THE ESTUARY HEALTH INDEX:

A STANDARDISED METRIC FOR USE IN ESTUARY MANAGEMENT AND THE DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS

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WRC REPORT No. 1930/1/12
2012

CERM
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This report should be cited as:

Turpie, J.K., Taljaard, S., van Niekerk, L., Adams, J., Wooldridge, T., Cyrus, D., Clark, B. & Forbes, N. 2012. The Estuary Health Index: a standardised metric for use in estuary management and the determination of ecological water requirements. WRC Report No. 1930/1/12

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ISBN 978-1-4312-0433-4
Printed in the Republic of South Africa

ACRONYMS

BAS	Best Attainable State
C.A.P.E	Cape Action for People and the Environment
CMA	Catchment Management Agency
CSIR	Council for Scientific and Industrial Research
CWAC	Coordinated Waterbird Counts
DAFF	Department of Agriculture, Forestry and Fisheries
DEAT	Department of Environmental Affairs and Tourism
D-GPS	Differential Global Positioning System
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EHI	Estuary Health Index
EIA	Environmental Impact Assessment
HPLC	High Performance Liquid Chromatography
IFR	In-stream Flow Requirement
MAR	Mean Annual Runoff
MSL	Mean Sea Level
NWRCS	National Water Resource Classification System
PES	Present Ecological Status
RC	Reference Condition
RDM	Resource Directed Measures
REC	Recommended Ecological Category
RQO	Resource Quality Objectives
SAIAB	South African Institute for Aquatic Biodiversity
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks Board
TPC	Threshold of Potential Concern

GLOSSARY

Abiotic: The non-living chemical and physical factors in the environment.

Bathymetry: The measurement of the depth of bodies of water.

Biotic: Of, pertaining to, or produced by life or living organisms.

Catchment area: An area drained by a river or a body of water.

Catchment Management Agency: An agency developed at the regional/catchment level that involves a multidisciplinary approach to water resources management.

Classification Process: The determination of an ecological class by taking ecological, social and economic factors into account, in a transparent participatory process.

Confidence Limits: A statistical term for a pair of numbers that predict the range of values within which a particular parameter lies for a given level of confidence.

Ecological Class: Defines the condition in which each resource will be managed.

Ecological Reserve: The quality, quantity and timing of freshwater inflows reserved to support ecosystem function.

Environmental Flow Assessment: The process of determining the amount of water that should purposefully be left in a river or be released from an impoundment in order to maintain a river in a desired state.

Estuary Health Index: An overall assessment of the condition of estuaries.

Preliminary Reserve: The determination of an initial reserve until such time as the resource can be properly classified.

Present Ecological Status: The present quality (water quantity, water quality, habitat and biota) of the resource – assessed in terms of the degree of similarity to the reference condition.

Recommended Ecological Category: The category allocated is the target for protection and management of the resource. The category could be the same as PES or higher if an improved condition is desired.

Reference Condition: The natural, un-impacted characteristics of a water resource, and represents a stable baseline.

Reserve specification: This entails the setting the Resource Quality Objectives (quantitative specifications), and the water quantity and quality parameters of the Reserve.

Resource Directed Measures: To ensure the protection of water resources, by protecting ecosystem functioning and maintaining a desired state of health of aquatic and groundwater dependent ecosystems.

Resource Quality Objectives: The setting of environmental flows and specific goals for the quality of the resource.

Socio-economic: Indicators/studies looking at both social and economic conditions relevant to well-being.

Source-directed controls: Controlling impacts on the water resource through the use of regulatory measures such as registration, permits, directives and prosecution, and economic incentives such as levies and fees, to ensure that the Resource Quality Objectives are met.

Water Management Area: An area defined for the purpose of water management and protection.

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2 INTRODUCTION

2.1 Introduction

This manual sets out a standardised and tested method for assessing the health of an estuary as a baseline and against which to set future objectives and measure progress according to management targets. Its intention is for use in the determination of the freshwater Reserve for estuaries (for which the method was originally developed by Turpie 1999), as well as for use in management of estuaries generally. The manual is written for use by estuary scientists in carrying out the assessment as well as for water, catchment and estuary managers who manage the process.

2.2 What is estuary health?

Health is used to describe an estuary's condition. That is, we wish to know to what extent an estuary's state differs from its pristine condition (= "reference condition"). A measure or index of estuarine health should reflect the degree to which the present characteristics and functioning of an estuary deviate from under the reference condition (Costanza *et al.* 1992).

The most obvious place to start in assessing a system's health is by examining the biotic and abiotic components of a system, such as the fish species assemblage. In deriving an index a range of appropriate measurable components would need to be selected and assembled into an index using a system of weightings and calculations. This has been the focus of most health assessment methods.

A further challenge is the issue of working with limited data from dynamic estuarine ecosystems. The loss of dynamic function *per se* may constitute an important measure of degradation in estuarine health, but is far more difficult to measure, especially in the absence of long term data series.

Note that the term 'integrity' is used in the assessment of river health. 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).

2.3 The need for an Estuary Health Index

2.3.1 The Ecological Reserve

The National Water Act of 1998 requires the implementation of 'Resource Directed Measures' (RDM) in order to make optimal use of our country's water resources while minimising ecological damage. The main focus of RDM is the determination of the 'Reserve', which is the water quality and quantity required for the protection of basic human needs and aquatic systems. The latter component, or 'Ecological Reserve', is the quality and quantity of water required to maintain a desired level of structure and function, or quality, of a specific aquatic system (e.g. river reach, wetland, estuary). The desired quality of the water resource will be defined by its 'Ecological Category' which can be A, B, C or D on a health scale of A to F (Table 2.1). While scientists are allowed to make recommendations for this category the "Recommended Ecological Category" (REC), the final decision will be based on ecological, social and economic criteria in a participative process called the National Water Resource Classification System's Classification Process (Dollar et al. 2010; gazetted in 2010). The Department of Water Affairs will be responsible for the Classification of all significant water resources in the country, including estuaries, and these decisions will be re-evaluated at intervals.

Table 2.1. Ecological Categories to describe ecosystem health

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

Although the Classification Process was gazetted only recently, the remaining steps were first developed in 1999, the Reserve determination methods were devised in 1999 (DWAF 1999) and have been in use since then, though having evolved over time following increased experience and understanding of the methods in practice. This method will continue to the part of the more formalised Classification Process. In the Reserve determination process for estuaries, the method involves (a) estimating the present health status of an estuary, (b) setting an REC on the basis of this and its importance using a simple set of rules (Table 2.2), (c) setting an EC based on the ecological, social and economic criteria, (d) predicting how health changes under a range of flow scenarios, and then (e) finding the flow scenario that most closely matches the REC in order to define the ecological Reserve. The Estuary Health Index (EHI) is central to the Reserve determination method.

Table 2.2. Rules for assigning Recommended Ecological Category (REC), based on Present Ecological Status (PES) and importance.

Current/Required Protection Status and Estuary Importance	REC (in terms of categories A – F)
Protected area/ Required Protected Area	A or BAS*
Highly important	PES + 1, min B, or BAS
Important	PES + 1, min C, or BAS
Of low to average importance	PES, min D

*Best Attainable State

2.3.2 Conservation planning

Conservation priorities are inextricably linked with water requirements, in that they form an important input into the determination of the Reserve is the status of the estuary as a Protected Area or “Required Protected Area” (Table 2.2). The latter refers to priorities identified through conservation planning.

Conservation planning is an evolving field that has allowed a move from *ad hoc* protection to systematic planning that takes pattern, process and biodiversity persistence into account. Conservation planning involves defining the planning domain and planning units, then setting targets, assessing how well the current protected areas meet those targets and selecting new planning units to meet the targets subject to some constraint such as minimising the number of sites or the costs. A variety of sophisticated algorithms have been developed for this purpose.

More recently, attention has been focused on incorporating socio-economic realities into conservation planning, particularly in terms of minimising the management and opportunity costs of protection. In the case of estuaries, conferring conservation status on an estuary is expected to lead to a recovery of ecosystem health and the supply of ecosystem services. This benefit is offset by the opportunity costs due to the increased water requirement of the estuary to maintain a high level of health, as well as limitations on development and use (Turpie & Clark 2007).

Understanding the opportunity cost of conserving estuaries in term of water supply means having a thorough understanding of the relationship between freshwater inflows and estuary health, and their relative importance compared to non-flow related factors. This understanding is gradually developing over time through application of the Reserve determination methods in which future health states arising from alternative future flow scenarios are estimated.

Estuary health itself is also an important factor in conservation planning. Turpie et al. (2012) used the existing health estimates including the application of the EHI at a desktop level for all estuaries in the country (van Niekerk et al. 2012) in developing a national-level conservation plan for estuaries. Estuaries in a better state were favoured more than unhealthy estuaries in the selection process, with deteriorating health represented as an exponentially increasing cost. This was done as a proxy for estimation of the water and other restoration costs that would be required in the conservation of a system.

Finally, estuaries that have high conservation priority status as formalised in the National Estuary Biodiversity Plan (Turpie *et al.* 2012) as part of the National Biodiversity Assessment (van Niekerk & Turpie 2012), are considered to be worth managing in an excellent state of health. This requires an understanding of their current health and the measures, including environmental flows, that are required to maintain or restore the estuary to the targeted level of health.

2.3.3 Management and monitoring

South Africa’s Estuary Management Protocol requires that Estuary Management Plans are developed for every estuary. Among other considerations, these management plans need to be guided by (a) the level of biodiversity protection required as defined by the National Estuary Biodiversity Plan (Turpie *et al.* 2012), and (b) by the Ecological Category of the estuary defined in terms of the National Water Act, which in turn defines the flow requirements of the system. As part of their management, estuaries will need to be monitored to assess the implementation and performance of management measures, including the freshwater Reserve. Again, this requires a robust and standardised means of assessing estuary health. It was the realisation of the usefulness of the EHI in estuary management that led to the publication of the estuary health assessment method as a stand-alone document.

3 TYPES AND DISTRIBUTION OF SOUTH AFRICAN ESTUARIES

An estuary is defined as “a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with freshwater derived from land drainage” (Day 1980).

There are a great many catchment systems that flow out into the sea, but many of these are extremely small and not generally considered to function as estuaries. Whitfield (2000) identified a total of 258 systems that fit the above definition of estuaries (Whitfield 2000; Figure 1). In a more recent assessment, van Niekerk & Turpie (2012) recognised a total of 289 estuarine systems.

There are several classifications of estuaries in terms of their physical characteristics. The geomorphological classification used by Harrison *et al.* (2000) recognises six main types based on mouth condition (open or closed), size and the presence of a bar. Whitfield’s (1992) better known classification recognises five types based on size of the tidal prism, mixing process and salinity (Box 1). Of these, estuarine bays, permanently open estuaries and river mouths tend to remain open to the sea on a permanent basis, whereas estuarine lakes and temporarily open/closed systems close periodically, sometimes for periods of years.

Table 3.1 Typical characteristics of the five types of estuaries defined by Whitfield (1992) and their relative prevalence in South Africa (289 estuaries) Turpie *et al.* 2012.

Type	Typical size	Typical mouth condition	Number in South Africa	%	Total area (ha)	%
Bay	Large	Open	3	1%	5 118	6%
Permanently open	Med to large	Open	44	15%	17 944	20%
River mouth	Small to large	Open	11	4%	4 947	5%
Lake	Large	Closed	9	3%	56 205	62%
Temporarily open	Small to med	Closed	222	77%	6 631	7%
TOTAL			**289**		**90 844**	

Van Niekerk & Turpie (2012) provided a finer-scale classification of estuaries based on mouth condition, water type, turbidity and size.

South African estuaries fall within three biogeographical zones: the Cool Temperate zone on the west coast, the Warm Temperate zone which extends approximately from Cape Point to the Mbashe River in the Eastern Cape, and the Subtropical Zone on the east coast. While relatively high numbers of estuaries are found in both the Warm Temperate and Subtropical zones, only 11 are found in the Cool Temperate zone on the west coast (Table 2). In general, estuaries increase in density along the coast from west to east.

Box 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 reflect 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.

(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.

Table 3.2 Summary of the estuary typology used and the numbers of estuaries associated with each type (Turpie *et al.* 2012)

	Large	Medium	Small	Total
Temporarily Closed Fresh Black	0	5	10	15
Temporarily Closed Fresh Turbid	2	4	0	6
Temporarily Closed Marine Clear	1	0	0	1
Temporarily Closed Mixed Turbid	1	16	0	17
Temporarily Closed Mixed Black	10	17	25	52
Temporarily Closed Mixed Clear	7	86	50	143
Permanently Open Fresh Black	0	0	6	6
Permanently Open Marine Black	1	0	0	1
Permanently Open Marine Clear	6	1	0	7
Permanently Open Marine Turbid	1	0	0	1
Permanently Open Mixed Clear	4	4	0	8
Permanently Open Mixed Black	5	1	3	9
Permanently Open Mixed Turbid	14	9	0	23
Total	**52**	**143**	**94**	**289**

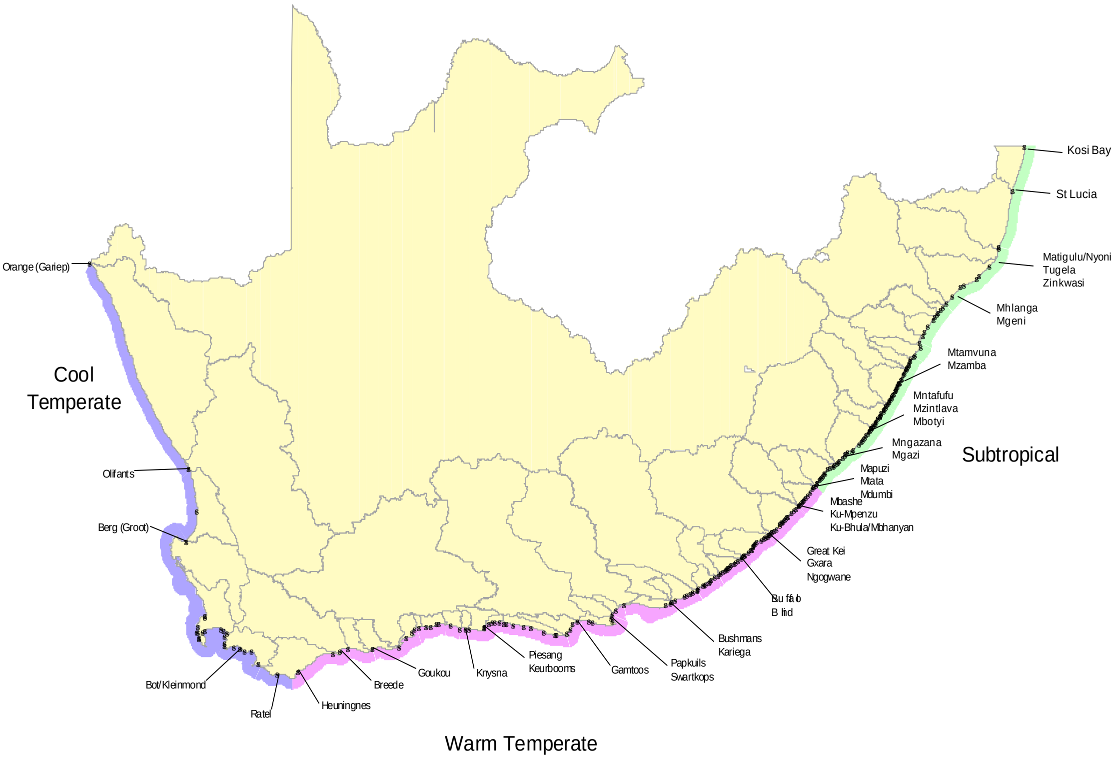


Figure 3.1 Distribution of estuaries in relation to the three biogeographic zones and secondary catchment areas (Turpie *et al.* 2012)

Estuaries within the three zones have been shown to have relatively distinct faunal communities, and have also been found to differ significantly in their physico-chemical characteristics (Harrison 2004). Estuarine temperatures follow the trend for marine coastal waters, being coldest on the west coast. Warm temperate estuaries are characterised by high salinities and low turbidities due to low rainfall and runoff, high seawater input and evaporative loss, while cold temperate, and especially subtropical, estuaries tend to have lower salinities and higher turbidity, due to relatively high runoff (Harrison 2004).

In spite of these generalisations, however, estuaries are known for their 'uniqueness', and it is difficult to generalise among types within any of the typologies and/or biogeographical zones. This poses a challenge for estuary management, and has been one of the factors that has led to the development of the Estuary Health Index.

4 BACKGROUND TO DEVELOPMENT OF THE EHI

4.1 Past methods for assessing estuary health

4.1.1 Heydorn's assessments 1980, 1986

The first broadscale assessment of estuary health in South Africa was by Heydorn & Tinley (1980) who reviewed the condition of the estuaries of the former Cape Province (from the Orange to the Great Kei). This was followed by a national assessment of the condition of South African estuaries (Heydorn 1986; Table 4.1). This assessment suggested that 11% of large estuaries and 22% of small estuaries were in a poor condition. This assessment did not include the estuaries of the former Ciskei and Transkei coasts, however, which span much of the eastern half of the present Eastern Cape Province.

Table 4.1. Condition of estuaries in the former Cape Province (Orange to Kei) (Heydorn 1986)

	No. of estuaries	Present condition (%)		
		Good	Fair	Poor
Large	35	6	83	11
Small	118	30	41	22
Total	153	24	50	20

4.1.2 Ramm's Community Degradation Index

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

4.1.3 Cooper's 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. They devised an "Estuarine Health Index" which was very similar to the Community Degradation Index, except it was adapted to reflect the degree of *similarity* to pristine condition, rather than dissimilarity. The Estuarine Health Index (EHI) was comprised of three equally-weighted components, *viz*. the Biological Health Index (BHI), Water Quality Index (WQI), and Aesthetic Quality Index (AQI), where each of the components is reflected as a score out of 10:

$$\text{EHI (score out of 10)} = (\text{BHI} + \text{WQI} + \text{AQI})/3$$

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 is 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 measure of interest in terms of health is the proportion of the original species richness remaining in the estuary, which could be expressed as a simple percentage. However 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 (a measure of importance). 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). This effect is dampened by its being log-transformed.

The WQI was based on House (1989) and is a simple weighted arithmetic mean, as follows:

$$WQI = 1/100 * \left(\sum_{i=1}^{n} q_i w_i \right)^2$$

where q_i is the rating (score out of 100) for the *i*th water quality variable; w_i is the weighting for the *i*th 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 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 (Cooper *et al.* 1994). Each of the conversion graphs is determined by experts with experience in water quality issues. Six water quality variables were used and weighted by Cooper *et al.* (1994) as follows (Table 3.2). The weights were provisionally assigned on the basis of estimated relative importance.

Table 3.2. 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	0.35
	Oxygen absorbed	Measure of organic loading	0.05	
	Ammonia nitrogen	Toxicity to aquatic fauna	0.10	
Suitability for human contact	E. coli	Evidence for human pathogens	0.30	0.30
Trophic status	Nitrate nitrogen	Aquatic plant growth stimulants	0.10	0.35
	Ortho-phosphate		0.15	
	Chlorophyll-a	Indicator of algal growth	0.10	

The AQI was calculated using nine weighted parameters (Table 2.3), in which each was scored from 0 (poor) to 10 (pristine) on the basis of observation. This index was applied to a large number of estuaries around the country (e.g. Cooper *et al.* 1994, Harrison *et al.* 1994) but has not been widely accepted. The three components do not include major influences such as hydrological, sediment or botanical changes. The WQI does not include variables such suspended solids and toxins.

Using the above, Harrison *et al.* (2000) presented an assessment of the health of all South African estuaries in terms of ichthyofaunal diversity, water quality and aesthetics.

Table 4.3. 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	

4.1.4 CERM's Index of Physical Health

As part of a Conservation Importance Index for estuaries, CERM (1996) developed an "Index of Physical Health" (IPH). The components and weightings, developed with experts using multi-criteria decision analysis techniques such as conjoint scoring, were as follows:

- 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.
- 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 (Table3.4).
- 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.
- 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).

This index has never been applied, however.

Table 4.4. Scores used in the CERM Index to indicate the health of estuarine mouth condition relative to the natural state

% open in Natural state	% open in 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

4.1.5 Van Driel's Estuary Habitat Integrity Index

Van Driel (1998) proposed a method of assessing estuarine integrity based on the procedure described for rivers (Kleynhans 1996), which includes an assessment habitat integrity and biological integrity (Table 4.5, Table 4.). 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 1996). This scoring system combines a measure of extent and intensity of each impact. 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. Rules were proposed for converting the Habitat Integrity score into a category (Table 4.7). A system was also devised 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.

The problem with indices of this nature is that the inclusion of many criteria into a weighted sum index reduces the potential impact of any single criterion. While this index has not been applied to estuaries, the indices from which it was derived have been applied in many river systems.

Table 4.5.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 4.6. 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

Table 4.7. 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

4.1.6 "Botanical Importance Rating" index

The Botanical Importance Rating index (Coetzee *et al.* 1997) was not designed as a health index, but it has been applied in this manner by comparing scores over time. The index, based on summed areas of different habitat types, each weighted by their functional importance. 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. For example it 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. Coetzee *et al.* (1997) and Colloty (2000) have classified selected estuaries in terms of their botanical integrity.

4.1.7 Whitfield's qualitative assessment

Whitfield (2000) conducted an assessment on the condition of estuaries of the entire coast. The estuaries were broadly classified by Whitfield (2000) as follows:

- **Excellent**: estuary in near pristine condition (negligible human impact)
- **Good**: no major negative human influences on either the estuary or catchment (low impact).
- **Fair**: noticeable degree of ecological degradation in the catchment and/or estuary (moderate impact)

- **Poor**: major ecological degradation arising from a combination of human influences (high impact).

Based on this assessment, the overall health of South African estuaries was considered to be relatively good. In the temperate regions, 28% of estuaries were considered to be in excellent condition, and another 44% in good condition, 21% in a fair condition, and 16% in poor condition (Whitfield 2000).

Turpie (2004) used Whitfield's assessment to derive a broad picture of estuarine health for the National Spatial Biodiversity Assessment (Figure 4.1). This analysis also noted that in the eastern part of the country, the estuaries fed by larger catchments tend to be in poorer health than the estuaries in adjacent smaller catchments.

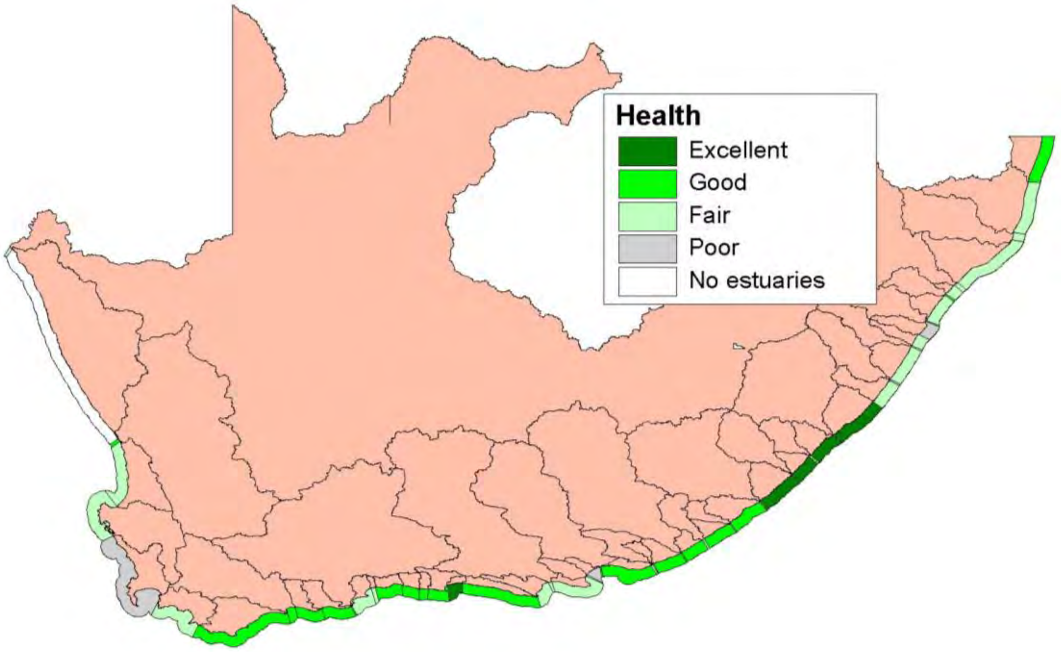


Figure 4.1. Map of the average state of health of estuaries per catchment (after Turpie 2004b)

4.1.8 Harrison & Whitfield's Estuarine Fish Community Index

More recently, Harrison & Whitfield (2004) developed a multimetric fish index, the Estuarine Fish Community Index (EFCI), as a single measure of estuarine condition. The index is made up of 14 measures that represent the species diversity, composition, abundance, nursery function and trophic integrity of fish communities. These measures are related to a reference condition deduced from fish community data collected by Harrison *et al.* (2000). Harrison & Whitfield (2006) then applied the index to data collected for 190 estuaries. Index values ranged from 18 (very poor) to 66 (very good).

4.2 Development of the Estuary Health Index

The above indices paved the way towards the formulation of a robust health index required for the RDM process for estuaries. The first version of the index was finalised in 1999 after a series of workshops with members of the Consortium for Estuary Research and Management (Turpie 1999), as a component of the methodology for determining the freshwater Reserve for estuaries (DWAF 1999). Since then this method has been applied in studies of over 26 estuaries, during which time the various aspects of the methods were fine-tuned. After another round of workshops and review, a second version of the method was developed in 2004 (officially published in 2008), and a third round of review and workshops by the Consortium for Estuary Research and Management led to the current version of the method. Details of the process and changes made are given in Turpie *et al*. (2012). In general the changes have focused on developing a more robust and quantitative method, as well as providing clearer guidelines for its application. Fundamentally, however, the method is still very similar to its original form.

5 BASELINE DESCRIPTION AND HEALTH ASSESSMENT METHOD

5.1 Overview and general considerations

The baseline study and health assessment **provides a description of the estuary in its present state and quantifies its health in terms of the Estuary Health Index**. This is an updated version of the methodology first described in Turpie (1999) and is a generic methodology that can be used for any estuary management purposes, e.g. in Environmental Impact Assessment and the development of Estuary Management Plans as well as for use in Reserve determination studies.

5.1.1 Baseline description

The baseline study and health assessment provides a description of the characteristics and functioning of all major abiotic and biotic aspects of the system and their relationships to one another, and the flow- and non-flow related pressures and impacts on the system. The components studied are as follows:

- 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 sediments and deposition and erosion areas)
    - 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)

5.1.2 Estuary Health Assessment

The estuary health assessment determines the Present Ecological Status (PES) of an estuary using a simple scale of A to F (Table 5.1).

Estimating the health of an estuary involves (a) estimating what the estuary was like in its natural condition (the Reference condition) in terms of physical and biological characteristics and processes, (b) scoring the present condition relative to this estimated Reference state using the Estuary Health Index, which provides a score out of 100, and (c) converting the score to its Present Ecological Status category.

5.1.3 Main components and structure of the EHI

The main challenge in developing the index was 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. 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 include both abiotic (driver) and biotic (response) variables. 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. Even within the abiotic and biotic categories, many of the variables considered were correlated with one another. In such cases, care was taken to choose 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, as follows.

Table 5.1. The six categories for indicating the Present Ecological Status of an estuary. Categories A to D are within the acceptable range, whereas E and F are not (Kleynhans 1996).

EC	Description
A	**Unmodified, or approximates natural condition**; *the natural abiotic template should not be modified. The characteristics of the resource should be determined by unmodified natural disturbance regimes. There should be no human induced risks to the abiotic and biotic maintenance of the resource. The supply capacity of the resource will not be used.*
B	**Largely natural with few modifications**. A small change in natural habitats and biota may have taken place, but the ecosystem functions are essentially unchanged. *Only a small risk of modifying the natural abiotic template and exceeding the resource base should not be allowed. Although the risk to the well-being and survival of especially intolerant biota (depending on the nature of the disturbance) at a very limited number of localities may be slightly higher than expected under natural conditions, the resilience and adaptability of biota must not be compromised. The impact of acute disturbances must be totally mitigated by the presence of sufficient refuge areas.*
C	**Moderately modified**. A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. *A moderate 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 generally be increased with some reduction of resilience and adaptability at a small number of localities. However, the impact of local and acute disturbances must at least partly be mitigated by the presence of sufficient refuge areas.*
D	**Largely modified**. A large loss of natural habitat, biota and basic ecosystem functions has occurred. *Large risk of modifying the abiotic template and exceeding the resource base may be allowed. Risk 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, and a reduction of resilience and adaptability at a large number of localities. However, the associated increase in the abundance of tolerant species must not be allowed to assume pest proportions. The impact of local and acute disturbances must at least to some extent be mitigated by refuge areas.*
E	**Seriously modified**. The loss of natural habitat, biota and basic ecosystem functions is extensive
F	**Critically modified**. Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible

5.1.3.1 Hydrology:

'*Changes in seasonal river inflow patterns*' and *'% of natural MAR currently abstracted '* were considered to be the main drivers of estuary systems. Of these the second was considered as an alternative measure to the first, to be used in data poor situations. '*Reduction in low flows*' is important in that it causes changes the salinity regime and a reduction in open mouth conditions, and '*reduction in high flows*' has an important impact in that it impairs scouring, resulting in accumulation of marine and fluvial sediments. However, both of these are correlated with the first pair of parameters.

5.1.3.2 Hydrodynamics and mouth condition:

'*Timing, frequency and duration of closure*' strongly affects abiotic habitats and biological communities found in estuaries. It is fairly difficult to get data, and it is correlated with hydrology, but can be influenced by other factors and thus has to be included. Since timing is correlated with duration, it was agreed that a measure of overall change in duration would suffice. Other important parameters include '*tidal flow modification*' and '*water level*', but these were considered to be correlated with several abovementioned variables and were excluded from the index.

5.1.3.3 Water chemistry/quality:

'*Axial salinity gradient and vertical salinity stratification*' was considered to be a very important system driver, as opposed to '*average 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, because the influence will differ for different types of estuaries, it was considered important to include. *'Nitrate and phosphate concentrations'* positively affect primary productivity in the estuary, and although it is related to inflow, are also affected by other inputs. '*Suspended solids*' 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'* negatively affect biota, and although these can be expensive and difficult to measure, it is desirable to derive estimates of health in this regard. '*Dissolved oxygen*', '*pH*' and '*temperature*' affect conditions for primary production, and may be affected by conditions in the catchment, e.g. pine plantations, or dams and water transfer schemes. '*Faecal coliform concentrations'* give an indication of suitability for human contact, but because they do not have a major impact on biota, this was not considered important in assessing estuary health.

5.1.3.4 Physical habitat alteration:

'*Change in sediment structure and distribution*' 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, '*changes to the estuary bed and channels*' , e.g. by infilling, was considered an important indicator of estuary health. 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 '*amount of channel* *obstructions*' (bridges, weirs, bulkheads, training walls, jetties, marinas) was considered important to include.

5.1.3.5 Biota:

A health index should include consideration of the structure and functioning of its biotic communities. The parameters or biotic groups for which sufficient information can be gathered within a relatively short space of time include vegetation types, phytoplankton and/or primary production, zooplankton, macro-invertebrates, fish and birds.

5.1.3.6 Overall structure

The index was designed to be simple, and with every component score representing percentage similarity to natural or reference condition, so that the overall weighted aggregate score reflects the overall similarity to natural condition. To account for cyclical variability, the mean conditions during reference conditions are compared with the mean conditions at present. The index has three tiers, with the basic measures grouped, using weighted means or minima, into four abiotic and five biotic measures based, the weighted averages of which form overall abiotic and biotic scores. These are then equally weighted to compute the overall Estuary Health Score (Figure 5.1).

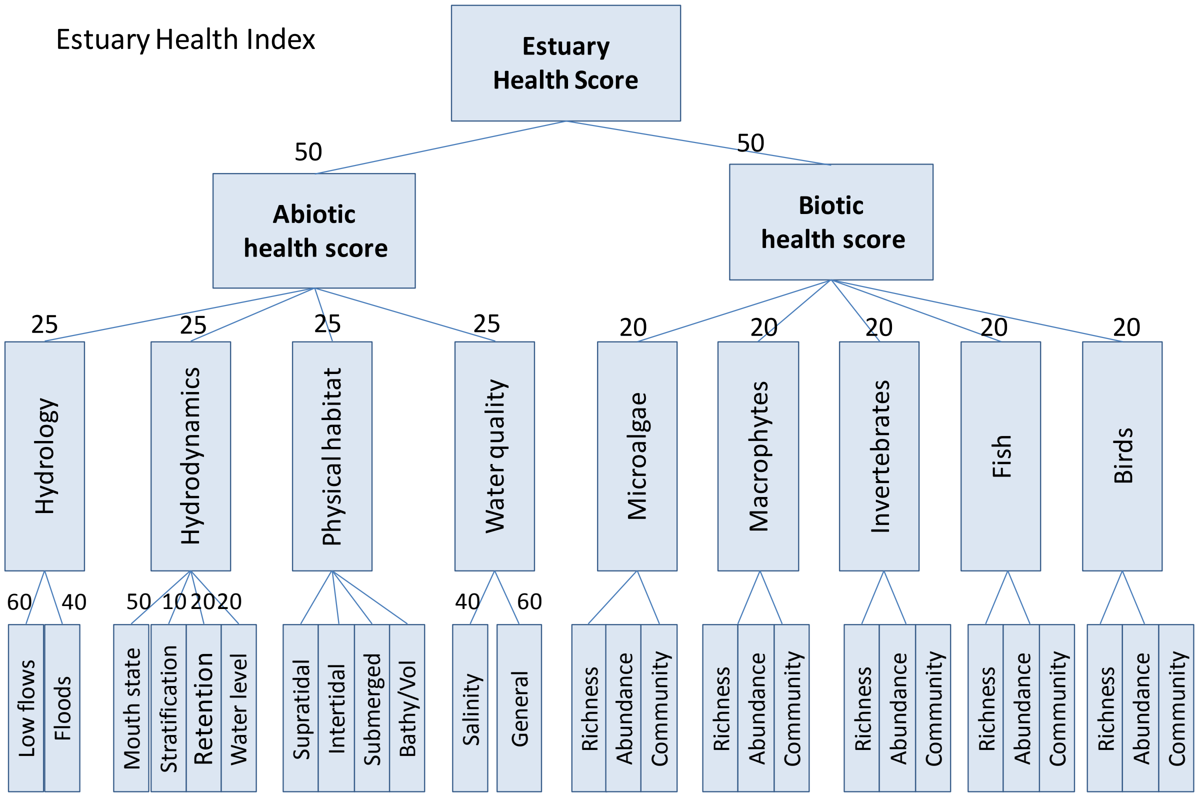


Figure 5.1. Structure of the Estuary Health Index (modified from Turpie 1999). Weightings are equal unless otherwise shown.

The computation of the first tier scores is summarized in Table 5.2. In all cases the scoring is based on available data (including data that might have been collected specifically for the study) for describing present day, and historical data (if available), models or expert opinion to describe the estimated reference condition.

Table 5.2. Summary description of the measures used in scoring the 1st tier variables that make up the 2nd and 3rd tier scores.

2nd Tier	1st Tier	Measures used in scoring
Hydrology	Low flows	Similarity in the amount of flow during a defined low flow period or simply % natural MAR (data poor).
	Floods	Similarity in the magnitude and frequency of floods. Usually summarized as the average volume of the highest 2% of average monthly flows, based on the simulated monthly flows described above.
Hydrodynamics	Abiotic/mouth states	Similarity in terms of proportion of time the estuary is in different states, e.g. closed, open freshwater dominated.
	Stratification	Similarity in the degree of mixing or stratification in the water column
	Retention	Similarity in the duration of water retention in different parts of the estuary
	Water level	Similarity in average water levels
Physical habitat	Supratidal area	Similarity in supratidal physical habitat
	Intertidal area	Similarity in intertidal extent and sediment characteristics
	Subtidal/ submerged area	Similarity in subtidal extent and sediment characteristics
	Bathymetry/volume	Similarity in channel morphology and estuary volume
Water quality	Salinity	Similarity in axial salinity gradient and vertical salinity stratification, based on the amount of time in which different zones of the estuary are within different salinity ranges, or at worst (data poor) considering just average salinity.
	General	Similarity among different variables (N & P, suspended solids, dissolved oxygen, toxins), based on a scoring guideline (Unmodified = 100; largely natural = 80; moderately modified = 60; largely modified = 40; seriously modified = 20; completely modified = 0).
Microalgae, macrophytes, invertebrates, fish and birds	Richness, abundance and community composition	Similarity in estimated average instantaneous species richness, total abundance (biomass or numbers), and community composition, with the latter being based on the estimated abundance of defined subgroups of the biotic component (e.g. waterfowl, waders, etc.).

5.1.4 General considerations in determining estuary health

5.1.4.1 Definition of Reference condition

The Reference Condition of an estuary refers to the ecological status that it would have had:

- before any human-induced changes to freshwater inputs
- before any human development in the catchment or within the estuary, and
- before any mouth manipulation practices (e.g. artificial breaching)

5.1.4.2 Describing Reference condition

The descriptions of the reference state need to highlight the differences from the present state and should include an explanation of the causes of the changes. Where human influences other than those related to changes in river inflow are the cause, these should be identified.

5.1.4.3 Scoring estuary health

Once the Reference condition has been described for all the abiotic and biotic components, the Estuary Health Index is applied, which entails estimating the degree to which features of the Present State (e.g. inflows, fish species richness, etc.) resemble those under 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. All scores involve a min-mean scoring system in which the weighted mean of the scores is combined with the minimum score. Scores are done quantitatively as far as possible, and using a similarity index wherever appropriate, in order to maximise comparability and standardise the procedure as far as possible.

5.1.4.4 Dealing with trajectories of change

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.

In general, where conditions are expected to improve or deteriorate over time under the prevailing flow regime, current condition should be scored, but the trajectory should be noted, and a do-nothing scenario should be included in the future scenarios considered (see Chapter 6).

5.1.5 Consideration of flow- vs. non-flow related impacts

Because the method needs to inform different types of management, it is useful to assess the degree to which the state of health of the system is due to flow-related versus non-flow related impacts. This is therefore built into the assessment in order to further guide management decisions on how to improve the state of a particular system.

5.1.6 Data requirements and confidence

The accuracy with which the ecological status of any estuary can be described will largely depend on the amount of available data (i.e. existing data and information, particularly historical data), 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.

The baseline study and health assessment is the only aspect of the Reserve determination that can vary in terms of the methods used, in that the approach for describing the system **can be applied with different levels of rigor to achieve different levels of confidence**. In the past, this was defined in terms of rapid, intermediate and comprehensive studies, with the latter studies taking 18-24 months to complete. The current version of the methods defines the level of data required to achieve the highest possible level of confidence within a 12-month period (assuming appropriate timing in terms of season of the study initiation), but recognises that the actual confidence level achieved will depend on the extent to which prior monitoring efforts or other studies (e.g. EIAs, academic studies) have occurred on the system. 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 (see Box 2). The detailed methods for each component of the study provide some indication as to how confidence is affected by study design and sampling effort, as a guideline to decision-makers funding the study. In this version of the methods, DWA or their co-funders, are now advised to commission an independent desktop study of available information and to provide guidance on the sampling effort required to achieve the desired level of confidence.

It should be noted that in some small systems it might be appropriate to **concentrate effort on the more important elements** of the ecosystem only. For example if the system currently supports very few birds, and would not be expected to do so in the reference condition either, then it would be appropriate to reduce the effort on this component. In such cases, the component should only be excluded altogether if it is virtually non-existent, and/or if scoring would be so unreliable that it would undermine the results of the rest of the study.

Box 2. Existing data source for estuary studies

- Gauging stations (measuring river inflow) installed upstream of some estuaries (managed by DWA)
- Continuous water level recorders installed in some estuaries (managed by DWA)
- 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)
- 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 habitat information is available for most South African estuaries: Water Research Commission Project K5/814, National Biodiversity Assessment 2010.
- Coordinated Waterbird Counts (CWAC) programme of the Animal Demography Unity, University of Cape Town.

Data requirements for the baseline study are explained in detail in the following sections, and summarised in Appendix C. A summary of available information should be included as an Appendix to the main Baseline Study or Reserve Determination Report of the form shown in (Table 5.3).

Table 5.3. Format for table on data available for the study (note: the table can be stretched to a landscape layout and may span a few pages if necessary). Requirements for a high confidence baseline study are summarised in Appendix C and can be copied into the summary table.

Component	Requirements for high confidence baseline study	Relevant data available	Additional data collected	Comment
General				
Hydrology and hydrodynamics				
Bathymetry and sediments				
Water quality				
Microalgae				
Macrophytes				
Invertebrates				
Fish				
Birds				

All studies apart from a desktop planning study **must involve a field trip** to achieve sufficient confidence to determine a preliminary Reserve. 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 high quality results to be obtained. However, if only two seasons can be sampled, then this should be the low and high flow season, and/or during different mouth states, if applicable. If only one season is sampled, then it should be the season of greatest diversity and abundance. Fieldwork costs can be minimised by **co-ordination of sampling between the different components**. The data collection for all components involves working along the full extent of the estuary, using the same sampling stations as far as possible (these must be sited by the co-ordinator and labelled in terms of distance from mouth). Simultaneous sampling can save on transport and labour costs and allows specialists to share instantaneous water quality data that would otherwise have to be repeated for the different surveys. Temporal co-ordination of fieldwork is also important to provide a better understanding of the interaction between the different components.

5.1.7 Expressing level of confidence

Descriptions and scores need to include an indication of the level of confidence of the specialist involved. This is a subjective assessment, based on the amount of available information as well as the experience of the specialist, though the effect of the latter should be minimised as far as possible by using suitably experienced specialists. Guidelines for describing confidence are as follows:

Limit	Degree of confidence
Very Low	If no data were available for the estuary or similar estuaries (i.e. < 40% certain)
Low	Limited data were available, and estimates could be out by >60% (40 - 60% certain of estimate)
Medium	If reasonable data were available for the estuary and estimates could be out by 20-60% (i.e. 60% – 80% certain of estimate)
High	If good data were available for the estuary and estimates are probably not more than 20% out (i.e. > 80% certain of estimate)

The confidence limits provided in the assessment should correspond with those provided in the scoring tables.

The following sections provide a detailed description of the steps to be followed in the estuary baseline description and health assessment.

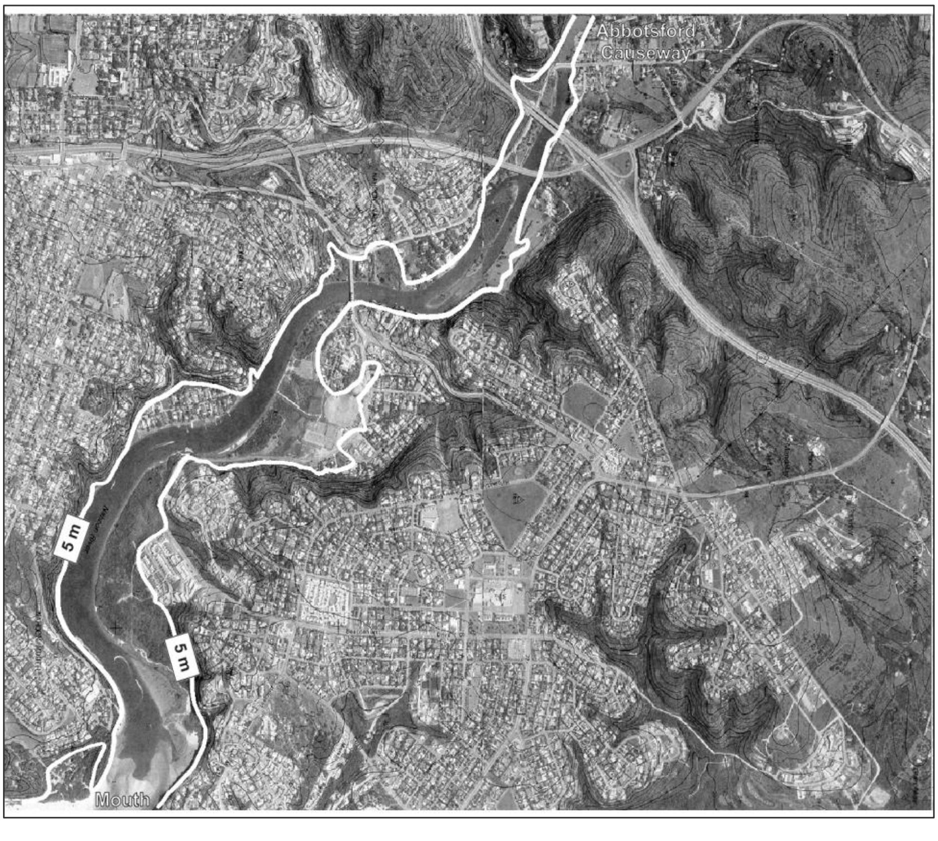
5.2 Estuary delineation

This step defines and maps the geographic boundaries of the estuary as follows:

Downstream boundary: The estuary mouth, including the surf zone, seaward extent of the flood delta and/or transitional waters. This extension can be determined on salinity observations, variations observed in historical aerial photographs or satellite imagery

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 whichever is furthest upstream.

Lateral boundaries: The lateral boundaries should include all areas below the high tide mark, all estuarine vegetation (including mangroves, swamp forest, reeds/sedges and supratidal saltmarsh), and any floodplain areas below the upstream boundary as determined by the 1:100 flood line (for temporarily closed systems the mouth have to be closed for accurate flood line delineation). Where these boundaries have not been defined by scientific methods, they can be defined using the 5 m topographical contour as indicative of the 5 m above Mean Sea Level (MSL) along each bank. Note that the littoral active zones adjacent to an estuary can stretch beyond the 5 m contour, e.g. dune field next to Duiwenhoks and Sundays, and should be incorporated in the estuarine functional zone in site specific cases.



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

Figure 5.2. An ortho-photo of the Nahoon Estuary showing the mouth (downstream boundary, the Abbotsford Causeway (upstream boundary and the +5 m MSL contour (lateral boundaries).

5.3 Description of context and pressures

A description of the catchment contributes to an enhanced understanding of the influences of major drivers and modifications to estuaries originating in the catchment, such as land-uses practices, wastewater discharges, water abstraction and dams. A description of the catchment provides an overview of large scale (“far field”) pressures on the estuary and helps to identify some of the key issues that need to be addresses as part of the health assessment.

A description must be provided of the geographical context of the estuary, focusing on the whole catchment area, and activities and infrastructure in the catchment that affect the estuary. This should include the following elements:

5.3.1 Catchment description

- Size and geomorphological characteristics (e.g. influencing the biogeochemistry and sediment loads into estuary)
- Details on the main tributaries to the main river

5.3.2 Human activities affecting the estuary

The main causes of modification between a Reference Condition and the Present State, or any projected future state, can be grouped into two main categories, namely **modification in river inflow** (in terms of water volume, water quality and sediment supply) and **human influences other than flow modification**. In order to ‘hind-cast’ a Reference Condition or ‘forecast’ a future state, flow modification and other human influences are key considerations. Thus it is important to describe both flow-related and non-flow related activities as far as possible, as follows:

Activities/modifications affecting flow

- Water abstraction and dams (including farm dams)
- Augmentation/Inter-basin transfer schemes.
- Infestation by invasive alien plants

Describe non-flow related impacts on hydrodynamics and water quality. The following checklist can be used for 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 barriers in river
- 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

Provide an overview of **influences other than modification of river inflow** that are presently <u>directly</u> affecting biotic characteristics in the estuary and how they are doing this, using the following checklist as guidance:

- 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 vegetation
- Translocated or alien fauna and flora
- Other …..

Whilst it is recognised that detailed quantification of all human influences may be unrealistic within the time and budgetary constraints of a Reserve study, effort should be made to collate as much **available information** as possible on the relevant factors within a particular system. Note that the details of how these factors affect health should be provided in the assessments of each component where appropriate.

5.4 Description and scoring of abiotic components

This section will provide a description of the abiotic aspects of the estuary itself, including flows into the system (hydrology). The following is a summary of the information to be provided, and templates in which information is summarised. The rationale and methods are described in detail in Turpie (2012). The components are highly interlinked and the ordering of the subsections in the write-up can be modified as appropriate.

5.4.1 Hydrology

5.4.1.1 Rationale

A description of the hydrology forms one of the most important components of the assessment. It helps to establish the extent to which **modification in river inflow** (in terms of water volume, water quality and sediment supply) is responsible for the deviation of health from Reference Condition.

5.4.1.2 Baseline description to be provided

The description of hydrology should include the following:

- **Simulated Monthly river inflow** (in m^3/s) at the head of the estuary under the Present State over a period of 50-70 years, derived from the most recently approved hydrological data from DWA (currently this is the 2005 data).
- **Simulated Daily river inflow (in m3/s)** at the head of the estuary under the Present State over a period of 20-50 years. This requirement is especially important in catchment with a very high variability of inflow feeding into small and medium size estuaries (~ 150 ha open water area).

The study should provide an indication (descriptive or statistical) of the monthly/daily flows in terms of:

- Magnitude of flow events (low and high flows)
- Frequency of flow events
- Duration of flow events
- Timing of flow events (seasonality)
- Rate of change

With regards to magnitude of flow events, flood hydrographs should be provided at the head of the estuary for the 1:1 to 1:200 year floods. This information should be provided as a volume (million m^3) and maximum flow rate (m^3/s). In high confidence studies the underlying simulated data used to estimate the flood events should be provided as an flow rate (m^3/s) in hourly time steps.

Details on the data and methods required are given in Box 5.4.

5.4.1.3 Estimate Reference condition

A description should be provided of estimated seasonal flow volumes and floods and droughts in the Reference Condition.

Box 5.1. Data requirements and methods for describing hydrology

Detailed data requirements and methods

The hydrological data for estuary Reserve studies is provided by the hydrologist appointed by DWA for the larger study. This data is provided in the format of simulated monthly or daily flows, generated by a stochastic hydrological model from measured rainfall data in the catchment (or in a representative adjacent catchment). The following data/information underpins a hydrological study:

- Measured rainfall data in the catchment (or in a representative adjacent catchment)
- Measured stream flow data (seldom available on the coast)
- Hydrological parameters (evaporation rates, radiation rates)
- Catchment size delineation
- Flow losses (e.g. abstraction, impoundment) and gains (e.g. discharges, transfer schemes) .

There are a number of hydrological models currently in use in South Africa and while the method is not prescriptive in which one can or should be used, it is import to realise that from an environmental flows perspective, base flows are a critical element (especially during the low flow period as this drives salinity penetration and mouth conditions). Hydrological models such as WR90 and WR2005 are often not capable of predicting this accurately. The simulated data should be as realistic as possible and include diversions of flow, operation rules of impoundments, and discharges from catchment and treatment works. As the estuary responds to flow in all it variability a realist simulation is required. Experience has shown that hydrological models that can simulate the yield from a catchment provide the best results in this regard.

It is strongly recommended that the simulated hydrological flow data to be used in the study first be reviewed by a representative of DWA. This review should focus on the input data sets, underlying assumptions (hydrological parameters used to model the river flows), catchment delineation, and especially any assumptions around baseflow conditions and abstractions. This will ensure that there is agreement on the input to the Reserves study, increase the overall confidence of the study and prevent rework.

5.4.1.4 *Score present hydrological health*

This score is calculated on the basis of the extent to which current **inflow patterns** resemble those of the Reference state, estimated on the basis of two parameters, as in Table 5.4: (a) general inflow patterns, highlighting the changes in low flows, and (b) the frequency and magnitude of flood events. The relative weighting of these two parameters (60:40) is set according to their assumed importance as drivers of the estuarine system. This may be altered *a priori* for particular systems, with justification.

Table 5.4. Calculation of the hydrological health score, giving examples in italics

Variable		Weight	Score
a.	% similarity in low flows (see Box 5.2) **OR** Present MAR as a % of MAR in the reference state (for estuarine lakes* and for other estuary types in the absence of better data)	60	*45*
b.	% similarity in frequency in floods of different size classes (see Box 5.2)	40	*95*
Hydrology health score = (min (a,b) + weighed mean (a,b))/2			*55*
Confidence			***M***

**because lakes can take extended periods to fill up*

Box 5.2. Scoring similarity in low flows

Similarity in low flows should be scored based on a comparison of the average of monthly flows in the lowest x% of months in terms of flow over the simulated period. The percentage is based on the proportion of months that are defined as low-flow months (typically the lowest 20%ile) during the present day.

If average monthly flow for the defined proportion of months is lower in the present day than in the reference state, then the percentage is used:

$$\%\ \text{Similarity} = 100*P/R$$

If the flow in the present day is greater, then a similarity index is used.

$$\%\ \text{Similarity} = \frac{\sum \min(Ref, Pres)}{(\sum Ref + \sum Pres)/2}$$

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.

Box 5.3. Scoring similarity in floods

The second parameter is % similarity in the frequency of floods, and in most cases this will be given a slightly lower weighting in the index than the first. The type of data to be used in scoring will depend on the degree to which hydrological analyses have been undertaken. A simple analysis will involve a comparison of the highest monthly flows, whereas a more complex analysis will take into account the magnitude and frequency of floods. Similarity should be expressed using Czekanowski's similarity index.

(a) % similarity in **highest flows.** This is based on a comparison of the average of the top 2% of monthly flows in the analysis (20 months in a 70-year analysis). This has been the method most commonly used in previous RDM studies.

(b) % similarity in **frequency and magnitude of different sized floods.** The table below gives an example, but the design of the table can vary as appropriate.

% SIMILARITY IN FLOOD PATTERN		**NUMBER OF OCCURRENCES PER FIXED TIME PERIOD**		**TOTAL CUMECS PER FLOOD CLASS**		
Magnitude m3/s	Cumecs	Reference	Present	Reference	Present	Min
Class 1	10	20	15	200	150	**150**
Class 2	50	8	6	400	300	**300**
Class 3	100	3	2	300	200	**200**
Sum Cumecs				**900**	**650**	
% similarity	% Similarity = $\frac{\sum \min(Ref, Pres)}{(\sum Ref + \sum Pres)/2}$					**84%**

5.4.2 Physical habitats (bathymetry and sediments)

5.4.2.1 Rationale

The size and shape of an estuary determines many of its inherit physical features – tidal variation, retention time, responsiveness to flow and structural habitat features such as inter- and supratidal area. The disturbance of the sediment erosion/deposition equilibrium in an estuary can lead to siltation, resulting in the estuary becoming shallower, or it can lead to the erosion of important estuarine 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). Particle size and organic content determine the cohesion of sediments, the understanding of which helps to predict response to flow changes.

5.4.2.2 Baseline description

The description of the Bathymetry/topography of an estuary primarily characterises the size and shape of the estuary and floodplain. This is achieved through addressing the following:

- Description of the average channel depth and average estuary depth
- Description of shallow areas
- Contour map depicting the estuary and floodplain (up to the 5 m MSL at least)
- Location map and cross section plots of system

The description of the sediment processes in an estuary primarily characterises the physical and structural habitat. This is achieved through describing the distribution of sediments in terms of sandy/muddiness and organic content, as well as the major factors influencing the, subtidal[1], intertidal, supratidal and floodplain areas. The description should include a simple sketch-map (produced in a GIS) showing the distribution of broad sediment types in the estuary, from which approximate areas (ha) of each should be computed.

5.4.2.3 Estimate Reference condition

Describe the 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) under the Reference condition, with an explanation of how these estimates were derived. The latter should include detailed models and explain assumptions where appropriate.

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[1] If the estuary is closed, the term “subtidal” should be replaced by “submerged”, and “intertidal areas” technically become replaced with “exposed margins”, but these are not considered in depth unless there is sufficient cause.

Changes in both of these habitat elements may have been due to changes in water flow into the estuary or human 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 human-induced changes. The **unadjusted score** is used in the health index, and the adjusted score serves to give a fuller explanation of the health status.

Box 5.4. Data requirements and methods for describing physical habitats (bathymetry and sediments)

Detailed data requirements and methods

Bathymetric/topographical surveys should be conducted using Differential Global Positioning System (D-GPS) and echo-sounding to measure berm height, cross section profiles upstream of the mouth and floodplain topography. Cross sections should be taken intensively in the mouth region (10 to 50 m interval depending on the size of the estuary) and variability in bathymetry, while upstream cross-section profiles should be taken along entire length of the system at 500 m to 1000 m intervals. Standard land surveying techniques should be used for topography survey of floodplain.

In addition to bathymetry, the following information should be obtained on sediments:

- Sediment grabs samples collected using a Van Veen or a Zabalocki-type Eckman grab (to characterize recent sediment movement) for particle size analyses, along entire estuary at 500 to 1 000 m intervals
- Sediment core samples collected using a corer (for historical sediment characterization) at intervals similar to cross-section profiles (see bathymetry) or where considered appropriate by sediment specialist; collected at 3 - 6 year intervals, as well as after flood events.
- Organic content of sediment in estuary: Sediment samples should be analysed for total organic matter (similar data are being collected as part of the microalgae and invertebrate sampling programme and needs to be coordinated during the study.
- Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition).

Sediment samples, bathymetric data and measurement of the sediment load in the inflowing water are required to describe the sediment distribution and dynamics, 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). These data can also be used to calculate the volume of the estuary and give an indication of flushing times. Note: 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. Typically, 2D numerical models have been applied to assess sediment processes in South Africa estuaries.

*Eff*ects of data on confidence

Sediment studies can be based solely on expert opinion and a site visit. Sediment samples are relatively straightforward to collect, while bathymetry data more difficult to collect but will boost confidence significantly when they are available. Historical data on sedimentation and erosion processes over 15 years or more will help to understand the impacts of changes in larger floods (e.g. >1:5 year floods). To really understand sediment loads, one needs to have daily data, preferably over a long time period of up to 5 years. This is seldom available unless the study is planned for well in advance. Confidence can also be increased by numerical modelling.

5.4.2.4 Score present physical habitat condition

In order to score the resemblance of physical habitats to the reference state, the changes described above must be estimated in terms of area coverage of different habitats. The variables of interest are sandy versus muddy intertidal areas, sandy versus muddy subtidal areas, and the channel morphology, which is represented as the relative amount of subtidal area that is shallow or deep (using an estuary-specific depth cut-off). If possible, these should be estimated for different zones of the estuary (e.g. upper, middle, lower). The health score is computed using a similarity index. In addition, the degree to which non-flow related changes in the estuary (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas), affect the physical habitat score are considered, to estimate what the score would be net of these influences.

Table 5.5. Calculation of the physical habitat score and adjusted score, with examples in italics.

	Variable	**Weight**	**Score**	**Adjusted score - net of non-flow impacts**
a	% similarity in supratidal area (see Box 5.5)	25	*80*	
b	% similarity in area of intertidal sand- and mudflats (see Box 5.5)	25	*70*	
c	% similarity in area of subtidal/submerged sand and mud substrates (see Box 5.5)	25	*70*	
d	% similarity in bathymetry/ estuary water volume (see Box 5.5)	25	*70*	
Hydrodynamics score = (min (a to d) + weighted mean (a to d))/2			*75*	*85*
Confidence			*M*	*M*

5.4.3 Hydrodynamics and abiotic states

5.4.3.1 Rationale

Hydrodynamics, together with sediment processes and water quality (biochemical) processes (i.e. the abiotic components) in estuaries are, in most instances, the components of an estuary where modification in flow and other human factors manifests influence first. For example, reduced river inflow changes water circulation and salinity distribution patterns in estuaries which in turn affect the biota, while wastewater discharges affect the chemistry of an estuary which in turn affects the biota. Exceptions which may have direct effects on biota, include influences such as living resource exploitation and human disturbance of biota. Knowledge and understanding of these abiotic components, therefore, are crucial in any baseline and health assessment study in estuaries.

Box 5.5. Scoring physical habitat health

With a good understanding of the estuary, the variables can be expressed in multiple dimensions, in terms of (a) categories, such as sand vs. mud and (b) estuary zones. At their simplest one can compare a single dimensional variable, such as water volume of the whole estuary. The figures for present day may be measured or estimated (the confidence level will be described, so it can even be rough). At the minimum the specialist may choose to simply estimate the % similarity for each component based on gut feel. However, it is recommended that an honest rough estimate is better than an unsubstantiated gut-feel estimate, because assumptions are made explicit. The other reason for this is that the % similarity (as per the similarity index used below) is difficult to compute as a gut feel.

For single dimension comparisons, where PD < Ref, then similarity can be expressed as a simple percentage (100xPD/Ref). Where Ref > PD, then the Czekanowski similarity index should be applied.

Example calculation of % similarity of single element variable such as total supratidal area, or estuary volume, using Czekanowski's similarity index.

Parameter	Reference	Present	Calculation	Score
Supratidal area	100	95	=100*95/100	95
Water volume	150	175	=min(150, 175)/((150+175)/2)	92

For multiple dimension variables, similarity should be calculated using a Czekanowski's index. The following is an example calculation of % similarity in multiple element variables such as area of sand and mud substrates for intertidal or subtidal/submerged areas, and of bathymetry, using Czekanowski's similarity index.

Continued over page

	Physical habitats	Reference			Present			Min		
		Zone 1	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
b	**Intertidal**									
	Sandy	5	5	10	5	5	30	5	5	10
	Muddy	5	10	20	5	5	0	5	5	0
	Total			55			50			30
	% similarity									**57%**
c	**Subtidal sediment**									
	Sandy	5	10	30	5	5	30	5	5	30
	Muddy	5	5	20	5	5	10	5	5	10
	Total			75			60			60
	% similarity									**89%**
d	**Channel morphology**									
	Area < 1.5m	10	14	40	10	15	50	10	14	40
	Area >1.5m	0	1	10	0	0	0	0	0	0
	Total			75			75			64
	% similarity									**85%**

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'. Typical 'abiotic states', therefore, need to be determined for a particular estuary linking it to typical river inflow patterns.

5.4.3.2 Baseline description

The description of estuarine hydrodynamics is used to characterise water circulation patterns. This is achieved by addressing the following:

- Water level variation (in the case of temporarily open/closed systems)
- Tidal variation
- Tidal flow
- State of the mouth, discussed in relation to different river inflow patterns
- Retention time (referring to the period in which water is "retained" in the water column of an estuary) and/or exposure time (referring to the cumulative period to which a specific region in an estuary is exposed to any substance or condition in the water column).

Determine the typical states (referred to as abiotic states) that occur in an estuary under different flow ranges. First provide a brief summary of the states (Table 5.6). A detailed description should then be provided of each abiotic state in terms of a range of variables in Table 5.7.

Table 5.6. Summary of the abiotic states that can occur in the estuary (example in italics).

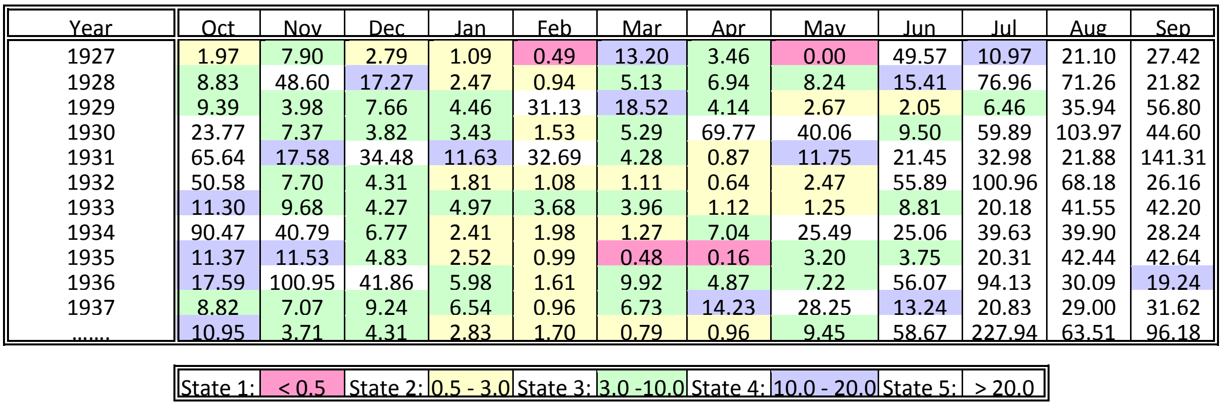
State	Name	Brief description	Flow range ($m^3.s^{-1}$)
1	*Severe marine-dominated*	*Saline intrusion extends further than 45 km upstream of mouth*	*< 0.5*
2	*Marine-dominated*	*Saline intrusion extends up to 45 km from mouth*	*0.5-1.0*
3	*Small to medium freshwater inflow*	*Marine influence evident up to 33 km from mouth*	*1.0-5.0*
4	*Medium to high freshwater inflow*	*Marine influence only evident up to 12 km from mouth*	*5.0-25.0*
5	*Freshwater-dominated*	*Estuary is fresh throughout*	*>25.0*

Table 5.7. Flow parameters associated with each abiotic state that can occur in the estuary.

Abiotic state	Description	Confidence
Typical flow patterns:		
State of the mouth:		
Flood plain inundation patterns:		
Amplitude of tidal variation (indicative of exposure of intertidal areas during low tide):		
Estimated (maximum) tidal velocities along the estuary:		
Retention times of water masses:		

Provide a detailed table of the monthly flows and occurrence and duration of different abiotic states for each year of the simulation period (Table 5.8). Provide a statistical summary of this distribution (Table 5.9). Inaddition, the pattern should be presented in diagrammes if possible, as illustrated below (Figure 5.3, Figure 5.4). Detailed methods are described in Box 5.6 and Box 5.7.

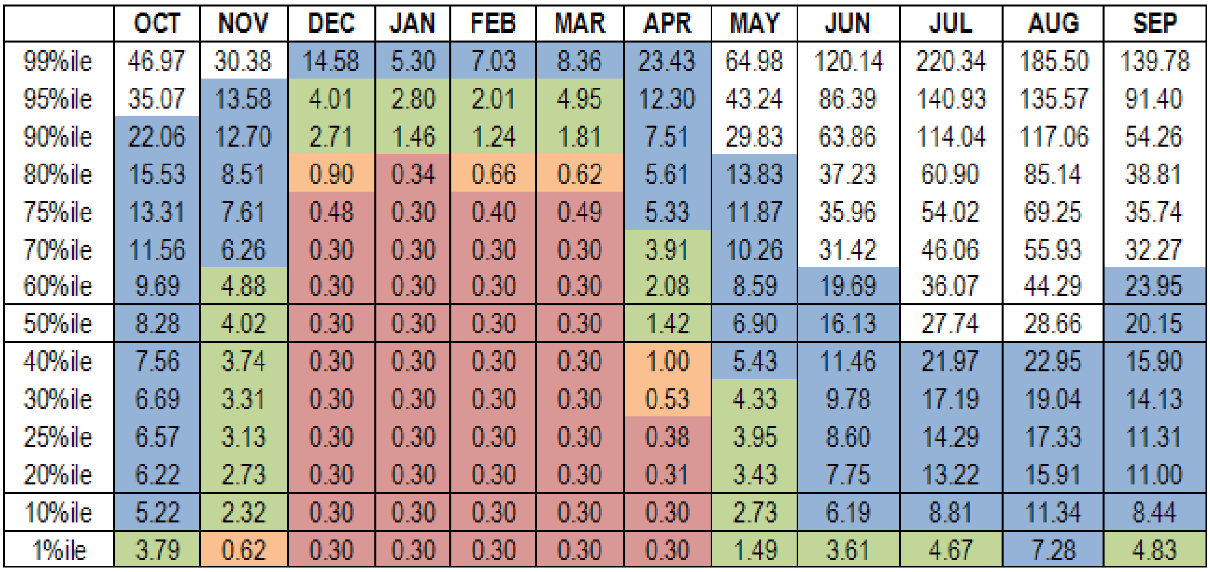
Table 5.8. Example of estimated monthly flows and occurrence and duration of different abiotic states during the Present State.



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 - 20.0	State 5:	> 20.0

Table 5.9. Example of summary of monthly flows and occurrence and duration of different abiotic states during the Present State.



	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
99%ile	46.97	30.38	14.58	5.30	7.03	8.36	23.43	64.98	120.14	220.34	185.50	139.78
95%ile	35.07	13.58	4.01	2.80	2.01	4.95	12.30	43.24	86.39	140.93	135.57	91.40
90%ile	22.06	12.70	2.71	1.46	1.24	1.81	7.51	29.83	63.86	114.04	117.06	54.26
80%ile	15.53	8.51	0.90	0.34	0.66	0.62	5.61	13.83	37.23	60.90	85.14	38.81
75%ile	13.31	7.61	0.48	0.30	0.40	0.49	5.33	11.87	35.96	54.02	69.25	35.74
70%ile	11.56	6.26	0.30	0.30	0.30	0.30	3.91	10.26	31.42	46.06	55.93	32.27
60%ile	9.69	4.88	0.30	0.30	0.30	0.30	2.08	8.59	19.69	36.07	44.29	23.95
50%ile	8.28	4.02	0.30	0.30	0.30	0.30	1.42	6.90	16.13	27.74	28.66	20.15
40%ile	7.56	3.74	0.30	0.30	0.30	0.30	1.00	5.43	11.46	21.97	22.95	15.90
30%ile	6.69	3.31	0.30	0.30	0.30	0.30	0.53	4.33	9.78	17.19	19.04	14.13
25%ile	6.57	3.13	0.30	0.30	0.30	0.30	0.38	3.95	8.60	14.29	17.33	11.31
20%ile	6.22	2.73	0.30	0.30	0.30	0.30	0.31	3.43	7.75	13.22	15.91	11.00
10%ile	5.22	2.32	0.30	0.30	0.30	0.30	0.30	2.73	6.19	8.81	11.34	8.44
1%ile	3.79	0.62	0.30	0.30	0.30	0.30	0.30	1.49	3.61	4.67	7.28	4.83

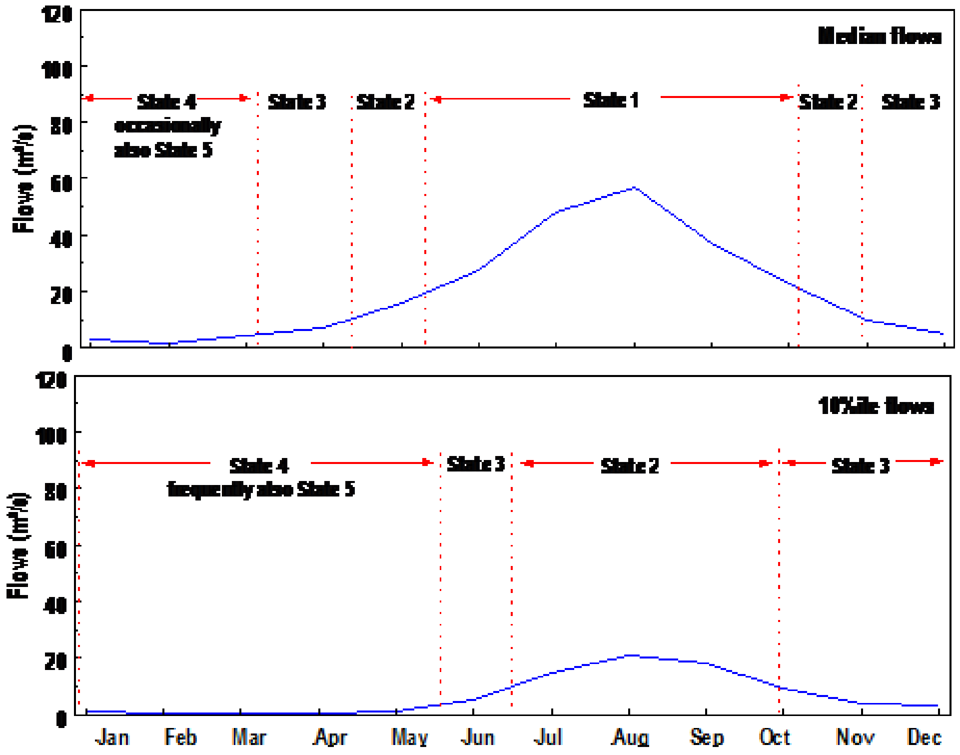


Figure 5.3. Option for summarising the seasonal distribution of flows, particularly for systems with strong seasonal variability in flows.

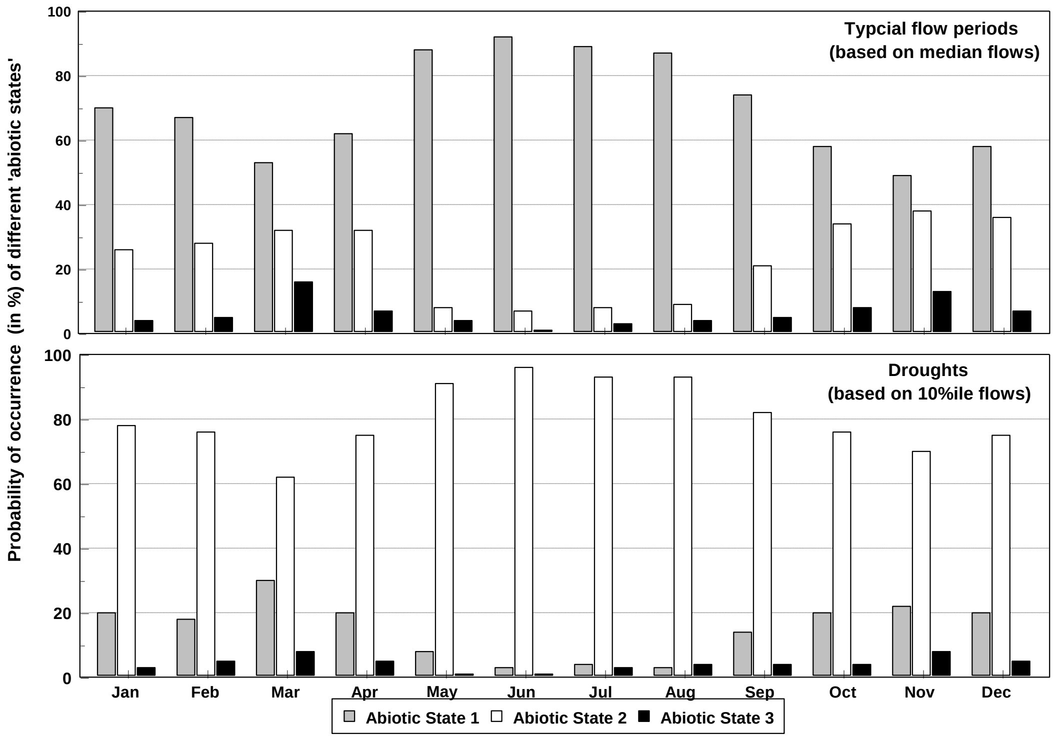


Figure 5.4. Option for summarising the seasonal distribution of flows, particularly for estuaries where variations within months are stronger than seasonal variation.

Box 5.6. Data requirements and methods for describing hydrodynamics

Detailed data requirements and methods

Continuous water level recordings: Data should be obtained from any continuous water level recorders installed in the estuary. Ideally, water levels recordings must be available or collected from at 2-6 stations along the length of the estuary, either using continuous water level recorders or water level gauging poles and manual observations. These data are invaluable for setting up and calibrating hydrodynamic models for estuaries.

- Daily mouth observations: Long term data on daily mouth state (open/closed/overtopping) are essential for understanding dynamics of temporarily open/ closed estuaries, particularly in systems that have a semi-closed mouth state. These data are invaluable for calibrating hydrodynamic models of these systems. The time at which the observation was made and the state of the tide must also be recorded, ideally at low tide.
- Wave conditions: Available data should be accessed, but no measurements are specified as part of the baseline monitoring activities.
- 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.

Methods that can be applied in assessing the hydrodynamics (or water circulation patterns) are numerous. These range from 3D numerical models, 2D numerical models, 1D numerical models, water balance models, statistical analysis to conceptual models (Van Ballegooyen *et al.* 2004). A simple decision tree for application of numerical modelling is provided (Figure 5.5). Numerical modelling is especially important in permanently open estuaries where the incremental effects of changes in river inflow are very difficult to derive from a number of once-off sampling surveys.

Effects of data on confidence

Confidence in the hydrodynamic description and predictions is largely dependent on long-term data. Continuous flow 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. About 5 years is needed for medium confidence and up to 15 years for high confidence.

Continuous water level recordings are currently available for only a few estuaries in the country. As a result, relevant information on water level variations for most estuaries will have to be derived from limited visual observations of tidal variation (i.e. over at least 2 tidal cycles), and will engender lower confidence in such a study. It is therefore strongly recommended that water level recorders be installed in all major systems in the country.

Water level and mouth records are helpful for calibrating understanding of mouth dynamics, with about 5 or 15 years of daily records required for medium and high confidence, respectively. These are also seldom available unless set up in advance. 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. Water level recording along the estuary is critical for permanently open estuaries where numerical modelling is used to predict change in the salinity profile. One neap and one high tide cycle is sufficient for med-high confidence. Information on wave conditions is used to correlate mouth closure with possible storms at sea (as reflected by the direction and amplitude of the waves) where long term data are available. 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). These are generally available.

Note that, in requesting continuous flow data for estuaries, the request is not for gauging weirs to be constructed at the top of each estuary, but rather that flows be monitored in appropriate ways that will not disturb migration of aquatic biota between these estuaries and the catchment upstream.

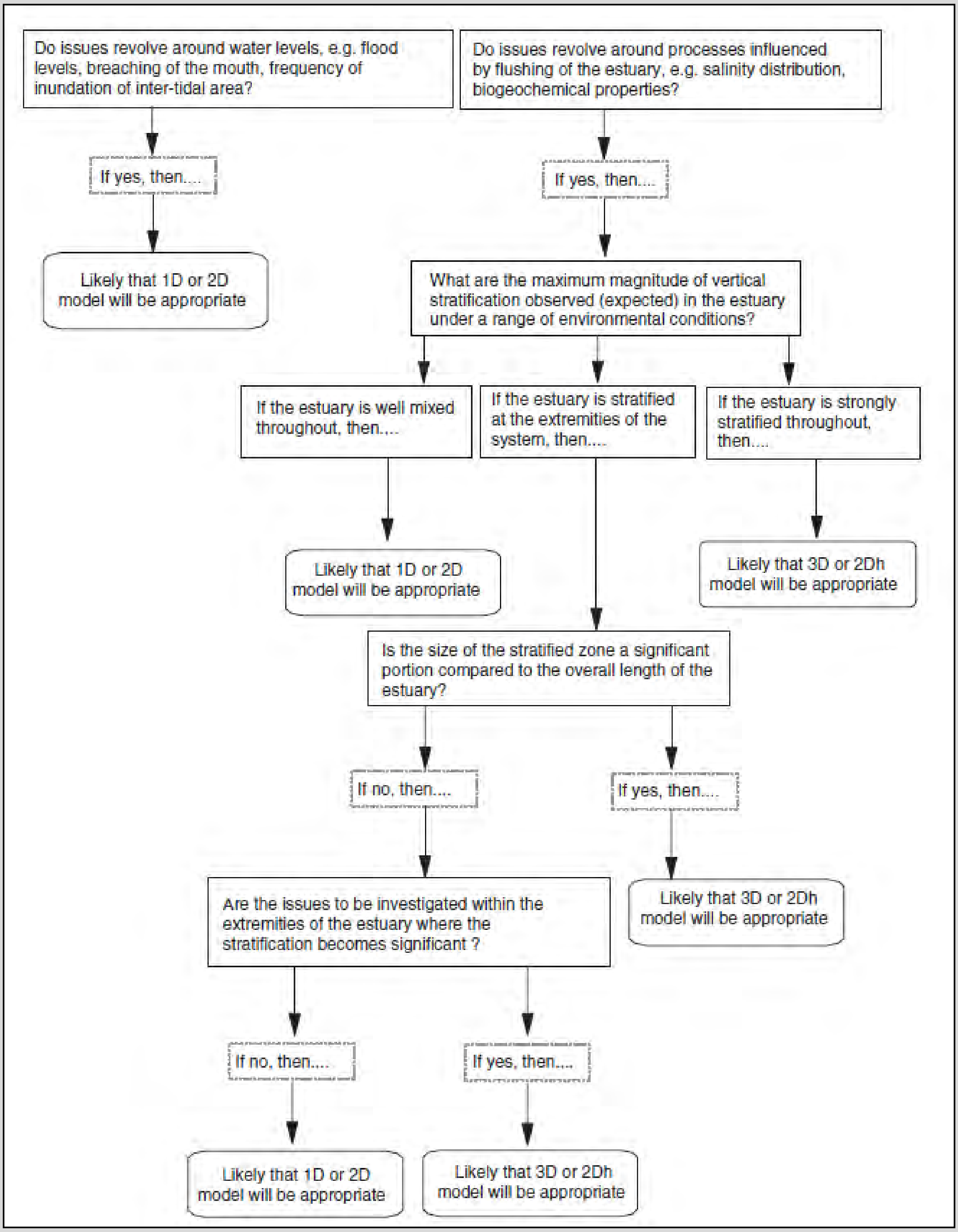


Figure 5.5. A robust decision tree to decide on to type of numerical model to be used for a particular application in estuaries (1D = one dimensional; 2D = two dimensional; 2Dh = two dimensional horizontal; 3D = three dimensional) (Van Ballegooyen *et al.* 2004).

Box 5.7. Approach for describing abiotic states

The abiotic states for an estuary are primarily controlled by hydrological characteristics, i.e. river inflow. The approach followed here is to analyse the hydrological data provided for the system and to identify typical flow distribution ranges. For each of the selected flow ranges, physical characteristics need to be defined in terms of salinity-induced stratification of the water column, flushing time and the mouth condition, based on the understanding gained in the baseline studies (hydrodynamics). Further the biogeochemical characteristics of each state is then derived, gained in the baseline studies (water quality).

Taljaard *et al.* (2009) demonstrated a simplified model for the derivation of such abiotic states. In their model they defined four dominant abiotic (or physical) states for South African estuaries: a freshwater-dominated state, freshwater pulsed/recovery state, marine-dominated state and the closed mouth state. However, in a specific application the range of states for a specific estuary may require further refinement within one of more of the dominant states, e.g. moderate marine-dominated and a strongly marine-dominated. The model is illustrated in Figure 5.6

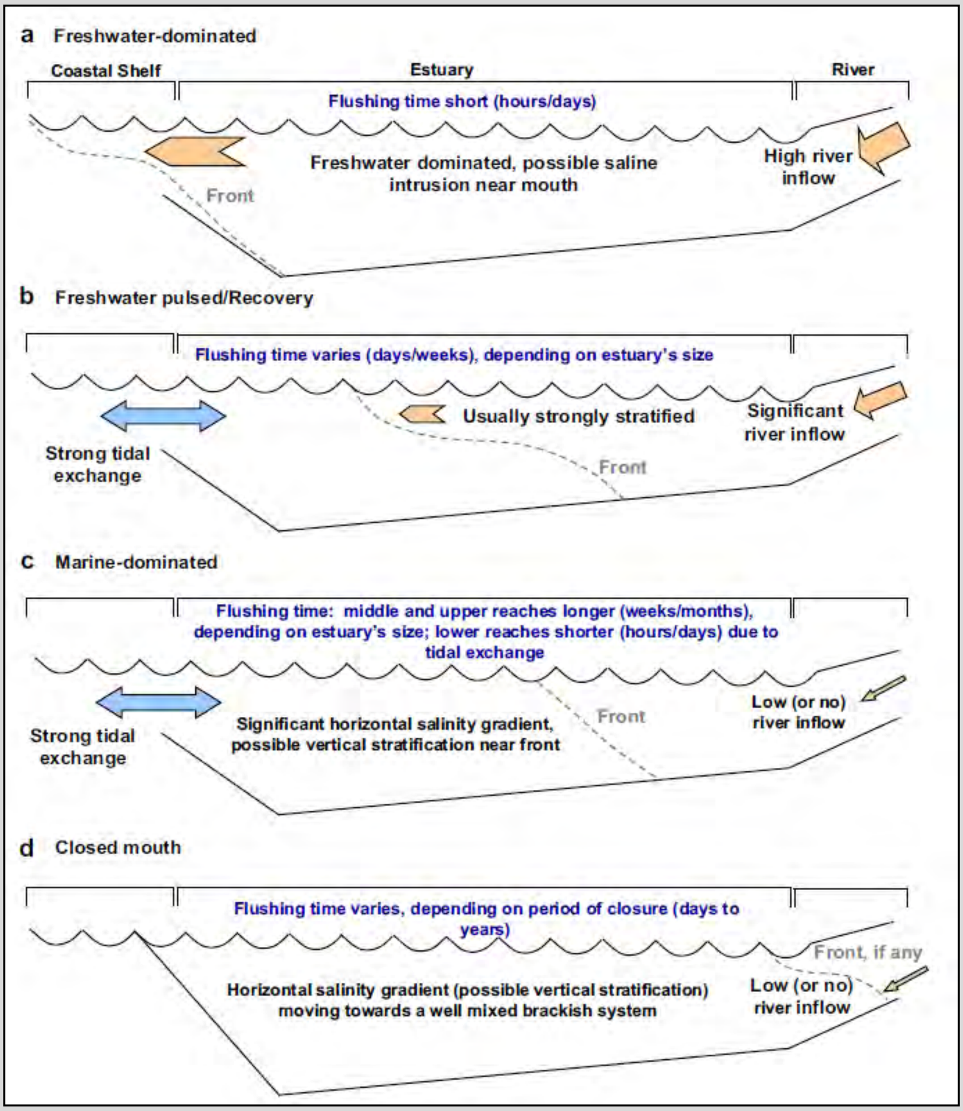


Figure 5.6. Qualitative models depicted dominant abiotic states in South African estuaries (left) and key nutrient dynamics within each abiotic states (right) (Taljaard *et al.* 2009).

5.4.3.3 Estimate Reference condition

In order to assess the above, the long-term (50-70 year) simulated runoff data provided for the Reference Condition and Present State is used. This needs to be assessed in different ways:

- The abiotic states defined earlier (each representing a specific flow range) need to be super imposed onto the simulated runoff data to illustrate the distribution of abiotic states (and associated hydrodynamic characteristics) under the Reference Condition over the simulation period in the same way as was done for the Present State
- Estimate the occurrence and duration of different abiotic states, 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, using colour coding to indicate the average distribution of abiotic states (and associated hydrodynamic characteristics) over the simulated period, in the same way as for the present state (Table 5.8).
- Estimate the occurrence and duration of abiotic states (and associated hydrodynamic characteristics) using median monthly flows calculated over the 50-70 year period. This is done in the same way as was presented for the Present state (Table 5.9, Figure 5.3, Figure 5.4).

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.

5.4.3.4 Score present hydrodynamic health

This score uses a similarity index to compare the proportion of time an estuary is in each state between the Reference and Present states (Table 5.10). It uses the similarity index. In cases of poor data, the first component of the index may be used alone. An estimate is also given of what the score would be if non-flow-related effects (e.g. artificial breaching) are removed.

Table 5.10: Calculation of the hydrodynamics score, giving examples in italics.

	Variable	Weight	Score	Adjusted score - net of non-flow impacts
a	% similarity in abiotic states and mouth condition (see Box 5.8)	50	*80*	
b	% similarity in the water column stratification (s see Box 5.8)	10	*70*	
c	% similarity in water retention time (see Box 5.8)	20	*70*	
d	% similarity in water level (see Box 5.8)	20	*70*	
Hydrodynamics score = (min (a to d) + weighed mean (a to d))/2			*73*	*85*
Confidence			*M*	*M*

Box 5.8. Scoring similarity for hydrodynamics parameters

For each parameter, types (for mouth condition and stratification) or ranges (for water retention time and water level) must first be defined giving rationale, then describe the % time the estuary has each mouth condition. Similarity is calculated using Czekanowski's similarity index. See example below:

Example calculation of % similarity of mouth condition, using Czekanowski's similarity index:

STATE	% REFERENCE	% PRESENT	MIN
Open	30	22	22
Semi-closed	40	45	40
Closed	30	33	30
Sum	100	100	92
% Similarity	% Similarity $= \frac{\sum \min(Ref, Pres)}{(\sum Ref + \sum Pres)/2} = \frac{92}{(100+100)/2} = 92\%$		

5.4.4 Water quality (biogeochemistry)

5.4.4.1 Rationale

Hydrodynamics, together with sediment processes and water quality (biochemical) processes (i.e. the abiotic components) in estuaries are, in most instances, the ecological components where modification in flow and several other human factors manifests influence first. For example, reduced river inflow changes water circulation and salinity distribution patterns in estuaries that affect the biota. Or wastewater discharges affect the chemistry of an estuary that affects the biota. Exceptions, which may have direct effects on biota, include influences such as living resource exploitation and human disturbance of biota. Knowledge and understanding of these abiotic components, therefore, are crucial in any baseline and health assessment study in estuaries.

Estuaries receive water from two sources - rivers or the 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 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 is longer, often observed in the middle reaches of an estuary during the low flow season. It is therefore also crucial that water samples are collected from both sources, i.e. river and sea.

5.4.4.2 Baseline description

The description of the water quality in an estuary primarily characterises the biogeochemistry in terms of system variables, nutrient dynamics and distribution of toxic substances (where appropriate). This is achieved through assessing the following:

- Longitudinal salinity distribution patterns and stratification in the estuary under a range of river inflow scenarios, based on measured salinity data or simulated profiles generated through numerical modelling (as discussed under hydrodynamics)
- Distribution patterns in temperature pH, dissolved oxygen, turbidity/suspended solids/Secchi depth (system variables) under a range of river inflows, based on the measured data. This data can be presented in different formats
- Distribution patterns on nutrients under a range of river inflows, based on the measured data based on measured data
- Contour maps displaying the distribution of total organic matter in sediments, based on measured data
- Contour maps depicting the distribution of toxic substances in sediments, based on measured data (where appropriate).

Longitudinal salinity contour plots are used to demonstrate salinity distribution patterns, while mixing diagrams (or property-salinity plots) – widely used to assess water column nutrient dynamics in estuaries – are used to describe inorganic nutrient distribution patterns. Nutrient concentrations are plotted against salinity along the estuarine gradient, providing a convenient method for displaying the net effect of nutrient processes within estuaries. For example, a linear relationship in the mixing diagram typically reflects straight mixing of the two water sources (i.e. the river and the sea), while downward curvature implies in situ nutrient uptake and upward curvature *in situ* nutrient release. Conservative behaviour tends to occur during high river inflow, when estuaries are rapidly flushed. High nutrient input from the catchment (relative to input from the sea) reveals a negative linear correlation, whereas high input from the sea shows a positive linear correlation. Deviation from the conservative mixing line tends to occur during periods of reduced or no river inflow, when long flushing times allow *in situ* processes to significantly influence nutrient dynamics (e.g. remineralisation releasing nutrients into the water column or primary production taking up nutrients from the water column) (Taljaard *et al.* 2009).

The water quality parameters associated with each abiotic state that can occur in the estuary are described (Table 5.11).

Table 5.11. Water quality parameters associated with each abiotic state that can occur in the estuary.

Abiotic state	Description	Confidence
Total volume and/or estimated volume of different salinity ranges:		
Salinity distributions in the estuary:		
System variables (Temperature, pH, suspended solids, turbidity and dissolved oxygen):		
Nutrients:		

Box 5.9. Data requirements and methods for describing water quality

Detailed data requirements and methods

Water quality of river inflow, to be sampled just upstream of the head of the estuary: 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. This type of data should be obtained from monitoring points at the head of estuaries to be included in the water quality monitoring programme of the DWA. 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 (Marine water quality 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: The following samples should be collected:
- Salinity and temperature profiles (also required for hydrodynamics)
- System variables (pH, DO, turbidity, suspended solids and Secchi depth)
- Inorganic nutrients, filtered through 0.45 µm filters (nitrate/nitrite, ammonia, reactive phosphate, total phosphorus and reactive silicate)
- Suspended particulate organic matter filtered onto a Whatman GF/F filter (loss on ignition)
- 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: At end of pipe just before entering the estuary, measure flow rate, and other parameters depending on the composition of the effluent. 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.
- 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). 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) (for substances such as trace metals and hydrocarbons it is considered most appropriate to sample environmental components which tend to integrate or accumulate change over time, such as sediments). To assist with the interpretation of results, samples should also be analysed for sediment particle size distribution and total organic matter content (see sediment quality above). Such surveys, however, need 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 small estuaries (< 5 km long), stations are distributed geographically along the entire estuary with a minimum of 5 sites, ensuring that all the salinity regimes are covered. For larger estuaries (> 5 km long), stations are 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 located 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). The analytical techniques used in the processing of marine and estuarine water quality samples vary greatly from 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.

Effects of data on confidence

Salinity and temperature measurements in the estuary, together with the river inflow data (which must all 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. The field work 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. 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.

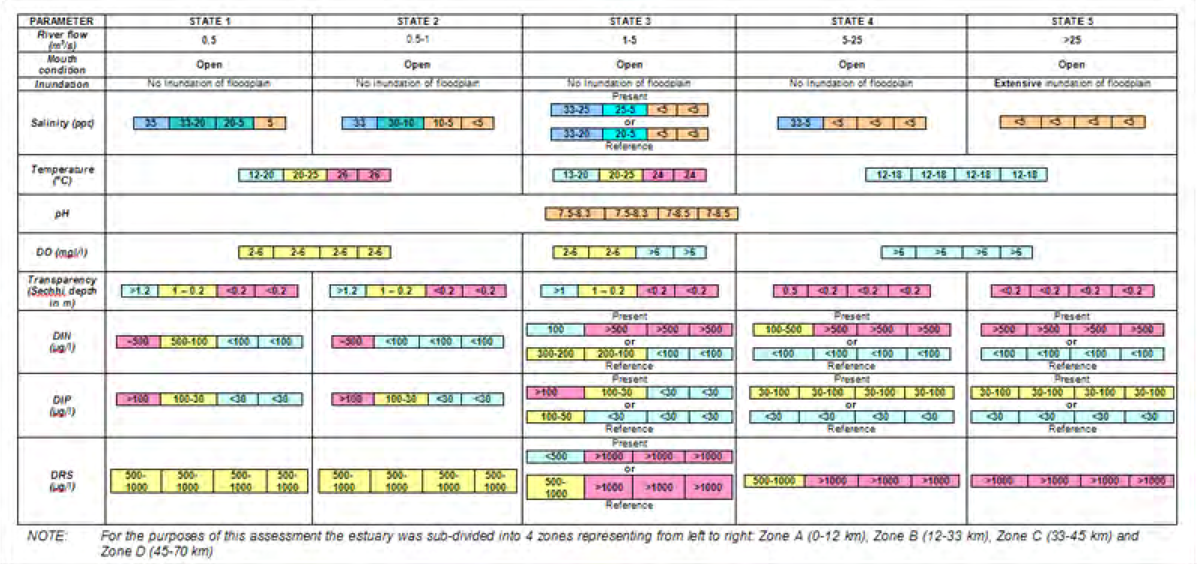
River water quality requires longer-term data sets and it is therefore necessary to start such baseline monitoring programmes well in advance (at least 5 years). Where data is not available near the head of an estuary, it needs to be extrapolated from a monitoring station further upstream or from an adjacent system with similar catchment characteristics.

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.

5.4.4.3 Estimate the Reference Condition

The water quality parameters in the Reference condition are estimated on the basis of the estimated pattern of abiotic states (and their associated water quality characteristics). Sometimes it is necessary to divide an estuary in to zones in the description of the states. These zones should be shown on a map. An example of the format in which the physical and biogeochemical characteristics of each of the zones within the defined abiotic states can be described is illustrated in Table 5.12.

Table 5.12. Example description of water quality characteristics under present and reference conditions



PARAMETER	STATE 1	STATE 2	STATE 3	STATE 4	STATE 5
River flow (m³/s)	0.5	0.5-1	1-5	5-25	>25
Mouth condition	Open	Open	Open	Open	Open
Inundation	No inundation of floodplain	No inundation of floodplain	No inundation of floodplain	No inundation of floodplain	Extensive inundation of floodplain
Salinity (ppt)	35, 33-20, 20-5, 5	33, 30-10, 10-5, <5	Present 33-25, 25-5, <5, <5 or 33-20, 20-5, <5, <5 Reference	33-5, <5, <5, <5	<5, <5, <5, <5
Temperature (°C)	12-20, 20-25, 26, 26		13-20, 20-25, 24, 24	12-18, 12-18, 12-18, 12-18	
pH			7.5-8.3, 7.5-8.3, 7-8.5, 7-8.5		
DO (mg/l)	2-6, 2-6, 2-6, 2-6		2-6, 2-6, >6, >6	>6, >6, >6, >6	
Transparency (Sechhi depth in m)	>1.2, 1 – 0.2, <0.2, <0.2	>1.2, 1 – 0.2, <0.2, <0.2	>1, 1 – 0.2, <0.2, <0.2	0.5, <0.2, <0.2, <0.2	<0.2, <0.2, <0.2, <0.2
DIN (µg/l)	>500, 500-100, <100, <100	>500, <100, <100, <100	Present 100, >500, >500, >500 or 300-200, 200-100, <100, <100 Reference	Present 100-500, >500, >500, >500 or <100, <100, <100, <100 Reference	Present >500, >500, >500, >500 or <100, <100, <100, <100 Reference
DIP (µg/l)	>100, 100-30, <30, <30	>100, 100-30, <30, <30	Present >100, 100-30, <30, <30 or 100-30, <30, <30, <30 Reference	Present 30-100, 30-100, 30-100, 30-100 or <30, <30, <30, <30 Reference	Present 30-100, 30-100, 30-100, 30-100 or <30, <30, <30, <30 Reference
DRS (µg/l)	500-1000, 500-1000, 500-1000, 500-1000	500-1000, 500-1000, 500-1000, 500-1000	Present <500, >1000, >1000, >1000 or 500-1000, >1000, >1000, >1000 Reference	500-1000, >1000, >1000, >1000	>1000, >1000, >1000, >1000

NOTE: *For the purposes of this assessment the estuary was sub-divided into 4 zones representing from left to right: Zone A (0-12 km), Zone B (12-33 km), Zone C (33-45 km) and Zone D (45-70 km)*

5.4.4.4 Score present Water Quality

This is assessed in terms of the degree of change in salinity and general water quality (Table 5.13). 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.

After providing the scores, estimate what the score might have been if non-flow-related impacts (e.g. wastewater discharges) were removed. Again, this is a theoretical construct to isolate the degree to which flow changes have impacted on health (and vice versa, if desired).

Table 5.13. Calculation of the water quality health score, with examples in italics.

	Variable	**Weight**	**Score**	**Adjusted score - net of non-flow impacts**
1	Salinity			
	Similarity in salinity (see)	40	*74*	*74*
2	General water quality in the estuary (see Box 5.10)			
a	N and P concentrations		*41*	*94*
b	Water clarity (measured as suspended solids/turbidity/transparency)		*100*	*100*
c	Dissolved oxygen (mg/l) concentrations		*94*	*99*
d	Toxic substances		*90*	*100*
	General water quality = (min (a to d) + weighted mean (a to d))/2	60	*61*	*94*
Water quality health score = (min (1,2) + weighted mean (1,2))/2			***64***	***86***
Confidence			***M***	***M***

Box 5.10. Scoring water quality parameters

Most of the water quality parameters can be scored using Czekanowski's similarity index. For each parameter, a table should be constructed that defines the percentage of time that each zone of the estuary spends in each of a series of defined states. These can pertain to the states described for hydrodynamics. In order to take intensity of the changes into account, or the occurrence of more than one new state, it is necessary to work either with loads (in the example below this is done by multiplying average salinity of each state by the volume of the zone), or with some related index of intensity (where computation of loads would seem overly accurate).

Cont'd

Example calculation of % similarity in salinity, using Czekanowski's similarity index.

	Vol	Reference						Present						
State	**M3**	**1**	**2**	**3**	**4**	**5**	**Kg Salt**	**1**	**2**	**3**	**4**	**5**	**Kg Salt**	**Min**
%Occur.		1	6	47	38	8		52	5.6	18.2	22.5	1.95		
Lower	50	35	33	30	20	5	**1222**	35	33	30	20	5	**1505**	**1222**
Middle	30	26	20	12.5	3	0	**254**	26	20	15	5	0	**555**	**254**
Upper	5	10	2	0	0	0	**1**	12.5	6	3	1	0	**38**	**1**
Sum	**85**						**1477**						**2098**	**1477**
% similarity														**83%**

Where construction of a similarity index is not practical due to data constraints, the following scoring guideline is used: unmodified = 100; modification = score is estimated % of reference condition

5.5 Description and scoring of biotic components

5.5.1 Biotic components

These descriptions provide the baseline against which future changes can be measured. It also provides the understanding used to generate models and predictions as to how these components have changed from the natural condition and how they might change under future management scenarios. Rationale for the inclusion of each group is as follows:

- **Microalgae**: 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 are important primary producers in shallow estuaries that close to the sea or those permanently open estuaries with large intertidal areas. This description is important for the understanding of higher taxa, such as invertebrates.
- **Macrophytes** represent both habitat and food for many of the estuarine fauna, and these descriptions are important for interpretation of data for those groups. Macrophytes are useful indicators of longer term changes in freshwater inflow as they respond to changes in salinity and water level. Changes over time in the area covered by different macrophyte habitats is easily measured from past aerial photographs and maps, and is an important input to the assessment of estuary health. Submerged macrophyte beds form important nursery areas for juvenile fish by providing food, shelter and protection from predators. Macrophytes also play an essential role in nutrient trapping and recycling, sediment stabilisation and bank protection. An increase in abundance of macroalgae, submerged macrophytes and reeds and sedges occurs in response to increased nutrient input and may be indicative of eutrophication.
- **Estuarine invertebrate** communities comprise zooplankton, nektonic (swimming) invertebrates and benthic (bottom-dwelling) invertebrates. These are all important food

sources for fish and birds, as well as being an important resource used by people for food and bait. They are also well known habitat formers in estuaries and provide additional niches for other organisms thereby increasing the diversity and carrying capacity of estuarine systems. These descriptions are also important for interpretation of fish and bird data. As many benthic invertebrates are estuarine residents they act a good long term integrators and indicators of conditions in the estuary. Known marine migratory species or those with a marine phase in their life cycle can also provide important indications of long- term mouth behaviour.

- **Fish** are important as a food source for one another and for birds, as well as being an important resource used by people for food and bait. They are also highly mobile and thus respond rapidly to changes in flow, mouth condition and water quality characteristics in an estuary (Whitfield & Elliot 2002). A good understanding of the composition and abundance of fish in an estuary is important for interpretation of bird data.
- **Birds** make an important contribution to the recreational and aesthetic value of estuaries, as well as contributing to the maintenance of estuarine processes through predation and nutrient inputs. Many birds are good indicators of estuarine conditions such as water quality, habitats and fish abundance.

For each of the biotic components (microalgae, macrophytes, invertebrates, fish and birds), the following should be provided and presented in logical sequence. Where appropriate, detailed specialist reports are provided for each biotic group and the main report contains a succinct summary of the descriptions required.

5.5.2 Definition of groupings within the biotic component

Provide a tabulated description of the main groupings of components (e.g. for birds – waders, herbivorous waterfowl, etc.) and the major defining features of each group in the estuary. In the case of macrophytes, the groupings are habitats and are typically constant from estuary to estuary (Table 5.14), and correspond to groupings commonly used in GIS mapping of habitats. Table 5.15 provides an example of groupings for one of the higher taxonomic groups (birds).

Table 5.14. Macrophyte habitats and functional groups recorded on the estuary (examples in italics)

Habitat type	Defining features, typical/dominant 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

Table 5.15. Example description of major bird groups found in the Berg Estuary, and their defining features.

Bird groups	Defining features, typical/dominant species
Herbivorous waterfowl	This group is dominated by species that tend to occur in low salinity or freshwater habitats and are associated with the presence of aquatic plants such as Potamageton and Phragmites. The group includes some of the ducks (e.g. Southern Pochard), and all the rallids (e.g. Redknobbed Coot, African Purple Swamphen). Some herbivorous waterfowl such as Egyptian Goose, Spurwinged Goose and South African Shelduck probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary. Note, birds do not eat the algae found in the lower estuary.
Omnivorous waterfowl	This group comprises ducks, which eat a mixture of plant material and invertebrate food such as small crustaceans - Yellow-billed Duck, African Black Duck, Cape Teal, Hottentot Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions, but African Black Duck tends to be restricted to areas of higher flow.
Piscivorous waterfowl	This group comprises the grebes – Great Crested, Black-necked and Little Grebe. The first two tend to be restricted to lower salinities and deeper water, and Little Grebe tends to be found where there is abundant marginal vegetation.
Wading/swimming piscivores	This group comprises the largest birds on the estuary – the wading and swimming birds (Ciconiiformes and Pelicaniformes), such as Reed Cormorant, Little Egret, Grey Heron. Loosely termed piscivores, their diet varies in plasticity, with fish usually dominating, but often also includes other vertebrates, such as frogs, and invertebrates. The ibises were included in this group, though their diet mainly comprises invertebrates and is fairly plastic. They tend to be tolerant of a wide range of salinities.
Perching/aerial piscivores	This group comprises the kingfishers and birds of prey, such as African Fish Eagle and Marsh Harrier. They are not confined to a diet of fish, also taking other vertebrates and invertebrates. These species are tolerant of a wide range of salinities but require marginal vegetation, particularly trees or shrubs, or marsh in the case of Marsh Harrier and Marsh Owl.
Lesser Flamingos	This species is unique in its diet (phytoplankton) and salinity tolerance, tolerating high salinity to hypersaline conditions.
Greater Flamingos	Greater Flamingos feed on benthic invertebrates in a wide range of salinities.
Macrobenthos-feeding waders	This group includes all the waders (e.g. Greenshank, Curlew Sandpiper). They are the smallest species and most numerous group on the estuary, and feed on benthic macroinvertebrates in exposed and shallow intertidal areas.
Piscivorous gulls and terns	This group comprises the rest of the Charadriiformes, and includes all the gull and tern species using the estuary. These species are primarily piscivorous, but also take invertebrates. Most are euryhaline, but certain tern species on the estuary tend to be associated with low salinity environments.
Marine cormorants	This group comprises cormorants that feed in marine environments and uses the estuary to roost – Cape, Bank and Crowned Cormorants. This group is neither directly nor indirectly sensitive to flow, and is thus not given much attention in this study.

5.5.3 Description of the component in the present state

Provide a brief description provided of the Present State of each of the biotic components, including:

- Species richness, rarity (e.g. Red data species), abundance and community composition. The latter is to be described in respect of the relative dominance of the functional groups described;
- Biomass distribution and productivity;
- Seasonal and inter-annual variability (assessment on changes in seasonal variability, without the necessary data are difficult to determine for other biotic components); and
- Assessment of any important (regional) relationship with other nearby estuarine and marine systems.

Detailed methods are described below for microalgae (Box 5.11), macrophytes (Box 5.12), invertebrates (Box 5.13), fish (Box 5.14) and birds (Box 5.15).

Box 5.11. Data requirements and methods for describing microalgae

Detailed data requirements and sampling methods:

Phytoplankton: To estimate phytoplankton biomass, collect duplicate samples for chlorophyll a at the surface and 0.5 m depth intervals. Use a spectrophotometer / fluorometer for sample analysis before and after acidification. Ideally size fractionated measurements of chlorophyll a should be made to determine the relative contribution of micro-, nano- and picophytoplankton. Do cell counts (at 400x magnification) to establish distribution and composition of the different phytoplankton groups, i.e. green algae, flagellates, dinoflagellates, diatoms and blue-green algae. Cell counts are done after settling 60 ml of sample and using a 4 ml sub-sample to read cell counts. Other scientifically acceptable methods such as the fluoroprobe could also be used.

Benthic microalgae: Collect intertidal and subtidal benthic samples for chlorophyll a (biomass) analysis. Collect minimum of 3 samples at each station. Record the relative abundance of dominant algal groups, i.e. green algae, diatoms and blue-green algae using an HPLC or fluoroprobe.

At each station also measure:

- Water salinity and inorganic nutrients
- Sediment particle size distribution and sediment total organic matter
- Light penetration PAR or Secchi depth

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 (typically: Fresh, 0-10ppt, 10-20ppt and 20-35ppt). Three stations are sufficient in an estuary less than 1 km in length. 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). In systems with large cross sectional areas (e.g. estuarine bays), sampling stations should also be selected along cross sections.

Data availability and influence on confidence

Ideally quarterly 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. However, if some historic data are available then sampling should take place 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. If effort is restricted, then a single field trip will suffice as long as it is at the most appropriate time of year, i.e. during the low flow season or during the stable closed phase for temporarily open / closed estuaries. Sampling should also coincide with the water quality survey and the invertebrate survey.

Water quality measurements (salinity, temperature, other physico-chemical properties and inorganic nutrients) need to be taken during the microalgae surveys. This can be done most cost-effectively by combining water and sediment quality surveys on a particular estuary with the microalgae survey.

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 far as possible.

Box 5.12. Data requirements and methods for describing macrophytes

Detailed data requirements and sampling methods:

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 each plant habitat. For the comprehensive method this should be addressed using GIS mapping.
- Extent of human 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 human 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. 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, should also be monitored
- Record percentage cover of each plant species in duplicate quadrats (1 m2) along transects
- Along each transect (minimum of 4) the following data need to be collected:
- Elevation profile, water level and depth
- Water column salinity and turbidity
- Sediment salinity, moisture content, organic content and sediment composition

In large supratidal salt marsh areas, boreholes are required to measure depth to water table and ground water salinity.

Data availability and influence on confidence

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) also completed a survey of Transkei and Ciskei estuaries and baseline information is now available for approximately 65% of South African estuaries. These data were updated in 2010 for SANBI and this database should be consulted at the start of a study to determine if there are available habitat maps for the estuary or whether this needs to be completed as part of the study.

Aerial photographs help to map the distribution of the different plant community types and to calculate the area covered by different plant community types, and can be used to monitor habitat change from reference to present day, e.g. reed encroachment, loss of habitat due to development.

The measurements made in these transects are used to relate changes in the flora to changes in salinity, water level, flooding and sedimentation. From these data the sensitivity of the plants 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.

For permanently open systems, a medium to high confidence estimate requires two sampling events, 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. If sampling has to be reduced to a single event, then this should be during summer and, for temporarily open/closed systems, preferably during the open phase.

Box 5.13. Data requirements and methods for describing invertebrates

Detailed data requirements and methods

Zooplankton: Collect quantitative samples using a flow meter after dark, 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 stations around dusk. 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 m3 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.

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 for 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 0.25m2, 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 m2).
- 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). Seven 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.
- 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.

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 appropriate 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 (this is only possible for the zooplankton and benthic core and grab samples).

Guidelines for the siting of sampling stations are the same as for microalgae and should be aligned as far as possible. As far as possible, the invertebrate and macrophyte sampling stations should also be matched to be able to link habitats with invertebrate characteristics. Within each salinity zone representative habitats need to be sampled such as Zostera beds, soft sediments (sand/muddy sand/fine mud), hard (rocky areas) and organic rich areas.

Data availability and influence on confidence

Because of the total lack of information on invertebrates in most of South Africa's estuarine systems, the number of sampling events has a direct bearing on confidence of the study. There is also a rapid change in community composition and abundance over time (weeks to months), particularly for zooplankton. Thus it would be ideal to sample in all four seasons and over two years to obtain relatively high confidence. If effort is to be reduced then at a minimum it could take the form of one survey in summer/spring and one in winter, as long as the state of the estuary at the time of sampling is representative of that particular season. For temporarily open/closed estuaries at least one survey must be conducted in a stable closed phase and in the stable open phase. Very reduced sampling to one season or state (preferably low flow/closed) will result in low confidence.

Box 5.14. Data requirements and methods for describing fish

Detailed data requirements and methods

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. 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). Monofilament gill nets of various mesh sizes can, for example be purchased from Laaiplek Handelshuis and ALNET (Pty) Ltd. 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.

Sampling should be carried out as follows:

- 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 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. 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
    - 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

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. 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).

Guidelines for the siting of sampling stations are the same as for other components and should be aligned as far as possible. As far as possible, the invertebrate and macrophyte sampling stations should also be matched to be able to link habitats with invertebrate characteristics. Salinity zones should consider 30-35pp separately, as 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, DAFF and P Cowley, SAIAB, pers. comm.). Within each salinity zone representative habitats need to be sampled such as *Zostera* beds, soft sediments (sand/muddy sand/fine mud), hard (rocky areas) and organic rich areas.

Data availability and influence on confidence

Limited data are available for most estuaries, but a few are well-sampled. In the latter the sampling has usually revealed a high degree of variability that makes prediction of fish communities very difficult, but also shows that once-off samples could give the wrong impression of the typical fish community. Highest confidence is dependent on long term monitoring data. Without this, one needs at least four seasons of sampling events to achieve medium confidence. If effort is reduced to a single survey, this should take place in summer, and in the closed phase for a temporarily open/closed system.

Box 5.15. Data requirements and methods for describing birds

Detailed data requirements and methods

- 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, record the number of birds of each species at low tide, the state of the habitat at the time of observation (or photo of site), the levels of human disturbance at time of counting.
- During the survey, 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.

Data availability and influence on confidence

Monitoring data (CWAC counts) are available for several estuaries, and sometimes provide summer and winter counts for over 10 years. The Coordinated Waterbird Counts (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. These data greatly increase the confidence of a study. However, even if they are available, detailed summer and winter counts provide important data on how the birds use the estuary. In the absence of long term data, increasing the number of counts can increase confidence, but not to a large degree, since natural fluctuations are over longer cycles. If effort has to be reduced, then a single summer count is a minimal requirement. A desktop study will yield very low confidence.

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 Palaearctic 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.

5.5.4 Description of factors influencing the biotic component

This understanding will be used to derive the response relationships used to estimate the Reference condition as well as future scenarios.

Provide descriptions of the abiotic and biotic factors influencing the productivity, biomass and diversity of the different biotic groups within each of the biotic components. A full description for each component is to be given in the text of the specialist reports, basing assumptions on the literature and quantitative analysis as far as possible. The following should be considered:

- 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

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.

A diagram indicating the key ecosystem links within the estuary under investigation can also be very useful. An example is provided below (Figure 5.7). 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.

Table 5.16. Example of the table to be provided for each component (microalgae, macrophytes, etc.), giving a part example for fish.

FISH	**Ia. Estuarine residents (breed only in estuaries)**	**Ib. Estuarine residents (breed in estuaries and the sea)**	**IIa. Estuary dependent marine species**	**IIb and c. Estuary associated species**	**III. Marine migrants**	**IV. Euryhaline freshwater species**
Salinity	Species in these categories have wide salinity tolerances but mostly favour intermediate salinities. They will be negatively affected by the loss of low salinity habitat at the head of the estuary.		Species in these categories have wide salinity tolerances but mostly favour intermediate salinities typically found in the middle and lower reaches of estuaries.		Species in this category have a narrow salinity tolerance range, will benefit from increasing salinity	Species in this category will be negatively affected by the loss of low salinity habitat at the head of the estuary.
Floods	etc.					
Shallow water habitat						
Phytoplankton biomass						
Benthic micro-algae biomass						
Zooplankton biomass						
Benthic invertebrate biomass						
Turbidity						
Aquatic macrophyte cover						
Dissolved oxygen						

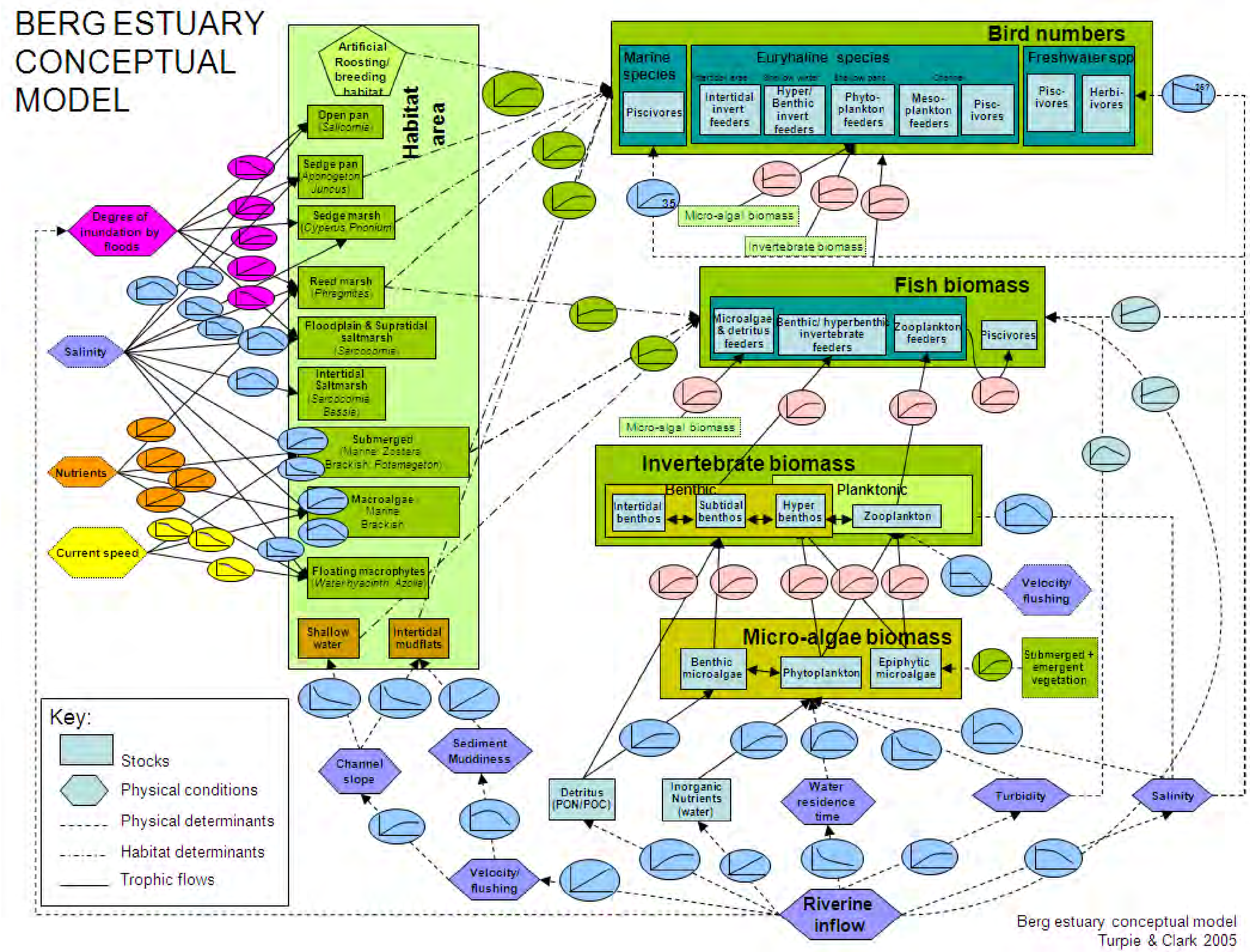


Figure 5.7. Conceptual model showing principal abiotic and biotic drivers and pathways for the Berg River Estuary (from DWAF 2007).

5.5.5 Description of biota in Reference state

For each of the biotic groups (microalgae, macrophytes, invertebrates, fish and birds), the specialists are required to estimate how they have changed from the Reference Condition, as well as the causes of these changes. Changes should be addressed in terms of:

- Changes in species diversity, richness, abundance and community composition
- Changes in biomass distribution and productivity
- Changes in seasonal and inter-annual variability.

Estimates of the reference condition should be quantitative as far as possible and should be computed in a spreadsheet if possible using predictions of changes in drivers made by other specialists. The assumptions made should be explicit in these descriptions. The reference condition can be summarised in a table (Table 5.17).

Table 5.17. Description of biotic components under the reference state.

Biotic component	Description of reference state	Confidence
Microalgae		
Macrophytes		
Invertebrates		
Fish		
Birds		

5.5.6 Scoring Biotic health

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 5.18). 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.

For each biotic group (e.g. macrophytes, fish), biotic health is scored in terms of (a) species richness and (b) abundance and composition. Change in **species richness** should be measured as the loss in the average species richness expected during a sampling event, excluding species that were not thought to have occurred under Reference Condition. Change in **abundance** is assessed in terms of the overall biomass (if possible) or numbers of each major group (e.g. fish, birds) as a whole. Change in **community composition** is assessed using a similarity index which is based on estimates of the abundance of each functional group in the reference and present state. New or alien species can be included as a subgroup. For the latter, quantitative estimates need to be made, making assumptions explicit. The overall score is a min-ave score (Table 5.18).

Table 5.18. Calculation of the biotic health score for each biotic group.

Variable	Measurement	Score	Adjusted score - net of non-flow impacts
a. Species richness	Average species richness per sampling event as a % of average expected during the Reference Condition (only consider original species)	75	
b. Abundance	Similarity in present overall abundance to that in reference state (see Box 6)	59	
c. Community composition	% similarity in community (see Box 7)	70	
Health score = (min (a to c) + ave (a to c))/2		***64***	***71***
Confidence		***M***	***M***

Again, the health of the biotic components may be due partly to modifications in river inflow, and partly to human disturbance (human 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. This produces an adjusted score which is only for descriptive purposes and is not used in the overall index (Table 5.18).

Box 5.16. Scoring similarity in abundance

Average overall abundance is the present state is compared with estimated average overall abundance in the reference state.

If present abundance is less than that of the reference state (e.g. 50 vs. 200), then the score is a simple percentage:

e.g. % Similarity = 100*R/P = 100*50/200 = 25

If present abundance is greater than that of the reference state (e.g. 200 vs. 50), then Czekanowski's similarity index is used:

$$\text{e.g. \% Similarity} = \frac{\sum \min(Ref, Pres)}{(\sum Ref + \sum Pres)/2} = \frac{50}{(200+50)/2} = 40\%$$

Box 5.17. Scoring similarity in community composition

In the case of any major biotic group (invertebrates, fish, etc.), the sub groups will need to be defined, and their percentage contribution to overall biomass or abundance estimated. The estimates for present day will be based on actual data, whereas those for reference state will be either estimated roughly by means of models. It is essential that these assumptions are given, even if confidence is low. Similarity is estimated using Czekanowski's similarity index:

Example calculation of % similarity in community composition, using Czekanowski's similarity index.

GROUP	REFERENCE	PRESENT	MIN
Group 1	50	20	20
Group 2	40	40	40
Group 3	10	3	3
Group 4	0	580	0
Sum	100	643	63
% similarity			**17%**

5.6 Determine overall Estuary Health Score (/100) and Present Ecological Status (A-F)

5.6.1 Calculate Estuary Health Score

The scores derived in the preceding sections (not the adjusted scores) are used to determine the Physical and biological health scores, which are then combined to generate the Estuary Health Score (Table 5.19). The Estuary Health Score represents the degree to which an estuary resembles its pristine ecological state.

5.6.2 Convert to Present Ecological Status

An estuary is assigned to a Present Ecological Status, which indicates six broad categories of estuarine health, as follows (Table 5.20). Thus in the example calculated above, an estuary scoring 68.5 points would be classified as 'C'.

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 (e.g. when confidence is low), 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).

Table 5.19. The Estuary Health Index used to estimate the overall Estuary Health Score, giving an example in italics.

Variable	Weight	Score
Abiotic (habitat) variables		
Hydrology	25	41
Hydrodynamics and mouth condition	25	80
Water quality	25	59
Physical habitat	25	80
1. Habitat health score = weighted mean	50	65
Biotic variables		
Microalgae	20	60
Macrophytes	20	60
Invertebrates	20	70
Fish	20	60
Birds	20	90
2. Biological health score = weighted mean	50	70
ESTUARY HEALTH SCORE = weighted mean of 1 and 2		68.5

Table 5.20. 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.

Estuary 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

5.6.3 Determine influence of non-flow related impacts on Present Ecological Status

Finally, the estimated state of the estuary in the absence of non-flow related impacts should be computed, and a short discussion should be made on the extent of this influence on the current state of the estuary.

5.7 Determine overall confidence of assessment

The prevalent or average level of confidence must be described for each of the abiotic and biotic components of the study, for the prediction of both present and reference state. Confidence categories can be translated to % certainty as per Table 5.21, or they can be specified more accurately:

Table 5.21. Guidelines for describing levels of confidence

Degree of confidence	Explanation	Score (~ % certainty)	Range
Very Low	If no data were available for the estuary or similar estuaries (i.e. < 40% certain)	30	≤40
Low	Limited data were available, and estimates could be out by 60% (40%-60 certain of estimate)	50	41 – 60
Medium	If reasonable data were available for the estuary and estimates could be out by 20-60% (i.e. 60% – 80% certain of estimate)	70	61 – 80
High	If good data were available for the estuary and estimates are probably not more than 20% out (i.e. > 80% certain of estimate)	90	81 - 100

Overall confidence is provided for each component of the Estuary Health Index, and weighted in the same way to obtain overall confidence. The overall confidence level is then converted back to a category (high, medium, etc.), using the guidelines above (Table 5.22). Key reasons for the overall level of confidence should be given.

Table 5.22. Example summary table of the confidence of the study

Variable	**Level**	**Confidence score**
Abiotic variables:		
Hydrology	H	90
Hydrodynamics and mouth condition	M	70
Water quality	L	50
Physical habitat	VL	30
Overall confidence for abiotic components		60
Biotic variables:		
Microalgae	H	90
Macrophytes	H	90
Invertebrates	M	70
Fish	L	50
Birds	L	50
Overall confidence for biotic components		70
OVERALL LEVEL OF CONFIDENCE		**65 (M)**

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7 APPENDIX A. SUMMARY OF DATA REQUIRED FOR A HIGH-CONFIDENCE BASELINE ASSESSMENT

Component	Baseline information requirements
General	Aerial photographs of the estuary (ideally 1:5000 scale) reflecting the present state, as well as the Reference condition (if available). Available orthophotographs
Hydrology	Catchment size delineation Measured river inflow data (gauging stations) at the head of the estuary over a 5-15 year period Measured rainfall data in the catchment (or in a representative adjacent catchment) Hydrological parameters (evaporation rates, radiation rates) Flow losses (e.g. abstraction, impoundment) and gains (e.g. discharges, transfer schemes) Flood hydrographs
Bathymetry	Bathymetric/topographical surveys including berm height, cross sections at 10 – 50 m in the mouth region, cross section profiles at 500 m to 1000 m intervals upstream of the mouth, and floodplain topography.
Hydrodynamics	Continuous water level recordings near mouth of the estuary Water level recordings at 2-6 stations along the length of the estuary over a spring and a neap tidal cycle (i.e. at least a 14 day period) Long term data on daily mouth state (open/closed/overtopping) for temporarily open/ closed estuaries, particularly in systems that have a semi-closed mouth state. Data on wave conditions. Aerial photographs which include the breaker zone near the mouth.
Sediments	Sediment grabs samples collected using a Van Veen or a Zabalocki-type Eckman grab (to characterize recent sediment movement) for particle size analyses, along entire estuary at 500 to 1 000 m intervals Sediment core samples collected using a corer (for historical sediment characterization) at intervals similar to cross-section profiles (see bathymetry) or where considered appropriate by sediment specialist; collected at 3 - 6 year intervals, as well as after flood events. Sediment load at head of estuary (including detritus component – particulate carbon/loss on ignition).

Component	Baseline information requirements
Water quality	Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary Water quality (e.g. system variables, nutrients and toxic substances) measurements on near-shore seawater Longitudinal salinity and temperature profiles (*in situ*) collected over a spring and neap tide during high and low tide at: end of low flow season (i.e. period of maximum seawater intrusion) peak of high flow season (i.e. period of maximum flushing by river water) Water quality measurements, i.e. system variables (pH, DO, turbidity, suspended solids, TDS and temperature) and nutrients (inorganic nitrogen [nitrite, nitrate and ammonia], reactive phosphate and silicate) taken along the length of the estuary (surface and bottom samples) on a spring and a neap high tide: end of low flow season peak of high flow season Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary Effluent discharges at end of pipe just before entering the estuary - measurements of flow rate and other parameters, depending on the composition of the effluent
Microalgae	Data on relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae, during typical high and low flow conditions, using a recognised technique, e.g. HPLC, fluoroprobe, based on: Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions,. Intertidal and subtidal benthic chlorophyll-a measurements, Along with measures of water salinity, inorganic nutrients, sediment particle size and total organic matter.
Macroalgae	Ground-truthed aerial photographs or maps Data on number of plant community types, identification and total number of macrophyte species, number of rare or endangered species or those with limited populations documented during a field visit Permanent transects along an elevation gradient with measurements of percentage plant cover, salinity, water level, sediment moisture content and turbidity Measurements of depth to water table and ground water salinity in supratidal marsh areas

Component	Baseline information requirements
Invertebrates	Species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. Benthic invertebrate species and abundance, based on subtidal grab samples and intertidal core samples at a series of stations up the estuary, and pump sampling or counts of hole densities. Macrocrustacean species and abundance, based on sampling at each station using a benthic sled with flow meter, prawn/crab traps, and appropriate gear for shoreline Measures of sediment characteristics at each station
Fish	Species and abundance data of fish, based on seine net and gill net sampling at about 2km intervals along the estuary, including all habitat types, e.g. Zostera beds, prawn beds, sand flats, and with at least one sample sets in the 0 to 1 ppt reach of the system. These data should be available for four seasons of the year, or for low and high flow periods in a series of years.
Birds	One year of monthly counts of all water associated birds, by species, for the whole estuary, preferably separated into counting areas and/or a series of at least 10 years of summer and winter counts, in addition to historical data on the same.

*historical data = prior to major human impacts on the system.

8 APPENDIX B. IMPORTANCE RATING, PROTECTION STATUS AND HEALTH OF SOUTH AFRICAN ESTUARIES

Estuary importance scores are listed in Table 8.1, existing protected areas are listed in Table 8.2, and conservation priorities (= desired protected areas) are listed in Table 8.3. The latter table also provides a desktop assessment of the EHI and the Recommended Ecological Category.

Table 8.1. Overall importance score* and rank of 256 South African estuaries (Turpie & Clark 2007), showing four component scores of the importance score (biodiversity, size, habitat and zonal type rarity (ZTR), and the four component scores of the biodiversity score (plants, invertebrates, fish and birds). * Note that this score does not include functional importance.

ESTUARY (West to East)	Plant	Invert	Fish	Bird	Bio-diver-sity	Size	Habitat	ZTR	Impor-tance Score*	Rank
Orange (Gariep)	90	90	100	100	98.0	100	100	90	98.5	2
Olifants	100	90	80	100	96.5	100	100	90	98.1	4
Verlorenvlei	90	0	20	100	81.5	70	70	60	71.9	58
Berg (Groot)	90	80	100	100	97.5	100	100	90	98.4	3
Rietvlei/Diep	100	80	80	100	96.0	100	10	60	72.5	55
Houtbaai	60	10	10	10	42.5	10	50	90	36.1	176
Wildevoëlvlei	100	30	30	100	86.0	80	90	60	82.0	29
Bokramspruit	10	10	10	40	29.5	10	10	60	19.9	233
Schuster	10	10	10	10	10.0	10	10	60	15.0	246
Krom	100	10	10	10	68.5	10	10	60	29.6	204
Silvermine	90	10	20	10	63.5	30	50	10	41.4	155
Sand	70	80	80	100	91.5	90	70	10	77.4	45
Eerste	50	10	30	80	64.5	40	40	10	43.1	149
Lourens	60	10	20	60	51.5	30	30	10	33.4	189
Sir Lowry's Pass	90	10	20	10	63.5	20	20	10	29.9	202
Steenbras	10	30	20	10	17.5	20	10	20	16.9	240
Rooiels	90	40	20	10	65.0	40	40	10	43.3	148
Buffels (Oos)	100	50	30	10	73.5	50	30	10	46.9	134
Palmiet	80	80	40	60	71.0	70	60	20	62.8	82
Bot/Kleinmond	90	100	100	100	98.5	100	100	70	96.6	8
Onrus	70	10	40	50	59.5	70	60	10	58.9	94
Klein	100	100	100	100	100.0	100	100	70	97.0	5
Uilskraals	90	80	40	90	82.0	80	90	10	76.0	47
Ratel	10	40	20	70	52.0	40	10	10	32.5	191
Heuningnes	100	90	60	80	90.5	90	90	20	83.1	24
Klipdrifsfontein	10	30	10	60	43.5	10	10	10	18.4	237
Breë	80	100	90	90	89.0	100	90	20	86.8	19
Duiwenhoks	60	100	70	80	76.5	100	90	20	83.6	23
Goukou (Kaffirkuils)	80	90	70	80	79.0	90	90	20	80.3	31
Gourits	90	80	80	90	88.0	90	60	20	75.0	49
Blinde	100	40	10	60	77.5	10	10	10	26.9	216
Hartenbos	100	70	40	80	86.5	70	60	10	65.6	75
Klein Brak	70	80	70	60	69.0	80	10	10	52.8	115
Groot Brak	80	100	70	80	79.5	90	80	10	76.9	46
Maalgate	10	60	50	70	57.5	50	10	10	37.9	172

ESTUARY (West to East)	**Plant**	**Invert**	**Fish**	**Bird**	**Biodiversity**	**Size**	**Habitat**	**ZTR**	**Importance Score***	**Rank**
Gwaing	10	40	10	10	11.5	10	10	10	10.4	254
Kaaimans	50	50	40	30	45.5	30	10	20	27.9	210
Wilderness	90	40	50	100	88.0	90	70	70	82.5	27
Swartvlei	100	90	100	100	99.5	100	100	70	96.9	7
Goukamma	50	100	90	80	83.0	70	40	10	59.8	59
Knysna	100	100	100	100	100.0	100	100	100	100.0	1
Noetsie	10	50	70	10	51.0	30	10	10	28.3	209
Piesang	80	80	70	40	72.5	80	80	10	71.1	62
Keurbooms	100	90	80	90	95.0	100	90	20	88.3	18
Matjies/Bitou	10	40	10	100	70.0	10	10	10	25.0	220
Sout (Oos)	70	80	70	50	67.5	70	50	20	59.4	91
Groot (Wes)	100	70	40	60	83.5	70	50	10	62.4	84
Bloukrans	90	40	10	10	63.5	70	10	50	51.4	120
Lottering	10	60	30	10	25.5	50	10	50	33.9	186
Elandsbos	10	50	20	10	18.5	30	10	50	24.1	223
Storms	10	40	10	10	11.5	60	10	50	34.4	182
Elands	10	40	10	10	11.5	10	10	50	14.4	247
Groot (Oos)	10	40	10	10	11.5	10	10	50	14.4	248
Tsitsikamma	60	40	20	10	45.5	10	20	10	21.4	228
Klipdrif	10	40	10	70	50.5	10	10	10	20.1	231
Slang	10	40	10	10	11.5	10	0	10	7.9	256
Krom Oos (Kromme)	80	100	90	100	95.5	100	90	20	88.4	17
Seekoei	60	90	70	90	82.5	90	80	10	77.6	43
Kabeljous	80	100	60	90	84.5	90	80	10	78.1	40
Gamtoos	100	100	90	100	98.5	100	100	20	91.6	13
Van Stadens	60	80	50	50	58.0	60	30	10	47.0	132
Maitland	60	50	60	50	58.0	10	70	10	37.0	174
Swartkops	100	100	100	100	100.0	100	100	20	92.0	12
Coega (Ngcura)	90	60	10	90	76.5	40	40	10	46.1	140
Sundays	80	100	90	90	89.0	90	70	20	77.8	42
Boknes	70	70	40	80	72.0	60	50	10	55.5	103
Bushmans	70	100	90	70	84.5	100	60	20	78.1	41
Kariega	100	100	100	80	97.0	90	80	20	82.3	28
Kasuka	10	70	50	70	58.0	70	70	10	61.0	87
Kowie	90	90	80	90	88.5	90	80	20	80.1	33
Rufane	80	50	10	10	57.5	10	10	10	21.9	227
Riet	90	80	70	10	74.5	80	80	10	71.6	60
Kleinemond Wes	80	80	60	40	71.0	80	90	10	73.3	50
Kleinemond Oos	90	90	90	50	84.0	70	90	10	72.5	56
Klein Palmiet	10	50	10	10	12.0	10	0	10	8.0	255
Great Fish	100	90	100	90	98.0	100	100	20	91.5	14
Old woman's	90	80	60	30	76.0	60	50	10	56.5	98
Mpekweni	100	90	70	80	92.0	90	100	10	85.0	22
Mtati	100	90	80	10	83.0	90	100	10	82.8	26
Mgwalana	70	90	80	80	79.0	90	100	10	81.8	30
Bira	90	90	80	60	84.0	80	70	10	71.5	61

ESTUARY (West to East)	Plant	Invert	Fish	Bird	Biodiversity	Size	Habitat	ZTR	Importance Score*	Rank
Gqutywa	50	90	70	30	62.0	70	70	10	62.0	85
Blue Krans	80	60	30	10	61.0	20	30	10	31.8	194
Mtana	80	60	40	10	62.5	50	70	10	54.1	110
Keiskamma	100	100	100	80	97.0	100	100	20	91.3	15
Ngqinisa	70	60	40	10	56.0	50	60	10	50.0	123
Kiwane	60	70	60	10	53.0	60	70	10	55.8	101
Tyolomnqa	90	90	80	40	81.0	80	60	10	68.3	68
Shelbertsstroom	10	50	30	10	25.0	10	0	10	11.3	252
Lilyvale	10	60	20	10	19.0	20	10	10	16.3	241
Ross' Creek	10	50	30	10	25.0	10	0	10	11.3	253
Ncera	10	70	60	40	50.0	60	50	10	50.0	124
Mlele	10	60	20	10	19.0	20	10	10	16.3	242
Mcantsi	10	60	40	10	32.0	40	20	10	30.0	201
Gxulu	10	80	90	50	71.5	70	50	10	59.4	92
Goda	10	60	70	40	56.0	50	30	10	42.5	154
Hlozi	10	50	20	50	39.5	10	10	10	17.4	239
Hickman's	10	60	20	40	33.5	30	10	10	23.9	224
Buffalo	10	90	80	40	64.0	80	40	20	60.0	89
Blind	100	50	40	10	75.0	10	10	10	26.3	218
Hlaze	10	50	40	10	31.5	10	10	10	15.4	245
Nahoon	90	100	90	70	87.5	80	60	20	70.9	63
Qinira	70	80	70	50	67.5	80	70	10	67.4	72
Gqunube	80	80	80	60	77.0	70	50	20	61.8	86
Kwelera	10	80	100	50	78.0	70	60	20	64.5	78
Bulura	50	70	50	60	57.5	70	50	10	55.9	100
Cunge	10	50	20	10	18.5	10	10	10	12.1	251
Cintsa	10	70	50	80	64.5	70	50	10	57.6	97
Cefane	10	80	60	70	60.0	80	80	10	68.0	70
Kwenxura	10	70	60	90	72.5	70	50	10	59.6	90
Nyara	60	60	30	10	48.0	50	40	10	43.0	151
Haga-haga	10	60	30	10	25.5	20	20	10	20.4	230
Mtendwe	10	60	20	10	19.0	40	40	10	31.8	195
Quko	80	80	60	10	66.5	70	40	10	55.6	102
Morgan	10	70	50	70	58.0	60	30	10	47.0	133
Cwili	10	50	30	10	25.0	10	10	10	13.8	249
Great Kei	80	100	90	50	83.0	100	70	20	80.3	32
Gxara	40	70	50	50	49.5	60	40	10	47.4	131
Ngogwane	60	60	40	40	54.0	40	30	10	38.0	171
Qolora	50	70	70	50	64.0	60	90	10	63.5	81
Ncizele	70	60	50	30	60.5	30	10	10	30.6	200
Kobonqaba	60	70	60	40	57.5	60	50	20	52.9	113
Nxaxo/Ngqusi	80	100	80	90	87.5	90	80	10	78.9	38
Cebe	60	60	50	50	57.0	50	40	10	45.3	142
Gqunqe	60	70	10	60	53.0	60	40	10	48.3	129
Zalu	10	60	40	50	43.0	40	20	10	32.8	190
Ngqwara	40	70	30	50	46.5	60	40	10	46.6	138

ESTUARY (West to East)	**Plant**	**Invert**	**Fish**	**Bird**	**Bio-diversity**	**Size**	**Habitat**	**ZTR**	**Importance Score***	**Rank**
Sihlontlweni/Gcini	60	60	10	60	52.5	40	20	10	35.1	179
Qora	40	90	90	90	82.5	80	70	20	72.1	57
Jujura	40	60	60	50	55.5	30	10	10	29.4	206
Ngadla	40	60	50	10	43.0	50	30	10	39.3	164
Shixini	50	70	50	70	64.0	60	40	20	52.0	117
Nqabara	50	90	10	10	40.0	90	70	20	65.5	76
Ngoma/Kobule	20	60	10	10	19.0	40	40	10	31.8	196
Mendu	50	70	10	10	39.0	60	40	10	44.8	145
Mbashe	70	100	90	80	86.0	90	90	30	83.0	25
Ku-Mpenzu	50	40	50	10	43.5	50	60	10	46.9	135
Ku-Bhula/Mbhanyana	60	30	30	30	49.5	30	70	10	42.9	152
Ntlonyane	50	70	60	40	56.0	70	50	10	55.5	104
Nkanya	30	40	60	30	50.0	50	50	10	46.0	141
Xora	90	90	70	60	82.5	90	80	30	79.6	36
Bulungula	70	50	10	40	55.5	60	40	10	48.9	127
Ku-amanzimuzama	30	30	10	10	24.0	20	20	10	20.0	232
Mncwasa	70	50	10	80	66.5	60	20	10	46.6	139
Mpako	30	40	10	10	24.5	50	30	10	34.6	180
Nenga	50	30	70	10	56.0	40	30	10	38.5	167
Mapuzi	40	40	60	10	48.5	50	30	10	40.6	160
Mtata	70	90	80	40	73.0	90	90	30	79.8	34
Mdumbi	60	80	80	50	72.5	80	60	30	68.1	69
Lwandilana	40	30	10	10	30.5	40	20	10	29.6	205
Lwandile	60	50	10	90	71.5	60	40	10	52.9	114
Mtakatye	70	90	10	30	56.0	90	70	30	70.5	64
Hluleka/Majusini	30	40	10	10	24.5	50	30	10	34.6	181
Mnenu	40	80	10	50	44.0	80	60	10	59.0	93
Mtonga	60	60	10	60	52.5	70	50	10	54.6	106
Mpande	50	40	50	50	49.5	50	30	10	40.9	159
Sinangwana	40	40	50	10	42.0	50	30	10	39.0	165
Mngazana	90	100	100	60	92.5	100	100	30	91.1	16
Mngazi	40	50	60	90	76.0	50	20	10	45.0	143
Bululo	30	40	80	10	60.0	50	30	10	43.5	146
Mtambane	50	30	40	10	41.5	40	20	10	32.4	193
Mzimvubu	40	90	70	80	73.0	90	90	30	79.8	35
Ntlupeni	20	20	30	70	54.0	30	10	10	29.0	208
Nkodusweni	40	60	10	60	49.5	70	40	10	51.4	121
Mntafufu	70	50	80	80	77.0	60	70	30	63.8	79
Mzintlava	50	50	10	60	50.5	60	50	30	52.1	116
Mzimpunzi	20	20	10	70	51.0	30	20	10	30.8	199
Mbotyi	80	70	40	90	80.0	70	70	10	66.5	73
Mkozi	90	20	10	80	73.0	30	30	10	38.8	166
Myekane	30	20	10	30	26.5	20	10	10	18.1	238
Lupatana	70	20	10	40	54.0	20	40	10	32.5	192
Mkweni	30	30	10	80	59.5	30	60	10	42.9	153
Msikaba	80	40	70	80	76.5	50	50	30	54.6	107

ESTUARY (West to East)	Plant	Invert	Fish	Bird	Biodiversity	Size	Habitat	ZTR	Importance Score*	Rank
Mgwegwe	60	30	80	70	73.0	40	80	10	55.3	105
Mgwetyana	70	20	70	50	64.5	20	10	10	27.6	212
Mtentu	90	70	90	90	89.0	70	80	30	73.3	51
Sikombe	30	30	10	60	46.5	40	50	10	41.1	157
Kwanyana	60	30	10	70	57.5	30	10	10	29.9	203
Mnyameni	50	60	10	70	57.5	60	40	30	51.4	122
Mpahlanyana	70	20	10	40	54.0	20	10	10	25.0	221
Mpahlane	70	20	10	50	55.5	30	10	10	29.4	207
Mzamba	80	80	100	60	90.0	80	80	30	77.5	44
Mtentwana	40	30	40	80	65.5	40	20	10	38.4	168
Mtamvuna	80	70	90	60	83.0	80	50	10	66.3	74
Zolwane	20	10	10	30	24.5	10	20	10	16.1	243
Sandlundlu	10	20	50	70	55.5	30	40	10	36.9	175
Ku-boboyi	20	10	10	50	37.5	10	20	10	19.4	236
Tongazi	30	10	40	80	63.0	10	70	10	38.3	169
Kandandhlovu	20	20	30	40	34.5	20	20	10	22.6	225
Mpenjati	20	30	90	70	73.5	40	50	10	47.9	130
Umhlangankulu	20	30	60	40	49.5	40	80	10	49.4	125
Kaba	10	20	20	30	25.0	20	40	10	25.3	219
Mbizana	10	30	100	80	80.0	40	70	10	54.5	109
Mvutshini	10	10	10	10	10.0	10	20	10	12.5	250
Bilanhlolo	100	20	30	40	76.5	20	60	10	43.1	150
Uvuzana	10	10	10	30	23.0	10	20	10	15.8	244
Kongweni	60	10	30	30	48.5	10	40	10	27.1	215
Vungu	20	10	20	50	39.0	10	30	10	22.3	226
Mhlangeni	10	20	30	80	59.0	20	40	10	33.8	187
Zotsha	60	30	40	60	55.5	30	80	10	46.9	136
Boboyi	10	10	60	30	45.5	10	40	10	26.4	217
Mbango	10	10	20	40	31.0	10	60	10	27.8	211
Mzimkulu	40	80	90	50	76.0	80	100	30	79.0	37
Mtentweni	10	30	40	10	30.5	30	80	10	40.6	161
Mhlangamkulu	10	20	20	10	17.0	30	10	10	19.8	235
Damba	30	20	20	10	25.0	20	90	10	37.8	173
Koshwana	30	10	20	10	24.5	10	80	10	31.1	198
Intshambili	30	10	30	10	26.0	20	80	10	35.5	178
Mzumbe	30	40	70	10	53.5	50	50	10	46.9	137
Mhlabatshane	30	20	30	10	26.5	20	90	10	38.1	170
Mhlungwa	40	20	10	60	47.5	20	60	10	35.9	177
Mfazazana	10	20	20	80	57.5	20	80	10	43.4	147
Kwa-Makosi	30	20	10	50	39.5	20	90	10	41.4	156
Mnamfu	10	10	10	10	10.0	10	80	10	27.5	214
Mtwalume	10	50	10	90	64.0	60	50	10	53.5	112
Mvuzi	10	10	10	40	29.5	10	50	10	24.9	222
Fafa	50	50	50	70	63.0	70	80	10	64.8	77
Mdesingane	10	10	10	40	29.5	10	30	10	19.9	234
Sezela	30	30	90	80	76.5	40	50	10	48.6	128

ESTUARY (West to East)	**Plant**	**Invert**	**Fish**	**Bird**	**Bio-diver-sity**	**Size**	**Habitat**	**ZTR**	**Impor-tance Score***	**Rank**
Mkumbane	10	10	20	70	50.5	10	40	10	27.6	213
Mzinto	40	30	30	80	64.0	30	80	10	49.0	126
Mzimayi	10	10	20	30	24.5	10	40	10	21.1	229
Mpambanyoni	10	20	50	60	49.0	20	50	10	33.8	188
Mahlongwa	30	20	50	40	44.0	30	40	10	34.0	185
Mahlongwana	20	30	30	60	48.0	30	80	10	45.0	144
Mkomazi	80	80	100	70	91.5	80	60	30	72.9	53
Ngane	40	20	10	90	67.0	10	40	10	31.8	197
Umgababa	80	40	10	50	63.0	50	60	10	51.8	118
Msimbazi	50	30	100	70	84.5	50	50	10	54.6	108
Lovu	40	30	90	80	78.0	40	80	10	56.5	99
Little Manzimtoti	40	20	30	40	37.5	10	80	10	34.4	183
Manzimtoti	40	20	100	80	84.0	30	70	10	51.5	119
Mbokodweni	20	30	60	90	72.0	30	40	10	41.0	158
Sipingo	50	30	60	70	63.5	30	100	10	53.9	111
Durban Bay	50	100	100	100	92.5	90	100	80	92.1	11
Mgeni	50	70	70	100	86.5	70	90	10	73.1	52
Mhlanga	30	80	80	90	79.0	80	70	10	70.3	65
Mdloti	30	70	60	80	69.0	80	90	10	72.8	54
Tongati	10	60	30	70	54.5	70	80	10	62.6	83
Mhlali	40	40	90	90	80.0	60	90	10	67.5	71
Seteni	20	10	10	50	37.5	10	80	10	34.4	184
Mvoti	60	40	30	100	80.5	60	30	70	58.6	95
Mdlotane	10	50	80	60	65.0	60	90	10	63.8	80
Nonoti	20	40	30	100	74.5	60	60	10	58.6	96
Zinkwasi	50	70	90	70	80.0	80	90	10	75.5	48
Tugela/Thukela	20	70	40	90	71.0	80	50	70	69.3	66
Matigulu/Nyoni	40	90	100	90	89.0	90	70	30	78.8	39
Siyaya	50	20	50	40	47.0	30	60	10	39.8	163
Mlalazi	70	100	100	100	95.5	90	90	30	85.4	21
Mhlathuze	10	100	70	10	53.5	100	100	80	86.4	20
Richard's Bay	10	100	90	100	85.0	100	0	80	69.3	67
Nhlabane	70	30	60	100	86.0	50	50	70	61.0	88
Mfolozi	70	90	100	90	93.5	100	100	70	95.4	10
St Lucia	90	100	100	100	98.5	100	100	70	96.6	9
Mgobezeleni	40	10	30	40	37.0	10	80	70	40.3	162
Kosi	100	100	100	100	100.0	100	100	70	97.0	6

Table 8.2. South African estuaries that have some level of protection

#	Estuary	Protected area	Agency	Amount of estuary in protected area	Level of protect-ion*
1	Orange	Planned	Provincial	Part	M
2	Spoeg	Namaqualand NP	SANParks	All	M
3	Groen	Namaqualand NP	SANParks	All	M
4	Diep	Rietvlei NR	Municipal	Part	L
5	Krom	Table Mountain NP	SANParks	Entirely	H
6	Wildevoëlvlei	Table Mountain NP	SANParks	Part	L
7	Sand	Sandvlei NR	Municipal	<10% of estuary (Top)	L
8	Heuningnes	De Mond NR	CapeNature	Part	M
9	Goukou	Stilbaai MPA	CapeNature	Part	M
10	Wilderness	Wilderness Lakes NP	SANParks	Part	L
11	Swartvlei	Wilderness Lakes NP	SANParks	Part	L
12	Goukamma	Goukamma NR	CapeNature	Most	M
13	Knysna	Knysna NP	SANParks	Part	L
14	Keurbooms	Keurbooms River NR	CapeNature	Part (upper reaches)	L
15	Sout	De Vasselot NP	SANParks	All	M
16	Groot (W)	Tsitsikamma NP	SANParks	All	H
17	Bloukrans	Tsitsikamma NP	SANParks	All	H
18	Lottering	Tsitsikamma NP	SANParks	All	H
19	Elandsbos	Tsitsikamma NP	SANParks	All	H
20	Storms	Tsitsikamma NP	SANParks	All	H
21	Elands	Tsitsikamma NP	SANParks	All	H
22	Groot (E)	Tsitsikamma NP	SANParks	All	H
23	Tsitsikamma	Huisklip NR	EC Parks	Lower reaches	L
24	Seekoei	Seekoei River NR	Municipal	Part (upper)	L
25	Gamtoos	Gamtoos R. Mouth NR	Municipal	Part	L
26	Van Stadens	Van Stadens NR	Municipal	All	L
27	Sundays	Addo Elephant NR	Municipal	Part	M
28	Nahoon	Nahoon Estuary NR	Municipal	Very small part	L
29	Mendu	Dwesa-Cwebe MPA	DEA/DAFF	Undefined as yet	M
30	Mendwana	Dwesa-Cwebe MPA	DEA/DAFF	Undefined as yet	M
31	Mbashe	Dwesa-Cwebe MPA	DEA/DAFF	All, but half in practice	H
32	Ku-Mpenzu	Dwesa-Cwebe NR	EC Parks	Undefined as yet	M
33	Ku-Bhula/Mbhanyana	Dwesa-Cwebe NR	EC Parks	Undefined as yet	M
34	Kwa-Suka	Dwesa-Cwebe NR	EC Parks	Undefined as yet	M
35	Ntlonyane	Dwesa-Cwebe NR	EC Parks	Undefined as yet	M
36	Nkanya	Dwesa-Cwebe NR	EC Parks	Undefined as yet	M
37	Hluleka	Hluleka NR	EC Parks	All	L
38	Nkodusweni	Pondoland MPA	DEA	Part	L
39	Mtafufu	Pondoland MPA	DEA	Part	L
40	Mzintlava	Pondoland MPA	DEA	Part	L
41	Mzimpunzi	Pondoland MPA	DEA	Part	L
42	Kwa-Nyambalala	Pondoland MPA	DEA	Part	L
43	Mbotyi	Pondoland MPA	DEA	Part	L
44	Mkozi	Pondoland MPA	DEA	Part	L

#	**Estuary**	**Protected area**	**Agency**	**Amount of estuary in protected area**	**Level of protect-ion***
45	Myekane	Pondoland MPA	DEA	Part	L
46	Sitatsha	Pondoland MPA	DEA	Part	L
47	Lupatana	Pondoland MPA	DEA	Part	L
48	Mkweni	Pondoland MPA	DEA	Part	L
49	Msikaba	Mkambati NR	EC Parks	All	H
50	Butsha	Mkambati NR	EC Parks	All	H
51	Mgwegwe	Mkambati NR	EC Parks	All	H
52	Mgwetyana	Mkambati NR	EC Parks	All	H
53	Mtentu	Mkambati NR	EC Parks	All	H
54	Sikombe	Pondoland MPA	DEA	Part	L
55	Kwanyana	Pondoland MPA	DEA	Part	L
56	Mtolane	Pondoland MPA	DEA	Part	L
57	Mnyameni	Pondoland MPA	DEA	Part	L
58	Mpahlanyana	Pondoland MPA	DEA	Part	L
59	Mpahlane	Pondoland MPA	DEA	Part	L
60	Mzamba	Pondoland MPA	DEA	Part	L
61	Mtentwana	Pondoland MPA	DEA	Part	L
62	Mtamvuna	Pondoland MPA	DEA	Part	L
63	Mpenjati	Mpenjati NR	EKZNW	Part	M
64	Mgeni	Beechwood NR	EKZNW	Part	M
65	Mhlanga	-	EKZNW	All	H
66	Mlalazi	Mlalazi NR	EKZNW	All	H
67	Mhlathuze	-	EKZNW	Part	M
68	St Lucia/Mfolozi	iSimangaliso WP	ISWP Authority	90%	H/M
69	Mgobozeleni	iSimangaliso WP	ISWP Authority	All	L
70	Kosi	iSimangaliso WP	ISWP Authority	All	M

Table 8.3. National and/or regional (C.A.P.E.) priorities for protection, the extent of protection required (Full = full no-take protection, partial includes no-take sanctuary zone where feasible), the recommended proportion of the estuary margin being undeveloped or with a >500m development setback line, and preliminary Ecological Reserve Category. Source: Turpie *et al.* 2012.

Estuary (West to East)	Current health category	Primary set for National and/or Cape	Recommended extent of protection	Recommended degree of undeveloped margin	Desktop estimate of Ecological Reserve Category
Orange	D	SA/C.A.P.E.	Full	50%	C*
Buffels	C				C
Spoeg	B	SA	Full	100%	A or BAS
Groen	B	SA	Full	100%	A or BAS
Sout	D				D
Olifants	C	SA/C.A.P.E.	Partial	50%	B*
Jakkalsvlei	D				D
Wadrift	E				D
Verlorenvlei	D	SA	Partial	50%	C
Berg	D	SA/C.A.P.E.	Partial	25%	C*
Rietvlei/ Diep	E	SA/C.A.P.E.	Partial	50%	C
Sout W	F				D
Hout Bay	E				D
Wildevoëlvlei	D				B
Bokramspruit	C				C
Schuster	A				A
Krom	A	SA/C.A.P.E.	Full	100%	A or BAS
Buffels Wes	F				D
Elsies	E				D
Silvermine	D				D
Sand	D	SA/C.A.P.E.	Partial	20%	C
Zeekoei	E				D
Eerste	E	SA/C.A.P.E.	Full	75%	D
Lourens	C	SA/C.A.P.E.	Full	75%	D
Sir Lowry's Pass	E				D
Steenbras	B				B
Rooiels	B				B
Buffels (Oos)	B				B
Palmiet	C	SA/C.A.P.E.	Full	50%	B*
Bot / Kleinmond	C	SA/C.A.P.E.	Partial	50%	B
Onrus	E				D
Klein	C	SA/C.A.P.E.	Partial	50%	B
Uilkraals	D	SA	Partial	75%	C
Ratel	C	SA	Full	75%	C
Heuningnes	D	SA/C.A.P.E.	Partial	75%	A or BAS
Klipdrifsfontein	A	SA/C.A.P.E.	Full	75%	A
Breede	B	SA	Partial	50%	B*
Duiwenhoks	B				A
Goukou	C	SA/C.A.P.E.	Partial	50%	B
Gourits	C	SA/C.A.P.E.	Partial	50%	B

Estuary (West to East)	**Current health category**	**Primary set for National and/or Cape**	**Recommended extent of protection**	**Recommended degree of undeveloped margin**	**Desktop estimate of Ecological Reserve Category**
Blinde	B				B
Hartenbos	D				C
Klein Brak	C				C
Groot Brak	E				C*
Maalgate	B				B*
Gwaing	B				C*
Kaaimans	B	SA	Full	50%	B*
Wilderness	B	SA/C.A.P.E.	Partial	50%	A or BAS
Swartvlei	B	SA/C.A.P.E.	Partial	50%	B*
Goukamma	B	SA/C.A.P.E.	Full	75%	A*
Knysna	B	SA/C.A.P.E.	Partial	50%	B*
Noetsie	B	C.A.P.E.			A*
Piesang	C	SA	Partial	50%	B
Keurbooms	A	SA/C.A.P.E.	Partial	50%	A*
Matjies	B				B*
Sout (Oos)	A	SA/C.A.P.E.	Full	100%	A*
Groot (Wes)	B	SA/C.A.P.E.	Full	75%	A or BAS
Bloukrans	A	SA/C.A.P.E.	Full	100%	A or BAS
Lottering	A	SA/C.A.P.E.	Full	100%	A or BAS
Elandsbos	A	SA/C.A.P.E.	Full	100%	A or BAS
Storms	A	SA/C.A.P.E.	Full	100%	A or BAS
Elands	B	SA/C.A.P.E.	Full	100%	A or BAS
Groot (Oos)	B	SA/C.A.P.E.	Full	100%	A or BAS
Tsitsikamma	B	SA	Full	50%	B*
Klipdrif	D				D
Slang	D				D
Kromme	D	SA/C.A.P.E.	Partial	25%	C*
Seekoei	D	SA/C.A.P.E.	Partial	25%	B*
Kabeljous	C				B
Gamtoos	C	SA/C.A.P.E.	Partial	50%	A or BAS
Van Stadens	B	SA/C.A.P.E.	Full	50%	A or BAS
Maitland	C	SA/C.A.P.E.	Full	75%	C
Bakens	E				D
Papkuils	F				D
Swartkops	C	SA/C.A.P.E.	Partial	25%	B
Coega (Ngcura)	F				D
Sundays	C	SA/C.A.P.E.	Partial	50%	A or BAS
Boknes	C				C
Bushman’s	B	SA/C.A.P.E.	Partial	50%	A*
Kariega	C	SA/C.A.P.E.	Partial	50%	B
Kasuka	B				A
Kowie	C				B
Rufane	C				C
Riet	B				A
West Kleinemonde	B				A

Estuary (West to East)	Current health category	Primary set for National and/or Cape	Recommended extent of protection	Recommended degree of undeveloped margin	Desktop estimate of Ecological Reserve Category
East Kleinemonde	B				B*
Klein Palmiet	D				D
Great Fish	C	SA/C.A.P.E.	Partial	50%	B
Old woman's	C				C
Mpekweni	B				A
Mtati	B	C.A.P.E.			A
Mgwalana	B	SA	Partial	50%	A
Bira	B	SA	Partial	50%	A
Gqutywa	B	SA/C.A.P.E.	Full	75%	A
Ngculura	B				B
Freshwaterpoort	A				A
Mtana	B				B
Keiskamma	C	SA/C.A.P.E.	Partial	50%	B
Ngqinisa	B	SA	Full	75%	B
Kiwane	B				B
Tyolomnqa	B				A
Shelbertsstroom	C				C
Lilyvale	B				B
Ross' Creek	B				B
Ncera	B	SA	Full	75%	B
Mlele	B				B
Mcantsi	C				C
Gxulu	B				B
Goda	B	C.A.P.E.	Full	75%	B
Hlozi	B				B
Hickman's	B				B
Mvubakazi	B				B
Ngqenga	C				C
Buffalo	D				C
Blind	C				C
Hlaze	C				C
Nahoon	C				B*
Qinira	B				A
Gqunube	B	SA	Partial	50%	A
Kwelera	B	SA	Partial	50%	A
Bulura	B				B
Cunge	A				A
Cintsa	C				C
Cefane	B				A
Kwenxura	B	SA/C.A.P.E.	Full	75%	A
Nyara	A				A
Mtwendwe	B				B
Haga-haga	B				B
Mtendwe	B				B
Quko	A	SA/C.A.P.E.	Full	50%	A

Estuary (West to East)	**Current health category**	**Primary set for National and/or Cape**	**Recommended extent of protection**	**Recommended degree of undeveloped margin**	**Desktop estimate of Ecological Reserve Category**
Morgan	C				C
Cwili	B				B
Great Kei	C	SA/C.A.P.E.	Partial	50%	B*
Gxara	B				B
Ngogwane	B				B
Qolora	B				A
Ncizele	B	SA	Full	75%	B
Timba	A				A
Kobonqaba	B				B
Nxaxo/Ngqusi	B	SA/C.A.P.E.	Full	75%	A
Cebe	B				B
Gqunqe	A				A
Zalu	A				A
Ngqwara	A	SA	Full	75%	A
Sihlontlweni/Gcini	B				B
Nebelele	A				A
Qora	B	SA/C.A.P.E.	Partial	75%	A
Jujura	B				B
Ngadla	A	SA	Full	75%	A
Shixini	B	C.A.P.E.			B
Beechamwood	A				A
Un-named EC	A				A
Kwa-Goqo	A				A
Ku-Nocekedwa	A				A
Nqabara	B	SA	Partial	75%	A
Ngoma/Kobule	A				A
Mendu	A	SA			A
Mendwana	A	SA			A
Mbashe	C	SA/C.A.P.E.	Partial	75%	A or BAS
Ku-Mpenzu	B	SA/C.A.P.E.	Full	75%	B
Ku-Bhula/Mbhanyana	A	SA/C.A.P.E.	Full	75%	A
Kwa-Suka	B	SA			B
Ntlonyane	B	SA/C.A.P.E.	Full	75%	B
Nkanya	B	SA/C.A.P.E.	Full	75%	B
Sundwana	A	SA	Full	75%	A
Xora	B	SA	Partial	75%	A
Bulungula	B				B
Ku-amanzimuzama	A				A
Ngakanqa	A	SA	Full	75%	A
Un-named KZN	A				A
Mncwasa	B				B
Mpako	B				B
Nenga	C				C
Mapuzi	B				B

Estuary (West to East)	**Current health category**	**Primary set for National and/or Cape**	**Recommended extent of protection**	**Recommended degree of undeveloped margin**	**Desktop estimate of Ecological Reserve Category**
Mtata	D	SA	Partial	50%	C*
Tshani	B				B
Mdumbi	B	C.A.P.E.			A
Lwandilana	A	SA	Full	75%	A
Lwandile	A				A
Mtakatye	B	SA	Partial	75%	B
Hluleka	A	SA	Full	75%	A or BAS
Mnenu	B				B
Mtonga	B				B
Mpande	B				B
Sinangwana	B				B
Mngazana	B	SA	Partial	50%	B
Mngazi	C				C
Gxwaleni	A				A
Bulolo	B				B
Mtambane	B				B
Mzimvubu	C	SA	Partial	50%	C
Ntlupeni	B				B
Nkodusweni	B	SA	Partial	75%	A or BAS
Mntafufu	B	SA	Full	75%	A or BAS
Mzintlava	B	SA	Full	75%	A or BAS
Umzimpunzi	B	SA	Full	75%	B
Kwa-Nyambala	B	SA	Partial	50%	B
Mbotyi	B	SA	Partial	50%	A or BAS
Mkozi	A	SA	Full	75%	A
Myekane	A	SA	Full	75%	A
Sitatshe	A	SA	Full	75%	A
Lupatana	A	SA	Full	75%	A
Mkweni	A	SA	Partial	75%	A or BAS
Msikaba	A	SA	Full	75%	A or BAS
Butsha	A	SA	Partial	100%	A
Mgwegwe	A	SA	Partial	100%	A
Mgwetyana	A	SA	Partial	100%	A
Mtentu	A	SA	Full	75%	A or BAS
Sikombe	A	SA	Partial	75%	A
Kwanyana	B	SA	Partial	75%	B
Mtolane	A	SA	Partial	75%	A
Mnyameni	B	SA	Partial	75%	A or BAS
Mpahlanyana	A	SA	Full	75%	A
Mpahlane	A	SA	Partial	75%	A
Mzamba	B	SA	Partial	75%	A
Mtentwana	C	SA	Full	75%	C
Mtamvuna	B	SA	Full	75%	A or BAS
Zolwane	B				B
Sandlundlu	C				C

Estuary (West to East)	Current health category	Primary set for National and/or Cape	Recommended extent of protection	Recommended degree of undeveloped margin	Desktop estimate of Ecological Reserve Category
Ku-Boboyi	B				B
Tongazi	B				B
Kandandhlovu	B				B
Mpenjati	B	SA	Partial	75%	A or BAS
Umhlangankulu	C				C
Kaba	B				B
Mbizana	B				B
Mvutshini	B				B
Bilanhlolo	C				C
Uvuzana	C				C
Kongweni	C				C
Vungu	B				B
Mhlangeni	C				C
Zotsha	C	SA	Partial	50%	C
Boboyi	C				C
Mbango	E				D
Mzimkulu	C	SA	Partial	50%	B
Mtentweni	C				C
Mhlangamkulu	C				C
Damba	C	SA	Partial	50%	C
Koshwana	C	SA	Partial	50%	C
Intshambili	B	SA	Partial	50%	B
Mzumbe	D				D
Mhlabatshane	B	SA	Partial	50%	B
Mhlungwa	C				C
Mfazazana	C	SA	Partial	50%	C
Kwa-Makosi	B	SA	Partial	75%	B
Mnamfu	C				C
Mtwalume	D				D
Mvuzi	C				C
Fafa	D				D
Mdesingane	C				C
Sezela	D				D
Mkumbane	C				C
Mzinto	C				C
Mzimayi	C				C
Nkomba	C				C
Mpambanyoni	C				C
Mahlongwa	C				C
Mahlongwana	B				B
Mkomazi	C	SA	Partial	25%	B
Ngane	B				B
Umgababa	B	SA	Full	50%	B
Msimbazi	B	SA	Full	75%	B
Lovu	C	SA	Partial	50%	C

Estuary (West to East)	Current health category	Primary set for National and/or Cape	Recommended extent of protection	Recommended degree of undeveloped margin	Desktop estimate of Ecological Reserve Category
Little Manzimtoti	D				D
Manzimtoti	D				D
Mbokodweni	E				D
Sipingo	F				D
Durban Bay	E	SA	Partial	25%	B
Mgeni	D	SA	Partial	25%	A or BAS
Mhlanga	D	SA	Full	75%	B*
Mdloti	D				C*
Tongati	E				D
Mhlali	C	SA	Partial	50%	B
Bobs Stream	C				C
Seteni	C				C
Mvoti	D	SA	Full	75%	D
Mdlotane	B	SA	Full	75%	A
Nonoti	B				B
Zinkwasi	C	SA	Partial	50%	B
Thukela	C				C*
Matigulu/Nyoni	B	SA	Partial	50%	A
Siyaya	F	SA	Full	50%	B*
Mlalazi	B	SA	Full	75%	A or BAS
Mhlathuze/R.Bay	C	SA	Partial	50%	A or BAS
Nhlabane	D				C
St Lucia/Mfolozi	D	SA	Full	75%	A*
Mgobezeleni	B	SA	Full	75%	A or BAS
Kosi	B	SA	Full	75%	A or BAS