organic rich areas.

Benthic invertebrate stations need to include in addition to the above inter-tidal bird feeding areas.

Where benthic invertebrates are included in long term monitoring programmes, stations need to incorporate areas within the estuary where the habitat types are vulnerable to changes in river inflow.

As a guideline, the number of stations in a small estuary (< 5 km long) should not be less than 5, distributed along the entire length of the estuary, covering the salinity zones and habitat types as described above. Small systems with high habitat diversity may require more stations (in estuaries where the salinity regime is uniform, the selection of stations should focus on different habitat types).

For larger estuaries (> 5 km long), 10 to 15 stations selected geographically along the entire length of the estuary, covering the salinity zones and habitat types as described above, can be used as the guideline (although this may vary depending on habitat diversity of a system). Stations should preferably be set at fixed intervals or positions. A rough estimate for setting the distance between stations is to divide the length of the estuary by 10 (i.e. if an estuary is 30 km long, the distance between stations should be about 3 km).

In systems with large cross sectional areas (e.g. estuarine bays), sampling stations should also be selected along cross sections.</td></tr>
<tr><td rowspan="2">TEMPORAL</td><td>INTERMEDIATE LEVEL</td><td>COMPREHENSIVE LEVEL</td></tr>
<tr><td>Zooplankton, benthic invertebrates and macrocrustaceans: One survey in summer/spring and 1 survey in winter. It is important that, at the time of sampling, the state of the estuary, as represented by the extent of saline intrusion and the state of the mouth, must be representative of that particular season.

For temporarily open/closed estuaries one survey needs to be conducted in a stable closed phase and one in a stable open phase.</td><td>Zooplankton, benthic invertebrates and macrocrustaceans: To be conducted in four seasons (i.e. in spring, summer, autumn and winter). At the time of sampling, the state of the estuary, as represented by the extent of saline intrusion and the state of the mouth must be representative of that particular season.

For temporarily open/closed estuaries at least one survey must be conducted in a stable closed phase and at least two surveys in the stable open phase.</td></tr>
</table>

IMPORTANT NOTES: INVERTEBRATES

- *Because of the high variability in invertebrates in response to flow it is important to sample over two years to obtain the required confidence level (medium for intermediate level and high for comprehensive level).*
- *Total lack of information on invertebrates in most of South Africa's estuarine systems is the reason from the greater intensity (temporal scale) of sampling for this component to get the required confidence. There is also a rapid change in community composition and abundance over time (weeks to months). Sampling is even more intensive for zooplankton because of their rapid response over time.*
- *As far as possible, the invertebrate and macrophyte sampling stations should be matched to be able to link habitats with invertebrate characteristics.*
- *Water (salinity, temperature, pH, dissolved oxygen & turbidity) and sediment quality (sediment grain size and organic content) measurements need to also be collected during the invertebrate surveys. Combining water and sediment quality surveys on a particular estuary with the invertebrate surveys does this most cost-effectively.*
- *For invertebrate surveys, 7 sediment grain size categories should be used, ranging from mud to very coarse sand. Each category relates to a particular size diameter in the following manner:*

  >2 mm: > very coarse sand; 2 - 1 mm: very coarse sand; 1 - 0.5 mm: coarse sand; 0.5 – 0.25 mm: medium sand; 0.25 – 0.125 mm: fine sand; 0.125 – 0.0625 mm: very fine sand; <0.0625 mm: mud (silt and clay)
- *The percentage organic content of sediments can roughly be classified as:*

  <0.5%: Very low; 0.5 – 2%: Low; 1 – 2%: Moderately low; 2 –4%: Medium; > 4%: High

TABLE 3.1h: Data requirements on fish for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

<table>
<tr><th>DATA</th><th>Seine and gill net sampling</th><th>To estimate biomass distribution and species of the fish.</th></tr>
<tr><td>SAMPLING PROCEDURE</td><td colspan="2">Conduct fish surveys using gear appropriate to the habitat of a particular estuary, but with seine nets and gill nets as primary gear.

Seine nets: 30 m x 2 m x 15 mm multifilament bar mesh in the wings and a 5 mm bar mesh in the purse.

Seine nets should be 30 m long by 2 m depth. The cod end (bag, purse) and the wings 5 m either side of it should be 5 mm bar whereas the remaining 15 m of each wing can be 15 mm bar mesh. This is required to adequately sample estuarine and ‘faster moving’ marine species. The net should be weighted such that it sinks below the surface when set in water deeper than 2 m (i.e. the distance between the lead and cork lines). A light net makes it more difficult to obtain a representative sample from weed and sandy areas, e.g. flatfish species tend to burrow in the sand and escape under a light seine.

Gill nets: Monofilament gill nets should comprise at least 3 different mesh sizes within the range 40-150 mm stretch mesh. Monofilament gill nets should comprise at least 4 nets (or panels) of which one net comprises 44, 48, 51 and 54 mm mesh, plus 3 more nets in the 75-150 mm stretched mesh range (e.g. 75, 100 and 145 mm stretched mesh). To prevent high sampling impact, nets should be deployed less than one hour during the day unless otherwise motivated.

Other sampling methods that may be used where primary gears are not appropriate, include:
• Scoop nets (e.g. in extensive submerged macrophyte beds)
• Otter trawls (e.g. in deep channel area)
• Cast nets (e.g. in inaccessible areas).

N.B. Where historic fish data for a particular estuary have been collected, using mesh sizes that differ from the above, it is recommended that previous net dimensions be used.

At each sampling station the following data need to be recorded:
• Species lists
• Number of each species
• Size frequency distributions in total length</td></tr>
<tr><td>SPATIAL</td><td colspan="2">A sampling station is defined as a specific location in the estuary (at a specific ’distance from the mouth’) from where fish samples are collected using appropriate sampling gear (see above).

Sampling stations must be representative of the salinity zones characteristic of a particular estuary, typically (these zone should be indicated on a map):
• Fresh (representative of river)
• 0 – 10 ppt
• 10 – 20 ppt
• 20 – 30 ppt
• 30 –35 ppt (at least one station should be in this range). It has been found that this salinity range supports a substantially different species composition than that found, for example in the range 20-30 ppt (S Lamberth, MCM and P Cowley, SAIAB, pers. comm.)

Within each salinity zone, representative habitats need to be sampled such as:
• Submerged macrophytes (e.g. Zostera beds)
• Sandy/muddy/rocky areas (representing different food sources)</td></tr>
</table>

	As a guideline, the number of seine net stations in a small estuary (< 5 km long) should not be less than 5, distributed along the entire length of the estuary, covering the salinity zones and habitat types as described above. Small systems with high habitat diversity may require more stations. Gill net samples do not need to be in the same quantity as seine samples. In small estuaries these nets could be used in the mouth, middle and upper reaches. *For larger estuaries (> 5 km long), 10 to 15 seine net stations selected geographically along the entire length of the estuary, covering the salinity zones and habitat types as described above, can be used as the guideline (although this may vary depending on habitat diversity of a system). Stations should preferably be set at fixed intervals. A rough estimate for setting the distance between stations is to divide the length of the estuary by 10 (i.e. if an estuary is 30 km long, the distance between stations should be about 3 km). For larger estuaries gill nets can be used at every 2-3 seine net sites. For example, the Breede River Estuary was sampled at the mouth and thereafter every 5 km upstream, approximately 9 gill net sites over 40 km.*	
	INTERMEDIATE LEVEL	**COMPREHENSIVE LEVEL**
TEMPORAL	*One survey in summer/spring and 1 survey in winter/autumn to sample the spectrum of species in the system. It is important that, at the time of sampling, the state of the estuary, as represented by the extent of saline intrusion and the state of the mouth must be representative of that particular season.* *For temporarily open/closed estuaries one survey needs to be conducted in a stable closed phase and one in a stable open phase.*	*Seasonally over 1 year, i.e. in spring, summer, autumn and winter. The temporal scale needs to address recruitment patterns as well as species distribution within habitats in different seasons. Also, at the time of sampling, the state of the estuary, as represented by the extent of saline intrusion and the state of the mouth must be representative of that particular season.* *For temporarily open/closed estuaries at least one survey must be conducted in a stable closed phase.*

IMPORTANT NOTES: FISH

- *Gill nets are extremely valuable in determining the seasonal changes in the along-stream distribution of the adults of large fish species. For example, it was found that a 44, 48, 51 and 54 mm mesh sizes were needed to obtain a representative sample of the different mullet species in the southwestern Cape. The 44 mm mesh catch tends to be dominated by Liza dumerilii, the 48 mm by L. richardsonii and the 51 and 54 by L. tricuspidens, Myxus capensis and Mugil cephalus. (Note: Monofilament nylon nets should be used, not woven nylon nets, as the latter have a completely different capture efficiency).*
- *Non-destructive sampling should be practiced where possible. The survival rate of larger fish is much greater if they are removed from a gill net by cutting the mesh (easily repaired afterwards) whereas most seined fish can be measured and released alive. If there are abundant fish in a sample, 100 individuals of a species should be measured, the rest counted and released. However, it must be accepted that some fish, especially clupeids, die very easily.*
- *The primary goal of fish sampling is to obtain species and size composition of the fish present in the system.*
- *Gill nets are necessary to sample those fast swimming species and larger individuals that are not captured in the seine nets.*
- *Monofilament gill nets of various mesh sizes can, for example be purchased from Laaiplek Handelshuis and ALNET (Pty) Ltd.*
- *Water quality measurement (salinity, temperature and other physico-chemical properties) need to be collected during the fish surveys. Combining water quality surveys on a particular estuary with the fish surveys does this most cost-effectively.*
- *Fish are more responsive to flow changes, than for example estuarine invertebrates or vegetation, making these good indicator species.*
- *In temporarily open/closed estuaries not all pre-selected sites may be assessable with the same gear during the various sampling trips. This would especially be the case for sites selected on habitat variability, e.g. protective backwater areas. This is an acceptable practice, as long as representative sites are monitored in the same salinity regime to allow for extrapolation.*

IMPORTANT NOTES: FISH

- *The advantages of using fish as indicators include (Whitfield and Elliot, 2002):*
  - *Fish are present in all aquatic systems*
  - *Life-history and environmental response information is available for most species*
  - *Relatively easy to identify and samples can be processed in the field, with the fishes being returned to the water (non-destructive sampling)*
  - *Communities usually include a range of species that represent a variety of trophic levels*
  - *Fish are relatively long-lived and therefore provide a integrative record of environmental stress*
  - *Fish contain many life forms and functional guilds and are likely to cover a number of components of aquatic ecosystems affected by change*
  - *Both sedentary and mobile and thus will reflect localized stressors as well as provide a broader assessment of effects*
  - *Acute toxicity and stress effects can be evaluated in the laboratory*
  - *High public awareness value, i.e. general public relate more to information on fish than on invertebrates or plants;*
  - *Societal costs of environmental degradation (e.g. cost-benefit analyses) are more readily determined in terms of the economic, aesthetic and conservation values attached to fishes.*
- *Difficulties associated with using fish as indicators include (Whitfield and Elliot 2002) include:*
  - *Selective nature of sampling gear for certain habitats and sizes and species of fishes*
  - *Mobility of fishes on seasonal time scales can lead to sampling bias*
  - *Fishes may be relatively tolerant to substances chemically harmful to other life forms*
  - *Can swim away from a disturbances, thus avoiding localized exposure to pollutants or adverse environmental conditions*
  - *Estuarine environments that have been physically altered by humans may still contain diverse fish assemblages.*

TABLE 3.1i: Data requirements on birds for the preliminary determination of the preliminary Ecological Water Requirements for estuaries

DATA	*Bird counts*	*To estimate biomass distribution and species of the birds.*
SAMPLING PROCEDURE	*Undertake full bird counts of all water-associated birds, recording the following information:* • *First, divide the estuary into counting sections on the basis of habitat type (e.g. sandy intertidal, muddy intertidal, mangroves, Zostera beds, salt marsh) and record on a map.* • *For each counting section and for all estuary, provide:* - *Species list* - *Number of birds of each species (at low tide)* - *State of the habitat at the time of observation (or photo of site)* - *Levels of human disturbance at time of counting* • *Identify key areas for feeding, roosting and breeding on the estuary and adjacent floodplain* • *Identify and count high tide aggregations of feeding or roosting birds as far as possible* • *Identify breeding areas and count breeding aggregations as far as possible.* *Analyse field data in conjunction with existing count data (e.g. CWAC data) where available.*	

SPATIAL	*The area covered must include the entire estuary and its floodplain, incorporating all habitats used by water-associated birds for feeding, breeding or roosting.* *The upper boundary of the study area is the same as that for the overall study, i.e. the upper geographical boundary of the estuary.* *The seaward boundary, which is regularly crossed by seabird species such as cormorants, gulls and terns, is most difficult to define. As a guideline, it should include the full tidal delta area and sand bars up to the back line of breakers outside the estuary mouth.* *The sensible lateral extension would be different for each estuary, and may include rocky bars, etc. Thus it is important to furnish a map of the area counted. Any major bird roost in close proximity to the estuary should be counted and mapped.*	
TEMPORAL	**INTERMEDIATE LEVEL**	**COMPREHENSIVE LEVEL**
	One summer month count when the tide in the estuary is at its lowest. In the case of temporarily open/closed estuaries this must be conducted when the mouth is open. However, in estuaries with a high seasonal variability in avifauna, five counts over one year may be required to obtain a medium confidence.	*Birds to be counted every month for one year. Alternatively, conduct five surveys. In the case of temporarily open/closed estuaries, at least one count must be done when the mouth is open (preferably in summer).*

IMPORTANT NOTES: BIRDS

- *Where bird sampling is done according to sections, the section or station number need to be labelled as 'distance from mouth'.*
- *Ideally, the summer count should be in a consistent month, with the same month being used for the monitoring programme. Thus, unless there is a problem with mouth closure, the summer count should always be in February or March, and never after the end of March. Numbers of birds in an estuary change markedly throughout the year, with summer numbers often continuing to increase from spring right up until the end of March, after which there is a dramatic drop in early April following the departure of long-distance Palearctic migrants. Counting birds earlier than February would not only potentially lead to an underestimate of maximum bird numbers, but would be compromised in quality by presence of summer holiday-makers. Human disturbance on estuaries is known to have a significant impact on numbers of birds counted on estuaries.*
- *Bird numbers fluctuate cyclically, in fact often with a 3-year periodicity. If you count every 2 years you will completely lose this pattern, which will make interpretation of trends very difficult indeed. Therefore, in the long-term monitoring programme birds should be sampled every year*
- *To investigate major food sources of key piscivorous, invertebrate and macrophyte feeders stomach content can be used, but this requires specialised equipment and expertise. Besides, estuarine birds are highly adaptive feeders, and describing the diet at one point in time (from a limited sample) may drive one to a rather simplistic and erroneous conclusion about the impacts of changes in the food base. Any trained ornithologist would be able to use available understanding on bird diets and behavioural ecology, coupled with an understanding of their food base, to predict what will happen, with no less certainty than if you went out and stomach-pumped a limited sample of birds.*
- *The Coordinated Waterbird Counts (CWAC) monitors South Africa's waterbird populations and the conditions of the wetlands which are important for waterbirds. This is being done by means of a programme of regular mid-summer and mid-winter censuses at a large number of South African wetlands and estuaries, at regular six-monthly intervals. CWAC currently monitors over 350 wetlands around the country. It is important top check the availability of CWAC data on a specific estuary. Where available, CWAC data can be acquired at a cost (allow for this in the budget) (http://web.uct.ac.za/depts/stats/adu/p_cwac.htm)*
- *It is recommended that the Directorate: Resource Directed Measures provide CWAC with a list of priority estuaries, and in this way those estuaries could be considered for inclusion in their monitoring network.*

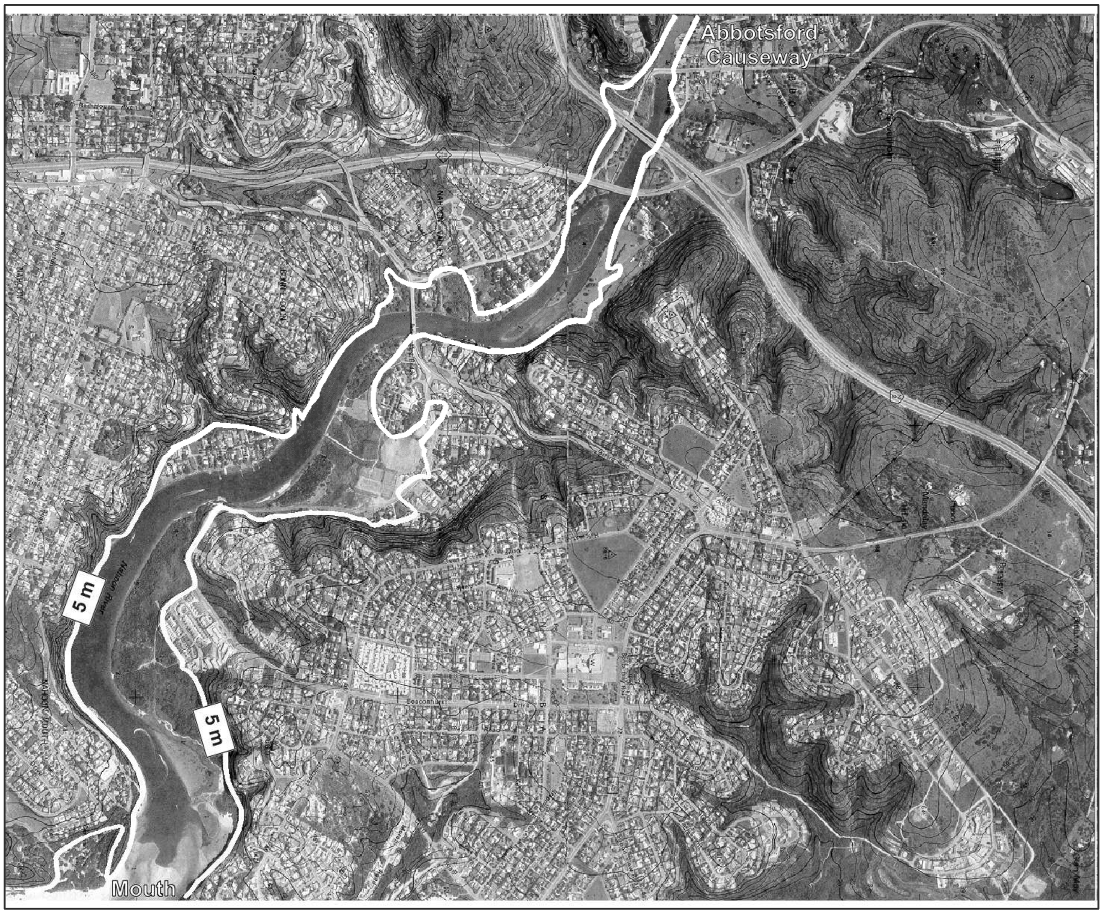
3.3 Delineation of Resource Units (Step 2)

Recognizing that each estuary is unique and different from any other estuary, it is considered appropriate to delineate each estuary as a separate resource unit within the larger catchment, characterised by site dependent abiotic and biotic characteristics. For estuaries, the geographical boundaries are typically defined as follows:

- ***Downstream boundary*:** The estuary mouth (However, there are systems where the 'estuary' often expands to the near-shore marine environment and where this boundary definition may need to be reconsidered in future).

- ***Upstream boundary*:** The extent of tidal influence, i.e. the point up to where tidal variation in water levels can still be detected <u>or</u> the extent of saline intrusion <u>or</u> the extent of back-flooding during the closed mouth state which ever is furthest upstream.

- ***Lateral boundaries*:** The 5 m above Mean Seal Level (MSL) contour along each bank.



Example: Geographical boundaries of the Nahoon Estuary indicated on an ortho-photo, showing the mouth (downstream boundary, the Abbotsford Causeway (upstream boundary and the +5 m MSL contour (lateral boundaries)

3.4 Determination of Recommended Ecological Category (Step 3)

NOTES:

- ***The project coordinator should produce a basic description of the estuary and circulate it to all team members to prevent repetition. In particular, this needs to include the geographical boundaries of the estuary and information on anthropogenic (human) interference.***

- ***All analyses, assumptions and interpretations of data and results must be fully documented in the individual specialist reports.***

- ***Templates need to be provided by the estuarine coordinator to the specialists (Appendix E). These templates provide a means of distilling key issues from the more detailed individual specialist reports for inclusion in the main Estuarine Ecological Water Requirement Report. These need to be completed prior to the specialist workshop and attached as Appendices to the individual specialist reports.***

- ***Specialist reports need to be staggered to ensure that ALL relevant information on other components is available to the specialists when writing their individual reports. The sequence should be as follows:***
  - ***Physical dynamics and water quality***
  - ***Microalgae***
  - ***Macrophytes***
  - ***Invertebrates***
  - ***Fish***
  - ***Birds.***

  Should time constraints prevent this, it is crucial that at least the specialist reports on physical dynamics and water quality (i.e. the driving components) be completed prior to the biotic (i.e. response) components.

- ***Criteria for confidence limits attached to statements in RDM reporting are as follows:***

LIMIT	***DEGREE OF CONFIDENCE***
Low	***If no data were available for the estuary or similar estuaries (i.e. < 40%)***
Medium	***If limited data were available for the estuary or other similar estuaries (i.e. 40% – 80%)***
High	***If sufficient data were available for the estuary (i.e. > 80%)***

3.4.1 Description of Present State

The Present State of an estuary (defined within the specified geographical boundaries) is a quantitative description of the present abiotic and biotic characteristics and functioning of the system.

The description of the Present State, together with the Reference Condition, forms the basis for the preliminary Determination of the Ecological Water Requirement study, for it is here where specialist scientists describe and document their understanding of the characteristics and functioning of an estuary (backed by appropriate field measurements and scientific expertise).

For estuaries, Present State needs to be described in terms of the following components, also documenting the level of confidence:

Abiotic (or driving components):

- Physical dynamics (measured in terms of seasonal river inflow patterns, floods, mouth dynamics, water level variations, water movement patterns, changes in cross section profiles and particle size distribution)

- Water quality (measured in terms of system variables, nutrients and toxic substances) (microbiological contaminants - linked to human health - are excluded as it does not pertain to the *ecological* component).

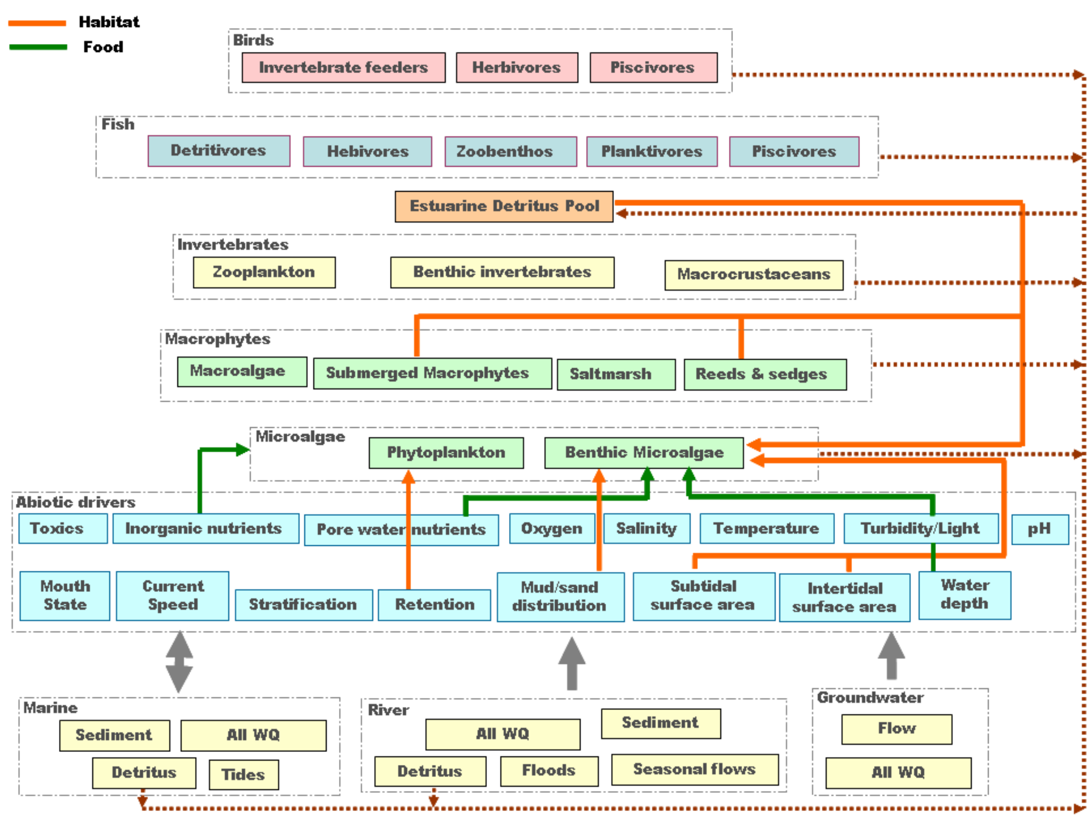
Biotic (response) components:

- Estuarine flora (microalgae and macrophytes)
- Estuarine fauna (invertebrates, fish and birds)

The accuracy with which the ecological status of any estuary can be described will largely depend on, the extent and detail of available data (i.e. existing data and information), additional data that could be collected within time/budget constraints and the complexity of processes in a particular estuary. The description of the Present State, in terms of the different abiotic and biotic components, can therefore vary from a detailed quantitative characterisation based on measured data, to a narrative statement based on expert opinion. For this reason, confidence in the assessment must be documented.

Results on abiotic components must be presented in a format that would be useful and appropriate for estuarine biologists to derive biological responses. The format in which information on the Present State of abiotic components needs to be presented is provided on the following pages.

A diagram indicating the key ecosystem links within the estuary under investigation can be very useful. An example is provided below. For each of the biotic components, the important links need to be highlighted. These links, both habitat and food links, can then be ranked in order of importance to the particular biotic component.



ABIOTIC COMPONENT

a. **Describe seasonal variability in river inflow under the Present State**, i.e. the average monthly simulated runoff data (in m^3/s) for the Present State.

b. Describe the **flood regime** (to be included in comprehensive level determinations)

c. Describe **anthropogenic influences, other than modification of river inflow**, that are presently affecting abiotic characteristics in the estuary and how, using the following checklist as guidance:

Land-use and development	*Artificial breaching*
	Mouth stabilization
	Bank stabilization & destabilization
	Bridge(s)
	Weirs
	Causeway
	Marina development
	Dredging
	Mining (e.g. sand winning)
	Poor agricultural practices (e.g. causing siltation)
	Exceedance of carrying capacity resulting from boating, bathers etc.
	Low-lying developments
	Lack of maintenance of infrastructure (e.g. roads and bridges)
	Migration barrier in river
	Other …
Water Quality and Quantity	*Waste water treatment works*
	Municipal waste (including sewage disposal)
	Industrial effluent (including cooling water) discharges
	Litter
	Mariculture waste products
	Pollution related to shipping activities in harbours
	Septic and conservancy tank seepage
	Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides
	The inflow of contaminated storm-water or groundwater
	Lack of maintenance of infrastructure (e.g. sewage works)
	Other water quality activity

d. Describe the **present sediment processes** (to be included in comprehensive level determinations)

e. **Determine typical states (referred to as abiotic states) that occur in an estuary under different flow ranges.** Because river inflow into an estuary, generally shows strong correlation with certain abiotic parameters, such as state of the mouth and longitudinal salinity distribution patterns, it is usually possible, for a particular estuary, to link or correlate river inflow ranges to typical 'abiotic states'. Based on the above assumption, typical 'abiotic states' therefore need to be determined for a particular estuary linking it to typical river inflow patterns, e.g.:

State 1: Strongly freshwater dominated (flows above 20 m^3/s)*
State 2: Freshwater dominated, but saline intrusion in lower reaches (between 10-20 m^3/s)*
State 3: Marine and freshwater influence on the estuary is balanced (between 3-10 m^3/s)*
State 4: Strongly marine dominated (below 0.5 – 3.0 m^3/s)*
State 5: Closed (below 0.5 m^3/s)*

**** These states and flow rates are for illustration purposes. Different states and associated flow rates will be required for different estuaries***

f. Describe each **abiotic state** in terms of the following abiotic characteristics and processes:

- Typical flow patterns
- State of the mouth
- Flood plain inundation patterns
- Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide)
- Retention times of water masses
- Total volume and/or estimated volume of different salinity ranges
- Estimated (maximum) tidal velocities along the estuary
- Salinity distributions in the estuary
- System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen)
- Nutrients(including the concentrations in the sea* and river** during such periods)
- Toxic substances

(*) Obtained from South African Water Quality Guidelines for Coastal Marine Waters. Volume 1: Natural Environment (DWAF, 1995) or available data sets
(**) Obtain these from Present State specified for 'river section' just upstream of estuary

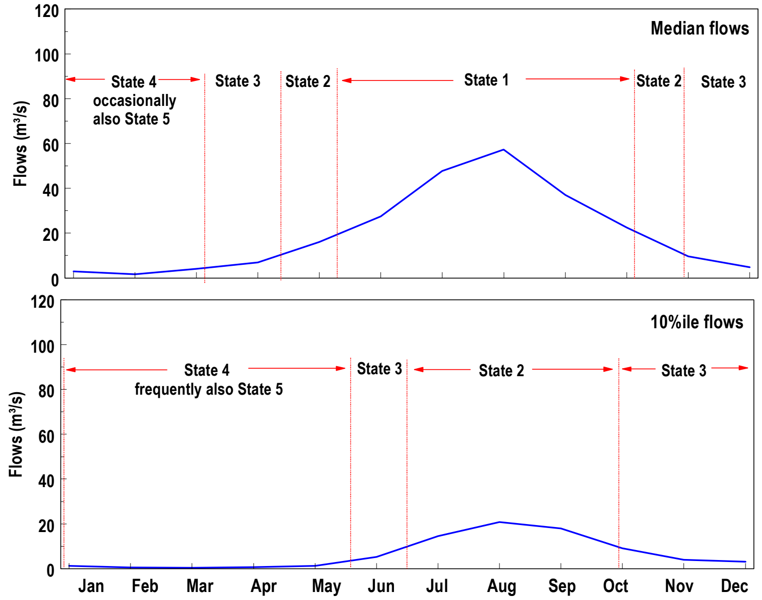
g. **Estimate the occurrence and duration of different abiotic states during the Present State**, using the median monthly flows and 10%ile flows, simulated for the 50-70 year period, to predict the situation for normal and drought periods, respectively. These results can be represented as follows:

- Use colour coding to indicate the average distribution of abiotic states over the simulated period:

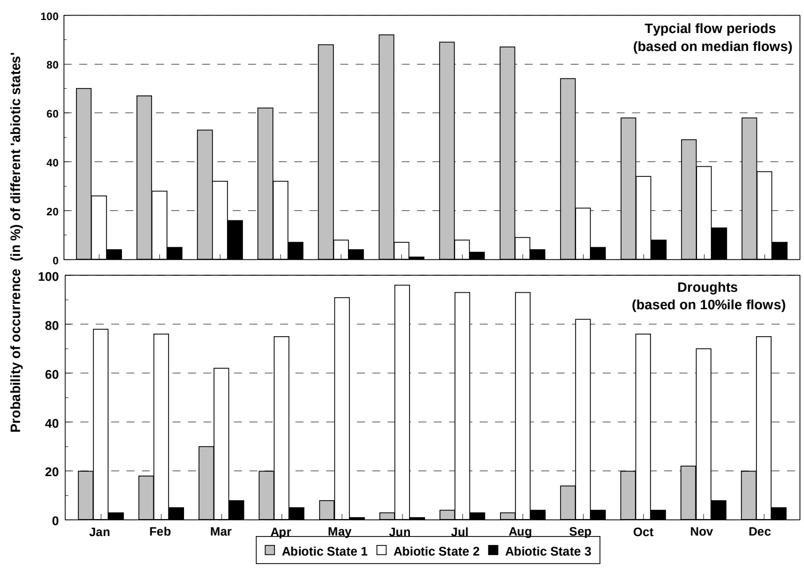
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.97	7.90	2.79	1.09	0.49	13.20	3.46	0.00	49.57	10.97	21.10	27.42
1928	8.83	48.60	17.27	2.47	0.94	5.13	6.94	8.24	15.41	76.96	71.26	21.82
1929	9.39	3.98	7.66	4.46	31.13	18.52	4.14	2.67	2.05	6.46	35.94	56.80
1930	23.77	7.37	3.82	3.43	1.53	5.29	69.77	40.06	9.50	59.89	103.97	44.60
1931	65.64	17.58	34.48	11.63	32.69	4.28	0.87	11.75	21.45	32.98	21.88	141.31
1932	50.58	7.70	4.31	1.81	1.08	1.11	0.64	2.47	55.89	100.96	68.18	26.16
1933	11.30	9.68	4.27	4.97	3.68	3.96	1.12	1.25	8.81	20.18	41.55	42.20
1934	90.47	40.79	6.77	2.41	1.98	1.27	7.04	25.49	25.06	39.63	39.90	28.24
1935	11.37	11.53	4.83	2.52	0.99	0.48	0.16	3.20	3.75	20.31	42.44	42.64
1936	17.59	100.95	41.86	5.98	1.61	9.92	4.87	7.22	56.07	94.13	30.09	19.24
1937	8.82	7.07	9.24	6.54	0.96	6.73	14.23	28.25	13.24	20.83	29.00	31.62
…….	10.95	3.71	4.31	2.83	1.70	0.79	0.96	9.45	58.67	227.94	63.51	96.18

State 1:	< 0.5	State 2:	0.5 - 3.0	State 3:	3.0 -10.0	State 4:	10.0 -	State 5:	> 20.0

- For systems with strong seasonal variability in flows results can, for example, be presented as follow:



- For estuaries where variations within months are stronger than seasonal variation results can, for example, be represented as follows:



BIOTIC COMPONENTS

a. For each of the biological component, describe **anthropogenic influences, other than modification of river inflow**, that are presently directly affecting biotic characteristics in the estuary and how, using the following checklist as guidance:

Living Resources	*Recreational fishing*
	Commercial/Subsistence fishing (e.g. gillnet fishery)
	Traditional fish traps
	Illegal fishing (Poaching)
	Bait collection
	Aquarium fish collecting
	Inappropriate levels of recreational activities (e.g. fishing competitions)
	Mariculture
	Harvesting of mangroves and reeds / sedges
	Grazing and trampling of saltmashes
	Translocated or alien fauna and flora
	Other …..

b. **Describe the Present State** of biotic components, i.e.:

- Microalgae
- Macrophytes
- Invertebrates
- Fish
- Birds

For each of the above, a concise assessment of the following needs to be provided:

- *Species diversity, richness, rarity and community composition* (e.g. provide details on endemic and Red Data species)
- *Biomass distribution and productivity*
- *Seasonal and inter-annual variability* (assessment on changes in seasonal variability, without the necessary data are difficult to determine, particularly for fish and birds).
- *Assessment of any important (regional) relationship* with other nearby estuarine and marine systems*.*

c. Provide a general overview on the **effect of abiotic characteristics and processes, as well as other biotic components on estuarine biota** for each of the biotic components (i.e. identifying key links and also indicate critical periods of the year):

Mouth condition (provide temporal implications where applicable)
Exposure of intertidal areas during low tide
Subtidal, intertidal and supratidal habitat (amended in 2008)
Sediment characteristics (including sedimentation)
Retention times of water masses
Flow velocities (e.g. tidal velocities or river inflow velocities)
Total volume and/or estimated volume of different salinity ranges
Salinities
Other water quality variables (see above)
Other biotic components

3.4.2 Determination of Reference Condition

For the purposes of the preliminary determination of the Ecological Water Requirements, the Reference Condition of an estuary refers to the ecological status that it would have had:

- when receiving 100% of the natural MAR
- before any human development in the catchment or within the estuary
- before any mouth manipulation practices (e.g. artificial breaching)

Typically, the Reference Condition in an estuary refers to its ecological status 50 to 100 years ago.

The Reference Condition needs to be described in terms of the different abiotic and biotic components, documenting the level of confidence.

ABIOTIC COMPONENTS

Results related to abiotic components must be presented in a format that is useful and appropriate for estuarine biologists to derive expected biological responses. The format in which information on the Reference Condition of abiotic components should be presented is provided below.

a. **Describe seasonal variability in river inflow under the Reference Condition**, i.e. the monthly-simulated runoff data (in m^3/s) for the Reference Condition.

b. Describe the **flood regime** under the Reference Condition (to be included in comprehensive level determinations)

c. Describe changes in **sediment processes** under Reference Condition compared with Present State (to be included in comprehensive level determinations)

d. **Assess the change in occurrence and variability of abiotic states under the Reference Condition**, using the median monthly flows and 10%ile flows, simulated for the 50-70 year period, to assess the situation for normal and drought periods, respectively. The format will be similar to that used for the assessment of occurrence and variability of states under the Present State (refer to Chapter 3.4.1).

BIOTIC COMPONENTS

Predict the **change in biotic characteristics from the Reference Condition** to the Present State, as well as the causes of these changes (where anthropogenic influences were responsible these should be flagged):

- Microalgae
- Macrophytes
- Invertebrates
- Fish
- Birds.

Changes should be addressed in terms of:

- Changes in species diversity, richness, rarity and community composition (e.g. provide details on endemic and Red Data species)
- Changes in biomass distribution and productivity
- Changes in seasonal and inter-annual variability (where data are available).

3.4.3 Determination of Present Ecological Status

Present Ecological Status (PES) is a measure of the health of a resource, based on a comparison between the Reference Condition (Chapter 3.4.2) and the Present State (Chapter 3.4.1). An Estuarine Health Index (EHI) is used to determine the PES for estuaries. The development and application of the EHI is described in detail in Appendix C. The structure of the index, its scoring methods and criteria weightings were refined during two workshop sessions. A summary of structure and criteria weightings of the EHI is provided below. Motivation for the scores allocated in the EHI should include the following:

- Brief description of the change(s) and the cause of such change(s)
- Level of confidence.

MEASUREMENT OF ABIOTIC COMPONENTS IN ESTUARINE HEALTH INDEX

For each variable, it will be necessary to estimate the degree to which the Present State resembles the Reference Condition. To account for cyclical variability, it is important that, in general, the **mean** conditions during pristine conditions are compared with the **mean** conditions at present. The % deviation from pristine state will be estimated for each component variable, which will be taken to be the inverse of % similarity. This means that % deviation cannot exceed 100%, and that it thus is necessary to be able to describe a zero resemblance in each case, in order to scale the observed change. Each score will be calculated to reflect % similarity to the pristine state. The following explanations are illustrated using a hypothetical example with calculated scores.

Hydrology

This score would be calculated on the basis of changes in **inflow patterns**, estimated on the basis of two parameters, as in Table 3.2a. Of major interest is the change in medium to high flows, and the concomitant change in months of low flow. Depending on how it is calculated, estimating the % change in conditions would achieve different results depending on whether it was calculated as % increase in low flow months or decrease in high flow months. In order to obviate this problem, a table of scores is given in Table 3.2b, which will give the same results whether the change in low flow or non-low flow months is considered. This table assumes a linear relationship, in that a change of one month from say one month to two months has the same significance as a change of one month from 11 to 12 months, and that this is the same in either direction. Future tests of this method should explore the possibility of non-linear and asymmetrical functions. In the absence of detailed information on flow patterns, or in permanently open estuaries, the % MAR can be used as a substitute for the change in low flow period. The median (50%ile) low flow months or the total % occurrence of low flow months for the full simulation period may be used to give an indication of the change in the low flow period.

The second parameter is % similarity in the frequency of floods, and this is given a slightly lower weighting in the index than the first. However, since this method is really only suitable for larger catchments or where a detailed analysis of hydrology has been done, an alternative method is provided for estuaries where this is not the case. The alternative is a measure of change in magnitude of major floods that are capable of 'resetting' an estuary. Because the magnitude of significant floods differs between estuaries, it is up to the specialist to decide which floods are to be considered in each individual study.

TABLE 3.2a: Calculation of the hydrological health score

VARIABLE		SCORE	WEIGHT
a.	*% similarity in period of low flows* *e.g. 2 months low flow to 4 months low flow (read score off Table 3.2b)* ***OR** Present MAR as a % of MAR in the reference state* *Guideline: we recommend the second measure for permanently open estuaries or for estuaries where information on flow levels is limiting*	*83*	*60*
b.	*% similarity in frequency of major floods (floods ≥ 1:20 year for a particular system) (= % of reference flood events still occurring in Present State).* *e.g. 4 events to 3 events = 3 / 4 X 100=* *Note: This method is more suitable for larger catchments or where a detailed analysis of hydrology has been done.* ***OR** % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the Reference Condition* *Guideline: Because the link between flood magnitude and sediment dynamics is not easily quantified, follow a precautionary approach by using the reciprocal of the % reduction (or increase for certain urban catchments) of the major flood the most affected by developments in the cathment.*	*75*	*40*
Hydrology health score = weighed mean of a and b		***80***	

TABLE 3.2b: Score chart for part (a) of the hydrological health score in terms of change in low flow period

PRESENT STATE	***REFERENCE CONDITION (months of low flow)***												
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0	**100**	92	83	75	67	58	50	42	33	25	17	8	0
1	92	**100**	92	83	75	67	58	50	42	33	25	17	8
2	83	92	**100**	92	83	75	67	58	50	42	33	25	17
3	75	83	92	**100**	92	83	75	67	58	50	42	33	25
4	67	75	83	92	**100**	92	83	75	67	58	50	42	33
5	58	67	75	83	92	**100**	92	83	75	67	58	50	42
6	50	58	67	75	83	92	**100**	92	83	75	67	58	50
7	42	50	58	67	75	83	92	**100**	92	83	75	67	58
8	33	42	50	58	67	75	83	92	**100**	92	83	75	67
9	25	33	42	50	58	67	75	83	92	**100**	92	83	75
10	17	25	33	42	50	58	67	75	83	92	**100**	92	83
11	8	17	25	33	42	50	58	67	75	83	92	**100**	92
12	0	8	17	25	33	42	50	58	67	75	83	92	**100**

(Formula: 100-[%occurrence under Reference Condition - % occurrence under Present State])

Hydrodynamics and mouth condition

This is a simple score (Table 3.3a), which is likely to be a fairly rough assessment accurate to within 20%. In order to score the health implication of a change in duration of mouth closure, CERM's scoring system has been adapted to a scale of 0 - 100 (Table 3.3b). The median flows (50%ile) should be used to indicate change in the mouth condition. The index uses the percentage change in the time an estuary is open during a year. The duration and seasonality of open mouth conditions under the Reference Condition determine the 'reference' biotic assemblage. The scoring system focuses on duration. Therefore, if seasonal changes in mouth conditions also occur, it might require a more severe score than indicated by the guidelines. For estuaries, which do not close annually, scores need to be calculated based on the changes in percentage years the estuary use to close under

Reference Condition versus percentage years the estuary is closing under the Present State or Scenario under evaluation.

TABLE 3.3a: Calculation of the mouth condition score

VARIABLE	*SCORE*
Change in mean duration of closure, e.g. over the simulation period (See Table 3.3b for scoring guide)	*80*
Mouth condition score	***80***
Anthropogenic influence (amended 2008):	
Percentage of overall change in mouth conditions caused by anthropogenic modifications (e.g. artificial breaching) (e.g. 50.% of the 20% change is caused by anthropogenic activities, other than flow)	*10*
Adjusted mouth condition score (attributed only to flow)	***90***

TABLE 3.3b: Scoring guideline for change in mouth condition. If the estuary is artificially breached, particularly during inappropriate times, then the score can be adjusted as appropriate

% OPEN IN REFERENCE CONDITION	*% OPEN IN PRESENT STATE*				
	100%	*75%*	*50%*	*25%*	*0%*
100%	*100*	*33*	*12*	*6*	*0*
75%	*82*	*100*	*48*	*12*	*0*
50%	*70*	*82*	*100*	*39*	*0*
25%	*40*	*50*	*70*	*100*	*0*
0%	*0*	*12*	*33*	*60*	*100*

Water quality

This is assessed in terms of the degree of change in five variables (Table 3.4). The first variable, salinity distribution, is treated separately from the others. The remaining variables are grouped to form a measure of general water quality. Each of the general variables may lead to an overall change in health, and the index does not average these variables so as not to dampen the effect of any one impact on the score, but the highest impact score is used. Scoring guidelines are provided for each variable. Scores for general water quality variables will be assigned by a water quality specialist on the basis of a combined understanding of concentrations in inflowing river and seawater and hydrodynamics within the estuary.

TABLE 3.4: Calculation of the water quality health score

	VARIABLE	*SCORE*	*WEIGHT*
1	*Salinity*		
	% change in axial salinity gradient and vertical salinity stratification *Scoring guideline: Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously modified = 20; completely modified = 0.*	*60*	*40*
2	*General water quality*		
a	*Nitrate and phosphate concentrations in the estuary* *Scoring guideline: Unmodified = 100; reduced = score is estimated % of original level; slightly increased = 75; moderately increased = 50; eutrophic = 0.*	*80*	
b	*Suspended solids in the estuary* *Scoring guideline: Unmodified = 100; slightly increased = 75; moderately increased = 50; heavy load = 25; excessive siltation = 0.*	*40*	
c	*Dissolved oxygen (mg/l) concentrations in the estuary* *Scoring guideline: Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously modified = 20; completely modified = 0.*	*80*	
d	*Level of toxins in the estuary* *Scoring guideline: Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously toxic = 20; completely toxic = 0.*	*80*	
	General water quality = Min (a to d)	*40*	*60*
	Water quality health score = Weighted mean	***48***	

	VARIABLE	SCORE	WEIGHT
Anthropogenic influence (amended 2008):			
	*Percentage of overall change salinity caused by **anthropogenic** activity as opposed to modifications to water flow into estuary (e.g. 50% of the 40% change (1) is caused by anthropogenic activities, other than flow)*	*20*	
	*Percentage of overall change in nitrate and phosphate caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 20% change in (2a) is caused by anthropogenic activities, other than flow)*	*10*	
	*Percentage of overall change in suspended solids caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 60% change in (2b) is caused by anthropogenic activities, other than flow)*	*30*	
	*Percentage of overall change in dissolved oxygen caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 20% change in (2c) is caused by anthropogenic activities, other than flow)*	*10*	
	*Percentage of overall change in toxic substances caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 20% change in (2d) is caused by anthropogenic activities, other than flow)*	*10*	
1	*Salinity score excluding anthropogenic effects*	*80*	*40*
2	*General water quality*		
a	*Nitrate and phosphate score excluding anthropogenic effects*	*90*	
b	*Suspended solids score excluding anthropogenic effects*	*70*	
c	*Dissolved oxygen score excluding anthropogenic effects*	*90*	
d	*Toxic substances score excluding anthropogenic effects*	*90*	
	Adjusted general water quality = Min (a to d)	*70*	*60*
	Adjusted water quality health score (attributed only to flow)	*74*	

Physical habitat alteration

Two main components make up the physical habitat health score: area and sediment composition of **intertidal** habitat and **submerged** areas (i.e. based on subtidal habitat, channel morphology, and taking degree of sedimentation, and obstruction or constriction into account).

Changes in both of these habitat elements may have been due to changes in water flow into the estuary or **anthropogenic** activities within the estuary, or both. Thus the team is required to estimate the degree to which each of the two component scores is influenced by water flow changes vs within-estuary anthropogenic changes (Table 3.5). The **unadjusted score** is used in the health index, and the adjusted score serves to give a fuller explanation of the health status.

TABLE 3.5: Calculation of the physical habitat health score

	VARIABLE	SCORE	WEIGHT
1	*Resemblance of <u>intertidal sediment</u> structure and distribution to Reference Condition*		
1a	*% similarity in intertidal area exposed*	*80*	*50*
1b	*% similarity in sand fraction relative to total sand and mud*	*60*	*50*
	Mean	*70*	*50*
2	*Resemblance of <u>submerged</u> habitat to Reference Condition: depth, bed or channel morphology* *Scoring guideline: No alteration = 0%, Total alteration = 100%.*	*90*	*50*
	Overall physical habitat health = Weighted mean	***80***	
Anthropogenic influence:			
	*Percentage of overall change in <u>intertidal habitat</u> caused by **anthropogenic** activity as opposed to modifications to water flow into estuary (e.g. 20% of the 30% change (1) is caused by anthropogenic activities, other than flow)*	*20*	
	*Percentage of overall change which in submerged <u>habitat</u> caused by **anthropogenic** modifications (e.g.bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary (e.g. 100% of the 10% change in (2) is caused by anthropogenic activities, other than flow)*	*100*	
1	*Health of <u>intertidal habitat</u> excluding anthropogenic effect (e.g. 20% of 30% change +*	*76*	*50*

	VARIABLE	***SCORE***	***WEIGHT***
	70% similarity)		
2	*Health of subtidal habitat excluding anthropogenic effect (e.g. 100% of 10% change + 90% similarity)*	*100*	*50*
	Adjusted physical habitat health score (attributed only to flow)	***88***	

MEASUREMENT OF BIOTIC COMPONENTS IN ESTUARINE HEALTH INDEX

A change in health may be reflected in a change in community composition, species diversity and biomass. With increased system perturbation, community composition may change in favour of more opportunistic species, while the numbers and biomass of more specialised species tend to decrease, or one might see a significant change in the trophic composition of a community. Thus a simple measure of species richness or abundance (biomass, area) is not a reliable indicator of health. The index has to be able to reflect changes as positive or negative, accordingly. Given that in most cases, the Reference Condition is estimated on the basis of modelled outputs and assumed relationships, the parameters within this index can only be estimated with a fairly rough degree of accuracy. It would thus be inappropriate to propose a highly quantitative index such as Shannon diversity to indicate change in biotic communities. It is proposed that three main factors are taken into account: species richness, abundance and community composition (Table 3.6a). In order to keep the score as simple as possible, the three attributes are considered separately, and the minimum score is taken as the indicator of health.

Change in **species richness** should only be measured as the loss of species that were part of the original community, and should not take new species (not thought to have occurred under Reference Condition) into account. The scoring system recommended for species richness has a concave relationship with percentage of average species richness remaining in the system. This reflects the fact that a few valuable, specialist species may be lost with initial perturbation of the system, and it is harder to restore health in terms of number of species when starting from a higher than a lower health level.

Abundance may decrease or increase with a decrease in estuarine health, and this is expressed as a % similarity rather than % change. Thus, while a decrease in abundance to 60% of original scores 60, and increase to 130% of original would score 70 (100 – 30% change).

Change in **community composition** is assessed as % resemblance to original composition. The simplest way of estimating this score is to consider the relative abundance of different trophic groups in the community. With better predictive ability, one can extend this to consider shifts in the relative abundance of individual species.

Note that there is no score dealing with overall change in community composition or trophic dominance across all the groups, as this would double-count the change in abundance scores given for the individual groups.

This index should be calculated for microalgae, macrophytes, invertebrates, fish and birds. Again, the points for comparison are the estimated mean conditions during the reference and present conditions, for variables that undergo cyclical or dynamic changes. The invertebrate health index would include the water column fauna (zooplankton) as well as benthic and hyperbenthic invertebrates (those living in or on the bottom, and those living close to the sediment, respectively). Although these components are not considered separately, the invertebrate specialist would have to consider both and integrate their health scores into an overall score on the basis of the relative importance of each group.

TABLE 3.6a: Calculation of the biotic health score for each biotic group

VARIABLE	***MEASUREMENT***	***SCORE***
a. Species richness	*Average species richness as a % of average species richness during the Reference Condition (only consider original species)* *Scoring guideline: 100% = 100, 90% = 80; 80% = 65; 70% = 50, 60% = 35; 50% = 25; 40% = 17; 30% = 10; 20% = 5; 10% = 0* *(Formula: $y = 0.009 x^2 +0.038x -0.433$)*	*90*
b. Abundance	*Estimated % of total numbers or biomass remaining of the original species*	*70*
c. Community composition	*Estimated % resemblance to original composition.* *Scoring guideline: No change = 100%; Original community totally displaced by opportunistic spp = 0%*	*40*
Microalgae / Macrophyte / Invertebrate / Fish / Bird community health score = minimum score of a, b and c		***40***

Again, the health of the biotic components may be due partly to modifications in river inflow, and partly to human disturbance (anthropogenic activities) within the estuary. The team is thus required to describe the extent to which the changes scored above are due to human activities within the estuary such as trampling, pollution and overexploitation (Table 3.6b). This produces an adjusted score which is only for descriptive purposes and is not used in the overall index.

TABLE 3.6b: Estimating the extent to which biotic health scores are affected by anthropogenic disturbance within the estuary, i.e. other than modifications in river inflows

COMPONENT	***HEALTH SCORE (e.g.)***	***DEGREE TO WHICH CHANGE CAUSED BY HUMAN ACTIVITY IN ESTUARY (%)***	***ADJUSTED HEALTH SCORE (HEALTH IN ABSENCE OF HUMAN DISTURBANCE)***
Microalgae	*70*	*10*	*= 70+((100-70)*0.10) = 73*
Macrophytes	*70*	*40*	*etc*
Invertebrates	*80*	*50*	
Fish	*60*	*70*	
Birds	*70*	*50*	

CONSTRUCTION OF ESTUARINE HEALTH INDEX

Construction of an index should be relatively simple. It is recommended that for each abiotic or biotic variable, the conditions be described, as quantitatively as possible that would be regarded as indicative of 0 to 100% of the pristine state. These can then be used as standard guidelines in what is otherwise a dangerously subjective assessment. Without strict guidelines, a method such as this would lead to a huge range of possible assessments by different practitioners, and could not be regarded as robust or legally defensible. Each variable, thus defined as % of pristine state, is weighted, and then aggregated, using the overriding rule. The final score should reflect the state as a % of pristine. This percentage can then be assigned to a management class.

The overall degree of health of the abiotic aspects of the estuary may be considered a measure of Habitat Health or Integrity, while the remaining variables make up the Biological Health Index. The two sub-components are calculated and combined as follows (Table 3.7).

TABLE 3.7: Calculation of the Estuarine Health Score

VARIABLE	***SCORE***	***WEIGHT***
Abiotic (habitat) variables		
Hydrology	*41*	*25*
Hydrodynamics and mouth condition	*80*	*25*
Water quality	*59*	*25*
Physical habitat	*80*	*25*
1. Habitat health score *= weighted mean*	*65*	***50***
Biotic variables		
Microalgae (minimum score of phytoplankton or benthic microalgae)	*60*	*20*
Macrophytes	*60*	*20*
Invertebrates (minimum score of Zooplankton, Benthic invertebrates, Macrocrustaceans)	*70*	*20*
Fish	*60*	*20*
Birds	*90*	*20*
2. Biological health score *= weighted mean*	*70*	***50***
ESTUARINE HEALTH SCORE *= weighted mean of 1 and 2*	*67.5*	

ASSIGNMENT OF PRESENT ECOLOGICAL STATUS

The Estuarine Health Score represents the degree to which an estuary resembles its pristine ecological state. An estuary is assigned to a Present Ecological Status, which indicates six broad categories of estuarine health, as follows (Table 3.8). Thus in the example calculated above, an estuary scoring 67 points would be classified as 'C'.

TABLE 3.8: Recommended guidelines for the classification of the Present Ecological Status (PES) of an estuary based on an integrity score which indicates Present State as a percentage of pristine state

ESTUARINE HEALTH INDEX (EHI) SCORE	***PRESENT ECOLOGICAL STATUS***	***DESCRIPTION***
100 - 91	*A*	*Unmodified, natural*
76 – 90	*B*	*Largely natural with few modifications*
61 – 75	*C*	*Moderately modified*
41 – 60	*D*	*Largely modified*
21 – 40	*E*	*Highly degraded*
0 – 20	*F*	*Extremely degraded*

Note that the conditions on the left start off as broader ranges in the lower classes, becoming narrower as an estuary approaches a pristine state. Where appropriate a border line Present Ecological Status can be defined, e.g. A/B when a score is within 3 points of the boundary score (88 - 93).

NOTE:

Where a number of ecological flow scenarios have similar impacts on the health of the estuary there is a number of non-flow related impacts that could influence the final selection of the Recommended Ecological Flow Scenario. Other consideration in selection of the Recommended Ecological Flow Requirement Scenario include, for example:

- ***Instream dam developments are migratory barriers to estuarine associated fish and invertebrates, while off-channel developments do not pose the same risk. In addition, off-channel developments also allow for greater natural variability in river flow, both in baseflows and floods.***

- ***Greater utilisation of the freshwater water resources often equates to more development adjacent to the estuary. In small estuaries the related increase in fishing effort, boating activities, human disturbance and nutrient loading from stormwater, may greatly impact on the health of the system and a more conservative flow scenario be selected as the Recommended Ecological Flow Scenario to limit these synergistic impacts.***

- ***<u>From an estuarine perspective</u>, dams sighted high in the catchment have less of an impact than dams just above the estuary as this allows for some variably in flow compared to a highly regulated system. Note, from a river perspective this might not be the optimum development scenario, but will allow for some protection of the estuary***

3.4.4 Trajectories of changes

It is important to note that the Present State simulated runoff scenario is usually based on recent modifications of river flow (e.g. irrigation abstractions or dam developments). Therefore, although the Present State scenario is simulated over a 50-70 year period, the actual period in which that flow regime existed in reality may be much shorter. As a result, the Present State measured in other components, particularly the biotic components, may not represent the full response to a flow regime as simulated for the Present State, i.e. it may still be on a *trajectory of change*. It is therefore important that information on the modifications to river flow that were taken into account for the hydrological modelling of the Present State scenario also be documented, as well as the extent to which such modifications have already been implemented in the catchment. This will provide estuarine specialists with some means of establishing trajectories of change, taking into account the anticipated response times of their individual components.

3.4.5 Determination of Estuarine Importance

NOTE:

The importance scores for the variables Size, Rarity of Estuary Type with regard to Geographic Position, Habitat Diversity and Biodiversity Importance (see below) has been derived for ALL South African estuaries as part of a project entitled: Classification and prioritisation of South African estuaries on the basis of health and conservation status for determination of the estuarine water requirements (Turpie et al., 2002). Scores are reported in Turpie et al. (2002) and updated in 2004 (Turpie 2004) and 2007 (Turpie and Clark, 2007). Details on the scoring system of these variables are therefore not discussed in detail in this section, but details can be obtained from Turpie and Clark. (2007). The scores are given in Appendix 4.

The only importance score that needs to be derived by the estuarine ecological team (at the specialist workshop) is that for the link with freshwater and marine environment (i.e. functionality score)

Estuarine Importance is an expression of the importance of an estuary to the maintenance of biological and ecological diversity and functioning on local and wider scales. Variables were discussed in a workshop setting, regarding their suitability for inclusion in an Estuarine Importance Index. The rationale for selecting these variables, as well as the estuarine importance index scoring system is discussed in detail in Appendix D. The variables selected were as follows:

- *Size.* Estuary size is defined as the total area (ha) within the geographical boundaries described in the RDM methodology.

- *Rarity of Estuary Type with regard to Geographic Position*. South African estuaries have been classified into five types (refer to Appendix D). There are only 3 estuarine bays and 4 estuarine lakes in the country therefore these estuaries would have a high importance. Geographic position is also important. The classification of an estuary in conjunction with the biogeographical zone determines how 'rare' or 'unique' the estuary is for the zone under consideration. For example there are only two permanently open estuaries (Olifants and Berg) in the cool temperate zone and therefore these systems are of national importance. The Palmiet Estuary in the south-western Cape is the only system along that stretch of coastline that remains open for any length of time, and is thus very important in this region for fish and invertebrate recruitment.

- *Habitat Diversity*. An estuary can be considered more important if it has a high diversity of habitat types, or on the basis of representativeness, in terms of the size and rarity of those habitat types that it contains. Estuarine habitats include physical (unvegetated) habitats such as channel area, sandflats, mudflats, and rock, and plant communities, such as salt marsh, mangroves, submerged macrophytes, reeds and sedges. The definition could be extended to include surrounding habitats such as floodplains and dunes.

- *Biodiversity Importance*. Biodiversity importance is determined on the basis of the importance of an estuary for each of the four biotic groups, which in turn is be based on a set of criteria appropriate to each group. The scoring for each group ideally contains the following elements:

    - Species Richness
    - Species Rarity or Endemism (weighted species richness)
    - Abundance (numbers, area or biomass).

- *Link with Freshwater and Marine Environment (Functional Importance).* Estuaries provide several ecological services to their surrounding environments. These have been identified in Table 3.9.

TABLE 3.9: Calculation of the functional importance score (on the regional scale)

CRITERIA FOR CONSIDERATION	*GUIDELINES FOR IMPORTANCE SCORE*
A Conduit for detritus, nutrients and sediments generated in the catchment to the sea	*0 none* *20 little* *40 some* *60 important* *80 very important* *100 extremely important*
b. Export of detritus and nutrients to the coastal zone generated within estuary	
c. Nursery function for fish and crustaceans (marine and riverine)	
d. Movement corridor for river invertebrates and fish breeding in marine environment (e.g. river crab Varuna litterata*)*	
e. Roosting area for marine or coastal birds	
Overall functional importance score	***Max (a to e)***

CONSTRUCTION OF ESTUARY IMPORTANCE INDEX

Again, construction of this index must be simple. All scores are presented on a scale of 0 (totally unimportant) to 100 (critically important). Thus overall **Estuary Importance** can be calculated as follows (Table 3.10a). As for all preceding indices, weightings were assigned on the basis of input from two specialist workshops.

TABLE 3.10a: Construction of the estuary importance index

CRITERION	SCORE (e.g.)	WEIGHT
Size	*50*	*15*
Zonal Type Rarity	*50*	*10*
Habitat Diversity	*70*	*25*
Biodiversity Importance	*88*	*25*
Functional Importance	*60*	*25*
ESTUARY IMPORTANCE SCORE = Weighted Mean	***70***	

Depending on the score, the importance of the estuary is described as in Table 3.10b below.

TABLE 3.10b: Interpretation of the estuary importance scores

IMPORTANCE SCORE	DESCRIPTION
Protected Status	*Protected*
80 – 100	*Highly important*
60 – 80	*Important*
0 – 60	*Of average importance*

3.4.6 Guidelines for assigning the Recommended Ecological Category

The Ecological Category is allocated on the basis of the importance score, using the PES (i.e. present ecological status), as a starting point. Relationship between the PES and Ecological Category are outlined in Table 3.11a. Note that the same percentage-classes are used as for the PES (Table C.8). It is assumed undesirable to manage an estuary in less than 40% of its original condition. Thus a Category D is the minimum desired future state for any estuary.

TABLE 3.11a: Relationship between PES and Ecological Category

EHI SCORE	PRESENT ECOLOGICAL STATUS (PES)	DESCRIPTION	ECOLOGICAL CATEGORY	CORRESPONDING MANAGEMENT CLASS (in terms of new categories)
91 – 100	*A*	*Unmodified, natural*	*A*	*Natural (Class I)*
76 – 90	*B*	*Largely natural with few modifications*	*B*	*Good (Class II)*
61 – 75	*C*	*Moderately modified*	*C*	*Fair (Class III)*
41 – 60	*D*	*Largely modified*	*D*	
21 – 40	*E*	*Highly degraded*	*E*	*Poor*
0 – 20	*F*	*Extremely degraded*	*F*	

An estuary cannot be managed for a ‘poor’ Management Class. Therefore systems that are in an Ecological Category ‘E’ or ‘F’ needs to be managed towards achieving at least an Ecological Category ‘D’, equivalent to an Management Class ‘Fair’. Where appropriate a border line Ecological Category can be defined, e.g. A/B when a score is within 3 points of the boundary score (88 - 93).

PES sets the minimum Ecological Category. The degree to which Ecological Category needs to be elevated higher than PES depends on level of **importance** and level of **protection or desired** protection of a particular estuary (Table 3.11b). Estuaries that currently have protection status and the current list of desired protected areas are given in Appendix D.

TABLE 3.11b: Guidelines for assigning the recommended Ecological Category

CURRENT/DESIRED PROTECTION STATUS AND ESTUARY IMPORTANCE	*RECOMMENDED ECOLOGICAL CATEGORY*	*POLICY BASIS*
Protected area	*A or BAS**	*Protected and desired protected areas should be restored to and maintained in the best possible state of health*
Desired Protected Area (refer to Turpie et al., 2002 and Turpie and Clark, 2007)		
Highly important	*PES + 1, min B*	*Highly important estuaries should be in an A or B class*
Important	*PES + 1, min C*	*Important estuaries should be in an A, B or C class*
Of low to average importance	*PES, min D*	*The remaining estuaries can be allowed to remain in a D class.*

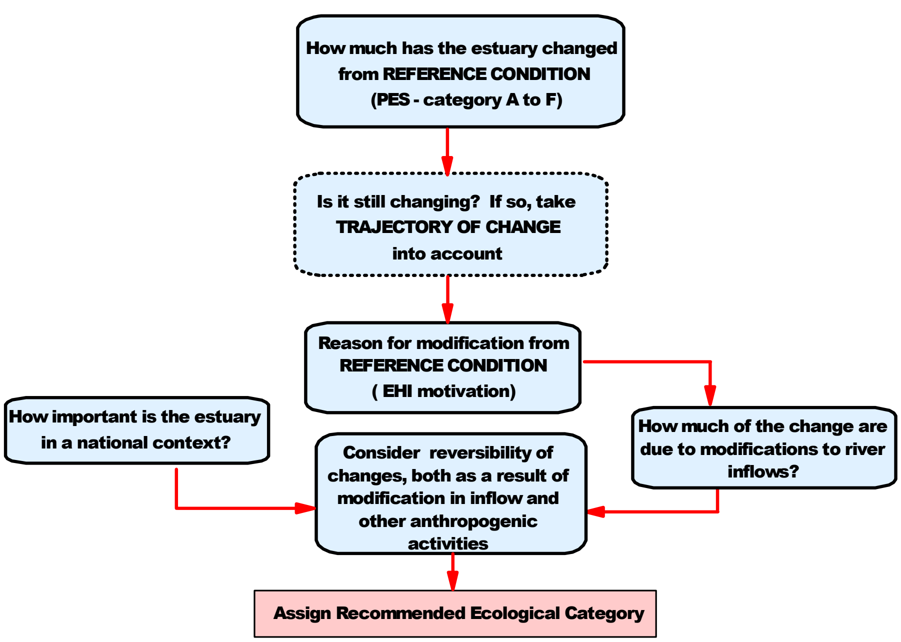
** BAS = Best Attainable State*

At the workshop specialists need to comment on the achievability of the allocated Ecological Category (based on the above guidelines). In doing so, the team need to consider aspects such as:

- Reversibility of changes associated with existing modifications to river inflow
- Reversibility of changes as a result of anthropogenic activities other than modifications of river inflows.

In some estuaries, changes have occurred that may be irreversible. If there is no practical way of restoring the original ecological characteristics of a particular water resource, then there may be justification for setting a Best Attainable State (BAS).

In essence, the procedures followed in the allocation of recommended Ecological Category for estuaries can be summarised as follows:



3.5 Quantification of Ecological Water Requirement Scenario (Step 4)

To set Ecological Water Requirement Scenarios for different Ecological Categories, future run-off scenarios (refer to Chapter 3.4.2), together with an understanding of the Present State, are used to estimate the occurrence and duration of typical abiotic states within an estuary for each of these runoff scenarios. Changes in abiotic characteristics are then assessed in terms of the biological implications (using the EHI). Results from these evaluations are then used to select 'recommended ecological flow scenario', defined as the run-off scenario, or a slight modification thereof, that represents the highest reduction in river inflow that will still protect the aquatic ecosystem of the estuary and keep it in the recommended Ecological Category. The following process is followed:

a. **Describe seasonal variability in river inflow for each of the runoff scenarios provided**, i.e. the monthly-simulated runoff data (in m^3/s) for each of the scenarios, using colour coding to indicate the distribution of different abiotic states.

b. Describe **flood regime** for each of the different flow scenarios

c. Describe changes in **sediment processes** under future scenario compared with Reference Condition

d. Predict the change in **occurrence and variability of abiotic states for each of the runoff scenarios,** using the median monthly flows and 10%ile flows, simulated for the 50-70 year period, to predict the situation for normal and drought periods, respectively. The format will be similar to that used for the assessment of occurrence and variability of states under the Present State (refer to Chapter 3.4.3)

e. Expected additional **modification in water quality characteristics** within an abiotic state, as a result of changes in river inflow patterns need to be assessed for each of the scenarios.

NOTE:

Although each abiotic state is characterised by certain water quality conditions, modification of river inflow (as predicted by simulated runoff scenarios) can result in additional modification to water quality within an abiotic state. Concentration-flow response curves can be used to establish such relationships and, ultimately, to predict modifications in water quality associated with specific runoff scenarios. Where such relationships have been derived as part of the river Ecological Water Requirement determination study, in particular the section just upstream of the estuary, these should be supplied to the estuarine team.

f. Predict the **response in biotic characteristics** for each of the runoff scenarios, based on the predicted changes in Abiotic components (as provided above):

MICROALGAE
Confidence:
MACROPHYTES
Confidence:
INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)
Confidence:
FISH
Confidence:
BIRDS
Confidence:

Changes should be addressed in terms of:

- Changes in species diversity, richness, rarity and community composition (e.g. provide details on endemic and Red Data species)
- Changes in biomass distribution and productivity
- Changes in seasonal and inter-annual variability (where data are available).

g. Use the **Estuarine health index to determine the Ecological Category for each scenario** (refer to Chapter 3.4.3), using the predicted changes in abiotic and biotic components as described in (c) to (d) above. Motivation for the scores allocated in the EHI should include the following:

- Brief description of change(s) and cause of such change(s)
- Level of confidence.

h. **Summarise** the EHI results in a table as follows:

VARIABLE	***% SIMILARITY TO REFERENCE CONDITION***			
	Present	***Scenario 1***	***Scenario 2***	***Scenario n***
Abiotic (habitat) variables				
Hydrology				
Hydrodynamics and mouth condition				
Water quality				
Physical habitat				
Human disturbance				
Habitat health score				
Biotic variables				
Microalgae				
Macrophytes				
Invertebrates				
Fish				
Birds				
Biological health score				
ESTUARINE HEALTH SCORE				
Corresponding Ecological Category				

Select the **'recommended Ecological Flow Requirement' scenario,** defined as the flow scenario (or a slight modification thereof) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category. Where an estuary is on a trajectory of change this approach may not be appropriate. In such instances the different flow scenarios and anthropogenic impacts must be evaluated within the context of achieving the recommended Ecological Category in the long-term. Where the biotic health score is less than 50% <u>and</u> much lower than the habitat health score, the latter also applies.

The specialists at the workshop need to conduct this evaluation. The recommended Ecological Flow Requirement Scenario must be provided as a summary of the flow distribution (mean monthly flows in m^3/s) derived from the monthly-simulated data generated for this scenario:

MONTH	*FLOW (in m^3/s) (i.e. flows should equal/exceed given % in a month)*									
	10%	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*99%*
Jan	…..									
Feb	…..									
Mar	…..									
Apr	…..									
May	…..									
Jun										
Jul										
Aug										
Sept										
Oct										
Nov										
Dec										

A **confidence limit** must be allocated to the recommended ecological category for water quantity, which is primarily determined by the confidence of the abiotic assessments, in particular the relationship between river inflow and Abiotic States.

3.6 Ecological Consequences of Operational Scenarios (Step 5)

For estuaries, it is advised that the future run-off scenarios used in the Quantification of Ecological Water Requirement Scenario (Chapter 3.5) include realistic operational scenarios in which case ecological consequences of operational scenarios (Step 5) can be addressed as part of Step 4. However, after requirements of other stakeholders have been taken into account and the results from different water resource components have been evaluated, a set of additional operational scenarios are produced, also simulated over a 50 – 70 year period, these can be assessed in a similar manner as described for Step 4, following steps (a) to (h).

3.7 Ecological Specifications (Input to Step 7)

During the Classification process the **Ecological Class** for the estuary will be decided taking ecological, social and economic criteria into account through stakeholder consultation (which may or may not be the *recommended* Ecological Category).

The estuarine specialist team is required to define Ecological Specifications for the estuary based on the Ecological Class. The Ecological Specifications are the Resource Quality Objectives for the estuarine ecosystem. (The estuarine specialist team can also set Ecological Specifications for the recommended Ecological Category if the Classification process has not been done, as has been the case in most of the Ecological Water Requirement studies completed to date).

Ecological Specifications are clear and measurable specifications of attributes that define a specific Category. Targets for Ecological Specifications for estuaries are set as 'Thresholds of Potential Concern' (TPCs). TPCs are defined as measurable end points related to specific abiotic or biotic indicators that if reached (or when modelling predicts that such points will be reached) prompts management action. In essence, TPCs concern endpoints should be defined such that they provide early warning signals of potential non-compliance to Ecological Specifications (i.e. not the point of 'no return'). In essence, this concept implies that the indicators (or monitoring activities) selected as part of long-term monitoring programmes need to include biotic and abiotic components that are particularly sensitive to ecological changes associated with changes in river inflow.

Ecological Specifications, including TPCs need to be determined for:

- Water Quantity (entering the estuary)
- Water Quality (entering the estuary)
- Habitat (including water quality within the estuary) and Biota.

ECOLOGICAL SPECIFICATIONS FOR WATER QUANTITY

The Ecological Specifications for Water Quantity is the EWR flow scenario. If the recommended Ecological Category is rejected (Step 4), then the flow scenario corresponding to the chosen **Ecological Class** is used.

The Ecological Specification is provided as a summary of the flow distribution (mean monthly flows in m^3/s) derived from the monthly-simulated data generated for that scenario:

MONTH	*FLOW (in m^3/s) (i.e. flows should equal/exceed given % in a month)*									
	10%	*20%*	*30%*	*40%*	*50%*	*60%*	*70%*	*80%*	*90%*	*99%*
Jan	…..									
Feb	…..									
Mar	…..									
Apr	…..									
May	…..									
Jun										
Jul										
Aug										
Sept										
Oct										
Nov										
Dec										

ECOLOGICAL SPECIFICATIONS FOR WATER QUALITY

In addition to the quality of river inflow, water quality in estuaries is also affected by other external sources, namely:

- Seawater quality entering the estuary
- Wastewater inputs directly into the estuary.

Ecological Specifications for Water Quality sets concentration limits for water quality constituents in river inflow so as to ensure that the estuary is protected. In addition, concentration limits should also be set for waste discharges directly into the estuary and seawater quality**.** The Department of Water Affairs and Forestry has sole administrative control over water quality matters in rivers and land-derived wastewater discharges. For discharges into the sea and estuaries, several other statutes may also apply, including those administered by Department of Environment Affairs and Tourism and Provincial authorities (Table 3.12).

Table 3.12: Important statutes relevant to management and protection of water quality, particularly at sea and in estuaries (CSIR, 1991)

STATUTES	*ADMINISTRATIVE AUTHORITY*
Marine Living Resources Act (Act 18 of 1998)	*Department of Environment Affairs & Tourism*
Dumping at sea control Act (No. 73 of 1980)	
Environmental Conservation Act (No. 73 of 1989)	
National Environmental Management Act (No. 107 of 1998)	
National Environmental Management: Coastal Zone Bill	
Prevention and combating of pollution of the sea by oil Act (No. 6 of 1981)	*Department of Transport*
International convention for prevention of pollution from Ships Act (No. 2 of 1986)	
International convention relating to intervention on the high seas in cases of oil pollution Act (No. 64 of 1987)	
Cape and Kwazulu Natal Conservation Ordinances	*Provincial Nature Conservation agencies*
Harbour Regulations	*National Ports Authority*

To facilitate integration between the river's and estuarine components the following approach should be followed in setting Ecological Specifications for Water Quality, specifically the quality of river inflow entering at the head of the estuary:

- Obtain the Ecological Specifications for Water Quality from the river resource unit just upstream of the estuary (this would specify the water quality at the end of that resource unit, and would therefore be representative of the river water entering the estuary)

- Assess the implications of these water quality parameters on the different **biotic** components by applying the **EHI**

- If the estuary remains in the recommended Ecological Category (or selected Ecological Class, if this had been determined) the **Water Quality Ecological Specifications (and TPCs) for the river is accepted for the estuary**. If not, these need to be adjusted so as to meet requirements.

ECOLOGICAL SPECIFICATIONS FOR HABITAT AND BIOTA WITHIN ESTUARY

Ecological Specifications and associated TPCs for habitat and biota include the following components within the estuary:

- Abiotic components within the estuary (hydrodynamics, sediment dynamics and water quality)
- Biotic components (microalgae, macrophytes, invertebrates, fish and birds).

It is important to note that there are also other statues that can set objectives for estuaries. Examples are listed in Table 3.13

Table 3.13: Important statutes relevant to management and protection of habitat and biota

STATUTES	*ADMINISTRATIVE AUTHORITY*
Marine Living Resources Act (Act 18 of 1998)	*Department of Environment Affairs & Tourism*
National Environmental Management Act (No. 107 of 1998)	
National Environmental Management: Coastal Zone Bill	
Integrated Environmental Management : Protected Areas Act (No. 57 of 2007)	
Integrated Environmental Management : Biodiversity Act (No. 10 of 2004)	
Local Government : Municipal Systems Act (No. 32 of 2000)	*Department of Provincial & Local Government*

The Ecological Specifications (and TPCs) for abiotic components cannot be set independently of the biota, as the Ecological Specifications for the abiotic components is largely a reflection of the 'habitat requirements' necessary to maintain the different Biotic Components as per the recommended Ecological Category (or selected Ecological Class if this had been determined). To illustrate this, some examples are listed below:

ABIOTIC COMPONENT	*ECOLOGICAL SPECIFICATION*	*THRESHOLD OF POTENTIAL CONCERN*
Water quality	*Salinity intrusion should not cause exceedence of TPCs for fish, invertebrates, macrophytes and microalgae (see above)*	*Salinity greater than 20 ppt for longer than 3 months at 7 km upstream from the mouth (this would have an impact on the brackish saltmarsh, reeds and sedges & invertebrates)* *Salinity greater than 10 ppt occurs above 16 km upstream of the mouth (this would have an impact on fish)*
Hydrodynamics	*Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality*	*River inflow below 2 m^3/s persist for longer than 4 months*
Sediment dynamics	*Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota*	*River inflow distribution patterns (flood components) differ by more than 10% (in terms of magnitude, timing and variability) from that of the Present State*

The Ecological Specifications (and TPCs) for biotic components, should describe the health status of the Biotic Component as per the recommended Ecological Category (or selected Ecological Class if this had been determined). To illustrate this, some examples are listed below:

COMPONENT	***ECOLOGICAL SPECIFICATION***	***THRESHOLD OF POTENTIAL CONCERN***
Microalgae	*Maintain high subtidal benthic microalgal biomass during the closed mouth phase and low intertidal benthic microalgal biomass during the open phase.*	*Deviation in benthic microalgal biomass by 20 % compared with Present State concentrations.* *No brackish epipelic diatoms are found during the closed phase*
Macrophytes	*Maintain the distribution of plant community types i.e. Submerged macrophyte,* Ruppia cirrhosa *beds during closed mouth brackish conditions (~29 ha), salt marsh,* Sarcocornia perennis *marsh during open mouth conditions (~1.2 ha),* Phragmites australis *stands in the middle / upper reaches (~0.18 ha) and salt marsh grasses (~1.6 ha).*	*Greater than 20 % change in the area covered by different plant community types for baseline open and closed mouth conditions.*
Fish	*Retain the following fish assemblages in the estuary (based on abundance): estuarine species (40-60%), estuarine associated marine species (30-50%) and indigenous freshwater species (1-5%). All numerically dominant species are represented by 0+ juveniles.*	*Level of estuary associated marine species drops below 30% of total abundance.* *Level of estuarine species increases above 60% of total abundance.* *Levels of* Mozambique tilapia *increases above 5% of total abundance.* *Absence of 0+ juveniles of any of the dominant fish species.*

3.8 Resource Monitoring Programme (input to Step 8)

A report detailing resource monitoring procedures for application in the Reserve process in estuaries has been completed as part of a Water Research Commission project (Taljaard *et al.*, 2003) and forms the basis for the following methods.

A resource monitoring programmes can be sub-divided:

- Baseline surveys (or studies), the purpose of which is to collect data and information to characterize and understand the ecosystem functioning of a specific system. The baseline studies that are carried out for determination of the Ecological Water Requirements at the comprehensive level may be considered as the baseline data against which the long-term monitoring is carried out on estuaries. If less than the recommended baseline studies for a comprehensive assessment is available, e.g. where a study was carried out at a rapid or intermediate level, *additional 'baseline' data* will be required to produce sufficient baseline data against which future long-term monitoring can be assessed.

- Long-term (or compliance) monitoring programmes, the purpose of which, in this context, is to assess (or audit) whether the Ecological Specifications are being complied with after implementation of the Reserve. In addition, these programmes can also be used to improve and refine Ecological Specification and TPCs through an iterative process.

Although baseline studies and long-term monitoring programmes have different purposes, it is extremely important that long-term monitoring programmes follow on from similarly structured baseline studies. In essence, the monitoring activities selected for the long-term monitoring programme should be derived from the monitoring activities conducted as part of the baseline studies, but implemented on less intensive spatial and/or temporal scales.

A list of abiotic indictors that should always be included in long-term monitoring programmes to allow for proper identification of 'cause and effect' links, in particular links to river inflow and water quality are (Taljaard et al. 2003):

- River inflow (i.e. flow gauging);
- Continuous water level recording at the estuary mouth (recording the state of the mouth, a key driver for most biotic components);
- Water quality of river inflow;
- Water quality and flow rate of effluent discharges into the estuary; and
- Salinity distribution patterns under different river flow ranges.

Aerial photographs, collected on a regular basis, are also considered as key components in the long-term monitoring of estuaries, as these provide useful information on both abiotic and biotic components (Taljaard et al. 2003).

The resource monitoring programme, as part of the determination of the preliminary Ecological Water Requirement studies should, therefore, include:

- Additional 'baseline' requirements, using the recommended baseline data requirements listed in Tables 3.1a to 3.1i as guidance.

- Long-term monitoring programme.

In both instances, the components listed should be prioritised, using for example colour coding, as indicated below:

	High priority, considered as a minimum requirement for a suitable baseline data set or as a minimum list of indicators to sufficiently monitor the effectiveness of the Reserve
	Medium priority will improve the confidence of the assessment or auditing process and should be added to the process if funding is available.
	Low priority, will add to the overall confidence of the assessment or auditing process, but not considered to be a critical indicator.

Criteria that could be considered in the prioritisation for long-term monitoring programmes include:

- The biotic indicators should be particularly sensitive to potential impacts associated with changes in river inflow and water quality, such as state of the mouth, tidal variation, sedimentation/erosion, salinity distribution patterns and deterioration in water quality.

- Biotic components considered to be on a 'trajectory of change' or that are particularly sensitive to abiotic components that are on a 'trajectory of change' (e.g. long term sedimentation), should also be considered for inclusion as indicators in long-term monitoring programmes.

- Biotic components that are of regional or national biodiversity importance are also suitable indicators, particularly when also sensitive to changes in river inflow and water quality.

- Biotic indicators should also be representative of the important food chains present in a particular system.

- The selection of biotic indicators should also present a balance between indicators that provides 'early warning' signals and those that reflect longer-term, more cumulative effects. For example, fish are often considered to be useful 'early warning' indicators, while macrophyte distribution patterns are often better indicators of cumulative, longer-term changes in estuaries.

- Biotic indicators should include economic important indicators where relevant.

The following details need to be provided as part of the long-term monitoring programme:

- Selection of indicators, motivated in terms of the relevant Ecological Specifications and TPCs
- Monitoring actions and temporal and spatial scales at which monitoring actions need to be executed
- Estimated human resource requirements to execute the resource monitoring actions.

The following can be used as guidelines in the design of long-term resource monitoring programmes for different abiotic and biotic components, should these be selected as indicators (Taljaard et al., 2003):

HYDRODYNAMICS	***Flow recording of river inflow***
	Water level recordings at mouth
	Aerial photos
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1c)*
SPATIAL	*As for Baseline data (see Table 3.1c)*
TEMPORAL	*Flow recording of river inflow: Continuous*
	Water level recordings at mouth: Continuous
	Aerial photos: Annually

SEDIMENT DYNAMICS	***Bathymetric/topographical surveys and grab samples***
	Sediment loads
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1b)*
SPATIAL	*As for Baseline data (see Table 3.1b)*
TEMPORAL	*Bathymetric/topographical surveys and grab samples: Every 3-6 years, depending on the time scale of dominant sedimentation/erosion processes in an estuary, as well as after flood events.*
	Sediment loads: Daily records

WATER QUALITY	***River inflow***
	Effluent discharges
	Water quality in estuary
	Sediment surveys of toxic substances
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1d)*
SPATIAL	*As for Baseline data (see Table 3.1d)*
TEMPORAL	*River inflow: At least monthly*
	Effluent discharges: Should be licensed under the National Water Act where operators are required to monitor effluent volume and composition. Spatial scale, e.g. daily or weekly will depend on the variability in effluent composition overtime.
	Water quality in estuary: Samples to be collected when related biological sampling surveys (requiring water quality data for interpretation) are conducted.
	Sediment surveys of toxic substances: Once every 3-6 years

MICROALGAE	***Phytoplankton (water column)*** ***Benthic microalgae***
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1e)*
SPATIAL	*As for Baseline data (see Table 3.1e)*
TEMPORAL	*Two years after implementation conduct a summer and winter survey followed by a summer and winter survey every 3 years thereafter.*

MACROPHYTES	***Aerial photos, transects and quadrats***
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1f)*
SPATIAL	*As for Baseline data (see Table 3.1f)*
TEMPORAL	*Two years after implementation conduct a summer survey, followed by a summer survey every 3 years thereafter (where aerial photographs are available for intermediate years these should also be analyzed). Temporarily open/closed system preferably sampled in stable open phase.*

INVERTEBRATES	***Zooplankton*** ***Benthic invertebrates*** ***Macrocrustaceans***
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1g)*
SPATIAL	*As for Baseline data (see Table 3.1g)*
TEMPORAL	*Two years after implementation conduct a summer and winter survey followed by a summer and winter survey every 3 years thereafter.*

FISH	***Seine and Gill net sampling***
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1h)*
SPATIAL	*As for Baseline data (see Table 3.1h)*
TEMPORAL	*Permanently open estuaries: Two years after implementation conduct as a summer and winter survey, followed by a summer and winter survey every 3 years thereafter.* *For temporarily open/ closed estuaries, summer and winter surveys to be conducted within a 3-year period to ensure that conditions representative of stable open and closed phases are captured.* *Sampling should be done immediately after any fish kill, followed by another 1-2 months after the event. This should be budgeted for in a contingency fund.*

BIRDS	***Full bird counts***
SAMPLING PROCEDURE	*As for Baseline (see Table 3.1i)*
SPATIAL	*As for Baseline data (see Table 3.1i)*
TEMPORAL	*Conduct a summer and a winter survey every year.*

REFERENCES

BEGG, GW (1984) The Estuaries of Natal. Part 2. *Natal Town and Regional Planning Report* **55**. 631 pp.

COLLOTY, BM, ADAMS, JB and BATE, GC (2001) The Botanical Importance Rating of the estuaries in the former Ciskei/Transkei. *Water Research Commission Report* **TT 160/01**. pp 119 + appendices.

COSTANZA, R, D'ARGE, R, DE GROOT, R, FARBER, S, GRASSO, M, HANNON, B, LIMBURG, K, NAEEM, S, O'NIELL, RV, PARUELO, J, RASKIN, RG, SUTTON, P and VAN DER BELT, M. (1997) The value of the world's ecosystem services and natural capital. *Nature* **387**:253-259.

CSIR (1991) The situation of waste management and pollution control in South Africa. Report to the Department of Environment Affairs bythe CSIR Programme for the Environment, Pretoria. *CSIR Report* **CPE 1/91**. Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF) (1999) Water resource protection and assessment policy implementation process. Volume 5: Resource directed measures for protection of water resources: estuarine ecosystems component. Report No. **N\31\99.** Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). (2000) Water use authorisation process for individual applications. Edition 1: Final Draft for implementation and use. Revision 3. Pretoria. ISBN 0-620-26602-3.

DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM (DEAT) (1998) Guideline document: EIA Regulations. Implementation of Sections 21, 22 and 26 of the Environmental conservation Act. Pretoria: Department of Environmental Affairs and Tourism.

LAMBERTH, S. and TURPIE, J (2001) The Role of Estuaries in South African Fisheries: Economic Importance and Management Implications. *Water Research Commission Report* Report no. **756/2/03.**

MANDERS, M (2001) The value of estuaries. In Breen, CM & McKenzie, M (eds.) *Managing estuaries in South Africa: An introduction*, pp 2 – 9. Pietermaritzburg: Institute of Natural Resources.

MANDERS, M, TURPIE, JK and LAMBERTH, SJ (2001) *Decision support in estuary management: A role for economics.* Pretoria: Water Research Commission.

TALJAARD, S, VAN NIEKERK, L, HUIZINGA, P and JOUBERT, W (2003) Resource monitoring procedures for estuaries for application in the Ecological Reserve determination and implementation process. *Water Research Commission Report* No. 1**308/1/03**. Pretoria.

TURPIE, JK with contribution from ADAMS, JB, COLLOTY, B, JOUBERT, A, HARRISON, T, MAREE, W, TALJAARD, S, VAN NIEKERK, L, WHITFIELD, A, WOOLDRIDGE, T, LAMBERTH, S, TAYLOR, R, WESTON, B and MacKAY H (2000) Classification and prioritisation of South African estuaries on the basis of health and conservation status for determination of the estuarine water reserve. A report submitted to the Department of Water Affairs and Forestry: Social and Ecological Services. Pretoria.

TURPIE, JK., ADAMS, J.B., JOUBERT, A., HARRISON, T.D., COLLOTY, B.M., MAREE, R.C., WHITFIELD, A.K., WOOLDRIDGE, T.H., LAMBERTH, S.J., TALJAARD, S. & VAN NIEKERK, L. (2002) Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA. 28: 191-206.

TURPIE, JK. (2004) Improving the biodiversity importance rating of South African estuaries. Unpublished report to the Water Research Commission.

TURPIE, JK and CLARK, B. (2007) The health status, conservation importance and economic value of Temperate South African estuaries and development of a regional conservation plan. C.A.P.E. Regional Estuarine Management Programme.

TALJAARD, S., VAN NIEKERK, L., HUIZINGA, P. and JOUBERT, W. (2003) Resource Monitoring Procedures for Estuaries. For application in the Ecological Reserve Determination and Implementation Process. Water Research Commission Report No.**1308/1/03**. Pretoria.

WARD, CJ and STEINKE, TD (1982) A note on the distribution and approximate areas of mangroves in South Africa. *South African Journal of Botany* **1**: 51-53.

WHITFIELD, AK (1992) A characterisation of southern African estuarine systems. *Southern African Journal of Aquatic Sciences* **12**: 89-103.

APPENDIX A

PREVIOUS ESTUARINE FLOW REQUIREMENT (EFR) METHODOLOGY

Senior Author:

Dr Alan Whitfield, Southern African institute for Aquatic Biodiversity

Contributing Authors:

Piet Huizinga, Private Consultant, Stellenbosch
Ms Susan Taljaard, CSIR, Stellenbosch
Ms Lara van Niekerk, CSIR, Stellenbosch

A.1 Introduction

The National Water Act (Act 36, 1998) that was implemented in 1999, makes provision for a Reserve to be determined prior to authorisation of water use. The Reserve is the quantity and quality of water required to satisfy basic human needs, considering both present and future needs and to protect aquatic ecosystems in order to secure ecological sustainable development and use of the resource. Protocols related to the determination of the Reserve are being developed at three levels, namely

Desktop Estimates: A desktop study to feed information into the national water balance model, which is part of a separate project, being undertaken by the DWAF. Planning estimates are intended to give an initial indication of the water availability in the country and could 'flag' sensitive and over-utilised catchment areas, or areas where demand will exceed or already exceeds available water supply. Desktop estimates may not be used to issue water- use authorisations.

Rapid determination: A desktop study (supplemented with limited field work), the goal of which is to provide a Rapid Reserve determination. Because of the limited information, this determination often has a low level of confidence. However, the determination must be scientifically based and legally defensible.

Intermediate determination: Limited specialist field studies involved which has to been interpreted by experienced specialists. The confidence level of the estimation is medium and the process could take in the order of two months to complete.

Comprehensive Reserve: This often involves intensive fieldwork and data collection, and interpretation by experienced specialists in the necessary fields. This determination aims at attaining a reasonably high-confidence determination of the water quantity and quality required for the Reserve.

The purpose of this document is to describe the methodology currently used by members of the Consortium for Estuarine Research and Management in estimating the Estuarine Flow Requirements (EFR) for the Department of Water Affairs & Forestry.

At the outset it is important to realize that estuaries do not only have one water source (i.e. the river), they also receives water from the sea. This complex hydrodynamic interaction between the river and sea has major implications for the state of an estuary mouth and hence the organisms that live in or around that particular estuary. Consequently, changes associated with a reduction in river inflow to an estuary cannot be simplified to a linear process. To a certain extent a linear approach prevailed in the early attempts by the Commission of Enquiry into Water Matters (Department of Water Affairs 1986) and others (e.g. Jezewski & Roberts 1986) to estimate the freshwater requirements of South African estuaries. Subsequent experience has shown that the values recommended by these studies are grossly inadequate to meet the physical, biological and ecological needs of our estuaries.

The main purpose for estimating EFRs is to provide decision-makers with a means of quantifying the water quantity (and quality) requirements of the biophysical environment of an estuary. It is important to understand at the outset that any reduction in river inflow to an estuary will result in change, albeit very small. However, the underlying goal of any EFR is to prevent measurable adverse effects on the ecosystem and, where a system is already in a degraded state, to recommend measures to improve the future management condition of that estuary.

A major threat of reduced river inflow is the risk of reducing natural variability in driving components (i.e. hydrodynamics, sediment dynamics and biogeochemistry) which, ultimately, play an important role in determining the biodiversity and processes operating in an estuary. However, the crucial decision that needs to be made in terms of EFRs is to predict at what river flows, or ranges of river inflows, these changes start to have significant effects on the biophysical environment of the estuary. By simulating the physical behaviour of a system under different river flow scenarios and assessing the probable responses of the various biotic components to these conditions, it becomes possible to identify when the estuary is likely to show rapid deterioration in it's ecological processes. These scenarios can then be used to estimate the amount of base flow, freshettes and flooding the system requires to remain in a particular management class (or be elevated to a higher management class). This is the underlying logic which underpins the current EFR methodology

A great advantage of the scenario-based approach is that where future developments scenarios are available these can be tested in terms of predicted impacts on the estuarine environment. Unfortunately, most assessments are done in the absence of future development scenarios, with the result that opportunities to assess the impact of future water resource development projects is lost.

A.2 Pre-feasibility Phase Process

EFR Project Co-ordinators, together with other estuarine scientists in South Africa, have been refining the protocol used for estimating EFRs over the past few years. Each study invariably throws up new challenges which have to met by adapting the methodology in one or more ways. The description of the EFR process given here is therefore a 'state of the art' assessment and will be subject to change and upgrading as new issues and problems arise.

A.2.1 Planning meeting

Once the contract to undertake an EFR has been awarded and signed by the Project Leader/Co-ordinator, a planning meeting is held between the Project Leader (key members of the EFR team may also be included in this meeting), Contractor and DWAF. At this meeting the EFR program and time schedule is dealt with and any specific issues or potential problems relating to the study are discussed.

A.2.2 Available Information

A preliminary list of information on a particular estuary can be obtained from WRC Report No. 577/1/95 (Available Scientific Information on Individual South African Estuarine Systems). An updated version of this report is available in electronic format from Dr A.K. Whitfield at the JLB Smith Institute of Ichthyology and will soon be placed on the Consortium for Estuarine Research and Management web page (www.ru.ac.za/cerm/index.html). However, the above database does not cover inaccessible 'grey' literature which certain individuals and organizations may possess.

A.2.3 Run-off Scenarios

In order to estimate the EFR of an estuary it is crucial to understand what the key indicators and processes in the physical, chemical and ecological functioning of the system are, as well as the influence of these on one another. Since river flow is a key parameter in the setting of the Reserve and governing the behavior of an estuary, this component is examined at the outset.

From an EFR perspective river inflow into an estuary can broadly be divided into:

- seasonal base flows, referring to the river inflow that mainly influences mouth conditions, as well as natural variability in physical dynamics and water quality.

- floods and freshets, referring to river inflow (usually flood peaks) required to maintain the sediment erosion/deposition equilibrium in the estuary, generally on a longer time scale.

To estimate changes in an estuary as a result of reduced river inflow, simulated run-off scenarios are required. Changes in hydrodynamics (water movement patterns), sediment dynamics and water quality (biogeochemical and microbiological parameters) are often important driving forces in, for example the changes observed in ecological components and other designated uses. As a result processes or activities can typically be divided into:

- Physico-chemical (driving) components
- Biological (ecological response) components
- Other components (e.g. recreation, mariculture)

Ideally, DWAF needs to provide realistic water abstraction scenarios, obtained from projections of future water needs. Presently, this information is supplied in the form of monthly simulated run-off data, although it is envisaged that eventually daily run-off simulation will be required as our understanding of the systems and assessment and prediction techniques become more sophisticated.

In the absence of realistic future run-off scenarios, hypothetical scenarios can be generated and the behavior of the estuary to each of these is then assessed.

To be able to assess the extent to which proposed development scenarios may alter the functioning of an estuary from the present state, it is also necessary that simulated run-off be supplied for present day conditions (or current status). Any change or impact which may have occurred in the system owing to present development, will obviously provide valuable 'calibration information' in predicting future change. For this reason, it is also important that simulated run-off data be supplied for the natural conditions (or reference conditions), i.e. before any development in the catchment.

It should be noted that for all scenarios used, flows are presented in m^3/s and not million cubic meters per month as is the norm, since ecologists need to be able to related their findings to the former units.

A.2.4 Specialist studies

In order to assess the biophysical functioning of an estuary, and the predicted impacts of proposed developments or hypothetical reductions in river flow on each component, a number of relevant specialist studies are commissioned. These studies usually include field work but may be restricted to a desktop report, dependent upon the availability of already published data (see section E1.2.2). Ideally, the specialist studies on the 'driving components' (hydrodynamics, sediment dynamics, water quality) should be conducted first, followed by specialist studies on the ecological components. In reality, time frames often necessitate simultaneous studies on both the biotic and abiotic components.

To guide specialists, a framework is provided highlighting important components that should be addressed:

- Define key indicators and processes within each component
- Define interactive processes amongst components
- Describe natural condition and present conditions
- Predict changes as a result of altered flow scenarios
- Evaluate the implications of possible future changes
- Recommended studies to address 'information gaps'

Using the above, anticipated responses of the ecological components under different scenarios are then described. Numerous tools are used to assess these responses, including field measurements, expert knowledge, importance rating indexes, systems models, ecological response models, etc.

With the above guidelines acting as a framework, each specialist assesses which questions can be answered directly from the available literature or data, and which questions require further investigation by means of an on-site visit to the estuary. If a site visit is required then the data collected is processed and included in a specialist report for electronic distribution to all members of the EFR team at least two weeks prior to the specialist workshop.

Hydrodynamics

i. Identification of key parameters and processes

Average seasonal flows (including base flows) play an important role in establishing the hydrodynamic characteristics of an estuary. Although factors such as wave conditions and tidal state are also important, river inflow is considered to be the dominant influencing parameter.

In order to quantify key processes for the interpretation of simulated run-off scenarios and for the calibration of prediction tools, e.g. numerical models (Mike II and Delft 3D), available data sets are analysed. These may include:

- river inflow patterns
- water level variations
- mouth observations (using water level data, aerial photographs, etc)
- estuary bathymetry (cross-sectional data)

Because river inflow is identified as a primary factor in this type of study, data analysis focuses at establishing links between river inflows and hydrodynamic characteristics in the estuary.

ii. Interpretation of simulated run-off data

Results from the above are then used to interpret the simulated run-off scenarios. Within the EFR process, simulated run-off scenarios are interpreted for:

- natural conditions, i.e. before any water were taken from the catchment.
- present conditions, i.e. current dam development, abstraction for irrigation, etc.
- future conditions, i.e. based on realistic or hypothetical future water resource use scenarios.

Interpretations are mainly focused at highlighting:

- changes in low base flows (often critical in keeping the mouth open).
- changes in typical seasonal flows (reflecting variability in hydrodynamic and water quality characteristics).
- changes in seasonal high flows and floods.

The above changes are assessed both in terms of magnitude and frequency.

iii. Prediction of changes in hydrodynamics

The available data set and information on the estuary is also used to calibrate predictions on future changes in hydrodynamic characteristics of the system. A variety of tools can be used to predict change, including:

- expert opinion, based on expert knowledge of hydrodynamic processes
- Mike II, a 1D numerical model, typically applied to well-mixed estuaries.

It is very important to note that the accuracy of any prediction is largely dependent on the quality of the input data, e.g. the accuracy of the simulated run-off scenarios. Because hydrodynamic processes are driving components in estuaries, and because results from these studies need to be extrapolated into anticipated changes in water chemistry, ecological responses and implications on other users of estuarine water, it is crucial that the information be presented in formats that are relevant to those specialists.

Typical information that the ecologists need, in terms of hydrodynamics, include:

- changes in river inflow patterns (e.g. colour-coded simulation tables)
- when and if mouth conditions (i.e. whether it is open or closed) change.
- changes in inundation/water level variations (both in terms of magnitude and frequency).
- changes in water circulation patterns and marine intrusion limits.

Predicted changes for future scenarios are presented relative to natural and present day conditions, to provide specialists with a perspective on change which has already occurred versus expected change.

iv. Future studies

As part of the EFR process, future data needs should also be identified. Monitoring programs are required to validate and refine the interpretations and predictions so as to ensure that management plans are continuously geared towards optimal utilisation of water from the resource.

Depending on the extent of available data, monitoring programs relevant to hydrodynamic processes may include:

- continuous water level recordings (i.e. installation of water level recorders)
- continuous monitoring of river inflow rates (i.e. installation of gauge stations)
- mouth observations (using techniques such as aerial photographs, visual observations, etc)

- cross-sectional surveys (so as to establish changes in sedimentation and to provide input to numerical models).

Sediment dynamics

If sediment erosion/deposition equilibrium in an estuary is disturbed it can either lead to siltation, resulting in the estuary becoming shallower, or it can result in the erosion of important sediment habitats. In estuaries, the sediment erosion/deposition equilibrium is primarily influenced by floods and high seasonal flows. Floods can alter important features within an estuary, such as the bathymetry (e.g. channel depth or the size of intertidal areas) and sediment composition (e.g. sand or mud).

One of the most limiting factors in accurately estimating EFRs is our inability to quantify the role of floods and seasonal high flows (magnitude and frequency) in maintaining this equilibrium. The need for further investigations on this topic has been identified at EFR Workshops and the CSIR is currently addressing this issue.

Water quality

i. Identification of key parameters and processes

In order to predict changes in water quality it is necessary to characterize important water quality processes in an estuary, using system variables such as:

- Temperature
- Salinity
- Dissolved oxygen
- PH
- Suspended solids
- Nutrients
- Toxic substances
- Microbiological indicators

In this characterization it is important to highlight natural variability which may, for example, be as a result of strong seasonal differences. Because river inflow is identified as a primary factor in EFR type studies, it is important to somehow link typical water quality ‘states’ or ‘conditions’ to river inflow patterns.

ii. Prediction of changes in water quality

A number of techniques/methodologies can be used to quantify predicted changes in water quality as a result of reduced river inflows (as described in terms of the simulated run-off scenarios). These include:

- expert opinion, based on available data and predicted hydrodynamics changes.
- numerical models (being investigated by the CSIR).

Because water quality is also treated as a driving component in EFR studies, results from the water quality assessment still need to be extrapolated into anticipated ecological responses and implications on other users of estuarine water. It is therefore crucial that the information be presented in formats that are relevant to those specialists.

iii. Future studies

As stated earlier, future studies should also be identified as part of the EFR. As with hydrodynamics, monitoring programs are generally required to validate and refine our interpretations and predictions so as to ensure that management plans are continuously geared towards optimal and sustainable utilisation of the water resource.

Depending on the extent of available data, monitoring programs relevant to water quality may include:

- monitoring variability in WQ at the estuary 'boundaries ' (i.e. river and sea)
- surveys to establish links between WQ and physical/ecological processes.

Biological components

In most EFR studies, the main biological/ecological components which are addressed include:

- Plants
- Invertebrates
- Fish
- Birds

In many cases these disciplines are subdivided further, e.g. plants (macrophytes, macroalgae, phytoplankton), invertebrates (zoobenthos, macrocrustacea, zooplankton), fish (marine, estuarine, freshwater) and birds (palaearctic migrants, residents).

For each of the above, the following is usually given:

- key indicator species and processes characteristic of each ecological component in the estuary
- background information on the distribution, abundance and importance of the biotic component within the ecosystem.
- influence (quantify as far as possible) of different driving components on the relevant biological constituent
- importance of the estuary to that biotic component in a regional and national context.

In addition, the presence of 'red data' and/or endemic species in the estuary is also given. Where known, the likely response of these species to altered river flow regimes and water quality is also documented.

Socio-economic components

Specialist studies on socio-economic issues have tended to be neglected, primarily through a focus on the Ecological Reserve within the EFR process, a lack of human capacity in this field within the Consortium for Estuarine Research and Management (CERM), and the limited funding levels available for most EFRs.

In South Africa, the recognized uses of estuarine waters (outside of ecology) include:

- recreation/tourism, e.g. swimming, boating and bird watching
- subsistence use, e.g. fish, invertebrates and reeds
- mariculture operations, e.g. prawn and oyster production
- industrial use, e.g. cooling water and salt production.

For each of the above it is necessary to define hydrodynamic and water quality (in terms of chemical and microbiological parameters) requirements so as to ensure that the water remains fit for use. This type of information is from water quality guideline documents. Compliance to user requirements are then tested by comparing constituent related criteria with the predicted changes in hydrodynamics and water quality.

A.2.5 Specialist workshop

To integrate the above information and estimate the freshwater requirements of an estuary, a workshop forum approach is used. At the workshop each specialist provides feed back on their particular component and, during this process, links between different components are highlighted and refined.

An important step undertaken at the workshop is to place the estuary in a present and future management class. Tables (see Addendum 1) are provided to each of the specialists and they assess in which category (A, B, C etc.) their component currently resides. The exercise is then repeated to determine a realistic future management class (FMC) around which the freshwater requirements of the estuary will be structured.

Depending on the availability of realistic future development scenarios, the workshop procedure follows one of two routes:

(A) Future development scenarios available

If future water resource development scenarios are available, considerable effort is expended in assessing the likely consequences of these developments on the estuarine ecosystem. During the feedback and refinement session, the implication of the different development scenarios on the ecological functioning of the estuary is determined and listed, including a rating (a judgement on the severity of the impact) as well as the confidence limit linked to each of the statements.

The success of this integration process is largely dependent on:

- communication and interaction between disciplines.
- strong feed-back loops based on the needs of the ecologists from the driving components, e.g. hydrodynamics.

Following this evaluation, recommendations for inclusion in the management plan is drafted. These would typically include:

- an estimate of the EFR, i.e. the amount and distribution of fresh water to an estuary that would be required to maintain natural physio- chemical and ecological functioning without any marked changes or effects.
- recommendations for the inclusion of water releases from the dam(s).
- future research and monitoring needs.

(B) No future development scenarios available

In the absence of future water resource development scenarios, a series of hypothetical run-off scenarios (e.g. 75%, 50% and 25% of MAR) are simulated and the likely consequences of such river flows on the physical behaviour of the estuary are examined and then discussed in terms of ecological consequences.

Using figures and predicted consequences from the discussions outlined above, each discipline then estimates the monthly base flows (m^3/s) that the estuary would require to maintain healthy functioning for that particular component. The exercise is repeated for both ‘maintenance’ and ‘drought’ years. The recommended base flows are then estimated from two composite tables (one ‘maintenance’ and one ‘drought’) in which all the individual disciplines and their monthly flow requirements are listed. Confidence limits (low = <40%, medium = 40-60%, high = >60%) are given for each month. In recent EFRs annual and seasonal estimates of river flood and freshette requirements have also been documented.

A.2.6 Pre-feasibility phase EFR report

For both types of EFR workshops (i.e. A or B) the preliminary findings from the integration process are presented to the client in the form of a summary report, together with the individual specialist studies which are incorporated as appendices. Each specialist report contains an executive summary, which is used in the EFR summary report.

A.2.7 Monitoring and follow-up studies

Monitoring is defined here as long-term investigations/recording of information (e.g. water level records) that will used by a specialist to inform the EFR process, whereas follow-up studies are conducted over a relatively short time frame and are then written up in the form of a definitive report.

A requirement before the commissioning of a dam or any other development affecting river flows, is the immediate implementation of high priority studies and monitoring programs that have been identified by the EFR team to be critical to improving the confidence associated with the EFR estimate.

A.3 Feasibility Phase Process

A.3.1 EFR Refinement Meeting

Once the initial follow-up studies have been completed a refinement meeting is held in which the EFR estimates from the pre-feasibility phase are reviewed in the light of new physical, chemical and biological data sets arising from the follow-up studies and monitoring program (see section A.2.7).

At this meeting new information on the behaviour of the estuary to changing river flows are discussed, and revised 'maintenance' and 'drought' base flow tables are created. These flows would then be integrated over time using the natural flow duration curve entering the estuary to identify the frequency of drought years. Once this exercise has been completed the final EFR can then be calculated.

A.3.2 EFR Refinement Meeting

EFR (estuary) and IFR (river) investigations are usually conducted simultaneously but independently of one another. If the EFR study is part of a larger catchment investigation of a proposed development, then a matching exercise to ascertain to what extent the river IFR caters for the EFR, is undertaken. If the IFR does not cater for the EFR then the latter takes precedence in terms of river flow requirements by the system.

A.3.3 Yield Analysis

This analysis, which calculates the amount of water that can be removed for human use, is conducted by the consulting engineer and takes into account both the IFR and EFR water requirements. A meeting between key role players in the EFR team and the consulting engineer is undertaken to ensure that the EFR is fully catered for in the yield analysis.

A.3.4 Feasibility Phase EFR Report

This Feasibility Phase EFR Report provides an update on the pre-feasibility phase report. Results from the EFR refinement meeting are presented and copies of all post-pre- feasibility studies are included in the document. Further follow-up studies and monitoring requirements not identified during the pre-feasibility phase are highlighted in this report.

Results from previous EFR studies conducted in recent years are summarized in Addendum 2.

References

Department of Water Affairs. 1986. Management of the water resources of the Republic of South Africa. Government Printer, Pretoria: 488 pp.

Jezewski, W.A. & Roberts, C.P. 1986. Estuarine and lake freshwater requirements. Department of Water Affairs Technical Report No. TR 129: 36 pp.

ADDENDUM 1: TO APPENDIX A

PRESENT STATE CATEGORIES BASED ON CURRENT ECOLOGICAL INTEGRITY STATUS

CATEGORY	DESCRIPTION
A	Unmodified, natural; The resource base has not been decreased; The resource capability has not been exploited.
B	Largely natural with few modification; The resource base has been decreased to a small extent; A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified; The resource base has been decreased to a moderate extent; A change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified; The resource base has been decreased to a large extent; Large changes in natural habitat, biota and basic ecosystem functions have occurred.
E	Seriously modified; The resource base has been significantly decreased; The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically modified; The resource base has been critically decreased; Modifications have reached a critical level and the resource has been modified completely with an almost total loss of natural habitat and biota.

DESCRIPTION OF ECOLOGICAL MANAGEMENT CLASSES

CLASS	DESCRIPTION
A	Unmodified, natural - the natural abiotic template should not be modified; The characteristics of the resource should be completely determined by unmodified natural disturbance regimes; There should be no human induced risks to the abiotic and biotic maintenance of the resource.
B	Largely natural with few modification – only a small risk of modifying the natural abiotic template and exceeding the resource base should be allowed. The risk to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may be slightly higher than expected under natural conditions.
C	Moderately modified - a moderate risk of modifying the abiotic template may be allowed. Risks to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may generally be increased with some reduction of resilience and adaptability at a small number of localities.
D	Largely modified - a large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risks to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may be allowed to generally increase substantially with resulting low abundances and frequency of occurrence.

ADDENDUM 2: TO APPENDIX A

RELEVANT DATA FROM ESTUARINE FRESHWATER REQUIREMENT STUDIES

Viability in both seasonal and long-term flow is of the utmost importance for the maintenance of an estuary ecosystem. Methods have therefore been developed and applied whereby assessments were undertaken of realistic runoff scenarios in terms of long-term (50 - 70 years) data sets. These data sets were based on realistic development scenarios for the catchment and were compiled by qualified hydrologists, taking for example feasible dam construction options into account.

The effects of these scenarios (impacts) on an estuary in the long term were then assessed. Based on this, the acceptability of these development scenarios could be investigated, taking wider aspects into account such as the needs to address demands for water for economical and social reasons.

The major benefit of this approach is that the scenarios investigated are realistic. Another advantage is that the setting of EFR as a mere percentage of the mean annual runoff (MAR) is avoided. Cases do unfortunately exist, where decisions were made on approvals for water abstraction based only on MAR percentages. This is usually not adequate to protect estuarine functions and processes.

In the EFR methodology a cautionary approach was therefore applied for very good reasons. The EFR's undertaken until now normally result in relatively conservative estimates in terms of the mean annual runoff (MAR) as can be seen in Table A.1. The principles of this EFR methodology are used in the Reserve determination for estuaries.

At a workshop held in February 1999 it was decided that data gathered during EFR studies should be investigated towards establishing relationships between a desired level of protection and the water quantity component of the Reserve. The following information was extracted from previous studies (Table A.1):

- Volume of natural MAR
- Permanently open mouth <u>or</u> Temporarily open/closed mouth
- River inflow (range) at which mouth closure is likely to occur (for the temporary open/closed systems)
- Estimated EFR (as % of natural MAR)
- Degree of confidence of the above information.

Although EMC's were not allocated to estuaries during EFR studies, a provisional classes, based on individual expert opinion, were allocated for the purposes of this investigation so as to be able to determine correlation's between EFR's and EMC's (Table A.1).

Important aspect to take into account : Allocation of a present status category lower than A to an estuary is not necessarily as a result of reduced river inflow or reduced river water quality. For example, one of the Pondoland estuaries was given a PES category B not because reduced river inflow had any impact, but because mangroves were exploited. The Swartkops estuary is also an example, where PES category D is not so much a result of reduced river inflow, but rather as a result of floodplain developments and waste discharges. It is therefore important to understand why an estuary fits into a specific PES category whether as a result of reduced river inflow and quality or as a result of other changes such as floodplain developments.

TABLE A.1: Relevant Data on Estuaries obtained from EFR studies

ESTUARY	NATURAL MAR (Mm^3)	EST. RIVER FLOW AT WHICH MOUTH IS LIKELY TO CLOSE (m^3/s)	PROVISIONAL PES CATEGORY (base on expert opinion)	EFR (as % of Nat. MAR)	CONFIDENCE
Orange	11 000	< 5 (?)	D	No real EFR done (~50)	-
Olifants	1042	Permanent open	B (changes in small and medium floods)	55	< 40%
Berg	903	Permanent open	C	No proper EFR was done by estuarine specialists	-
Palmiet	255	0.3 - 0.7	B	63	40 - 80%
Great Brak	255 - 310	< 0.5	C	No proper EFR done only a EIA with a given allocation	-
Keurbooms	207	Very sensitive to mouth closure owing to the shallow lower reaches	A/B	~ 90	40 - 80 %
Swartkops	75 - 84	0.2 - 0.5 (not sensitive because its protected)	D (mainly as a result of urban development NOT reduced river inflow)	~ 100	40 - 80%
Sundays	269	Permanent open	C	?	
Great Fish	~ 480	< 1.0 (?)	C	?	
Mvoti	420	0.2 - 0.5	B (heritage site for avifauna)	52	40 - 80 %

APPENDIX B:
INTEGRATION WITH RIVER METHODS

Senior Authors:

Ms Delana Louw, IWR Source to Sea
Ms Susan Taljaard, CSIR, Stellenbosch

B.1 Ecological Reserve Category Process

Both rivers and estuaries have detailed documented processes to determine the PES, the ecological importance and to derive the EC. The basic principles are similar and the two processes are illustrated in Figure B.1.

The dotted line around the second estuary block represents the issue regarding the Trajectory of Change. The estuary method does not at this stage directly address trajectory of change but will investigate the necessity of how this can be incorporated into the process.

B.2 Matching of River and Estuary Results

A suggested approach (that will be tested during the Thukela Reserve study in 2002/2003) is the following:

- Compare the flow requirement allocated to a specific state (EC) of the river with the related estuary EC.
- Establish whether these can be matched or whether minor changes are required that do not impact on the relevant EC for either the river or estuary.
- Make the changes and supply the Reserve scenario for a specific EC (for the river and estuary) in the required format to the yield modeller.

Where the water quantity reserves allocated to different EC do not match for the river and estuary then:

- Compare the flow requirements allocated to different river EC's with those allocated to different estuarine EC's.
- Establish whether any of these can be matched or whether minor changes are required that do not impact on the relevant EC for either the river or estuary.
- Make the changes and supply the results in the correct format to the yield modeller. This matched Reserve scenario will result in an EC for the river and a different EC for the estuary.

Or, if the results are significantly different then:

- The obvious solution, in this instance, will be to accept the highest flow requirement of either the river or the estuary as the reserve, assuming that the required flow are not higher than would have been the case under the Reference Condition. Averaging of flow requirements to set a reserve are not considered to be an appropriate solution, or
- Accept the estuary scenario for a specific EC and extrapolate the resulting river inflow required for this. Determine the consequences and resulting EC for the river and;
- Accept the river scenario for a specific EC and determine the consequences and resulting EC for the estuary.
- Supply both (or more) of these scenarios to the yield modeller as Reserve Scenarios.
- These do not represent matched scenarios. They do however represent a scenario which will supply a Reserve scenario to the river or estuary with an associated description of the consequences on either.

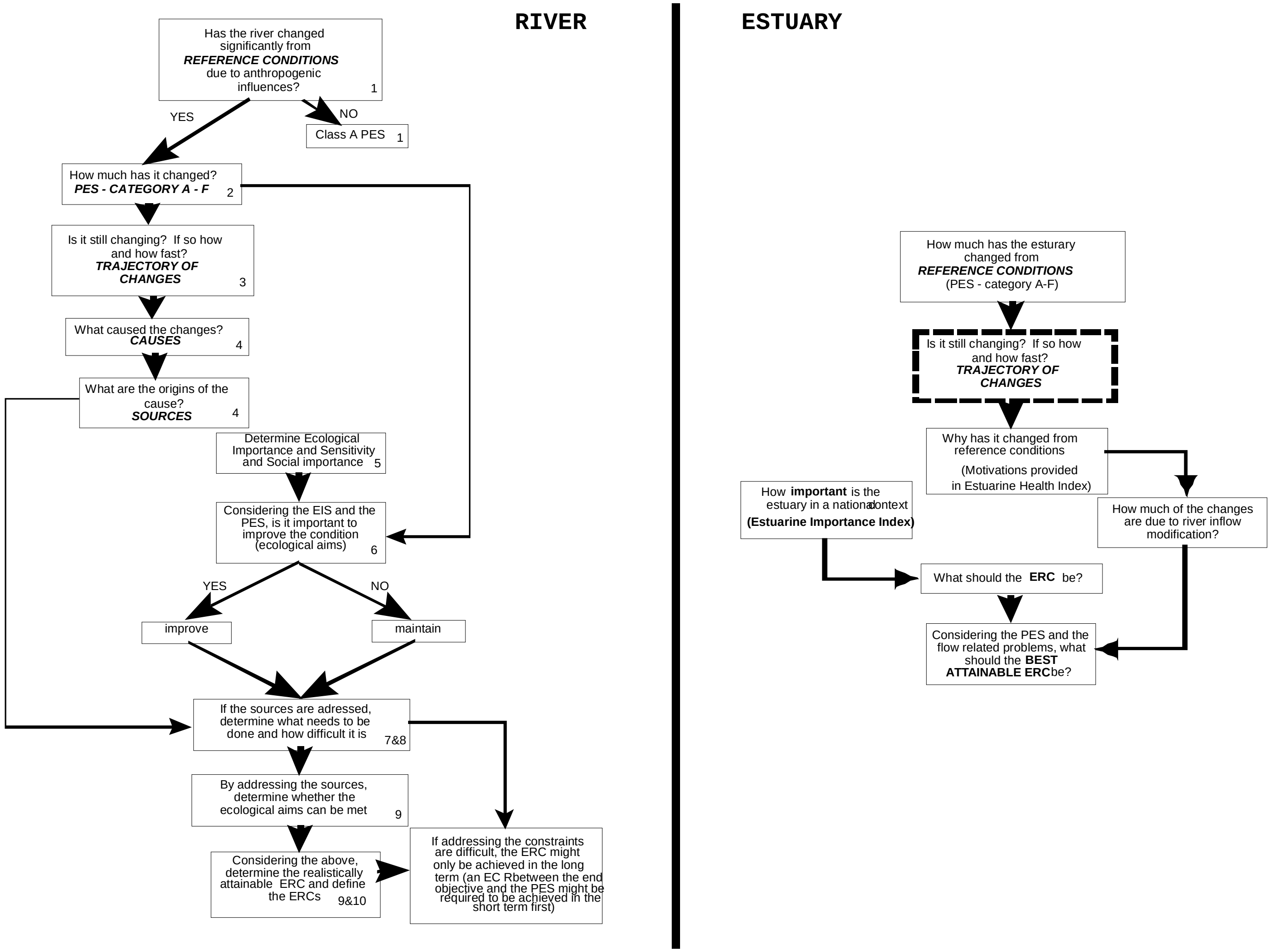


Figure B.1: ***Ecological Reserve Category process***

B.3 Comparison of Estuary and River Results

B.3.1 Past comparison of % of Mean Annual Runoff (MAR)

Previously the results as a % of MAR for the downstream river IFR site (i.e. closest to the estuary) were compared to the EFR results. The comparison usually indicated a marked difference in requirements, mostly a much larger requirement for the estuary. The estuary and river results were provided as different outputs and were therefore not comparable as a % of the MAR.

IFR methods such as the BBM follow a 'bottom-up' approach where, in terms of the ecological requirements, monthly base flow rates are provided for both maintenance and drought flows. These flows are motivated for. Added to these requirements, certain flood events are identified as necessary and motivated for. The monthly flow volumes and flood volumes are added and the % of the MAR calculated. This does NOT reflect a realistic flow scenario, which includes wetter and drier periods as well as all the additional flows that will pass the IFR site over and above those flows specified. These are therefore not modelled / realistic flow regimes which include all the incidental flows over and above requested and motivated for. It also does not include floods larger than, for example the 1:3 year event. These large events are important for the functioning of the ecosystem, but as it is assumed that these cannot be controlled, limited emphasis is made on motivating for these flows. This assumption, however, needs to be verified as major dam developments may strongly reduce the occurrence and magnitude of very large floods in which case the requirements for such large floods should be assessed.

Due to the complex dynamics of estuaries, methods for assessing flow requirements follow a scenario based approach (top-down approach) rather than the bottom-up approach. The EFR group is provided with various scenarios (including natural and present day), which are assessed, and the ecological consequences supplied to each scenario. These scenarios represent the output of a yield model such as the Water Resources Yield Model (WRYM) model that provides monthly volumes modelled over a time period, typically 50 to 70 years. The % of MAR is calculated based on these realistic flow scenarios which include all flows that will reach the estuary and does not include only specific identified flow blocks such as in the rivers approach. Inherently, if these % of the MARs are compared, the results of the estuary would appear higher. This however does not mean that the estuaries per se require more water. Additionally, the estuarine methodology recognises the requirement for large floods.

B.3.2 Rationale for Differences in Flow Requirements for Rivers and Estuaries

Estuaries are driven by both catchment-derived runoff and seawater intrusion, unlike river that are only influenced by catchment-derived runoff. The responses to stressors such as decreased freshwater flows are therefore vastly different between estuaries and rivers.

In estuaries, river inflow patterns (i.e. water quantity) do show strong correlation with important hydrodynamic and sediment characteristics, such as state of the mouth, amplitude of tidal variation, water circulation patterns and sediment deposition/erosion. However, the relationships between these characteristics and river inflow are generally not linear, but often rather complicated to interpret, owing to the influence of the sea. The manner in which these characteristics are influenced by river flows is often also not the result of a single flow event, but rather that of characteristic flow patterns occurring over weeks or months.

In addition, marked differences exist between the chemistry (or water quality) of river water and seawater, particularly in terms of system variables (e.g. salinity, temperatures, oxygen levels, pH and suspended solids) and *nutrients* (e.g. nitrate, ammonium, phosphate). As a result, river inflow (i.e. water quantity) also have a strong influence on water quality characteristics of estuaries (in addition to the water quality of river inflow). The water quality characteristics along the length of the estuary, therefore are often driven by the quantity of river water entering the estuary during that period.

It can therefore be argued that estuaries, having two counter-acting water sources, in general are 'more sensitive' and less robust than rivers to changes in river inflow and to accommodate this, often require a higher % of the natural flow regimes.

In estuaries there is a much larger buffer or delay-effect between river inflow patterns and their effect on abiotic parameters than in rivers. This, in addition to the complex relationship between river inflow patterns and processes in estuaries, requires a much more holistic and processed-orientated approach for setting the reserve for estuaries.

B.3.3 Scales of data collection

Both rivers and estuaries have different data requirements for the three levels of Reserve determination methods. These are however not necessarily comparable in effort and cost due to various complexities; some of which are mentioned below:

- Calibrating the relationship between river inflow and saline penetration in estuaries requires measurements under different flow conditions even at the intermediate level.

- The river study area usually includes an extensive study area (main river and tributaries), which includes various IFR sites, each of which requires site-specific data collection. This limits the amount of data that can cost-effectively be collected. (e.g. the Thukela Comprehensive Reserve study addresses 16 IFR sites). Therefore, even at the comprehensive level, budgetary limitations limits the amount of data that can be collected by river specialists at a specific IFR site. On the other hand, estuaries are complicated systems with the added consideration of the seawater inflow and associated hydrodynamics and water quality, which requires intensive surveys to provide results at an adequate confidence level.

- The Rapid ecological reserve determination should usually be applied when the proposed development will mainly impact on low flows, not flooding, e.g. single point abstraction. Based on this assumption, and acknowledging the risk involved, the river methods use only the key in stream specialists, focussing on low flow impacts. The estuarine components however all play a role under all flow conditions and the estuarine Rapid ecological reserve determination therefore requires the full (apart from sediment dynamics which is usually only considered during the Comprehensive ecological reserve determination) suite of disciplines.

B.3.4. Desktop Model: Potential for Similar Estuarine Developments

The Desktop model is used for planning purposes to accommodate the myriad of rivers for which no IFR or Reserve results are available. Previous medium to high confidence IFR results were used to identify environmental water requirement trends in different hydrological regions. These results are of low confidence and, as no EFR results were used to calibrate the model, NOT applicable for estuaries. The potential for using existing EFR results to develop a similar model has been questioned. Taking into account that there are only about 260 estuaries of which a large number of different types of estuaries will have to be assessed to allow for such a model, it is doubtful whether such an exercise will be cost-effective. A proposed alternative would be to undertake a desktop planning estimate for estuaries and to define EFR estimates for each estuary, rather than extrapolating from the limited existing results. Such an approach is currently being explored.

APPENDIX C: DETAILED DOCUMENTATION ON ESTUARINE HEALTH INDEX

Senior Author:

Dr Jane Turpie, Anchor Environmental Consultants, Cape Town

Contributing authors:

Prof Janine Adams, Nelson Mandela Metropolitan University (NMMU), PE
Dr Brian Colloty, formerly NMMU
Dr Alison Joubert, University of Cape Town
Trevor Harrison, formerly CSIR, Durban
Ralton Maree, MCM, DEAT
Susan Taljaard, CSIR, Stellenbosch
Lara van Niekerk, CSIR, Stellenbosch
Dr Alan Whitfield, JLB Smith Institute
Prof Tris Wooldridge, NMMU
Steve Lamberth, MCM, DEAT
Ricky Taylor, Kwazulu-Natal Nature Conservation
Pat Morant, formerly CSIR, Stellenbosch
Adnan Awad, MCM, DEAT
Barbara Weston, Department of Water Affairs and Forestry
Dr Heather MacKay, formerly CSIR, Pretoria

C.1 Introduction

Each estuary will be classified in terms of its present condition and the desired future condition. These conditions are termed Present Ecological Status (PES) and Ecological Category (EC), respectively. It is proposed that the PES is defined on the basis of 'Integrity' or 'Health' (i.e. present condition) and that EC of estuaries should be defined on the basis of PES and 'Importance'. The latter process should also take into account modifying determinants, such as protected area status, and restorability.

Health is used to describe an estuary's condition. That is, we wish to know to what extent an estuarine state differs from its pristine condition (= “reference condition”). Thus a measure or index of estuarine health should reflect the degree to which the present condition of an estuary deviates from its reference condition. The term 'integrity' is used in the classification of rivers. Integrity implies an unimpaired condition or the quality or state of being complete or undivided (Karr 1992). However, among the estuarine research community, it is generally agreed that the word integrity encompasses more than just health (= condition), and health is a more appropriate term to describe what it is we are measuring (see also Costanza et al. 1992). The term health is thus used throughout this document for clarity, although it is acknowledged that the term may revert to ‘integrity’ in order to be consistent with other areas of RDM.

Probably the most challenging aspect that we face with regard to developing a health index, is not only determining the appropriate criteria, their calculation and weightings, but the issue of working with limited data from **dynamic estuarine ecosystems**. The assessment of ecological integrity and importance is riddled with the dogma of stable systems and climax communities (e.g. Ulanowicz 1992). Many of us are working with data sets which represent one-off measurements of abiotic or biotic aspects of estuaries, while knowing that for many of these aspects the variability and medium to long term dynamics are very poorly understood. In assessing ecosystem health in particular, we need to recognise the difference between dynamic and unidirectional change. Shifts in dynamic state are far more difficult to detect.

The fact that estuarine systems undergo significantly greater dynamic changes than river systems means that they are likely to be more resilient to disturbance than rivers. This would suggest that rivers have a fairly good potential for restoration. Severe degradation of an estuary may involve a shift from dynamic change to dominantly unidirectional change. The loss of dynamic function *per se* may thus constitute an important measure of degradation in estuarine health.

The Present Ecological Status of an estuary is a measure of its present condition or 'ecological status', and should thus be defined on the basis of Estuarine Health. Six classes can be broadly described as follows (Table C.1).

Table C.1: Ecological Management Categories

PES Category	***Description***
A	*Unmodified, natural*
B	*Largely natural with few modifications*
C	*Moderately modified*
D	*Largely modified*
E	*Highly degraded*
F	*Extremely degraded*

In developing an index, an important challenge lies in finding measures to signify these different states which are sufficiently robust that different practitioners will come to the same categorisation. The index will measure the degree to which present conditions resemble pristine conditions. The reference and present conditions will be determined for:

1. Hydrology
   -monthly average base flow, timing and frequency of freshets and floods,
2. Hydrodynamics and mouth condition
   - including timing, frequency and duration of closure,
3. Water chemistry
   - salinity in relation to freshwater inflows,
   - axial salinity gradient and vertical salinity stratification,

- temperature, dissolved oxygen, pH, turbidity,
- nitrate and phosphate concentrations

4. Biological attributes
   - microalgae
   - macrophytes
   - zooplankton
   - macroinvertebrates
   - fish
   - birds

The reference state is predicted by a multidisciplinary group of estuarine scientists based on the present status of the estuary and knowledge of the impacts that affect the system. Expert knowledge, local knowledge, historical data and analysis of measured historical trends are all used to build up a “picture” of the probable reference conditions. The above parameters thus form the potential basis from which we can create an **index of estuarine heath**.

C.2 Existing indices: summary, critique and applicability to RDM

C.2.1 "Community Degradation Index"

The first index of estuarine health was developed by Ramm (1988, 1990). This Community Degradation Index (CDI) compares the observed fish community (species richness) with that which would have occurred prior to degradation.

C.2.2 The original "Estuarine Health Index"

After the development of the CDI, it was acknowledged that other factors should also be taken into account in measuring ecosystem health (Cooper *et al*. 1994). The rationale was that whereas the fish community is likely to reflect estuarine health to a certain extent, there are also water quality and aesthetic aspects whose degradation may not be reflected in that community. The estuarine health index was thus devised, which is the sum of three separate indices:

- Biological Health Index,
- Water Quality Index, and
- Aesthetic Quality Index.

The index sparked a series of sampling around the country, and has now been applied to a large number of estuaries, and the results are summarised in numerous reports (e.g. Cooper *et al*. 1994, Harrison *et al*. 1994).

The **Biological Health Index** developed by Cooper *et al*. (1994) is based on the Community Degradation Index. Whereas the latter measured the degree of *dissimilarity* (or degradation), the Biological Health Index adapted the CDI to reflect the degree of *similarity* to pristine conditions (or health).

Calculation of the Biological Health Index required the development of a reference list of fish related to each group of estuaries, and this was done by consulting available records and pooling the species list for estuaries of the same physical character (Cooper *et. al* 1994). The Biological Health Index was then calculated using the following formula:

$$BHI = 10(J)[Ln(P)/Ln(Pmax)]$$

where J is the number of species in the system divided by the number of species in the reference community, P is the potential species richness (number of species) of each reference community and Pmax is the maximum potential species richness from all reference conditions. The index gives values ranging from 0 (=poor) to 10 (=good).

The main criticism of this index is that it mixes up two concepts: biodiversity importance and estuarine health, and in so doing, also complicates what is actually a very simple measure. The measure of interest here is the proportion of the original species richness remaining in the estuary, which could be expressed as a simple percentage. The complicating factor is the fact that it brings in a measure of how the estuary rates with respect to the total diversity of the region. Thus for example, if 30 out of 50 species remain in an estuary, and a total of 75 species occur in the region, then

$$\begin{aligned} BHI &= 10(30/50)[Ln(50)/Ln(75)] \\ &= 10 \times 0.60 \times (3.91/4.32) \\ &= 10 \times \mathbf{0.60} \times 0.90 \end{aligned}$$

Thus the figure of main interest is that 60% of species richness remains. This figure is downweighted by the fact that this estuary only contains 66% of the total diversity in the region, although the downweighting effect is dampened by the log function. Nevertheless the latter expression reflects a biodiversity importance assessment and actually does not reflect the health of the estuary. The effect of the biodiversity importance component of the index is that an estuary's degradation is magnified if it is also one which contains relatively few species in its pristine state (e.g. a small system).

A second potential concern is that the assessment of health via species richness does not account for the **replacement** of specialist species by other generalist species as ecosystems degrade. Thus the index should at least endeavour to estimate the % change in species composition, not just in species richness.

The **Water Quality Index** was based on House's (1989) recommended method, which was in turn based on thorough review of water quality indices: this is a simple weighted arithmetic mean, as follows:

$$\text{Water quality index} = 1/100\left(\sum_{i=1}^{n} q_i w_i\right)^2$$

where q_i is the rating (score out of 100) for the ith water quality variable; w_i is the weighting for the ith water quality variable, and n is the number of water quality variables. The "1/100" simply has a scaling effect, while the square serves to exaggerate the results: these terms can thus be ignored.

Following the method of House (1989), the water quality rating value for each variable is determined from a rating curve, which relates the observed concentration to a corresponding water quality rating between 0 and 100 (Fig 1, Cooper *et al*. 1994). Each of the conversion graphs is determined by experts with experience in water quality issues. Figure C.1 illustrates a linear relationship, but the relationship could take any shape.

Figure C.1: Transformation of measured water quality variables into a water quality index range

Six water quality variables are used and weighted as follows (Table C.2, Cooper *et al*. 1994). The weights were provisionally assigned by the authors on the basis of estimated relative importance.

Table C.2: Variables and weightings used in the Water Quality Index

Category	*Variable*	*Basis for inclusion*	*Weight*	
Suitability for aquatic life	*Dissolved Oxygen*	*Essential to aquatic fauna*	*0.20*	
	Oxygen absorbed	*Measure of organic loading*	*0.05*	
	Ammonia nitrogen	*Toxicity to aquatic fauna*	*0.10*	*0.35*
Suitability for human contact	*E. coli*	*Evidence for human pathogens*	*0.30*	*0.30*
Trophic status	*Nitrate nitrogen*	*Aquatic plant growth stimulants*	*0.10*	
	Ortho-phosphate		*0.15*	
	Chlorophyll-a	*Indicator of algal growth*	*0.10*	*0.35*

The **Aesthetic Quality Index** was calculated using the following weighted parameters (Table C.3), in which each was scored from 0 (poor) to 10 (pristine).

Table C.3: Parameters and weights used in the Aesthetic Quality Index

Parameter	*Approximate Weight*
Floodplain landuse	*25*
Naturalness of channel margins	*25*
Appearance of floodplain surrounds	*10*
Presence of bridges	*10*
Smell	*5*
Water turbidity or oil sheen	*5*
Exotic vegetation	*4*
Solid waste	*5*
Presence of algal blooms or invasive plants	

The index is applied subjectively on the basis of observation, and bearing the above parameters and weightings in mind. Some concern has been expressed that the index should consider how built up the estuary surrounds are, and how altered the catchment area is. Some of the parameters are rather transient, e.g. smell, and may not be a sufficiently robust measure of health. Some parameters seem to double-count certain measures used in the Water Quality Index. In general, it is felt that this index is rather unfocussed.

Each of the three indices is reduced to a value out of 3.3, and the composite Estuarine Health Index is the sum of these values, giving a score out of 10. In other words, the three indices are weighted equally.

The three components do not include major influences such as hydrological, sediment or botanical changes. The water quality variables do not include all of those considered to be important by the Consortium for Estuarine Research and Management in their proposal for a water quality index, such as suspended solids, and toxins (CERM 1996; see below). Nevertheless, the project has yielded some valuable data and approaches which will be useful in assigning PES to estuaries.

C.2.3 CERM's "physical health index"

CERM's (1996) conservation importance index (see section 4) included an index of **physical health** of an estuary, which was the most rigorously tested component of the index. This index contained a measure of degree of siltation, tidal exchange (=mouth condition), water quality and hydrodynamics (= salinity). The way in which the index and each of its components was scored, was determined using multicriteria decision analysis techniques such as conjoint scoring. Thus scores were assigned as follows:

(1) Siltation (0 - 26)
Little or no erosion in catchment: 26, some erosion: 20, serious erosion so that the estuary may be reduced in size within 50 years: 7; and extremely high erosion: 0.

(2) Mouth condition. (0 - 33)
A matrix of scores was devised to guide the scoring of a change in percentage time the mouth is open in the pristine state to present state, as follows (Table C.4).

Table C.4: Scores used in the CERM Index to indicate the health of estuarine mouth condition relative to the natural state

Natural state	***Current state***				
	100	***75***	***50***	***25***	***0***
100%	*33*	*11*	*4*	*2*	*0*
75	*27*	*33*	*16*	*4*	*0*
50	*23*	*27*	*33*	*13*	*0*
25	*0*	*23*	*27*	*33*	*0*
0	*0*	*0*	*23*	*27*	*33*

(3) Water quality (0 - 19)
This was based on how many out of five indicators were in a healthy state: suspended solids, organic toxins, dissolved oxygen, nutrients (eutrophication), and faecal coliforms. Scores were then assigned as 0, 3, 8, 12, 15, or 19, for zero to all five items in a satisfactory condition, respectively.

(4) Hydrodynamics / Salinity (0 - 22)
This score was devised from two components (out of 15 and 7 respectively). The estuary was first scored as to how many of 3 criteria were in a satisfactory state: the volume of the freshwater component, the frequency/duration of hypersaline events, and changed vertical salinity gradient. The second component was whether the dominance of freshwater flushing has been partially or fully replaced by seawater flushing (yes = 7, no = 0).

C.2.4 "Estuarine Integrity Index"

An integrity index has been developed for river systems, which takes into account two aspects of ecological integrity, namely habitat integrity and biological integrity (Kleynhans 1995). Biological integrity is the ability of the system "to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitat of the region" (Karr & Dudley 1981). Habitat integrity is essentially a broad assessment of the condition of the physical and chemical template to which biota react and adapt, and can be considered as a precursor or indicator of biological integrity (Kleynhans 1995). Thus in the intermediate RDM procedure for rivers, only habitat integrity is assessed in order to provide a rapid approximation of estuarine health (integrity).

Van Driel (1998) has recently proposed a method of assessing estuarine habitat integrity and biological integrity, based on a procedure described for rivers (Kleynhans 1995). The method includes a site visit as well as an assessment of past literature, aerial photographs and maps. Current status is assessed according to deviation from a reference state. The method is summarised below, and its application to the Swartkops estuary is available (van Driel *et. al*. in prep.).

<u>Habitat integrity</u>

This indicates the extent to which an estuary has been degraded by human impacts from its reference condition. Human impacts include:

- physical habitat destruction,
- water quality impacts,
- modification of the flow regime and
- over-exploitation of the natural biota.

In order to improve the accuracy and confidence levels of estuary habitat assessments, assessment criteria have been selected and weightings have been given to each of the criteria (Table C.5). The relevance of each of the impact criteria selected is expanded on at a later stage. The weight reflects the relative effect of the criterion on the whole estuary. Each of the criteria is then given a score, which is combined into a single representative score for the whole estuary (Table C.6). The scoring should be done by a team conversant with the estuary to be assessed, rather than by a single individual. Following extensive discussion of each of the impacts, members of the team should arrive at a common score.

Table C.5: Selection of impacts as criteria of habitat integrity for estuaries, and their relative weights

Impact	*Weight*
Low flow reduction	*12*
High flow reduction	*20*
Tidal flow modification	*12*
Estuary bed modification	*8*
River mouth stabilisation	*8*
Water quality modification	*8*
Translocated (=invasive) vegetation	*8*
Infilling	*8*
Disturbance of biota, e.g. trampling, over-fishing	*8*
Migration barriers (obstructions, e.g. weirs)	*8*

Table C.6: Rating and scoring of impacts according to the estimated severity of such impacts on estuaries

Impact rating	*Description of impact*	*Score*
None	*No discernible impact*	*0*
Small	*Affects < 10% of estuary's length, and impact is small*	*1 - 20*
Moderate	*Affects 10-50% of estuary's length, and impact is clearly discernible*	*21 - 40*
Large	*Affects > 50 % of estuary's length and impact is serious*	*41 - 60*
Serious	*Affects > 50 % of estuary's length and impact is serious*	*61 - 80*
Critical	*Affects entire estuary and the impact is devastating*	*81 - 100*

This scoring system gives high values to large impacts. The weighted scores and are summed and subtracted from 100 so that a high score signifies a more pristine estuary, as follows:

$$\text{Estuary habitat integrity} = |(\sum sw/100)-100| ,$$

where s = score; and w = weight. It is then proposed that the Habitat Integrity score be transformed into a class (PES) as follows (Table C.7).

Table C.7: Transformation of Habitat Integrity score into Present Ecological Status

Class	*Description*	*Score*
A	*Unmodified, pristine*	*100*
B	*Largely natural with a small number of localised impacts*	*81-99*
C	*Limited stretches of estuarine habitat are lost, but the ecosystem is largely still functional*	*61-80*
D	*No more than half of the estuary is impacted and the loss of ecosystem function is evident*	*41-60*
E	*More than half of the estuary has been impacted and ecosystem loss is serious*	*21-40*
F	*Impacts effect the entire estuary with an almost complete loss of ecosystem function*	*0-20*

How does this index work? The scoring system combines a measure of **extent** and **intensity** of each impact. It can be tested using a scenario of a totally polluted inflow - pure oil, but no other impacts. This give a water quality impact of 100, weighted to 8, while all other impacts are assigned a zero impact score. Thus the index determines that such an estuary scores 92 points, which, according to the above, signifies a largely natural estuary. Simple mathematical games will show that the more criteria that are included in the index, the smaller the potential impact that any one can have on the score.

What is the solution? This type of multicriteria index possibly needs a different method of scoring and aggregation, or a different method of interpreting the results in terms of health status. If it can be said that health is erodable by one or a number of variables, then, large impacts should be able to override or dominate the whole score. That is, a full scale impact of any sort should be able to erode significantly into the score. The analogy would be that someone could be rendered equally weak by sustaining a number of small injuries or one very large one.

One way to achieve this result is to simply take the minimum or maximum score, as applicable. Alternatively, this extreme score can be averaged with the overall weighted mean to achieve a less radical effect.

Table C.8: Different approaches to the problem of finding the overall impact of a large number of impacts. In this example, one impact is much greater than the other two.

	Impact Score (extent x intensity of impact)
Impact 1	*100*
Impact 2	*30*
Impact 3	*50*
WEIGHTED MEAN (analagous to above method)	*60*
MAXIMUM	*100*
AVERAGE (MAXIMUM, WEIGHTED MEAN)	***80***

Biological Integrity

Van Driel (1998) has also proposed a system for transforming biotic indices into estuarine integrity classes. This works in the same way as Cooper et al.'s (1994) treatment of water quality variables. Measured values are transformed graphically by the relevant experts to a health score out of 100. These values would then be translated into integrity classes A to F.

C.2.5 "Botanical Importance Rating" index

The Botanical Importance Rating index (Coetzee *et al*. 1996) was not designed as a health index, but it has been applied in this manner. The index, based on summed areas of different habitat types, each weighted by their functional importance, is described in more detail in the following section. The only possible problem with this is that cases of excessive dominance by reeds or eelgrass may yield a higher, rather than a lower score. The implications of the index under different circumstances need to be tested to ensure that it does reflect health.

The index has been used to illustrate the degradation of the Swartkops estuary over time (Colloty *et al*. 1998). For the period prior to 1939, when human impacts were not apparent, an index value was calculated of 397 027, compared to a present score of only 179 936. The present status thus represents 45% of the pristine score, which, assuming a linear relationship between the score and % deviation from pristine, suggests that the estuary has deviated from its pristine botanical state by 55%. It is acknowledged that this relationship may not be linear, however, and that an appropriate transformation equation should be found.

C.3 Recommended approach to assessing estuarine health

The above indices have some problems, but have paved the way towards the formulation of a robust health index required for the RDM process for estuaries. The approach will need to use some or all of the parameters that will be used to determine reference and present conditions. In essence this index simply needs to reflect the overall change in condition relative to pristine condition, which can be assessed separately for each of these different parameters. The main challenge in developing the index is to determine which variables should be included, how they would be used to indicate health (e.g. via transformation of measurements to health scores), and how they should be grouped and weighted.

C.3.1 Identification of criteria or variables for inclusion

Based on the above-mentioned indices and with the aid of two workshop sessions with a range of estuarine experts, a number of **potential variables** for inclusion in a health index were identified, together with a reason for how they would indicate and vary with a change in ecosystem health.

These variables could be grouped as Habitat variables (which include some elements of vegetation) and Biotic (or Biodiversity) variables, but it is better to view them simultaneously in respect of determining the final set.

Table C.9: Possible variables for inclusion in an estuarine health index, and those selected (✓) for inclusion in the index. Reasons for exclusion of variables is explained below.

Abiotic and Biotic Variables			
Hydrology:			
1. Changes in seasonal river inflow patterns	✓	*3. Low flow reduction*	
2. % of natural MAR currently abstracted	✓	*4. High flow reduction*	
Hydrodynamics and mouth condition:			
5. Timing, frequency and duration of closure	✓	*7. River mouth stabilisation*	
6. Tidal flow modification		*8. Water levels*	
Water chemistry/quality:			
9. Salinity			
10. Axial and vertical salinity gradients	✓	*14. Dissolved oxygen*	✓
11. Nitrate and phosphate concentrations	✓	*15. pH*	
12. Suspended solids	✓	*16. Temperature*	
13. Organic and inorganic toxins	✓	*17. Faecal coliforms*	
Physical habitat alteration:			
18. Change in sediment structure and distribution	✓	*21. Migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas*	✓
19. Estuary bed and channel modification	✓		
20. Infilling		*22. Human disturbance of habitats and biota*	
Changes in biotic habitats and communities:			
23. Plants – area or biomass of different communities, community composition, diversity	✓	*25. Fish – community composition, diversity, biomass*	✓
24. Invertebrates – community composition, diversity, biomass	✓	*26. Birds - community composition, diversity, biomass*	✓
27. Change in ecosystem complexity			
Alteration of estuary margins and floodplain and catchment area			
28. Amount of floodplain vegetation remaining		*30. Degree of human habitation and use*	
29. Degree of industrial development within floodplain		*31. Alteration in catchment area. e.g. plantation forestry*	

Many of the variables in Table C.9 are likely to be **correlated** with one another. Inclusion of correlated variables leads to **unnecessary complexity**. When different variables are closely correlated, then a decision as which variables to use will depend on where our ultimate **interests** lie (e.g. concentrate on biotic variables if biological health is the main issue), or which is the more **reliable**, **stable** or **easily measured** parameter. With this in mind, the above variables were discussed in a workshop setting, in order to select those to be used in the health index. The reasons for possible inclusion of each, and for accepting or rejecting the variable are discussed below, and for selected variables, their quantification for use in the index is discussed below.

Hydrology:

Variables 1 and 2 are considered to be the main drivers of estuary systems. Variable 2 (% MAR) is considered as an alternative measure to Variable 1, but should only be used in rapid RDM processes in the absence of understanding of Variable 1. Variable 3 (low flow reduction) is important in that it causes changes the salinity regime and a reduction in open mouth conditions, and variable 4 (high flow reduction) has an important impact in that it impairs scouring, resulting in accumulation of marine and fluvial sediments. However, both 3 and 4 are correlated with variables 1 and 2 and the effects are also reflected in other variables, and they are thus excluded.

Hydrodynamics and mouth condition:

Timing, frequency and duration of closure (variable 5) is important in that it strongly affects abiotic habitats and biological communities found in estuaries. It is fairly difficult to get data, and it is correlated with 1 and 2. Nevertheless it is considered important to include this variable. However, it is agreed that timing is correlated with duration, and thus a measure of overall change in duration would suffice.

Both tidal flow modification (var 6) and water level (var 8) can have serious impacts on habitats and biota, affecting the degree of exposure of intertidal areas and vegetated habitats. However, these variables are correlated with 1 and 2 to a large extent, and are captured in variables of abiotic and biotic habitat changes. Therefore they do not need to be included in the index.

Many South African river mouths migrate along a sandy shore, thereby maintaining a larger estuarine surface area. However, river mouth stabilisation (variable 7) was considered difficult to measure and not sufficiently important to include.

Water chemistry/quality:

Axial salinity gradient and vertical salinity stratification (var 10) was considered to be a very important system driver, and is included instead of var 9 (salinity), as it gives a more detailed picture of change. Salinity patterns are influenced by hydrological and mouth conditions, and thus could be said to be accounted for in the above variables. However, an important aspect is that the above conditions will variously affect salinity patterns, depending on the **type of estuary** (see Whitfield's classification in section 4). Thus the inclusion of a separate salinity variable obviates the necessity of devising different scoring systems in the above variables for different estuary types.

Nitrate and phosphate concentrations (var 11) is included as it positively affects primary productivity in the estuary, and although it is related to variable 2, it is also affected by other inputs.

Suspended solids (var 12) reflect disturbance (erosion) in the catchment area, and change habitat conditions for biota e.g. through increased turbidity. This is considered an important health indicator.

Organic and inorganic toxins (var 13) negatively affect biota. Contamination can be expensive to measure, and toxin levels can be event-related, and thus variable on a short time scale. However, based on existing measures of toxins in inflowing water, coupled with an understanding of estuarine hydrodynamics, it would be possible and desirable to derive estimates of health in this regard.

Dissolved oxygen (var 14), pH (var 15) and temperature (var 16) affect conditions for primary production, and may be affected by conditions in the catchment, e.g. pine plantations, or dams and water transfer schemes. Variables 15 and 16 were excluded on the basis that they are not sufficiently important in determining estuarine health.

Faecal coliform concentrations (var 17) give an indication of suitability for human contact. It was not considered to have a major impact on biota, and thus is not considered important in assessing estuary health.

Physical habitat alteration:

Change in sediment structure and distribution (var 18), such as the mud-sand ratios and bank height, e.g. due to changes in hydrology, have important impacts on biota, and excessive siltation may decrease the ability of floods to scour out estuaries. This variable is probably one of the more difficult to estimate, also being a fairly dynamic aspect of an estuary, but nevertheless is considered important.. In addition, man made changes to the estuary bed and channels (var 19) may also affect estuary habitats.

Infilling (var 20), or reclamation of parts of the area leads to loss of habitat. This is essentially a change in estuary size, which should be reflected in an overall habitat variable (see below).

Obstructions in estuarine migratory routes from the mouth to the head, may prevent some estuarine organisms from completing their life cycles. Other structures impede flow and may also create new habitats for certain organisms. Thus the impact of migration barriers, bridges, weirs, bulkheads, training walls, jetties, marinas (var 21) is considered important to include.

Human disturbance of habitats and biota (var 22), may have major impacts and thus should be included, despite the fact that it may be difficult to quantify these effects. Motor vehicles, pedestrians and farm animals often degrade salt marsh vegetation, reeds and sedges. People and boats trample mudflats. Some estuaries are subject to persistent over-fishing of bait species. Illegal bait-digging, in particular, causes significant damage to mudflat habitats. Because of its somewhat different nature, it is recommended that this variable be kept in a separate category.

Changes in biotic habitats and communities**:**

Biotic variables are response variables, in that they respond to changes in all the abiotic variables (= driver variables) listed in Table C.9. Thus the inclusion of both abiotic and biotic variables in an index could be deemed unnecessary. However, because the relationships between the abiotic and biotic variables are not well understood, and because the biotic response to certain abiotic variables can be slow, it was considered important to include measures of both abiotic and biotic changes in the index. It was generally agreed at the workshop that all of the biotic variables 23 to 26 should be included.

Ecosystem complexity (var 27) is also considered as an important measure of ecosystem integrity. A system which has a complex food web is likely to be more resilient than one with a simple trophic chain. A change in ecosystem complexity would be fairly complex to measure, however, as important changes in the relative sizes of energy flows would not be detectable without extensive study of the system. Thus it will have to be assumed that the degree of change in the different biotic communities adequately reflects the changes to the overall system integrity.

Alteration of estuary margins, floodplain and catchment area**:**

Because the effects of floodplain and catchment developments are captured in several other abiotic and biotic variables, and because these variables are not of primary interest in the context of this work, it is generally agreed that variables 28 to 31 should be excluded. The state of the floodplain vegetation, within the study area will be captured in var 24, and any effects of catchment, industrial and housing development will be reflected in water quality and habitat measures, and in the human disturbance variable.

The scoring system devised on the basis of these criteria (see following sections) was successfully tested on a case study on the Nahoon Estuary, resulting in a few minor revisions which have been incorporated in this document.

C.3.2 The measurement of abiotic variables for inclusion in the estuarine health index

For each variable, it will be necessary to estimate the degree to which the present state resembles the reference condition. To account for cyclical variability, it is important that, in general, the **mean** conditions during pristine conditions are compared with the **mean** conditions at present. The % deviation from pristine state will be estimated for each component variable, which will be taken to be the inverse of % similarity. This means that % deviation cannot exceed 100%, and that it thus is necessary to be able to describe a zero resemblance in each case, in order to scale the observed change. Each score will be calculated to reflect % similarity to the pristine state. The following explanations are illustrated using a hypothetical example (all figures down the right hand margin).

Hydrology:

This score would be calculated on the basis of changes in **seasonal inflow patterns**, estimated on the basis of two parameters, as in Table C.10. Of major interest is the change in medium to high flows, and the concomitant change in months of low flow. Depending on how it is calculated, estimating the % change in conditions would achieve different results depending on whether it was calculated as % increase in low flow months or decrease in high flow months. In order to obviate this problem, a table of scores is given in Table C.11, which will give the same results whether the change in low flow or non-low flow months is considered. This table assumes a linear relationship, in that a change of one month from say one month to two months has the same significance as a change of one month from 11 to 12 months, and that this is the same in either direction. Future tests of this method should explore the possibility of non-linear and asymmetrical functions. In the absence of detailed information on flow patterns, or in permanently open estuaries, the % MAR can be used as a substitute for the change in low flow period. The median (50%ile) low flow months or the total % occurrence of low flow months for the full simulation period may be used to give an indication of the change in the low flow period.

The second parameter is % similarity in the frequency of floods, and this is given a slightly lower weighting in the index than the first. However, since this method is really only suitable for larger catchments or where a detailed analysis of hydrology has been done, an alternative method is provided for estuaries where this is not the case. The alternative is a measure of change in magnitude of major floods that are capable of ‘resetting’ an estuary. Because the magnitude of significant floods differs between estuaries, it is up to the specialist to decide which floods are to be considered in each individual study.

Table C.10 Calculation of the hydrological health score

	Variable	***e.g.***	***Weight***
a.	*% similarity in period of low flows* *e.g. 2 months low flows to 4 months low flows (read score off Table C.11)* ***OR** Present MAR as a % of MAR in the reference state* *Guideline: we recommend the second measure for permanently open estuaries or for estuaries where information on flow levels is limiting*	*83*	*60*
b.	*% similarity in frequency of major floods (floods ≥ 1:20 year for a particular system) (= % of reference flood events still occurring in present state).* *e.g. 4 events to 3 events = 3 / 4 X 100=* *Note: This method is more suitable for larger catchments or where a detailed analysis of hydrology has been done.* ***OR** % similarity in the magnitude of major floods (e.g. 1:20, 1:50 and 1:100) in comparison with the reference condition* *Guideline: Because the link between flood magnitude and sediment dynamics is not easily quantified, follow a precautionary approach by using the reciprocal of the % reduction (or increase for certain urban catchments) of the major flood the most affected by developments in the catchment.*	*75*	*40*
Hydrology health score = weighed mean of a and b		***80***	

Table C.11. Score chart for part (a) of the hydrological health score in terms of change in low flow period.

Current state	***Reference state (months of low flow)***												
	0	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
0	***100***	*92*	*83*	*75*	*67*	*58*	*50*	*42*	*33*	*25*	*17*	*8*	*0*
1	*92*	***100***	*92*	*83*	*75*	*67*	*58*	*50*	*42*	*33*	*25*	*17*	*8*
2	*83*	*92*	***100***	*92*	*83*	*75*	*67*	*58*	*50*	*42*	*33*	*25*	*17*
3	*75*	*83*	*92*	***100***	*92*	*83*	*75*	*67*	*58*	*50*	*42*	*33*	*25*
4	*67*	*75*	*83*	*92*	***100***	*92*	*83*	*75*	*67*	*58*	*50*	*42*	*33*
5	*58*	*67*	*75*	*83*	*92*	***100***	*92*	*83*	*75*	*67*	*58*	*50*	*42*
6	*50*	*58*	*67*	*75*	*83*	*92*	***100***	*92*	*83*	*75*	*67*	*58*	*50*
7	*42*	*50*	*58*	*67*	*75*	*83*	*92*	***100***	*92*	*83*	*75*	*67*	*58*
8	*33*	*42*	*50*	*58*	*67*	*75*	*83*	*92*	***100***	*92*	*83*	*75*	*67*
9	*25*	*33*	*42*	*50*	*58*	*67*	*75*	*83*	*92*	***100***	*92*	*83*	*75*
10	*17*	*25*	*33*	*42*	*50*	*58*	*67*	*75*	*83*	*92*	***100***	*92*	*83*
11	*8*	*17*	*25*	*33*	*42*	*50*	*58*	*67*	*75*	*83*	*92*	***100***	*92*
12	*0*	*8*	*17*	*25*	*33*	*42*	*50*	*58*	*67*	*75*	*83*	*92*	***100***

(Formula: 100-[%occurrence under Reference Condition - % occurrence under Present State])

Hydrodynamics and mouth condition

This is a simple score (Table C.12), which is likely to be a fairly rough assessment accurate to within 20%. In order to score the health implication of a change in duration of mouth closure, CERM's scoring system has been adapted to a scale of 0 - 100 (Table C.13). Intermediate scores may be used as appropriate. In order to assess change in timing, the index uses the % change in the amount of time an estuary is open during **spring** (Aug to Oct).

Table C.12 Calculation of the mouth condition score

VARIABLE	***e.g.***
Change in mean duration of closure e.g. over the simulation period (See Table 3.3b for scoring guide)	*80*
Mouth condition score	***80***
Anthropogenic influence (amended 2008):	
Percentage of overall change in mouth conditions caused by anthropogenic modifications (e.g. artificial breaching 50.% of the 20% change is caused by anthropogenic activities, other than flow)	*10*
Adjusted mouth condition score (attributed only to flow)	***90***

Table C.13. Scoring guideline for change in mouth condition. If the estuary is artificially breached, particularly during inappropriate times, then the score can be adjusted as appropriate.

% open in Natural state	***% open in Current state***				
	100%	***75%***	***50%***	***25%***	***0%***
100%	*100*	*33*	*12*	*6*	*0*
75%	*82*	*100*	*48*	*12*	*0*
50%	*70*	*82*	*100*	*39*	*0*
25%	*40*	*50*	*70*	*100*	*0*
0%	*0*	*12*	*33*	*60*	*100*

***Water quality*:**

This is assessed in terms of the degree of change in five variables (Table C.14). The first variable, salinity distribution, is treated separately from the others. The remaining variables are grouped to form a measure of general water quality. Each of the general variables may lead to an overall change in health, and the index does not average these variables so as not to dampen the effect of any one impact on the score, but the highest impact score is used. Scoring guidelines are provided for each variable. Scores for general water quality variables will be assigned by a water quality specialist on the basis of a combined understanding of concentrations in inflowing river and seawater and hydrodynamics within the estuary.

Table C.14: Calculation of the water quality health score

	VARIABLE	SCORE (e.g.)	WEIGHT
1	Salinity		
	% change in axial salinity gradient and vertical salinity stratification Scoring guideline: Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously modified = 20; completely modified = 0.	60	40
2	General water quality		
a	Nitrate and phosphate concentrations in the estuary Scoring guideline: Unmodified = 100; reduced = score is estimated % of original level; slightly increased = 75; moderately increased = 50; eutrophic = 0.	80	
b	Suspended solids in the estuary Scoring guideline: Unmodified = 100; slightly increased = 75; moderately increased = 50; heavy load = 25; excessive siltation = 0.	40	
c	Dissolved oxygen (mg/l) concentrations in the estuary Scoring guideline: Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously modified = 20; completely modified = 0.	80	
d	Level of toxins in the estuary Scoring guideline: Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously toxic = 20; completely toxic = 0.	80	
	General water quality = Min (a to d)	40	60
	Water quality health score = Weighted mean	**48**	
Anthropogenic influence (amended 2008):			
	Percentage of overall change in salinity caused by **anthropogenic** activity as opposed to modifications to water flow into estuary (e.g. 50% of the 40% change (1) is caused by anthropogenic activities, other than flow)	20	
	Percentage of overall change in nitrate and phosphate caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 20% change in (2a) is caused by anthropogenic activities, other than flow)	10	
	Percentage of overall change in Suspended solids caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 60% change in (2b) is caused by anthropogenic activities, other than flow)	30	
	Percentage of overall change in dissolved oxygen caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 20% change in (2c) is caused by anthropogenic activities, other than flow)	10	
	Percentage of overall change in toxic substances caused by **anthropogenic** modifications (e.g. wastewater discharges) rather than modifications to water flow into estuary (e.g. 50% of the 20% change in (2d) is caused by anthropogenic activities, other than flow)	10	
1	Salinity score excluding anthropogenic effects	80	40
2	General water quality		
a	Nitrate and phosphate score excluding anthropogenic effects	90	
b	Suspended solids score excluding anthropogenic effects	70	
c	Dissolved oxygen score excluding anthropogenic effects	90	
d	Toxic substances score excluding anthropogenic effects	90	
	Adjusted general water quality = Min (a to d)	70	60
	Adjusted water quality health score (attributed only to flow)	74	

***Physical habitat alteration*:**

Two main components make up the physical habitat health score: area and sediment composition of **intertidal** habitat and depth and volume of **subtidal** areas (ie based on channel morphology, and taking degree of sedimentation, and obstruction or constriction into account).

Changes in both of these habitat elements may have been due to changes in water flow into the estuary or **anthropogenic** activities within the estuary, or both. Thus the team is required to estimate the degree to which each of the two component scores is influenced by water flow changes vs within-estuary anthropogenic changes. The **unadjusted score** is used in the health index, and the adjusted score serves to give a fuller explanation of the health status.

Table C.15: Calculation of the physical habitat health score

	VARIABLE	*SCORE*	*WEIGHT*
1	*Resemblance of intertidal sediment structure and distribution to Reference Condition*		
1a	*% similarity in intertidal area exposed*	*80*	*50*
1b	*% similarity in sand fraction relative to total sand and mud*	*60*	*50*
	Mean	*70*	*50*
2	*Resemblance of submerged habitat to Reference Condition: depth, bed or channel morphology* *Scoring guideline: No alteration = 0%, Total alteration = 100%.*	*90*	*50*
	Overall physical habitat health = Weighted mean	***80***	
Anthropogenic influence:			
	*Percentage of overall change in intertidal habitat caused by **anthropogenic** activity as opposed to modifications to water flow into estuary (e.g. 20% of the 30% change (1) is caused by anthropogenic activities, other than flow)*	*20*	
	*Percentage of overall change which in submerged habitat caused by **anthropogenic** modifications (e.g.bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary (e.g. 100% of the 10% change in (2) is caused by anthropogenic activities, other than flow)*	*100*	
1	*Health of intertidal habitat excluding anthropogenic effect (e.g. 20% of 30% change + 70% similarity)*	*76*	*50*
2	*Health of subtidal habitat excluding anthropogenic effect (e.g. 100% of 10% change + 90% similarity)*	*100*	*50*
	Adjusted physical habitat health score (attributed only to flow)	***88***	

C.3.3 The measurement of biotic variables in the estuarine health index

A change in health may be reflected in change in **community composition**, **species diversity** and **biomass**. With increased system perturbation, community composition may change in favour of more opportunistic species, while the numbers and biomass of more specialised species tend to decrease, or one might see a significant change in the trophic composition of a community. Thus a simple measure of species richness or abundance (biomass, area) is not a reliable indicator of health. The index has to be able to reflect changes as positive or negative, accordingly. Given that in most cases, the reference condition is estimated on the basis of modelled outputs and assumed relationships, the parameters within this index can only be estimated with a fairly rough degree of accuracy. It would thus be inappropriate to propose a highly quantitative index such as Shannon diversity to indicate change in biotic communities. It is proposed that three main factors are taken into account: species richness, abundance and community composition (Table C.16). In order to keep the score as simple as possible, the three attributes are considered separately, and the **minimum score** is taken as the indicator of health.

Change in **species richness** should only be measured as the loss of species that were part of the original community, and should not take new introductions into account. The scoring system recommended for species richness has a concave relationship with percentage of species remaining in the system. This reflects the fact that a few valuable, specialist species may be lost with initial perturbation of the system, and it is harder to increase health in terms of number of species when starting from a higher than a lower health level.

Abundance may decrease or increase with a decrease in estuarine health, and this thus is expressed as a % similarity rather than % change. Thus, while a decrease in abundance to 60% of original scores 60, and increase to 130% of original would score 70 (100 – 30% change).

Change in **community composition** is assessed as % resemblance to original composition. The simplest way of estimating this score is to consider the relative abundance of different trophic groups in the community. With better predictive ability, one can extend this to consider shifts in the relative abundance of individual species.

Note that there is no score dealing with overall change in community composition or trophic dominance across all the groups, as this would double-count the change in abundance scores given for the individual groups.

This index should be calculated for macrophytes, microalgae, invertebrates, fish and birds. Again, the points for comparison are the estimated mean conditions during the reference and present conditions, for variables that undergo cyclical or dynamic changes. The **invertebrate health index** would include the water column fauna (zooplankton) as well as benthic and hyperbenthic invertebrates (those living in or on the bottom, and those living close to the sediment, respectively). Although these components are not considered separately, the invertebrate specialist would have to consider both and integrate their health scores into an overall score on the basis of the relative importance of each group.

Table C.16: Calculation of the biotic health score for each biotic group

Variable	***Measurement***	***e.g.***
a. Species richness	*Average species richness as a % of average species richness during the Reference Condition (only consider original species)* *Scoring guideline: 100% = 100, 90% = 80; 80% = 65; 70% = 50, 60% = 35; 50% = 25; 40% = 17; 30% = 10; 20% = 5; 10% = 0*	*90*
b. Abundance	*Estimated % of total number or biomass remaining*	*70*
c. Community composition	*Estimated % resemblance to original composition.* *Scoring guideline: No change = 100%* *Original community totally displaced by opportunistic spp = 0%*	*40*
Macroalgaee / Microphyte / Invertebrate / Fish / Bird community health score = minimum score of a, b and c		*40*

Again, the health of the biotic components may be due partly to changes in **river inflow**, and partly to **human disturbance** within the estuary. The team is thus required to describe the extent to which the changes scored above are due to human activities within the estuary such as trampling, pollution and overexploitation. This produces an **adjusted score** which is only for descriptive purposes and is not used in the overall index.

Table 3.17: Estimating the extent to which biotic health scores are affected by anthropogenic disturbance within the estuary.

Component	***Health score (e.g.)***	***Degree to which change caused by human activity in estuary (%)***	***Adjusted health score (health in absence of human disturbance)***
Microalgae	*70*	*10*	*= 70+((100-70)*0.10) = 73*
Macrophytes	*70*	*40*	*etc*
Invertebrates	*80*	*50*	
Fish	*60*	*70*	
Birds	*70*	*50*	

C.3.4 Construction of the Estuarine Health Index

Construction of an index should be relatively simple. As used in some of the indices described above, I recommend that for each abiotic or biotic variable, we describe the conditions, as quantitatively as possible, that would be regarded as indicative of 0 to 100% of the pristine state. These can then be used as standard guidelines in what is otherwise a dangerously subjective assessment. Without strict guidelines, a method such as this would lead to a huge range of possible assessments by different practitioners, and could not be regarded as robust or legally defensible. Each variable, thus defined as % of pristine state, will be weighted, and then aggregated, possibly using the overriding rule recommended above. The final score, should reflect the state as a % of pristine.

The overall degree of health of the abiotic aspects of the estuary may be considered a measure of Habitat Health or Integrity, while the remaining variables make up the Biological Health Index. The two sub-components are calculated and combined as follows (Table C.18).

Table C.18: Calculation of the Estuarine Health Score

	Variable	**e.g.**	**Weight**
Abiotic (habitat) variables			
1	Hydrology	41	25
2	Hydrodynamics and mouth condition	80	25
3	Water quality	59	25
4	Physical habitat	80	25
1. H**abitat health score** = weighted mean		65	**50**
Biotic variables			
1	Macrophytes	60	20
2	Microalgae	60	20
3	Invertebrates	70	20
4	Fish	60	20
5	Birds	90	20
2. Biological health score = weighted mean		70	**50**
ESTUARINE HEALTH SCORE = weighted mean of 1 and 2		67.5	

APPENDIX D: DETAILED DOCUMENTATION ON ESTUARINE IMPORTANCE RATING

(amended)

Senior Author:

Dr Jane Turpie, Anchor Environmental Consultants, Cape Town

Contributing authors:

Prof Janine Adams, Nelson Mandela Metropolitan University (NMMU), PE
Dr Brian Colloty, formerly NMMU
Dr Alison Joubert, University of Cape Town
Trevor Harrison, formerly CSIR, Durban
Ralton Maree, MCM, DEAT
Susan Taljaard, CSIR, Stellenbosch
Lara van Niekerk, CSIR, Stellenbosch
Dr Alan Whitfield, JLB Smith Institute
Prof Tris Wooldridge, NMMU
Steve Lamberth, MCM, DEAT
Ricky Taylor, Kwazulu-Natal Nature Conservation
Pat Morant, formerly CSIR, Stellenbosch
Adnan Awad, MCM, DEAT
Barbara Weston, Department of Water Affairs and Forestry
Dr Heather MacKay, formerly CSIR, Pretoria

D.1 Introduction

The Ecological Reserve Category (ERC) (formerly referred to as the Ecological Management Class) will be defined as the desired quality (= health) of the system and will be used in determining the ecological reserve. The ERC cannot be permitted to be in a class lower than D and should the present status be either an E or F, recommendations must be made as to how the status can be lifted at least to a D class (Table D.1).

Table D.1. Proposed relationships between Ecological Reserve Category based on an present ecological status, for a comprehensive reserve determination

Present health status: ***Present Ecological Status***	***Desired future health status:*** ***Ecological Reserve Category***
A	*A*
B	*B or A*
C	*C or higher*
D	*C/D or higher*
E	*D or higher*
F	*D or higher*

The level to which Ecological Reserve Category is elevated relative to current status will be motivated on the basis of its present health status (PES) and the **importance** of the system. Thus:

Health	+	*Importance*	$\Rightarrow$	*Future health*
(PES)				*(ERC)*

Importance of an estuary can be considered in a number of ways. This can include biodiversity importance in terms of containing populations of species which are rare or endangered etc, high species diversity, important habitats, unique physical attributes, etc. The notion of importance is usually based on two main concepts:

- **rarity**: this pertains to rare physical types, rare habitats or rare species, where rarity implies scarcity, and means limited abundance or geographical range; and

- **quantity** (=abundance): estuaries are seen as important when they are large, support large areas of habitats, large numbers of species, large populations and are productive.

A third component which should be considered is:

- **ecosystem function** (e.g. nursery areas for marine fish)

Thus an estuary may be considered important when it contains rare elements of biodiversity, large quantities of flora or fauna, or when it provides an important ecosystem service.

In using importance status for determining the EC, it may be argued that the importance of an estuary is <u>influenced</u> by its health status. Thus the question arises as to whether, if these indices are to be combined, we should use the reference condition to determine biophysical importance. Use of the present biophysical importance status, which is determined to some degree by biophysical health, would amount to double counting in a decision process. This is illustrated by using a simple example in Table D.2, where the decision is determined by a combined index.

Table D.2: Example of considering pristine or present importance status in allocating EC

Biophysical health (% of pristine)	***Biophysical Importance***		***Integrated score (BH x BI)***	
	Pristine state	*Present state*	*Based on Pristine state*	*Based on Present state*
60%	*100 points*	*72 points*	*60*	*43*

A point that has been raised is the possibility of an altered state being more important than the pristine state. An example of this might be the Mhlatuze system, where a change in hydrology has allowed colonisation of large areas by mangroves, with the result that this estuary now contains a major proportion of the country's mangroves. However, a more holistic look at the estuary would establish that the hydrological changes have also led to an equally or more important loss in ecosystem function, in that important outputs to the marine environment have been lost.

Of further interest in this regard, and with assigning an EC, is whether the notion of **pristine state** is appropriate. For example, in the above example, assigning importance on the basis of a pristine condition makes an implicit assumption that this condition is attainable.

It is probably more useful to consider the **best attainable state**. For example, if estuarine health has been impaired by the construction of a marina, this damage may be largely irreversible apart from some degree of possible alteration. Thus an estimate of the biophysical importance in terms of its best attainable state would probably be more appropriate than in its pristine state. See the first example in Table D.3: the best attainable state provides the realistic upper limit for an EC, but is still higher than the ERC that would be allocated on the basis of its present, somewhat degraded importance status.

Table D.3: Possible different outcomes of allocating an EC on the basis of importance of the reference condition (RC) or best attainable state (BAS)

	(1) PES based on present health status	***(2) Present Importance Status***	***EC based on 1 and 2***	***(3) Potential Importance Status based on RC***	***EC based on 1 and 3***	***(4) Potential Importance Status based on BAS***	***EC based on 1 and 4***
e.g. 1	*C*	*65*	*C*	*100*	*A*	*75*	*B*
e.g. 2	*A*	*5*	*C*	*5*	*C*	*5*	*C*

A description of the best attainable state would require some idea of **reversibility** of damage. This presents a potential problem in that the degree of reversibility carries a cost function, and ecologists would have to second-guess the planners in terms of what restoration procedures would be feasible. Thus an alternative approach could be to provide an indication of how the health status might change for every major restoration step, or what steps are required to move to each higher EC. The easiest way to resolve this problem is to take BAS as the best state that could be achieved without removing major structures (e.g. buildings, large dams), but which could be achieved through flow alteration, or the adjustment or removal of minor structures (e.g. small dams, weirs). Then the steps required to reach different possible EC would be detailed, and one of these states selected on the state of BAS importance status, but **not based on cost**: stakeholders are left to weigh up costs and benefits at a later stage in the process.

The second example in Table D.3 serves to illustrate the case of an **unimportant** estuary. Current protocol will not allow the allocations shown in this example, but EC will remain at A in all cases. Thus a totally unimportant estuary, if in a pristine condition, cannot be altered to a significantly less pristine state. Thus from an ecological point of view, the policy is to prevent any further degradation. Ultimately, however, the FMC may be lower than EC or PES, as it will be set on the basis of stakeholder wants, as well as ecosystem needs. In other workds, the EC recommended by ecologists can be reduced by stakeholders, should economic development be considered more valuable than well-functioning estuarine ecosystems. The **Ecological Reserve**, set to maintain EC, **is not sacrosanct**, and will only serve to inform the stakeholder decision process. The EC set by this methodology is a the ecologists' recommendation, and stakeholders will then determine the final EC. Thus ecologists have no need to make allowances for society in their allocation of EC.

Several protocols have been suggested for assigning a management class and can be applied to estuaries. Which protocol is used may depend on which reserve method (rapid, intermediate or comprehensive) is being used. This study aims to define a methodology which will determine the PES and EC in a comprehensive determination. It has been suggested that the PES or Present Status be used as a temporary estimate of EC in the case of intermediate assessments. However, this goes against the precautionary principle. It is thus recommended that where certainty levels are reduced in Intermediate and Rapid Determinations the EC should be provisionally set at one and two levels higher than PES, respectively, until a comprehensive assessment can be carried out.

D.2 Review of indices of estuarine importance

D.2.1 The CERM Index

A Consortium for Estuarine Research and Management project was initiated in 1995 to establish a decision support system to produce rankings of the most important estuaries according to specified attributes. The system developed incorporated a rarity, biological and physical value score. The system was not implementable due to a lack of data for estuaries particularly those in the former Transkei and Ciskei (CERM 1996). Since then both fish and botanical surveys have taken place in these areas and the opportunity now arises to develop further an overall importance rating system for South African estuaries. CERM's (1996) importance rating index was constructed as follows (Table D.4).

Table D.4: Criteria and score construction of CERM's proposed importance rating system

Rarity		***Biological***		***Physical***	
Criterion	*Score*	*Criterion*	*Score*	*Criterion*	*Score*
Whitfield classification	*0 - 25*	*Habitat*	*0 - 20*	*Siltation*	*0 - 26*
Geomorphology type	*0 - 25*	*Plants*	*0 - 20*	*Tidal exchange*	*0 - 33*
Size	*0 - 25*	*Inverts*	*0 - 20*	*Water quality*	*0 - 19*
Condition	*0 - 25*	*Fish*	*0 - 20*	*Hydrodynamics*	*0 - 22*
		Birds	*0 - 20*		
TOTAL	*0 – 100*	*TOTAL*	*0 - 100*	*TOTAL*	*0 - 100*

This index picked up many of the critical elements, but its main drawback for application in this context is that it combines measures of health and importance. The **rarity criteria** include three measures of importance and one of health. Most of the **biological criteria** are measures of importance, except the fish index, which includes a health score (difference from the reference community). All of the **physical criteria** are measures of health which assess the difference between present and reference state.

This CERM project led to the rating of South African estuaries in terms of their avifauna (Turpie 1995) and vegetation (Coetzee *et al*. 1996, 1997 and Colloty *et al*. 1998), and a project is currently underway to rate estuaries in terms of fish. These efforts are described below. No prioritisation exercise has been undertaken with respect to estuarine invertebrates, although, this group has the potential to contribute significantly to an importance rating system for South African estuaries. This is probably due to the extreme paucity of quantitative data on invertebrates.

D.2.2 Prioritisation of estuaries for waterbird conservation

Commissioned by the CERM team, Turpie (1995) used existing count data to explore methods and criteria for determining the importance of estuaries for birds. Detailed summer counts of non-passerine waterbirds (species wholly or partially dependent on aquatic habitats) exist for most of South Africa's estuaries, with the exception of the Transkei region. Much of this data comes from a published series of single summer counts of coastal wetlands that was carried out systematically around the coast during the two summer periods between 1979 and 1981 (Ryan & Cooper 1985, Ryan *et al*. 1988, Underhill & Cooper 1984, Ryan *et al.* 1986). On the basis of these counts, there are estimates of the total coastal population for each species.

Estuaries were ranked according to Species Richness, Species Diversity (Shannon Index), Rarity and Conservation Status. The latter two indices weighted each species according to their rarity along the SA coast, and according to conservation status (endangered, endemic etc), respectively. These indices tested the effect of using limited (presence-absence) as well as abundance data. With the exception of the diversity index, which was shown not to be a useful tool for evaluating conservation importance, the resulting rankings were significantly correlated. A key point made in the study was that the final evaluation of sites should ideally involve a subjective assessment of the results of single-criterion rankings, rather than using a multicriteria index.
The data upon which the study was based are now 20 years old, and the counting effort has unfortunately never been repeated to date. Since then counts have been undertaken in a number of sites at various times, and regular counts now take place of the more important areas under the University of Cape Town's CWAC (Co-ordinated Waterbird Counts) programme. A synopsis of these counts to date has recently been released, but does not contain full details of counts.

D.2.3 The Botanical Importance Rating (BIR) Index

This index, developed by Coetzee *et al.* (1997), assigned values on the basis of percentage area cover, condition (degree of impact), functional importance and plant community richness.

The index is constructed as follows:

$$BIR = 1(A_{supra} \times MF) + 1.75\ (A_{inter} \times MF) + 2\ (A_{subm} \times MF) + 1.5\ (A_{reed} \times MF)$$

where A_{supra}, A_{inter}, A_{subm} and A_{reed} are the area cover of supratidal saltmarsh (e.g. *Sarcocornia pillansii*), intertidal saltmarsh (e.g. *Triglochin* spp), submerged macrophytes (e.g. *Zostera, Ruppia*) and reed and sedge communities, MF is a multiplication factor representing community condition, and the weightings are community importance values based on association, or functional importance, within the estuary: i.e. water dependence, primary productivity and the richness of the community they support.

The area cover was originally a score based on percentage cover of the estuary: % cover of <5, 5-25, 25-50, 50-75, >75 were scored 20, 40, 60, 80 and 100, respectively. Thus a 5 ha estuary and a 500 ha estuary, each having the same % cover distribution of macrophytes will receive the same score. This meant that the index measured **health**, in as much as high scores represented a healthy and diverse plant community, irrespective of size. The index was first applied to 33 estuaries in the Cape, and the results were found to accord with the perceived botanical condition of those estuaries. The score has now been changed to use actual area, and no longer includes a measure of condition. Thus its emphasis is now more as a measure of **importance.** A large proportion of SA estuaries have now been surveyed for plants, and a database exists which includes the components and scores of the index, in addition to species lists.

Although it now contains a measure of abundance, the BIR does not, however, include some other aspects usually associated with importance, such as species richness, habitat or species rarity, endemism etc. In some respects these aspects may be less important for estuarine plants, which are mostly widespread and common. However, the index will not reflect the greater importance of an estuary by virtue of containing a rare mangrove species, except inasmuch as mangroves is an additional habitat component in the system. These components need to be tested separately, and if there is a high degree of correlation with the existing index, then it would make sense to retain this as a relatively easy measure of botanical importance.

D.2.5 The Fish Importance Rating Index

Maree, Whitfield & Quinn have compiled a presence-absence database of estuarine fish species for 251 estuaries, based on their distributions around the South African coast. These presence absence data will eventually be refined to lists of species which have been recorded in these estuaries, and which are sufficiently abundant to make up more than 1% of samples, and are thus assumed to be present in reasonable (conservable) abundance. The data upon which this study is based is, however, difficult to work with due to differences in sampling effort and techniques, making comparison difficult.. Different sampling methods tend to be biased towards different groups or life-history stages. Harrison has carried out limited, but uniform, sampling in most estuaries. However, a good knowledge of estuarine ichthyofauna only exists for a relatively small number of estuaries.

Maree, Whitfield & Quinn are currently devising a Fish Importance Rating for South African estuaries. This index is provisionally constructed from seven weighted measures of species and estuarine importance, as follows (Table D.5).

Table D.5: Criteria being used to evaluate importance of estuaries for fish

Measures of species importance			***Measures of estuarine importance***			
Number of economically important species	*Number of estuarine-dependent species*	*Number of endemic species*	*Type* *Est. Bay >* *Perm Open >* *Est Lake >* *Temp Open >* *River Mouth*	*Size* *large >* *>* *small*	*Condition* *Excellent >* *Good >* *Fair >* *Poor*	*Isolation* *Isolated >* *>* *>* *Grouped*

The rationale for including the estuarine measures *within* the fish importance rating is that these variables are assumed to affect abundance, and can be used as a surrogate for the lack of quantitative data. Thus the measures of estuarine condition are scored on four or five categories of decreasing value (see table) according to how they might positively or negatively affect the importance of the fish community.

D.3 Recommended approach for determining estuarine importance

D.3.1 Identification of criteria for inclusion in the index

Ecological importance is an expression of the importance of an estuary to the maintenance of ecological diversity and functioning on local and wider scales. Some of the variables that can be considered as the basis for the estimation of ecological importance of estuaries are listed in Table D.6. These variables can each be categorised as measures of rarity, abundance or ecological function.

Table D.6: Possible variables for inclusion in an Estuarine Importance Index. Variable categories are rarity (R), abundance (A) and ecological function (F)

Variable	***Type***	***Include?***
1. Estuary size	*A*	✓
2. Rarity of the estuarine type and physical features, in relation to geographic area	*R*	✓
3. Habitat diversity	*A*	✓
4. Biodiversity importance in terms of plants, invertebrates, fish and birds.	*R, A, F*	✓
5. Proximity of other estuaries	*R, F*	✗
6. Ecological services to neighbouring environments	*F*	✓
7. The sensitivity and resilience of the system to environmental change.	-	✗
8. Naturalness	-	✗
9. Conservation status e.g. protected area, Ramsar or natural heritage site.	-	✗

These variables were discussed in a workshop setting, regarding their suitability for inclusion in an Estuarine Importance Index. **Size** was initially rejected because it is a driving variable for diversity and abundance of biota**,** and is thus likely to be highly correlated with these. However, it is included because of the general paucity of information on the abundance of certain biota. It was agreed that **sensitivity** of an estuary does not confer importance, although it does become an important issue in the setting of the Reserve. Similarly, **naturalness** was not considered as an appropriate indicator of importance, and has more of a health connotation. **Proximity of other estuaries** will be covered by the second variable. **Conservation status** does not confer importance per se. However, it is an important consideration in determining the Ecological Reserve Category of estuaries. This will thus be taken into account as a **modifying determinant** in EC allocation.

The measurement of the remaining variables is discussed below. In each case the score will be converted to a measure out of 100. All variables will be measured based on an estimate of the **best attainable state** (BAS).

D.3.2 Size

Estuary size is defined as the total area (ha) within the geographical boundaries described in the RDM methodology. Estuary size is then converted to a measure of importance using the following scoring guideline (Table D.7), which is based on 10% rank percentiles of estuaries of known size.

Table D.7: Importance scores assigned to estuary size classes

Estuary size (ha)	*Size Importance Score*	*Estuary size*	*Size Importance Score*
0 -1.5	*10*	*17.6 - 30*	*60*
1.6 - 4	*20*	*30.1 - 50*	*70*
4.1 - 8.5	*30*	*50.1 - 100*	*80*
8.6 - 12.5	*40*	*100 .1- 200*	*90*
12.6 - 17.5	*50*	*> 200*	*100*

D.3.3 Rarity of estuary type wrt to geographic position

South African estuaries have been classified into five types (Box 3.1, Whitfield 1992). There are only 3 estuarine bays and 4 estuarine lakes in the country, therefore these estuaries would have a high importance. Geographic position is also important. The classification of an estuary in conjunction with the biogeographical zone determines how "rare" or "unique" the estuary is for the zone under consideration. For example there are only two permanently open estuaries (Olifants and Berg) in the cool temperate zone and therefore these systems are of national importance. The Palmiet estuary in the south-western Cape is the only system along that stretch of coastline that remains open for any length of time, and is thus very important in this region for fish and invertebrate recruitment.

It is proposed that estuary type and geographical position are taken into account in a **Zonal Type Rarity Score**, as follows:

$$ZTR = 100 \times 1/N_{tz},$$

where N_{tz} is the number of estuaries of type *t* within the same biogeographical zone *z*.

This index yields scores in the range from 1 to 100, (Table D.8). In order to dampen the 100-fold difference in the highest and lowest scores, these are converted to importance scores ranging from 10 to 100 (Table D.9).

Table D.8: Number of estuaries of each physical type in each biogeographical zone, and their ZTR scores

	Cool Temperate		***Warm Temperate***		***Subtropical***	
	NUMBER	*SCORE*	*NUMBER*	*SCORE*	*NUMBER*	*SCORE*
Estuarine Bay	*0*	*-*	*1*	*100*	*3*	*33*
Permanently open	*2*	*50*	*29*	*3*	*16*	*6*
River mouth	*2*	*50*	*6*	*17*	*4*	*25*
Estuarine lake	*0*	*-*	*4*	*25*	*4*	*25*
Temporarily closed	*5*	*20*	*85*	*1*	*94*	*1*

Table D.9: Importance scores assigned to Zonal Type Rarity scores

ZTR	***ZT Importance Score***	***ZTR***	***ZT Importance Score***
1	*10*	*20*	*60*
3	*20*	*25*	*70*
6	*30*	*33*	*80*
17	*50*	*50*	*90*
		100	*100*

This index can potentially be extended to include the existence of **unique physical features** which would add to the reason for desiring a high management class. For example, these could be canyons e.g. Msikaba, ravines or gorges, physical features such as the hole in the wall, small estuaries that remain permanently open e.g. Lupatana. Then the estuary's ZTR might change from 1/16 permanently open subtropical to 1/1 permanently open subtropical with feature X.

Box 3.1: Whitfield's (1992) Physical Classification of Estuaries

Type	Tidal prism	Mixing process	Average salinity *
Estuarine Bay	Large (>10 x 10^6 m^3)	Tidal	20 - 35
Permanently Open	Moderate (1-10 x 10^6 m^3)	Tidal/riverine	10 - >35
River Mouth	Small (<1 x 10^6 m^3)	Riverine	<10
Estuarine Lake	Negligible (<0.1 x 10^6 m^3)	Wind	1 - > 35
Temporarily Open	Absent	Wind	1 - > 35

* Total amount of dissolved solids in water in parts per thousand by weight (seawater = ~35)

(a) ***Estuarine bay:*** Water area exceeds 1 200 ha. Natural bays (Knysna) and artificially formed bays (Durban Bay) are permanently linked to the sea and the salinity within them reflects this. Hypersaline conditions are not common and water temperatures are strongly influenced by the sea. Marine and estuarine organisms dominate these systems and extensive wetland/mangrove swamps occur (Whitfield, 1992).

(b) ***Permanently open estuaries:*** Vertical and horizontal salinity gradients are present and are modified by the river flow, tidal range and mouth condition. Wetlands (salt marshes), as well as submerged macrophyte beds are common and the fauna is predominantly marine and estuarine. Hypersaline conditions in the upper reaches can occur during times of severe drought. Water temperatures in this estuary type are controlled by the sea during normal conditions and by river input during flood conditions.

(c) ***River mouths:*** Riverine influences dominate the physical processes in these estuaries. Oligohaline conditions are often found. The mouth is generally permanently open but the tidal prism is small and strong riverine outflow prevents marine intrusion. During strong flood conditions the outflow of these mouths can influence the sea salinity for many kilometres. Heavy silt loads are frequent in these estuaries often resulting in shallow mouths (<2m). Water temperatures are strongly influenced by river inflow although the sea can influence bottom waters.

(d) ***Estuarine lakes:*** **W**ater area exceeds 1 200 ha. These are usually drowned river valleys filled in by reworked sediments and separated from the sea by vegetated sand dune systems. The dune can result in complete separation of the lake from the sea that then results in a loss of estuarine characteristics and the system can be referred to as a coastal lake. Estuarine lakes can be either permanently or temporarily linked to the sea and salinity within them is highly variable. Freshwater input, evaporation and the magnitude of the marine connection are the main causes of this large salinity fluctuation. The tidal prism is small, and marine and river input have little influence on water temperatures, which are directly related to solar heating and radiation. Estuarine, marine and freshwater organisms all occur depending on the salinity condition of the system.

(e) ***Temporarily open estuaries:*** Sand bars often form in the mouths of these estuaries blocking off connection with the sea. Sand bars form as a result of a combination of low river flow conditions and longshore sand movement on the adjacent coast. Flooding is frequently the cause of mouth opening, which also results in large amounts of sediment removal. However, infilling from marine and fluvial sediment can be rapid. Hypersaline conditions occur in these estuaries during times of drought. Tidal and riverine inputs control the water temperature in these systems when the mouth is open, but is independent of them when the mouth is closed. Marine, estuarine and freshwater life forms are all found in these systems, depending on the state of the mouth.

D.3.4 Habitat diversity

An estuary can be considered more important if it has a high **diversity** of habitat types, or on the basis of **representativeness**, in terms of the **size and rarity** of those habitat types that it contains. Estuarine habitats include **physical** (**unvegetated) habitats** such as channel area, sand flats, mudflats, and rock, and **plant communities**, such as salt marsh, mangroves, submerged macrophytes, reeds and sedges. The definition could be extended to include **surrounding habitats** such as floodplains and dunes. These can be incorporated into an index as follows (refer to Table D.10 as an example data set):

<u>Habitat rarity score</u>:
This score will be influenced by the number of habitats in an estuary, and by the extent to which rare habitats occur within the estuary (Table D.10). With area data for all (or most) estuaries, this can be calculated as

$$HR = 1000 \text{ x } \Gamma a_i/A_i$$

where a_i is area of the *i*th habitat in the estuary and A_i is the total area of that habitat in the country. The multiplication factor is necessary because without it the score yields very small values, such that the sum of all scores for all estuaries is equal to the number of habitats considered.

Table D.10. Estuarine habitats and total areas for incorporation in the habitat rarity score. Total areas are based on Brian Colloty's CD database, July 2000, covering 92% of the country's estuaries.

Category	*Habitat*	*Area (ha) (e.g.)*	*National area (ha)**
Physical	*Channel area (MSL) (= phytoplankton habitat)*	*30*	*47 539*
	Intertidal Sandflats and mudflats (benthic microalgae)	*15*	*4 234*
	Intertidal Rock (macroalgae)	*0*	*227*
Plant	*Supratidal saltmarsh*	*20*	*5 093*
	Intertidal saltmarsh	*30*	*2 720*
	Mangroves	*0*	*1 575*
	Submerged macrophytes	*35*	*1 141*
	Swamp Forest		*273*
	Reeds and sedges	*10*	*7 187*
	TOTAL ESTUARY AREA	*140 ha*	*69 805*

Data requirements are fairly simple. The plant community areas have been measured for a large proportion of South African estuaries. Detailed maps from which physical data can be extracted are available for a number of estuaries, and detailed physical data are currently being compiled for all KZN estuaries (Ricky Taylor, pers comm). However, there is probably not a lot of data at a sufficiently detailed level to divide intertidal flats into sand and mudflats.

It should be borne in mind that several of these habitat categories may undergo **dynamic changes** in area over the medium to long term (e.g. Cooper 1991, Swartkops, pers obs, Adams in prep). Dynamic changes in habitat areas are a major consideration in the assessment of estuarine importance with respect to habitats. Any snapshot measurement only records habitats at one particular part of an estuary's cycle. Thus snapshot measures of potentially highly unstable elements, such as *Zostera* cover, do not reflect the range or average level of availability of that habitat. Again, this should be dealt with by using the estimated mean level of abundance over the full range of existing conditions.

The habitat rarity index needs to be translated into an importance score for use in the index. Because the distribution of scores is heavily skewed towards the smallest scores, simply normalising the scores on a scale of 0 – 100 has the danger of relegating low scores to estuaries that are relatively high in their ranking. Using a known range of scores for approximately half of the country's estuaries, the following scoring guidelines can be used (Table D.11). Thus, roughly ten percent of estuaries are categorised in each percentile.

Table D.11: Importance scores assigned to habitat rarity scores

Habitat rarity score	*Corresponding Habitat importance score*	*Habitat rarity score*	*Corresponding Habitat importance score*
0.0 – 0.3	*10*	*5.1 – 10*	*60*
0.31 – 0.9	*20*	*10.1 – 15*	*70*
0.91 – 1.5	*30*	*15.1 – 25*	*80*
1.51 – 2.5	*40*	*25.1 – 50*	*90*
2.51 – 5.0	*50*	*> 50*	*100*

D.3.5 Biodiversity importance

Biodiversity importance will be determined on the basis of the importance of an estuary for each of the four biotic groups, which in turn will be based on a set of criteria appropriate to each group. Thus biodiversity importance is a two step process in which individual specialists will need to play a major role in the first step. The scoring for each group should ideally contain the following elements.

- Species Richness
- Species Rarity or Endemism (weighted species richness)
- Abundance (numbers, area or biomass)

It has been established that these measures are fairly well correlated. Here it is argued that a **species rarity score** would suffice as a measure of biodiversity importance for each group, as it incorporates all of these aspects. Where possible this index should use abundance data, but it is recognised that in some cases (e.g. invertebrates, to some extent, fish), estimates of overall species richness, abundance, or presence-absence data will have to suffice.

Species rarity: is usually described in terms of endangered species (i.e. red data classified), rarity in terms of occurrence at all sites, or endemism (important by virtue of the fact that they have restricted ranges and occur mainly or entirely in SA). The rarity index below will tend to give weight to the species that fall in any of these categories.

The rarity score is a simple addition of a score for each species present in viable quantity in the system:

$$R = 100 \times \Sigma r_i,$$

where r_i is the rarity score of the ith species. The multiplier is smaller than for the habitat index because the larger number of species makes the index values larger. The way in which the rarity score for each species can be calculated differs depending on the level of data available, as follows:

With abundance data:

$$r_i = q_i/Q_i,$$

where q_i = number or area in estuary and Q_i = total number or area in whole country (not in biog zone – this will confer undue importance to spp which only just occur in that zone)

With species presence-absence data only:

$$r_i = 1/N_i.$$

where N_i = the number of estuaries in which the species occurs in SA. If possible presence absence data should be refined to only count species as present where they known or thought to be in viable population numbers. It is up to the specialist to decide this.

Thus each species gets a score as a fraction of 1. For example, if the only population of a species is on that estuary, it scores 1. If the population is 100 out of 100000 of the national population, it gets a score of 0.001. Alternatively, if the population is one out of 35 estuarine populations it gets 1/35. Scores calculated using abundance are far more sensitive than scores done on presence/absence, and will tend to produce lower species weights. An estuary will score more highly if there are more species, and more highly if there are many rare species.

The biotic rarity scores have been calculated for plants (based on presence-absence data), invertebrates (based on modelled presence-absence data - Turpie et al. 2004), fish (based on abundance data (Turpie & Clark 2007) and birds (based on abundance data, Turpie et al. 2004, Turpie & Clark 2007). The rarity scores have been translated into importance scores for use in the index. The importance scores are based on tenth percentiles. For example, an estuary whose plant rarity score falls within the top 10% of all estuary scores is given the top plant importance score of 100 points. As databases improve with further sampling of estuary, the spread of rarity scores will change, and the rarity scores corresponding to the importance scores will change, thus these scores will have to be updated from time to time using the evolving central database with each reserve determination, and scores applied as appropriate. In any event, a central database will need to be maintained which is kept up to date on a yearly basis. It is suggested that a copy of the database compiled in this study is housed at the Department of Water Affairs and Forestry, accessible to RDM practitioners on the internet, and that it is maintained by scientist(s) based at DWAF and/or other institutions, under the co-ordination of the original compiler (Dr Jane Turpie, Anchor Environmental Consultants).

The results of the four biotic indices can either be weighted and summed in a combined index or subjectively assessed to create an overall ranking. The main purpose of subjective ranking, is that if one aspect comes out important, it may be dampened by low corresponding values, and the dampened effect in the final index will not alert the expert to the reason for a site's importance. In the case of this study, there is a high number of estuaries to deal with. One could create a composite index and then forget those with very low scores and then subjectively re-rank the higher-ranking sites. Or one could create a ranking system which is explicitly based on an **if-then structure** or a set of **overriding rules** which pick up flagged values, to eliminate the dangers of a composite index.

It is proposed that biodiversity importance score is calculated using a **maximum function**, or weighted maximum, rather than a just weighted mean, so that it scores highly in terms of biodiversity if it is important for any group (Table D.12). Thus, in order to weight the maximum importance rating for any single group, the estuary's biodiversity score is calculated using both the maximum score and the mean score of the four groups, as follows:

Biodiversity Importance Score = (Mean score + Max score) / 2

where Mean score is a weighted mean of the four groups. It is proposed that the score for each group carries an equal weighting. This means that the weight of an individual species is inversely related to the number of species in the same taxonomic group.

Table D.12: Calculation of the biodiversity importance score

Parameter	***e.g.***	***Weight***
Plant importance score	*20*	*25*
Invertebrate importance score	*60*	*25*
Fish importance score	*100*	*25*
Bird importance score	*80*	*25*
Mean score	*65*	***50***
Max score	*100*	***50***
Biodiversity Importance Score	***82.5***	

***Biogeographic considerations and protected area status*:**

South African estuaries are grouped into three broad geographical regions: cool temperate, warm temperate and subtropical. Cool temperate systems extend from north of Walvis Bay in Namibia to Cape Point; warm temperate from Cape Point to about Mbashe and subtropical estuaries north of Mbashe (Whitfield 1998). Faunal composition therefore changes around the coast, with the highest number of species associated with warm temperate and subtropical systems, and highest productivity associated with the west coast. A species richness dominated index would thus result in a general increase in importance from west to east. Taking abundance into account will temper this trend to some extent. Nevertheless, biogeographic zonation is an important aspect to take into account when prioritising sites for conservation in order to maximise representativeness, and hence should also play a role in determining the estuarine reserve.

The most efficient way to ensure that a representative system of estuaries is assigned to a high Ecological Reserve Category, is to use **complementarity analysis**. This determines the core set of estuaries required for a conservation network to adequately represent estuarine biodiversity in South Africa (Turpie 1995, Turpie *et al.* 2000). Such a core system could be seen as the highest priority, despite the fact that certain sites would have lower importance scores than estuaries in the top ten or twenty. The core estuaries would then be categorised as having '**required protected area status'** and should be included alongside current protected area status as a **modifying determinant.**

D.3.6 Link with freshwater and marine environment

Estuaries provide several ecological services to their surrounding environments, particularly the marine environment. These have been identified as follows:

Table D.13: Calculation of the functional importance score

Criteria For Consideration	*Guidelines For Importance Score*
a Conduit for detritus, nutrients and sediments generated in the catchment to the sea	*0 none*
b. Export of detritus and nutrients to the coastal zone generated within estuary	*20 little*
c. Nursery function for fish and crustaceans (marine and riverine)	*40 some*
d. Movement corridor for river invertebrates and fish breeding in marine environment (e.g. river crab Varuna litterata*)*	*60 important* *80 very important*
e. Roosting area for marine or coastal birds	*100 extremely important*
Overall functional importance score	***Max (a to e)***

D.4 Construction of the Estuary Importance Index

Again, construction of this index must be simple. All scores are presented on a scale of 0 (totally unimportant) to 100 (critically important). Thus overall **Estuary Importance** can be calculated as follows (Table D.14). As for all preceding indices, weightings are assigned on the basis of two specialist workshops.

Table D.14: Construction of the estuary importance index

Criterion	*Score (e.g.)*	*Weight*
Size	*50*	*15*
Zonal Type Rarity	*50*	*10*
Habitat Diversity	*70*	*25*
Biodiversity Importance	*88*	*25*
Functional Importance	*60*	*25*
ESTUARY IMPORTANCE SCORE = Weighted Mean	*70*	

Depending on the score, the importance of the estuary is described as in Table D.15 below.

Table D.15: Interpretation of the estuary importance scores

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

Results of a prioritisation exercise on 250 of South Africa's estuaries, using the above Importance index, are shown in Tables D.16 (in order of importance). Table D.16 was extracted from Turpie *et al*. (2002).

Table D.16. Updated estuary importance scores for all South African estuaries (Turpie and Clark 2007). The overall importance score (Imp) is calculated from the size score (S), habitat importance score (H), zonal type rarity score (Z) and the updated biodiversity importance score (B). Estuaries are listed from west to east.

ESTUARY	S	H	Z	B	Imp
Orange (Gariep)	100	100	90	98.0	98.5
Olifants	100	100	90	96.5	98.1
Verlorenvlei	70	70	60	81.5	71.9
Berg (Groot)	100	100	90	97.5	98.4
Rietvlei/Diep	100	10	60	96.0	72.5
Houtbaai	10	50	90	42.5	36.1
Wildevoëlvlei	80	90	60	86.0	82.0
Bokramspruit	10	10	60	29.5	19.9
Schuster	10	10	60	10.0	15.0
Krom	10	10	60	68.5	29.6
Silvermine	30	50	10	63.5	41.4
Sand	90	70	10	91.5	77.4
Eerste	40	40	10	64.5	43.1
Lourens	30	30	10	51.5	33.4
Sir Lowry's Pass	20	20	10	63.5	29.9
Steenbras	20	10	20	17.5	16.9
Rooiels	40	40	10	65.0	43.3
Buffels (Oos)	50	30	10	73.5	46.9
Palmiet	70	60	20	71.0	62.8
Bot/Kleinmond	100	100	70	98.5	96.6
Onrus	70	60	10	59.5	58.9
Klein	100	100	70	100.0	97.0
Uilskraals	80	90	10	82.0	76.0
Ratel	40	10	10	52.0	32.5
Heuningnes	90	90	20	90.5	83.1
Klipdrifsfontein	10	10	10	43.5	18.4
Breë	100	90	20	89.0	86.8
Duiwenhoks	100	90	20	76.5	83.6
Goukou (Kaffirkuils)	90	90	20	79.0	80.3
Gourits	90	60	20	88.0	75.0
Blinde	10	10	10	77.5	26.9
Hartenbos	70	60	10	86.5	65.6
Klein Brak	80	10	10	69.0	52.8
Groot Brak	90	80	10	79.5	76.9
Maalgate	50	10	10	57.5	37.9
Gwaing	10	10	10	11.5	10.4
Kaaimans	30	10	20	45.5	27.9
Wilderness	90	70	70	88.0	82.5
Swartvlei	100	100	70	99.5	96.9
Goukamma	100	40	10	83.0	71.8
Knysna	100	100	100	100.0	100.0
Noetsie	30	10	10	51.0	28.3
Piesang	80	80	10	72.5	71.1
Keurbooms	100	90	20	95.0	88.3
Matjies/Bitou	10	10	10	70.0	25.0
Sout (Oos)	70	50	20	67.5	59.4
Groot (Wes)	70	50	10	83.5	62.4
Bloukrans	70	10	50	63.5	51.4
Lottering	50	10	50	25.5	33.9
Elandsbos	30	10	50	18.5	24.1
Storms	60	10	50	11.5	34.4
Elands	10	10	50	11.5	14.4
Groot (Oos)	10	10	50	11.5	14.4
Tsitsikamma	10	20	10	45.5	21.4

ESTUARY	S	H	Z	B	Imp
Klipdrif	10	10	10	50.5	20.1
Slang	10	0	10	11.5	7.9
Kromme	100	90	20	95.5	88.4
Seekoei	90	80	10	82.5	77.6
Kabeljous	90	80	10	84.5	78.1
Gamtoos	100	100	20	98.5	91.6
Van Stadens	60	30	10	58.0	47.0
Maitland	10	70	10	58.0	37.0
Swartkops	100	100	20	100.0	92.0
Coega (Ngcura)	40	40	10	76.5	46.1
Sundays	90	70	20	89.0	77.8
Boknes	60	50	10	72.0	55.5
Bushmans	100	60	20	84.5	78.1
Kariega	90	80	20	97.0	82.3
Kasuka	70	70	10	58.0	61.0
Kowie	90	80	20	88.5	80.1
Rufane	10	10	10	57.5	21.9
Riet	80	80	10	74.5	71.6
Kleinemond Wes	80	90	10	71.0	73.3
Kleinemond Oos	70	90	10	84.0	72.5
Klein Palmiet	10	0	10	12.0	8.0
Great Fish	100	100	20	98.0	91.5
Old woman's	60	50	10	76.0	56.5
Mpekweni	90	100	10	92.0	85.0
Mtati	90	100	10	83.0	82.8
Mgwalana	90	100	10	79.0	81.8
Bira	80	70	10	84.0	71.5
Gqutywa	70	70	10	62.0	62.0
Blue Krans	20	30	10	61.0	31.8
Mtana	50	70	10	62.5	54.1
Keiskamma	100	100	20	97.0	91.3
Ngqinisa	50	60	10	56.0	50.0
Kiwane	60	70	10	53.0	55.8
Tyolomnqa	80	60	10	81.0	68.3
Shelbertsstroom	10	0	10	25.0	11.3
Lilyvale	20	10	10	19.0	16.3
Ross' Creek	10	0	10	25.0	11.3
Ncera	60	50	10	50.0	50.0
Mlele	20	10	10	19.0	16.3
Mcantsi	40	20	10	32.0	30.0
Gxulu	70	50	10	71.5	59.4
Goda	50	30	10	56.0	42.5
Hlozi	10	10	10	39.5	17.4
Hickman's	30	10	10	33.5	23.9
Buffalo	80	40	20	64.0	60.0
Blind	10	10	10	75.0	26.3
Hlaze	10	10	10	31.5	15.4
Nahoon	80	60	20	87.5	70.9
Qinira	80	70	10	67.5	67.4
Gqunube	70	50	20	77.0	61.8
Kwelera	70	60	20	78.0	64.5
Bulura	70	50	10	57.5	55.9
Cunge	10	10	10	18.5	12.1
Cintsa	70	50	10	64.5	57.6

ESTUARY	S	H	Z	B	Imp
Cefane	80	80	10	60.0	68.0
Kwenxura	70	50	10	72.5	59.6
Nyara	50	40	10	48.0	43.0
Haga-haga	20	20	10	25.5	20.4
Mtendwe	40	40	10	19.0	31.8
Quko	70	40	10	66.5	55.6
Morgan	60	30	10	58.0	47.0
Cwili	10	10	10	25.0	13.8
Great Kei	100	70	20	83.0	80.3
Gxara	60	40	10	49.5	47.4
Ngogwane	40	30	10	54.0	38.0
Qolora	60	90	10	64.0	63.5
Ncizele	30	10	10	60.5	30.6
Kobonqaba	60	50	20	57.5	52.9
Nxaxo/Ngqusi	90	80	10	87.5	78.9
Cebe	50	40	10	57.0	45.3
Gqunqe	60	40	10	53.0	48.3
Zalu	40	20	10	43.0	32.8
Ngqwara	60	40	10	46.5	46.6
Sihlontlweni/Gcini	40	20	10	52.5	35.1
Qora	80	70	20	82.5	72.1
Jujura	30	10	10	55.5	29.4
Ngadla	50	30	10	43.0	39.3
Shixini	60	40	20	64.0	52.0
Nqabara	90	70	20	40.0	65.5
Ngoma/Kobule	40	40	10	19.0	31.8
Mendu	60	40	10	39.0	44.8
Mbashe	90	90	30	86.0	83.0
Ku-Mpenzu	50	60	10	43.5	46.9
Ku-Bhula/Mbhanyana	30	70	10	49.5	42.9
Ntlonyane	70	50	10	56.0	55.5
Nkanya	50	50	10	50.0	46.0
Xora	90	80	30	82.5	79.6
Bulungula	60	40	10	55.5	48.9
Ku-amanzimuzama	20	20	10	24.0	20.0
Mncwasa	60	20	10	66.5	46.6
Mpako	50	30	10	24.5	34.6
Nenga	40	30	10	56.0	38.5
Mapuzi	50	30	10	48.5	40.6
Mtata	90	90	30	73.0	79.8
Mdumbi	80	60	30	72.5	68.1
Lwandilana	40	20	10	30.5	29.6
Lwandile	60	40	10	71.5	52.9
Mtakatye	90	70	30	56.0	70.5
Hluleka/Majusini	50	30	10	24.5	34.6
Mnenu	80	60	10	44.0	59.0
Mtonga	70	50	10	52.5	54.6
Mpande	50	30	10	49.5	40.9
Sinangwana	50	30	10	42.0	39.0
Mngazana	100	100	30	92.5	91.1
Mngazi	50	20	10	76.0	45.0
Bululo	50	30	10	60.0	43.5
Mtambane	40	20	10	41.5	32.4
Mzimvubu	90	90	30	73.0	79.8
Ntlupeni	30	10	10	54.0	29.0
Nkodusweni	70	40	10	49.5	51.4
Mntafufu	60	70	30	77.0	63.8

ESTUARY	S	H	Z	B	Imp
Mzintlava	60	50	30	50.5	52.1
Mzimpunzi	30	20	10	51.0	30.8
Mbotyi	70	70	10	80.0	66.5
Mkozi	30	30	10	73.0	38.8
Myekane	20	10	10	26.5	18.1
Lupatana	20	40	10	54.0	32.5
Mkweni	30	60	10	59.5	42.9
Msikaba	50	50	30	76.5	54.6
Mgwegwe	40	80	10	73.0	55.3
Mgwetyana	20	10	10	64.5	27.6
Mtentu	70	80	30	89.0	73.3
Sikombe	40	50	10	46.5	41.1
Kwanyana	30	10	10	57.5	29.9
Mnyameni	60	40	30	57.5	51.4
Mpahlanyana	20	10	10	54.0	25.0
Mpahlane	30	10	10	55.5	29.4
Mzamba	80	80	30	90.0	77.5
Mtentwana	40	20	10	65.5	38.4
Mtamvuna	80	50	10	83.0	66.3
Zolwane	10	20	10	24.5	16.1
Sandlundlu	30	40	10	55.5	36.9
Ku-boboyi	10	20	10	37.5	19.4
Tongazi	10	70	10	63.0	38.3
Kandandhlovu	20	20	10	34.5	22.6
Mpenjati	40	50	10	73.5	47.9
Umhlangankulu	40	80	10	49.5	49.4
Kaba	20	40	10	25.0	25.3
Mbizana	40	70	10	80.0	54.5
Mvutshini	10	20	10	10.0	12.5
Bilanhlolo	20	60	10	76.5	43.1
Uvuzana	10	20	10	23.0	15.8
Kongweni	10	40	10	48.5	27.1
Vungu	10	30	10	39.0	22.3
Mhlangeni	20	40	10	59.0	33.8
Zotsha	30	80	10	55.5	46.9
Boboyi	10	40	10	45.5	26.4
Mbango	10	60	10	31.0	27.8
Mzimkulu	80	100	30	76.0	79.0
Mtentweni	30	80	10	30.5	40.6
Mhlangamkulu	30	10	10	17.0	19.8
Damba	20	90	10	25.0	37.8
Koshwana	10	80	10	24.5	31.1
Intshambili	20	80	10	26.0	35.5
Mzumbe	50	50	10	53.5	46.9
Mhlabatshane	20	90	10	26.5	38.1
Mhlungwa	20	60	10	47.5	35.9
Mfazazana	20	80	10	57.5	43.4
Kwa-Makosi	20	90	10	39.5	41.4
Mnamfu	10	80	10	10.0	27.5
Mtwalume	60	50	10	64.0	53.5
Mvuzi	10	50	10	29.5	24.9
Fafa	70	80	10	63.0	64.8
Mdesingane	10	30	10	29.5	19.9
Sezela	40	50	10	76.5	48.6
Mkumbane	10	40	10	50.5	27.6
Mzinto	30	80	10	64.0	49.0
Mzimayi	10	40	10	24.5	21.1
Mpambanyoni	20	50	10	49.0	33.8

ESTUARY	***S***	***H***	***Z***	***B***	***Imp***
Mahlongwa	*30*	*40*	*10*	*44.0*	*34.0*
Mahlongwana	*30*	*80*	*10*	*48.0*	*45.0*
Mkomazi	*80*	*60*	*30*	*91.5*	*72.9*
Ngane	*10*	*40*	*10*	*67.0*	*31.8*
Umgababa	*50*	*60*	*10*	*63.0*	*51.8*
Msimbazi	*50*	*50*	*10*	*84.5*	*54.6*
Lovu	*40*	*80*	*10*	*78.0*	*56.5*
Little Manzimtoti	*10*	*80*	*10*	*37.5*	*34.4*
Manzimtoti	*30*	*70*	*10*	*84.0*	*51.5*
Mbokodweni	*30*	*40*	*10*	*72.0*	*41.0*
Sipingo	*30*	*100*	*10*	*63.5*	*53.9*
Durban Bay	*90*	*100*	*80*	*92.5*	*92.1*
Mgeni	*70*	*90*	*10*	*86.5*	*73.1*
Mhlanga	*80*	*70*	*10*	*79.0*	*70.3*
Mdloti	*80*	*90*	*10*	*69.0*	*72.8*
Tongati	*70*	*80*	*10*	*54.5*	*62.6*

ESTUARY	***S***	***H***	***Z***	***B***	***Imp***
Mhlali	*60*	*90*	*10*	*80.0*	*67.5*
Seteni	*10*	*80*	*10*	*37.5*	*34.4*
Mvoti	*60*	*30*	*70*	*80.5*	*58.6*
Mdlotane	*60*	*90*	*10*	*65.0*	*63.8*
Nonoti	*60*	*60*	*10*	*74.5*	*58.6*
Zinkwasi	*80*	*90*	*10*	*80.0*	*75.5*
Tugela/Thukela	*80*	*50*	*70*	*71.0*	*69.3*
Matigulu/Nyoni	*90*	*70*	*30*	*89.0*	*78.8*
Siyaya	*30*	*60*	*10*	*47.0*	*39.8*
Mlalazi	*90*	*90*	*30*	*95.5*	*85.4*
Mhlathuze	*100*	*100*	*80*	*53.5*	*86.4*
Richard's Bay	*100*	*0*	*80*	*85.0*	*69.3*

Estuaries that currently have protection status and the current list of required protected areas to sustain biodiversity are given in Tables D.17 and D.18, respectively.

Table D.17: Estuaries with protected area status. Estuaries marked with a # are only partially protected

Bloukrans	*Kabeljous*	*Mhlanga*	*Sand#*
Diep #	*Keurbooms #*	*Mhlatuze*	*Siyaya*
Elands	*Knysna #*	*Mlalazi*	*Sout (east)*
Elandsbos	*Krom*	*Mpenjati*	*Storms*
Gamtoos #	*Kosi*	*Msikaba*	*St Lucia*
Goukamma #	*Lottering*	*Mtentu*	*Swartvlei #*
Goukou#	*Mbashe*	*Nahoon #*	*Tsitsikamma#*
Gqutywa	*Mbizana #*	*Ngoma*	*Van Stadens*
Groot (east)	*Mendu*	*Nyoni*	*Wilderness #*
Groot (west)	*Mfolozi*	*Orange #*	
Heuningnes	*Mgeni #*	*Quko*	
Hluleka	*Mgobozeleni*	*Seekoei #*	

Table D.18: Required protected areas: Minimum set of estuaries required in a protected area network to represent 100% of species in the analysis, based on complementarity analysis. Estuaries which are already protected are marked with an asterisk.

	Estuary	Additional spp conserved	Cumulative spp conserved	%		Estuary	Additional spp conserved	Cumulative spp conserved	%
1	St Lucia *	246	246	44.9	17	Bot	2	518	94.5
2	Berg	95	341	62.2	18	Bushmans	1	519	94.7
3	Kosi*	17	358	65.3	19	Nhlabane	1	520	94.9
4	Swartkops	74	432	78.8	20	Rietvlei*	2	522	95.3
5	Nyoni*	16	448	81.8	21	Mtamvuna	3	525	95.8
6	Wildevoelvlei	11	459	83.8	22	Palmiet	4	529	96.5
7	Wilderness*	10	469	85.6	23	Mvoti	2	531	96.9
8	Manzimtoti	4	473	86.3	24	Great Kei	2	533	97.3
9	Gouritz	4	477	87.0	25	Mgeni*	2	535	97.6
10	Swartvlei	8	485	88.5	26	Mpenjati*	2	537	98.0
11	Heuningnes*	5	490	89.4	27	Mntafufu	2	539	98.4
12	Olifants	6	496	90.5	28	Mhlali	2	541	98.7
13	Knysna*	5	501	91.4	29	Mlalazi*	2	543	99.1
14	Keiskamma	5	506	92.3	30	Kromme	2	545	99.5
15	Kariega	6	512	93.4	31	Goda	2	547	99.8
16	Lovu	4	516	94.2	32	Mbashe	1	548	100.0

The recommended extent of protection required and priority for rehabilitation for temperate estuaries (Orange to M are also provided in Table D.19 (Turpie and Clark, 2007).

Table D.19: Summary of the recommended extent of protection required and priority for rehabilitation for each of the estuaries in the CFR area, giving whether the estuary is part of the core set required to meet biodiversity targets, the extent of protection required (in terms of proportion of targeted habitats and populations requiring full protection in a sanctuary), the recommended proportion of terrestrial marginal area to be included as a no-development area, and the water requirement, designated in terms of the recommended management class. Note that the recommended extent of protection and water requirements should be seen as ideal goals. Source: Turpie & Clark 2007.

Estuary (West to East)	Core biodiversity set	Recommended extent of sanctuary protection	Recommended extent of undeveloped margin	Recommended minimum Ecological Management Class[1]	Priority for rehabilitation (blank = not required)
Orange	Core	Half	50%	B/C[2]	High
Olifants	Core	Half	50%	A/B	High
Verlorenvlei		Half	50%	B/C	High
Berg	Core	Half	50%	A/B	High
Rietvlei/ Diep	Core	Half	50%	A/B	High
Hout Bay		None	-	D	Low
Wildevoëlvlei		None	-	D	Low
Bokramspruit		None	-	D	Low
Schuster		None	-	D	
Krom	Core	All	100%	A/B	
Silvermine		All	25%	B/C	Low
Sand	Core	Half	25%	A/B	High
Eerste	Core	All	75%	A/B	High
Lourens	Core	All	75%	A/B	Med
Sir Lowry's Pass		None	-	D	Low
Steenbras		All	50%	B/C	
Rooiels		All	50%	B/C	
Buffels (Oos)		All	50%	B/C	
Palmiet	Core	All	50%	A/B	
Bot / Kleinmond	Core	Half	50%	A/B	High
Onrus		None	-	D	Med
Klein	Core	Half	50%	A/B	High
Uilkraals		All	75%	B/C	High
Ratel		All	75%	B/C	
Heuningnes	Core	All	75%	A/B	
Klipdrifsfontein	Core	All	75%	A/B	
Breede[3]		Part	25%	B/C	High
Duiwenhoks		None	-	D	High
Goukou	Core	Half	50%	A/B	High
Gourits	Core	Half	50%	A/B	High
Blinde		None	-	D	
Hartenbos		None	-	D	Med
Klein Brak		None	-	D	High
Groot Brak		None	-	D	High
Maalgate		None	-	D	
Gwaing		None	-	D	Med
Kaaimans		None	-	D	
Wilderness	Core	Half	50%	A/B	High
Swartvlei	Core	Half	50%	A/B	High

[1] Management class denotes the future state of health of the estuary, from A (near natural) to D (functional), and with A-class systems having greater water requirements than D-class systems.
[2] Cannot allow for special water requirement due to cost
[3] Included post-hoc due to stakeholder concern for its biodiversity importance, but cannot allow for special water requirement due to cost

Estuary (West to East)	Core biodiversity set	Recommended extent of sanctuary protection	Recommended extent of undeveloped margin	Recommended minimum Ecological Management Class[1]	Priority for rehabilitation (blank = not required)
Goukamma	Core	All	75%	A/B	High
Knysna	Core	Half	50%	A/B	High
Noetsie	Core	Half	50%	A/B	
Piesang		None	-	D	Med
Keurbooms[4]	Core	Half	50%	A/B	High
Matjies		None	-	D	
Sout (Oos)	Core	All	100%	A/B	
Groot (Wes)	Core	Half	75%	A/B	High
Bloukrans	Core	All	100%	A/B	
Lottering	Core	All	100%	A/B	Low
Elandsbos	Core	All	100%	A/B	Low
Storms	Core	All	100%	A/B	
Elands	Core	All	100%	A/B	Low
Groot (Oos)	Core	All	100%	A/B	Low
Tsitsikamma		None	-	D	Low
Klipdrif		None	-	D	Med
Slang		None	-	D	Low
Kromme	Core	Half	50%	A/B	High
Seekoei	Core	Half	50%	A/B	High
Kabeljous		Half	50%	B/C	High
Gamtoos	Core	Half	50%	A/B	High
Van Stadens	Core	Half	50%	A/B	
Maitland	Core	All	75%	A/B	Low
Swartkops	Core	Half	50%	A/B	High
Coega (Ngcura)		None	-	D	
Sundays	Core	Half	50%	A/B	High
Boknes		None	-	D	
Bushman’s	Core	Half	50%	A/B	High
Kariega	Core	Half	50%	A/B	High
Kasuka		Half	50%	B/C	
Kowie		Half	50%	B/C	High
Rufane		None	-	D	
Riet		All	75%	B/C	
West Kleinemonde		Half	50%	B/C	
East Kleinemonde		Half	50%	B/C	
Klein Palmiet		None	-	D	
Great Fish	Core	Half	50%	A/B	High
Old woman's		All	75%	B/C	Low
Mpekweni		Half	50%	B/C	Med
Mtati	Core	Half	50%	A/B	
Mgwalana		Half	50%	B/C	
Bira		Half	50%	B/C	
Gqutywa	Core	All	75%	A/B	
Blue Krans		None	-	D	
Mtana		All	75%	B/C	
Keiskamma	Core	Half	50%	A/B	High
Ngqinisa		All	75%	B/C	
Kiwane		All	75%	B/C	

[4] Included Keurbooms instead of Piesang due to biodiversity importance, but it may not be possible to make special provision for water due to cost.

Estuary (West to East)	**Core biodiversity set**	**Recommended extent of sanctuary protection**	**Recommended extent of undeveloped margin**	**Recommended minimum Ecological Management Class[1]**	**Priority for rehabilitation (blank = not required)**
Tyolomnqa		*Half*	*50%*	*B/C*	*Low*
Shelbertsstroom		*None*	*-*	*D*	*High*
Lilyvale		*All*	*50%*	*B/C*	
Ross' Creek		*None*	*-*	*D*	
Ncera		*All*	*75%*	*B/C*	
Mlele		*All*	*75%*	*B/C*	
Mcantsi		*All*	*75%*	*B/C*	*Med*
Gxulu		*Half*	*50%*	*B/C*	*High*
Goda	*Core*	*All*	*75%*	*A/B*	
Hlozi		*None*	*-*	*D*	
Hickman's		*All*	*75%*	*B/C*	*Low*
Buffalo		*None*	*-*	*D*	*High*
Blind		*None*	*-*	*D*	*Low*
Hlaze		*None*	*-*	*D*	*High*
Nahoon		*None*	*-*	*D*	*High*
Qinira		*Half*	*50%*	*B/C*	
Gqunube		*Half*	*50%*	*B/C*	*Med*
Kwelera		*Half*	*50%*	*B/C*	*Med*
Bulura		*Half*	*50%*	*B/C*	*Med*
Cunge		*None*	*-*	*D*	
Cintsa		*Half*	*50%*	*B/C*	*Med*
Cefane		*Half*	*50%*	*B/C*	
Kwenxura	*Core*	*All*	*75%*	*A/B*	
Nyara		*All*	*75%*	*B/C*	
Haga-haga		*All*	*75%*	*B/C*	
Mtendwe		*All*	*75%*	*B/C*	
Quko	*Core*	*Half*	*50%*	*A/B*	
Morgan		*None*	*-*	*D*	*Med*
Cwili		*None*	*-*	*D*	*Low*
Great Kei	*Core*	*Half*	*50%*	*A/B*	*Low*
Gxara		*All*	*75%*	*B/C*	*Low*
Ngogwane		*All*	*75%*	*B/C*	*Low*
Qolora		*All*	*75%*	*B/C*	
Ncizele		*All*	*75%*	*B/C*	
Kobonqaba		*All*	*75%*	*B/C*	*Low*
Nxaxo/Ngqusi	*Core*	*All*	*75%*	*A/B*	
Cebe		*All*	*75%*	*B/C*	
Gqunqe		*All*	*75%*	*B/C*	
Zalu		*All*	*75%*	*B/C*	
Ngqwara		*All*	*75%*	*B/C*	
Sihlontlweni/Gcini		*All*	*75%*	*B/C*	
Qora	*Core*	*Half*	*75%*	*A/B*	
Jujura		*None*	*-*	*D*	*Low*
Ngadla		*All*	*75%*	*B/C*	*Low*
Shixini	*Core*	*All*	*75%*	*A/B*	*Low*
Nqabara		*Half*	*75%*	*B/C*	
Ngoma/Kobule		*All*	*75%*	*B/C*	
Mendu		*All*	*75%*	*B/C*	
Mbashe	*Core*	*All*	*75%*	*A/B*	*Low*
Ku-Mpenzu	*Core*	*All*	*75%*	*A/B*	
Ku-Bhula/Mbhanyana	*Core*	*All*	*75%*	*A/B*	

Estuary (West to East)	***Core biodiversity set***	***Recommended extent of sanctuary protection***	***Recommended extent of undeveloped margin***	***Recommended minimum Ecological Management Class[1]***	***Priority for rehabilitation (blank = not required)***
Ntlonyane	*Core*	*All*	*75%*	*A/B*	
Nkanya	*Core*	*All*	*75%*	*A/B*	
Xora		*Half*	*75%*	*B/C*	
Bulungula		*All*	*75%*	*B/C*	
Ku-amanzimuzama		*None*	*-*	*D*	
Mncwasa		*All*	*75%*	*B/C*	
Mpako		*All*	*75%*	*B/C*	
Nenga		*All*	*75%*	*B/C*	
Mapuzi		*All*	*75%*	*B/C*	*Med*
Mtata		*None*	*-*	*D*	*High*
Mdumbi	*Core*	*Half*	*75%*	*A/B*	

References

Begg, G. 1978. *The estuaries of Natal*. Natal Town and Regional Plannning Report 41. Backhouse Press, Pietermaritzburg.

Coetzee, J.C.; Adams, J. B. & Bate, G.C. 1997. A botanical importance rating of selected Cape estuaries. *Water SA*, **23**: 81 - 93.

Colloty, B.M. 1999. Database of estuarine habitats on Compact Disc. University of Port Elizabeth.

Colloty, B.M., Adams, J.B. & Bate, G.C. 1998. The use of a botanical importance rating system to assess changes in the flora of the Swartkops estuary. Department of Water Affairs and Forestry, Pretoria.

Consortium for Estuarine Research and Management (CERM) 1996. *A co-ordinated research programme on decision support for the conservation and management of estuaries*. Unpublished report to the Water Research Commission.

Cooper, J.A.G. 1991. *Sedimentary models and geomorphological classification of river mouths on a subtropical, wave-dominated coast, Natal, South Africa*. PhD thesis, University of Natal, Durban.

Cooper, J.A.G., Ramm, A.E.L. & Harrison, T.D. 1994. The Estuarine Health Index: a new approach to scientific information transfer. *Ocean & Coastal Management* **25**: 103-141.

Costanza, R., Norton, B.G. & Haskell, B.D. 1992. *Ecosystem health: new goals for environmental management.* Island Press, Washington D.C.

Harrison, T D., Cooper, J.A. G., Ramm, A.E.L. & Singh, R.A. 1994. Application of the estuarine health index to south Africa's estuaries, Orange River - Buffels (Oos). (Executive report & Technical report). Department of Environment Affairs, Pretoria

Harrison, T.D., Cooper, J.A.G., Ramm, A.E.L. 1999. *Geomorphology, ichthyofauna, water quality and aesthetics of South African estuaries*. Unpublished report to Department of Environmental Affairs and Tourism.

House, M.A. 1989. A water quality index for river management. *J.IWEM*., **3**: 336 - 344.

Jezewski, W.A. and C.P.R. Roberts 1986. Estuarine and Lake Freshwater requirements. Technical Report No. TR 129. Department of Water Affairs. Government Printer. 22 pp.

Karr, J.R. 1992. Ecological integrity: protecting Earth's life support systems. In: Costanza, R., Norton, B.G. & Haskell, B.D. (eds.) *Ecosystem health. New goals for environmental management*. Island Press, Washington, D.C.

Karr, J.R. & Dudley, D.R. 1981. Ecological perspective on water quality goals. *Envir. Management* **5**:55-68.

Kleynhans, C.J. 1995. A qualitative procedure for the assessment of the habitat integrity status of the Levuvhu River (Limpopo system, South Africa). *Journal of Aquatic Ecosystem Health* **5**: 41 - 54.

Pressey, R.L. Humphries, C.J., Margules, C.R., Vane-Wright, R.I. & Williams, P.H. 1993. Beyond opportunism: key principles for systematic reserve selection. *TREE* **8**: 124-8.

Ramm, A.E.L. 1988. The Community Degradation Index: a new method for assessing the deterioration of aquatic habitats *Water Res*. **22**: 293-301.

Ramm, A.E.L. 1990. Application of the community degradation index to South African estuaries. *Water Res* **24**: 383-389.

Ryan, P.G. & Cooper, J. 1985. Waders (Charadrii) and other coastal birds of the northwestern Cape Province, South Africa. *Bontebok* **4**: 1-8.

Ryan, P.G., Cooper, J. Hockey, P.A.R. & Berruti, A. 1986. Waders (Charadrii) and other water birds on the coast and adjacent wetlandsd of Natal, 1980-1981. *Lammergeyer* **36**: 1 - 33.

Ryan, P.G., Underhill, L.G., Cooper, J. & Waltner, M. 1988. Waders (Charadrii) and other waterbirds on the coast, adjacent wetlands and off shore islands of the south-western Cape Province, South Africa. *Bontebok* **6**:1-19.

Steinke, T. 1999. Mangroves in South African estuaries. Pp. 119-140 in: Allanson, B.R. & Baird, D. (eds). *Estuaries of South Africa*. Cambridge University Press, Cambridge.

Turpie, J.K. 1995. Prioritizing South African estuaries for conservation: a practical example using waterbirds. *Biological Conservation* **74**: 175-185.

Turpie, J.K., Beckley, L.E. & Katua, S.M. 2000. Biogeography and the selection of priority areas for conservation of South African coastal fishes. *Biological Conservation* **92**: 59-72.

Turpie, JK., Adams, J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. & Van Niekerk, L. 2002 Assessment of the conservation priority status of South African estuaries for use in management and water allocation. Water SA. 28: 191-206.

Turpie, J.K., Clark, B., Knox, D., Martin, P., Pemberton, C. & Savy, C. 2004. Improving the biodiversity rating of South African estuaries. Vol 1. Contributions to information requirements for the implementation of Resource Directed Measures for estuaries. WRC Report no. 1247/1/04. 121pp.

Turpie, J.K. and Clark, B.M. 2007 Development of a conservation plan for temperate South African estuaries on the basis of biodiversity importance, ecosystem health and economic costs and benefits. Report to the C.A.P.E. Estuaries Management Programme, CapeNature.

Ulanowicz, R.E. 1992. Ecosystem health and trophic flow networks. In: Costanza, R., Norton, B.G. & Haskell, B.D. *Ecosystem health: new goals for environmental management.* Island Press, Washington D.C.

Underhill, L.G. & Cooper, J. 1984. *Counts of waterbirds at southern African coastal wetlands*. Western Cape Wader Study Group and Percy FitzPatrick Institute of African Ornithology, Cape Town (Unpublished report).

Whitfield, A.K. 1992. A characterisation of southern African estuarine systems. *Southern African Journal of Aquatic Sciences* **12**: 89-103.

Whitfield, A.K. 1998. Biology and ecology of fishes in southern African estuaries. J.L.B. Smith Institute of Ichthyology, Grahamstown.

APPENDIX E:
TEMPLATES TO BE COMPLETED BY SPECIALISTS AS PART OF PRELIMINARY DETERMINATION OF THE ECOLOGICAL WATER REQUIREMENTS FOR ESTUARIES

IMPORTANT NOTES

- The purpose of these templates is to provide a means of distilling key issues from the more detailed individual specialist reports for inclusion in the main Estuarine Ecological Reserve Report. Individual specialists can best extract key issues on their specific components, therefore they are asked to complete these.

- It is very important that specialists familiarise themselves with the method for determination of the Estuarine Ecological Water Requirements to be able to put these templates in context and participate efficiently in this process. In particular, it is important that specialists consult the RDM Methodology to determine the scoring rules for the Estuarine Health Index.

- Templates need to be completed prior to the specialist workshop, in the following sequence:

  Abiotic components:
  - Hydrology
  - Hydrodynamics
  - Water quality
  - Sediment dynamics

  Biotic components:
  - Microalgae
  - Macrophytes
  - Invertebrates
  - Fish
  - Birds

- Criteria for confidence limits attached to statements in this study are as follows:

LIMIT	DEGREE OF CONFIDENCE
Low	If no data were available for the estuary or similar estuaries (i.e. < 40%)
Medium	If limited data were available for the estuary or other similar estuaries (i.e. 40% – 80%)
High	If sufficient data were available for the estuary (i.e. > 80%)

- NOTE: If the hydrology has low confidence, then the overall confidence of a study is low. Similarly, if the links between flow and abiotic processes (especially mouth status) are poorly quantified then the overall confidence of a study is low

- The templates provided in this Appendix should be used as a guideline only. These can be modified if deemed necessary, provided that the required information is still reported on.

E.1 Templates for Baseline Data Availability

E.1.1 Rapid Level

COMPONENT	DESCRIPTION OF AVAILABLE DATA (including DATE)	REFERENCE
Hydrology	1. ……….. 2. ………. 3. ……….	1. ……….. 2. ………. 3. ……….
Hydrodynamics		
(Sediment Dynamics)		
Water Quality		
Microalgae		
Macrophytes		
Invertebrates		
Fish		
Birds		

E.1.2 Intermediate and Comprehensive Levels

Data availability on hydrology, hydrodynamics and water quality (see Table 3.1a-d in the Main Report for details)

REQUIRED DATA	AVAILABILITY	COMMENT
Simulated runoff data for Reference Condition, Present State and a range of future run-off scenarios		
Flood hydrographs		
Sediment grabs, Sediment cores, Bathymetric/topographical surveys and Sediment load at head of estuary		
Continuous flow gauging		
Water level recordings and mouth observations		
Water levels along estuary		
Wave conditions		
Aerial photographs		
Water quality of river inflow		
Water quality in estuaries		
Toxic substances		
Effluent discharges		

Data availability on microalgae (see Table 3.1e in Main Report for details)

DATA	AVAILABILITY	COMMENTS
Phytoplankton		
Benthic microalgae		

Data availability on macrophytes (see Table 3.1f in the Main Report for details)

REQUIRED DATA	AVAILABILITY	COMMENTS
Aerial photographs		
Number of plant community types		
Permanent transects		

Data availability on invertebrates (see Table 3.1g in the Main Report for details)

REQUIRED DATA	AVAILABILITY	COMMENTS
Zooplankton		
Benthic invertebrates		
Bacrocrustaceans		

Data availability on fish (see Table 3.1h in the Main Report for details)

REQUIRED DATA	AVAILABILITY	COMMENTS
Seine and gill nets open phase.		

Data availability on birds (see Table 3.1i in the Main Report for details)

REQUIRED DATA	AVAILABILITY	COMMENTS
Full bird count		

E.2 Templates for Determination of Recommended Ecological Category (All Levels)

E.2.1 Present State

ABIOTIC COMPONENT

1. **Described seasonal variability in river inflow** (based on present state simulated runoff scenario)

2. **Describe present flood regime** (to be included in Comprehensive level determinations)

3. Describe **anthropogenic influences**, other than modification of river inflow, that are presently affecting the abiotic characteristics in the estuary and how, e.g.:

Land-use and development	Artificial breaching	Timing of breaching events; Breaching at too low water levels resulting in increased sedimentation.
	Mouth stabilization	Modifying tidal flows and mouth status
	Bank stabilization & destabilization	Loss/ degradation of habitat
	Bridge(s)	Structures impedes tidal and/or floods flows
	Weirs	Loss/ degradation of habitat; Structures impedes tidal and/or floods flows
	Causeway	Loss/ degradation of habitat; Structures impedes tidal and/or floods flows
	Marina development	Structures impedes tidal and/or floods flows; and cause modification in habitat
	Dredging	Modifies mouth status or cause destruction/alternation in habitat
	Mining (e.g. sand winning)	Activity causes destruction/alternation in habitat and water quality
	Poor agricultural practices (e.g. causing siltation)	Destruction/alternation in habitat
	Carrying capacity exceeded resulting from boating, bathers etc.	Number of boats/people/windsurfers; Possible secondary effects such as habitat alteration, increase in resuspended sediment and turbidity
	Low-lying developments	Area (ha) of habitat lost or degraded
	Lack of maintenance of infrastructure (e.g. roads and bridges)	Alteration in habitat and water quality
	Migration barrier in river	Structures impeding migration of biota
	Other …	
Water Quality and Quantity	Waste water treatment works	Location; load/volume/rate
	Municipal waste (including sewage disposal)	Source and load/volume/rate
	Industrial effluent (including cooling water) discharges	List contaminants (e.g. toxic substances)
	Litter	Source and loads
	Mariculture waste products	Source and loads
	Pollution related to shipping	List contaminants (e.g. toxic substances)

	activities in harbours	
	Septic and conservancy tank seepage	Location; loads
	Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides	Source and load, List contaminants (e.g. toxic substances)
	Contaminated storm-water or groundwater	Source and load/volume/rate
	Lack of maintenance of infrastructure (e.g. sewage works)	Source and load, List contaminants (e.g. toxic substances)
	Other water quality activities	…..

4. **Describe the present sediment processes** (to be included in comprehensive level determinations)

   NOTE: A description of sediment processes needs to include reference to supratidal, intertidal and subtidal habitat

5. **Determine typical states** (referred to as abiotic states), e.g.:

STATE		FLOW RANGE (m^3/s)
State 1:	Strongly freshwater dominated	> 20 m^3/s
State 2:	Freshwater dominated, but saline intrusion in lower reaches	10-20 m^3/s
State 3:	Marine and freshwater influence on the estuary is balanced	5-10 m^3/s
State 4:	Strongly marine dominated	<5 m^3/s

6. **Describe each abiotic state in terms of the following abiotic characteristics and processes:**

ABIOTIC STATE:
Typical flow patterns: Confidence:
State of the mouth: Confidence:
Flood plain inundation patterns: **Confidence:**
Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide): Confidence:
Retention times of water masses: Confidence:
Total volume and/or estimated volume of different salinity ranges: Confidence:
Estimated (maximum) tidal velocities along the estuary: Confidence:
Salinity distributions in the estuary: Confidence:
System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen): Confidence:
Nutrients (inorganic nutrients and organic nutrients, where available): Confidence:
Toxic substances: Confidence:

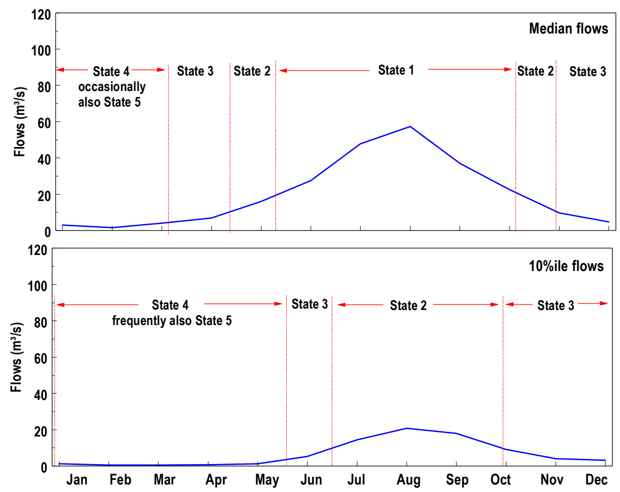
6. Estimate the occurrence and duration of different abiotic states during the Present State:

Use colour coding to indicate the average distribution of abiotic states over the simulated period, e.g.:

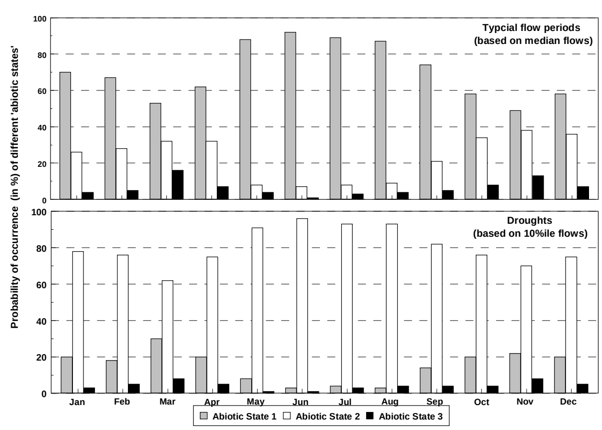
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.97	7.90	2.79	1.09	0.49	13.20	3.46	0.00	49.57	10.97	21.10	27.42
1928	8.83	48.60	17.27	2.47	0.94	5.13	6.94	8.24	15.41	76.96	71.26	21.82
1929	9.39	3.98	7.66	4.46	31.13	18.52	4.14	2.67	2.05	6.46	35.94	56.80
1930	23.77	7.37	3.82	3.43	1.53	5.29	69.77	40.06	9.50	59.89	103.97	44.60
1931	65.64	17.58	34.48	11.63	32.69	4.28	0.87	11.75	21.45	32.98	21.88	141.31
1932	50.58	7.70	4.31	1.81	1.08	1.11	0.64	2.47	55.89	100.96	68.18	26.16
1933	11.30	9.68	4.27	4.97	3.68	3.96	1.12	1.25	8.81	20.18	41.55	42.20
1934	90.47	40.79	6.77	2.41	1.98	1.27	7.04	25.49	25.06	39.63	39.90	28.24
1935	11.37	11.53	4.83	2.52	0.99	0.48	0.16	3.20	3.75	20.31	42.44	42.64
1936	17.59	100.95	41.86	5.98	1.61	9.92	4.87	7.22	56.07	94.13	30.09	19.24
1937	8.82	7.07	9.24	6.54	0.96	6.73	14.23	28.25	13.24	20.83	29.00	31.62
…….	10.95	3.71	4.31	2.83	1.70	0.79	0.96	9.45	58.67	227.94	63.51	96.18

State 1:	< 0.5	State 2:	0.5 - 3.0	State 3:	3.0 -	State 4:	10.0 -	State 5:	> 20.0

For systems with strong seasonal variability in flows results can, for example, be presented as follow:



For estuaries where variations within months are stronger than seasonal variation results can, for example, be represented as follows:



BIOTIC COMPONENTS

NOTES:

- ***In the Description of the Present State for each of the biotic components, a concise description of the following should be provided:***
  - ***Species diversity, richness, rarity and community composition (e.g. provide details on endemic and Red Data species)***
  - ***Biomass distribution and productivity***
  - ***Seasonal and inter-annual variability***
  - ***Assessment of any important (regional) relationship with other nearby estuarine and marine systems.***
- ***When describing the effect of abiotic characteristics, as well as other biotic components on a biotic component, also indicate temporal dependencies, e.g. critical periods of the year or exposure times, where relevant.***
- ***In the assessment of Reference Condition, changes in biotic components should be addressed in terms of:***
  - ***Species diversity, richness, rarity and community composition (e.g. provide details on endemic and Red Data species)***
  - ***Biomass distribution and productivity***
  - ***Seasonal and inter-annual variability.***

  The causes of such changes should be provided. Where anthropogenic influences, other than those related to changes in river inflow, are the cause, these should be identified.
- ***Present Ecological Status (PES) is a measure of the health of a resource, based on a comparison between the Reference Condition and the Present State***
- ***Motivations provided in the EHI should include a description of the change, as well as the cause of this change. Motivations for the EHI score, therefore, could largely be obtained from relevant sections in the Assessment of the Reference Condition (i.e. 'cut-and-paste'). Please make sure that the confidence limits provided in the assessment correspond with those provided in the EHI tables.***

1. Anthropogenic influences, other than modification of river inflow, that are presently affecting the biota in the estuary directly:

Living Resources	Recreational fishing	Number of anglers; Number of boats; Tonnage harvested; and Species targeted and their status (e.g. collapsed).
	Commercial/Subsistence fishing (e.g. gillnet fishery)	Number of licensed operators; Tonnage harvested; and Species targeted and their status (e.g. collapsed).
	Traditional fish traps	Number of traps; Tonnage harvested; and Species targeted and their status (e.g. collapsed).
	Illegal fishing (Poaching)	Number of operators; Tonnage harvested; and Species targeted and their status (e.g. collapsed).
	Bait collection	Number of harvesters; Biomass harvested; Species targeted
	Aquarium fish collecting	Biomass harvested; Species targeted and their status (e.g. collapsed).
	Inappropriate levels of recreational activities (e.g. fishing competitions)	How many events; Number of participants; Species targeted and their status (e.g. collapsed).

	Mariculture	Number of licensed operators; Species targeted and their status (e.g. collapsed).
	Harvesting of mangroves and reeds / sedges	Biomass harvested; Species targeted
	Grazing and trampling of salt mashes	Extent of habitat damaged Affected species
	Translocated or alien fauna and flora	Species; Numbers or area(ha) inhabited
	Other …..	

2. Describe the Present State of the biotic components:

MICROALGAE

Confidence:

MACROPHYTES

Confidence:

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macrocrustaceans)

Confidence:

FISH

Confidence:

BIRDS

Confidence:

3. Describe the effect of abiotic characteristics and processes, as well as other biotic components on estuarine biota:

Microalgae:

ABIOTIC COMPONENT OR PROCESS	BIOLOGICAL RESPONSE
Mouth condition (provide temporal implications where applicable)	
Exposure of intertidal areas during low tide	
Subtidal, intertidal and supratidal habitat (amended in 2008)	
Sediment characteristics (including sedimentation)	
Retention times of water masses	
Flow velocities (e.g. tidal velocities or river inflow velocities)	
Total volume and/or estimated volume of different salinity ranges	
Salinities	
Other water quality variables (see above)	
Other biotic components	

Macrophytes:

ABIOTIC COMPONENT OR PROCESS	BIOLOGICAL RESPONSE
Mouth condition (provide temporal implications where applicable)	
Exposure of intertidal areas during low tide	
Subtidal, intertidal and supratidal habitat (amended in 2008)	
Sediment characteristics (including sedimentation)	
Retention times of water masses	
Flow velocities (e.g. tidal velocities or river inflow velocities)	
Total volume and/or estimated volume of different salinity ranges	
Salinities	
Other water quality variables (see above)	
Other biotic components	

Invertebrates:

ABIOTIC COMPONENT OR PROCESS	BIOLOGICAL RESPONSE
Mouth condition (provide temporal implications where applicable)	
Exposure of intertidal areas during low tide	
Subtidal, intertidal and supratidal habitat (amended in 2008)	
Sediment characteristics (including sedimentation)	
Retention times of water masses	
Flow velocities (e.g. tidal velocities or river inflow velocities)	
Total volume and/or estimated volume of different salinity ranges	
Salinities	
Other water quality variables (see above)	
Other biotic components	

Fish:

ABIOTIC COMPONENT OR PROCESS	BIOLOGICAL RESPONSE
Mouth condition (provide temporal implications where applicable)	
Exposure of intertidal areas during low tide	
Subtidal, intertidal and supratidal habitat (amended in 2008)	
Sediment characteristics (including sedimentation)	
Retention times of water masses	

ABIOTIC COMPONENT OR PROCESS	BIOLOGICAL RESPONSE
Flow velocities (e.g. tidal velocities or river inflow velocities)	
Total volume and/or estimated volume of different salinity ranges	
Salinities	
Other water quality variables (see above)	
Other biotic components	

Birds:

ABIOTIC COMPONENT OR PROCESS	BIOLOGICAL RESPONSE
Mouth condition (provide temporal implications where applicable)	
Exposure of intertidal areas during low tide	
Subtidal, intertidal and supratidal habitat (amended in 2008)	
Sediment characteristics (including sedimentation)	
Retention times of water masses	
Flow velocities (e.g. tidal velocities or river inflow velocities)	
Total volume and/or estimated volume of different salinity ranges	
Salinities	
Other water quality variables (see above)	
Other biotic components	

E.2.2 Reference Condition

ABIOTIC COMPONENTS

1. **Described seasonal variability in river inflow** (based on Reference Condition simulated runoff scenario)

2. **Describe flood regime for the reference condition** (to be included in comprehensive level determinations)

3. **Describe changes in sediment processes under reference compared with present state** (to be included in comprehensive level determinations)

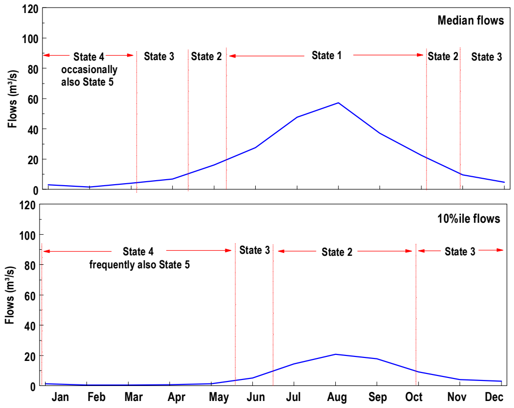
4. **Estimate the occurrence and duration of different abiotic states during the Reference Condition:**

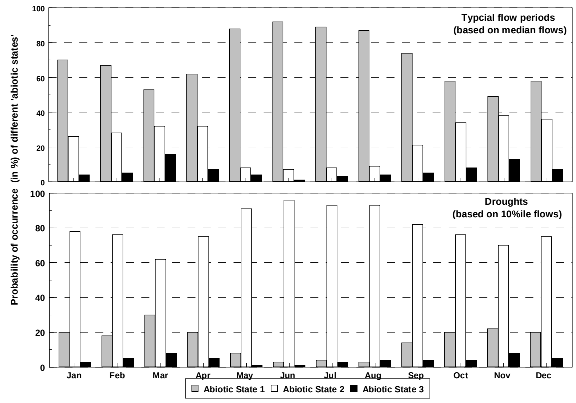
   Use colour coding to indicate the average distribution of abiotic states over the simulated period:

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.97	7.90	2.79	1.09	0.49	13.20	3.46	0.00	49.57	10.97	21.10	27.42
1928	8.83	48.60	17.27	2.47	0.94	5.13	6.94	8.24	15.41	76.96	71.26	21.82
1929	9.39	3.98	7.66	4.46	31.13	18.52	4.14	2.67	2.05	6.46	35.94	56.80
1930	23.77	7.37	3.82	3.43	1.53	5.29	69.77	40.06	9.50	59.89	103.97	44.60
1931	65.64	17.58	34.48	11.63	32.69	4.28	0.87	11.75	21.45	32.98	21.88	141.31
1932	50.58	7.70	4.31	1.81	1.08	1.11	0.64	2.47	55.89	100.96	68.18	26.16
1933	11.30	9.68	4.27	4.97	3.68	3.96	1.12	1.25	8.81	20.18	41.55	42.20
1934	90.47	40.79	6.77	2.41	1.98	1.27	7.04	25.49	25.06	39.63	39.90	28.24
1935	11.37	11.53	4.83	2.52	0.99	0.48	0.16	3.20	3.75	20.31	42.44	42.64
1936	17.59	100.95	41.86	5.98	1.61	9.92	4.87	7.22	56.07	94.13	30.09	19.24
1937	8.82	7.07	9.24	6.54	0.96	6.73	14.23	28.25	13.24	20.83	29.00	31.62
…….	10.95	3.71	4.31	2.83	1.70	0.79	0.96	9.45	58.67	227.94	63.51	96.18

State 1:	< 0.5	State 2:	0.5 - 3.0	State 3:	3.0 -	State 4:	10.0 -	State 5:	> 20.0

Provide an overview of the seasonal distribution of states, e.g.:





<u>BIOTIC COMPONENTS</u>

Predict the change in biotic characteristics from the Reference Condition to the Present State, as well as motivate the cause of such changes:

MICROALGAE

Confidence:

MACROPHYTES

Confidence:

INVERTEBRATES (including Zooplankton, Benthic invertebrates and Macro crustaceans)

Confidence:

FISH

Confidence:

BIRDS

Confidence:

E.2.3 Present Status Category

<u>ABIOTIC COMPONENT</u>

Hydrology

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
a. % similarity in period of low flows OR Present MAR as a % of MAR in the reference condition			
b. % similarity in mean annual frequency of floods			

Hydrodynamics and mouth condition

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Change in mean duration of closure, e.g. over a 5 or 10 year period			
Anthropogenic influence (amended 2008):			

Percentage of overall change in mouth conditions caused by anthropogenic modifications (e.g. artificial breaching)			

Water quality

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Change in the longitudinal salinity gradient (%) and vertical salinity stratification			
2a. Nitrate/phosphate concentration in the estuary			
2b. Suspended solids in present in inflowing freshwater			
2c. Dissolved oxygen in the estuary			
2d. Levels of toxins			
Anthropogenic influence (amended 2008):			
Percentage of overall change salinity caused by anthropogenic activity			
Percentage of overall change in nitrate and phosphate caused by anthropogenic modifications			
Percentage of overall change in suspended solids caused by anthropogenic modifications			
Percentage of overall change in toxic substances caused by anthropogenic modifications			

Physical habitat alteration

	VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Resemblance of <u>intertidal sediment</u> structure and distribution to reference condition				
1a	% similarity in intertidal area exposed			
1b	% similarity in sand fraction relative to total sand and mud			
2	Resemblance of subtidal estuary to reference condition: depth, bed or channel morphology			
Anthropogenic influence:				
	Percentage of overall change in <u>intertidal habitat</u> caused by **anthropogenic** activity as opposed to modifications to water flow into estuary			
	Percentage of overall change which in sub<u>tidal habitat</u> caused by **anthropogenic** modifications (e.g.bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary			

BIOTIC COMPONENT

Microalgae

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Phytoplankton			
1. Species richness			
2a. Abundance			
2b. Community composition			
Benthic microalgae			
1. Species richness			
2a. Abundance			
2b. Community composition			

Macrophytes

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness			
2a. Abundance			
2b. Community composition			

Invertebrates

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
Zooplankton			
1. Species richness			
2a. Abundance			
2b. Community composition			
Macroinvertebrates			
1. Species richness			
2a. Abundance			
2b. Community composition			
Macrocrustacea			
1. Species richness			
2a. Abundance			
2b. Community composition			

Fish

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness			
2a. Abundance			
2b. Community composition			

Birds

VARIABLE	SCORE	MOTIVATION	CONFIDENCE
1. Species richness			
2a. Abundance			
2b. Community composition			
Bird score			

COMPONENT	DEGREE (%) TO WHICH CHANGE IS CAUSED BY NON-FLOW RELATED ACTIVITIES	MOTIVATION	CONFIDENCE
Microalgae			
Macrophytes			
Invertebrates			
Fish			
Birds			

E.3 Quantification of Ecological Flow Requirement Scenarios

NOTES:

- ***These templates need to be completed for each of the additional scenarios provided for a specific study.***

- ***Changes in biotic components should be predicted in terms of:***

    - ***Changes in species diversity, richness, rarity and community composition (e.g. provide details on endemic and Red Data species)***
    - ***Changes in biomass distribution and productivity***
    - ***Changes in seasonal and inter-annual variability.***

  The specific causes of predicted changes should be provided.

- ***Motivations provided in the EHI tables should correspond with the predicted changes discussed for each of the scenarios (i.e. one should be able to 'cut-and-paste' relevant paragraphs). It is also important that the confidence limits correspond.***

- ***When allocating a score for the future scenario, it should also represent similarity to Reference Condition (it often helps to use the Present State score as starting point and work from there).***

- ***For the rapid level determination only abiotic templates need to be completed prior to workshop for future scenarios.***

ABIOTIC COMPONENTS

1. **Describe seasonal variability in river inflow for each of the different flow scenarios** (based on simulated future runoff scenario)

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

2. **Describe flood regime for each of the different flow scenarios** (to be included in Comprehensive level determinations)

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

3. Describe changes in sediment processes under future scenarios compared with Reference Condition (to be included in Comprehensive level determinations)

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

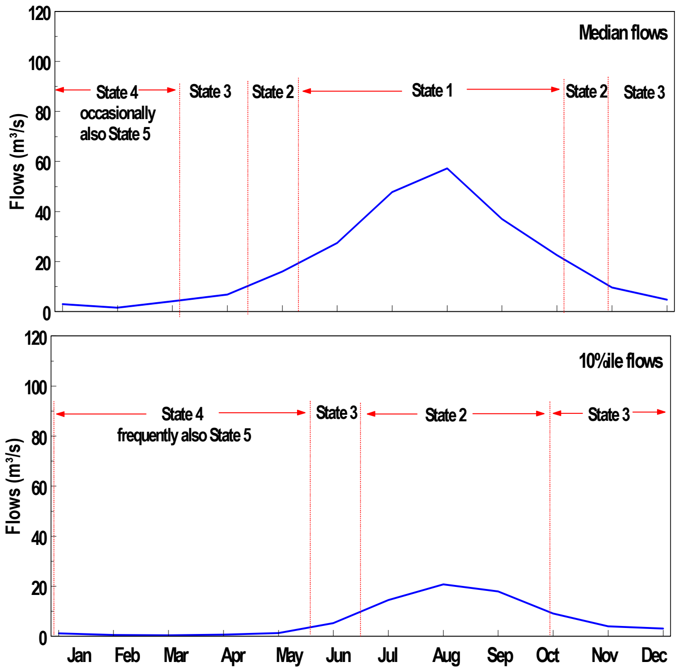
4. Estimate the occurrence and duration of different abiotic states during the Reference State for each of the Future Scenarios:

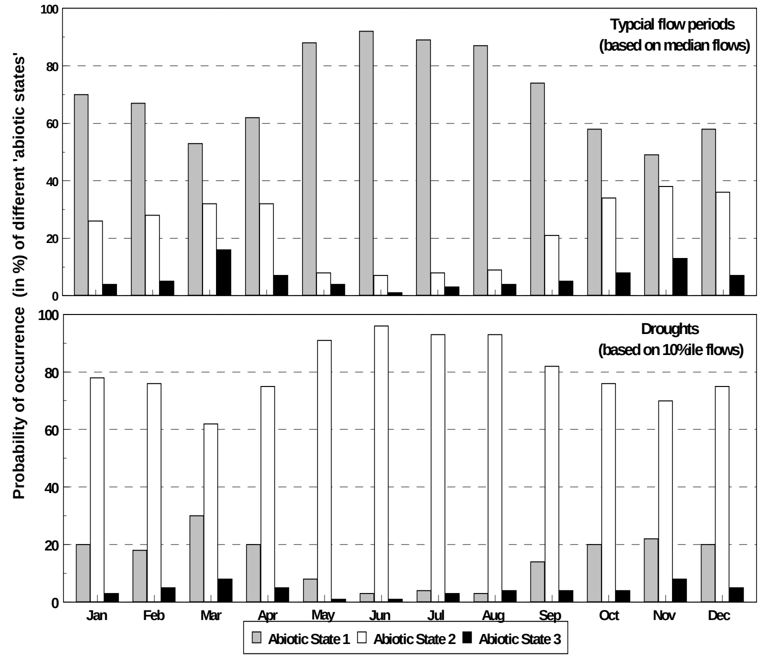
Use colour coding to indicate the average distribution of abiotic states over the simulated period), e.g.:

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1927	1.97	7.90	2.79	1.09	0.49	13.20	3.46	0.00	49.57	10.97	21.10	27.42
1928	8.83	48.60	17.27	2.47	0.94	5.13	6.94	8.24	15.41	76.96	71.26	21.82
1929	9.39	3.98	7.66	4.46	31.13	18.52	4.14	2.67	2.05	6.46	35.94	56.80
1930	23.77	7.37	3.82	3.43	1.53	5.29	69.77	40.06	9.50	59.89	103.97	44.60
1931	65.64	17.58	34.48	11.63	32.69	4.28	0.87	11.75	21.45	32.98	21.88	141.31
1932	50.58	7.70	4.31	1.81	1.08	1.11	0.64	2.47	55.89	100.96	68.18	26.16
1933	11.30	9.68	4.27	4.97	3.68	3.96	1.12	1.25	8.81	20.18	41.55	42.20
1934	90.47	40.79	6.77	2.41	1.98	1.27	7.04	25.49	25.06	39.63	39.90	28.24
1935	11.37	11.53	4.83	2.52	0.99	0.48	0.16	3.20	3.75	20.31	42.44	42.64
1936	17.59	100.95	41.86	5.98	1.61	9.92	4.87	7.22	56.07	94.13	30.09	19.24
1937	8.82	7.07	9.24	6.54	0.96	6.73	14.23	28.25	13.24	20.83	29.00	31.62
....	10.95	3.71	4.31	2.83	1.70	0.79	0.96	9.45	58.67	227.94	63.51	96.18

State 1:	< 0.5	State 2:	0.5 - 3.0	State 3:	3.0 -	State 4:	10.0 -	State 5:	> 20.0

Provide an overview of the seasonal distribution of states, e.g.:





5. EHI Scoring of abiotic components

Hydrology: Describe the changes in the hydrology for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	a. % similarity in period of low flows OR MAR as a % of MAR in the reference condition		b. % similarity in mean annual frequency of floods		Overall score
	Score L/M/H	Summary of change	Score L/M/H	Summary of change	
Present	50 M	50% or 6 months	80 M	1:20 year flood reduced by 20%	
1					
2					
3					
4					
n					

Hydrodynamics and mouth condition: Describe the changes in the hydrology for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	**Change in mean duration of closure, e.g. over a 5 or 10 year period**		**Overall score**
	Score L/M/H	**Summary of change**	
Present	50 M	50% or 6 months	
1			
2			
3			
4			
n			

Water quality: Describe the changes in the hydrology for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	**1. Changes in longitudinal salinity gradient and vertical stratification**		**2a. Nitrate/ phosphate concentration in the estuary**		**2b. Suspended solids in the estuary**		**2c. Dissolved oxygen in the estuary**		**2d. Levels of toxins in the estuary**		**Overall score**
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	**Scor e L/M/H**	**Summary of change**	
Present	72 L	⇩stratified ⇩Salinity: 0-20 ppt									
1											
2											
3											
4											
n											

Physical habitat alteration: Describe the changes in the hydrology for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	**1. Resemblance of intertidal sediment structure and distribution to reference condition**				**2. Resemblance of submerged estuary to reference condition: depth, bed or channel morphology (i.e. based on subtidal habitat, channel morphology, and taking degree of sedimentation, and obstruction or constriction into account)**		**Overall score**
	a. % similarity in intertidal area exposed % similarity in intertidal area exposed		**% similarity in sand fraction relative to total sand and mud**				
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	
Present	75 M	⇧ 25% (~50 Ha)	75 M	⇧ 25% muddy	90	⇩10% (~20 Ha)	
1							
2							
3							
4							
n							

BIOTIC COMPONENTS

Predict the change in biotic characteristics of the future Scenarios compared with the Reference Condition, list the causes of these changes and provide the confidence (H/M/L) in the predictions. Apply the guidelines for the EHI scoring:

Microalgae: Describe the changes for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Phytoplankton:

Scenario	**1. Species richness (% similarity in brackets)**		**2a. Abundance**		**2b.Community composition**	
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**
Present	72 (60) L		85 M		80 L	
1						
2						
3						
4						
n						

Benthic microalgae:

Scenario	**1. Species richness (% similarity in brackets)**		**2a. Abundance**		**2b.Community composition**	
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**
Present	72 (60) L		85 M		80 L	
1						
2						
3						
4						
n						

Scenario	Minimum score Species richness	Minimum score Abundance	Minimum score Community composition	Overall score
Present				
1				
2				
3				
4				
n				

Parameters used as a proxy for change:

PARAMETERS, e.g.	PRESENT	FUTURE SCENARIO 1	FUTURE SCENARIO 2	FUTURE SCENARIO 3	FUTURE SCENARIO 4	FUTURE SCENARIO 5
Mouth Closure	⇧ 50%	⇧75%				
Floods						
Salinity						
Nutrients						
…….						

Macrophytes: Describe the changes for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	1. Species richness (% similarity in brackets)		2a. Abundance		2b.Community composition		Overall score
	Score L/M/H	Summary of change	Score L/M/H	Summary of change	Score L/M/H	Summary of change	
Present	72 (60) L		85 M	Reeds & Sedges⇩ 5% (7 Ha) Saltmarsh ⇩ 5% (7 Ha) Mangroves⇧ 2% (3 Ha)	80 L		
1							
2							
3							
4							
n							

Parameters used as a proxy for change:

PARAMETERS, e.g.	PRESENT	FUTURE SCENARIO 1	FUTURE SCENARIO 2	FUTURE SCENARIO 3	FUTURE SCENARIO 4	FUTURE SCENARIO 5
Mouth Closure	⇧ 50%	⇧75%				
Floods						
Salinity						
Nutrients						
……..…						

Invertebrates**: Describe the changes for the different run-off scenarios**

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Zooplankton:

Scenario	**1. Species richness (% similarity in brackets)**		**2a. Abundance**		**2b.Community composition**	
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**
Present	72 (60) L		85 M		80 L	
1						
2						
3						
4						
n						

Benthic invertebrates:

Scenario	72 **Species richness (% similarity in brackets)**		**2a. Abundance**		**2b.Community composition**	
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**
Present	72 (60) L		85 M		80 L	
1						
2						
3						
4						
n						

Macrocrustaceans:

Scenario	1. Species richness (% similarity in brackets)		2a. Abundance		2b.Community composition	
	Score L/M/H	Summary of change	Score L/M/H	Summary of change	Score L/M/H	Summary of change
Present	72 (60) L		85 M		80 L	
1						
2						
3						
4						
n						

Scenario	Minimum score Species richness	Minimum score Abundance	Minimum score Community composition	Overall score
Present				
1				
2				
3				
4				
n				

Parameters used as a proxy for change:

PARAMETERS, e.g.	PRESENT	FUTURE SCENARIO 1	FUTURE SCENARIO 2	FUTURE SCENARIO 3	FUTURE SCENARIO 4	FUTURE SCENARIO 5
Mouth Closure	⇧ 50%...	⇧75%...				
Floods						
Salinity						
Nutrients						
……						

Fish: Describe the changes for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	**1. Species richness (% similarity in brackets)**		**2a. Abundance**		**2b.Community composition**		**Overall score**
	Score L/M/H	**Summary of change**	**Score L/M/H**	**Summary of change**	**Score L/M/H**	**Summary of change**	
Present	72 (60) L		85 M	Estuarine residents ⇩ 5% Estuarine dependent ⇧ 7% Marine ⇩ 20% Freshwater … Catadromous….	80 L		
1							
2							
3							
4							
n							

Parameters used as a proxy for change:

PARAMETERS ,e.g.	**PRESENT**	**FUTURE SCENARIO 1**	**FUTURE SCENARIO 2**	**FUTURE SCENARIO 3**	**FUTURE SCENARIO 4**	**FUTURE SCENARIO 5**
Mouth Closure	⇧ 50%	⇧75%				
Floods						
Salinity						
Nutrients						
Etc…						

Birds: Describe the changes for the different run-off scenarios

Future Scenario 1	
Future Scenario 2	
Future Scenario 3	
Future Scenario 4	
Future Scenario n	

Scenario	1. Species richness (% similarity in brackets)		2a. Abundance		2b.Community composition		Overall score
	Score L/M/H	Summary of change	Score L/M/H	Summary of change	Score L/M/H	Summary of change	
Present	72 (60) L		85 M	Herbivores ⇩ 2% Invertebrate feeders ⇧ 7% Piscivores ⇩ 20%	80 L		
1							
2							
3							
4							
n							

Parameters used as a proxy for change:

PARAMETERS, e.g.	PRESENT	FUTURE SCENARIO 1	FUTURE SCENARIO 2	FUTURE SCENARIO 3	FUTURE SCENARIO 4	FUTURE SCENARIO 5
Mouth Closure						
Floods						
Salinity						
Nutrients						
Etc…						

E.4 Ecological Specifications

NOTES:

The estuarine specialist team is required to define Ecological Specifications for the estuary based on the Ecological Class. (The estuarine specialist team can also set Ecological Specifications based on the recommended Ecological Category if the Management Class Decision making process is delayed, as has been the case in most of the studies completed to date).

Ecological Specifications are clear and measurable specifications of ecological attributes that define a specific ecological category. Although procedures for setting Ecological Specifications for estuaries have not been formulated, it is envisaged that the concept of 'Thresholds of Potential Concern' (TPCs) will be used. Thresholds of potential concern are defined as measurable end points related to specific abiotic or biotic indicators that if reached (or when modelling predicts that such points will be reached) prompts management action. In essence, thresholds of potential concern endpoints should be defined such that they provide early warning signals of potential non-compliance to Ecological Specifications (i.e. not the point of 'no return'). In essence, this concept implies that the indicators (or monitoring activities) selected as part of long-term monitoring programme need to include biotic and abiotic components that are particularly sensitive to ecological changes associated with changes in river inflow.

Templates are provided on the following page.

ABIOTIC COMPONENTS:

COMPONENT	ECOLOGICAL SPECIFICATION	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
Hydrodynamics			
Sediment dynamics			
Water Quality			

BIOTIC COMPONENTS:

COMPONENT	ECOLOGICAL SPECIFICATION	THRESHOLD OF POTENTIAL CONCERN	POTENTIAL CAUSES
Microalgae			
Macrophytes			
Invertebrate			
Fish			
Birds			

E.5 Resource Monitoring Programme

NOTES:

The Resource Monitoring Programme, as part of the determination of the preliminary Ecological Water Requirement studies should, therefore, includes:

- ***Additional 'baseline' requirements, using the recommended baseline data requirements listed in Tables 3.1a to 3.1i as guidance.***
- ***Long-term monitoring programme.***

In both instances, the components listed should be been prioritised, using for examples colour coding, as indicated below:

(red)	***High priority, considered as a minimum requirement for a suitable baseline data set or as a minimum list of indicators to sufficiently monitor the effectiveness of the Reserve***
(orange)	***Medium priority, will improve the confidence of the assessment or auditing process and should be added to the process if funding is available.***
(green)	***Low priority, will add to the overall confidence of the assessment or auditing process, but not considered to be a critical indicator.***

The following details need to be provided as part of the long-term monitoring programmes:

- ***Selection of indicators, motivated in terms of the relevant Ecological Specification and TPCs***
- ***Monitoring actions and temporal and spatial scales at which monitoring action needs to be executed***
- ***Estimated human resource requirements to execute the resource monitoring programme.***

Templates are provided on the following page.

Additional Baseline data requirements:

ABIOTIC COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
Hydrodynamics			
Sediment Dynamics			
Water Quality			

BIOTIC COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations)
Microalgae			
Microalgae			
Invertebrates			
Fish			
Birds			

Long-term monitoring programme:

ABIOTIC COMPONENT	MONITORING ACTION	RELATED TPC	TEMPORAL SCALE (FREQUENCY AND WHEN)	SPATIAL SCALE (STATIONS)	HUMAN RESOURCES (AS DAYS/YEAR)					
					SAMPLING		ANALYSIS		REPORTING	
					Scientist	Tech	Scientist	Tech	Scientist	Tech
Hydrodynamics										
Sediment Dynamics										
Water Quality										

BIOTIC COMPONENT	MONITORING ACTION	RELATED TPC	TEMPORAL SCALE (FREQUENCY AND WHEN)	SPATIAL SCALE (STATIONS)	HUMAN RESOURCES (AS DAYS/YEAR)					
					SAMPLING		ANALYSIS		REPORTING	
					Scientist	Tech	Scientist	Tech	Scientist	Tech
Microalgae										
Macrophytes										
Invertebrates										
Fish										
Birds										