DESKTOP PROVISIONAL ECOCLASSIFICATION OF THE TEMPERATE ESTUARIES OF SOUTH AFRICA

Report to the
Water Research Commission

compiled by

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EXECUTIVE SUMMARY

Rationale and Aim of this Project

In South Africa the National Water Act 36 of 1998 (NWA) mandates the classification of water resources (including estuaries) through the Water Resources Classification process. This process sets the Management Class (describing the degree of use and desired condition of a water resource), the freshwater quality and quantity allocation (the "Reserve") and the Resource Quality Objectives for all water resources. A major challenge in this process is the EcoClassification of South Africa's diverse range of estuaries. Currently, such information is available for only 15% of the country's estuaries collected over a period of more than ten years as part of Ecological Water Requirement (EWR) studies. In the short-term, therefore, it is unrealistic to rely on the rollout of EWR studies to inform strategic water resource planning processes. Historical practices of using desktop river methods to determining estuary water requirements led to gross underestimations of flows. For example, unlike rivers, estuaries need significantly higher base flows and major flood events to maintain connectivity with the sea and to reset on-going marine sedimentation processes. Therefore, unless innovative methods are developed to realistically reflect the water requirements of estuaries in strategic water resource planning the biodiversity, an array of services provided by these ecosystems may be severely compromised.

In the light of the above, the aim of this project was to develop a desktop method for the Provisional EcoClassification (the term used for the Ecological classification process under the NWA) for estuaries that provided for a comparative, regional scale assessment. The Provisional EcoClassification – in the context of this study – refers to the Present Ecological Status (PES), the ecological importance and protection status, a Provisional Recommended Ecological Category (REC), as well as mitigation measures towards achieving the Provisional REC. The desktop method was then applied to the estuaries of the Cool- and Warm-Temperate biogeographical regions of South Africa (Orange to Mbashe).

***Note*: The Provisional EcoClassification of the Temperate Estuaries aims to provide planners with regional-scale knowledge that will inform strategic planning processes, at least in the short- to medium-term pending the outcome of more detailed scientific studies. It is not suitable for operational management processes and can therefore not be used for detailed fine-scale planning, such as for approvals of dam developments or waste water treatment work discharges. Those types of assessments still require detailed, site-specific studies (e.g. ecological water requirement and/or environmental impact assessment studies).**

The Desktop Method

For the desktop method, stochastic and rule-based models were developed for the health assessment of a number of abiotic components (hydrology, hydrodynamics and water quality), while the health assessment of the biotic components were reliant on available national-scale data sets and collated unpublished data, complemented by expert opinion. In order to ensure alignment, this desktop method applied the same indices and rules as the official EWR method for estuaries under the NWA. Both methods therefore applied the Estuarine Health Index that rates health in six categories, ranging from natural (A) to critically modified (F). It must be emphasised that the A to F scale represents a continuum, and that the boundaries between categories are conceptual points along the continuum. There may therefore be cases where there is uncertainty as to which category a particular estuary belongs, potentially having components with membership in two categories. To reflect this, straddling categories (+/- 3 from the category scoring range) were therefore introduced in this study, denoted by A/B, B/C, C/D, and so on.

The official EWR method requires that a multidisciplinary group of estuarine scientists assess the health of a particular estuary in a workshop setting, based on their collective understanding of the key pressures impacting on a system. Similarly, the desktop method uses available information and expert knowledge in a workshop setting to build a 'mental picture' of the probable natural (reference) states of estuaries and the changes that have led to the Present Ecological Status (PES).

The Provisional EcoClassification is guided by the PES which set the minimum Provisional REC whereas the degree to which the Provisional REC needed to be elevated above the PES is determined by the ecological importance and protection status (current or desired) of a particular estuary. If the importance and/or protection statuses are high, the Provisional REC should be set high depending on the level of current use, the reversibility of the pressure and the resilience of the system. Where the estuary importance is moderate or low, the aim is to maintain the PES. Where the Provisional REC is higher than the PES, key mitigation measures should be provided to attain the Provisional REC. If the Provisional REC and PES matches, the provision of mitigation measures is usually not required, except where the estuary is considered to be on a downward trajectory of change. Even for estuaries of moderate or low importance, Ecological Categories E and F are regarded as unacceptable and mitigation measures must be identified to restore some ecosystem functionality in these systems. Here the aim is not to return the estuary to its pristine state, but to ensure that essential ecosystem services are maintained or reinstated where possible. Key mitigation measures are subdivided into broad management sectors relating to water, land-use and development, and fisheries, to assist with the coordination of cross-sectorial management responses and ultimately achieve the overarching objectives set as part of the Provisional EcoClassification process. Important nursery estuaries must also be highlighted as these systems often require additional management interventions to achieve biodiversity objectives and fisheries management targets.

Provisional EcoClassification of the Temperate Estuaries

To validate the desktop method a Provisional EcoClassification of South Africa's temperate estuaries was conducted. A summary of the results is provided in the table below. Listed are the PES, importance and protection status, and Provisional REC for each estuary. Results derived from previous EWR studies are highlighted in blue text (these were not reassessed as part of this desktop assessment unless experts were concerned with change in estuary condition since the study). Estuary Importance is rated as 3 = "Average Importance" (Score 0-60), 4 = "Important" (score 61-80) or 5 = "High Importance" (Score > 80). Priority estuaries identified in the South African National Estuary Biodiversity Plan are allocated a rating of 5 for protection status. Finally, the table lists the recommended mitigation measures to achieve the Provisional REC. These are organised in the various management sectors, namely water, land-use and development, and fisheries. Estuaries in which gillnetting needs to be addressed are marked with an *.

Summary of the Provisional EcoClassification for estuaries in South Africa's Temperate region.

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES											
					Water			Land-use and development						Fisheries		
	Present Ecological Status	Importance	Protection Status	Provisional REC	Restore base flows	Restore Floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish
Orange (Gariep)	D	5	5	C	●	●	●	●		●				✓	●	
Buffels	B/C	3	1	B/C					●					✓		
Spoeg	A/B	3	5	A	●											
Groen	A/B	3	1	A	●											
Sout	D	3	1	D												
Olifants	C	5	5	B	●	●	●			●				✓	●*	
Jakkalsvlei	D	3	1	D	●		●		●							
Wadrift	D/E	3	1	D	●		●	●		●						
Verlorenvlei	D	4	5	C	●		●	●							●*	●
Groot Berg	C	5	5	C	●	●				●			●	✓	●*	
Rietvlei/Diep	E	4	5	D	●		●	●		●				✓	●	
Sout (Wes)	E/F	3	1	E			●									
Disa (Houtbaai)	E	3	1	D			●						●			
Wildevoëlvlei	D	5	1	C			●	●		●				✓		
Bokramspruit	C	3	1	C												
Schuster	A/B	3	1	A/B												
Krom	A	3	5	A												
Buffels Wes	A/B	3	1	A/B												
Elsies	D/E	3	1	D				●		●						
Silvermine	D/E	3	1	D	●		●	●	●				●			
Sand	D	4	5	D	●		●	●	●	●			●	✓	●	
Zeekoei	E	3	1	E	●		●	●	●				●			
Eerste	E	3	5	D	●		●	●	●	●						
Lourens	C/D	3	5	C	●		●									
Sir Lowry's Pass	D/E	3	1	D			●									
Steenbras	B	3	1	B	●											
Rooiels	A	3	1	A												
Buffels (Oos)	B	3	1	B												
Palmiet	C	4	5	B	●	●										
Bot/Kleinmond	C	5	5	B/C	●		●		●				●	✓	●*	
Onrus	E	3	1	D	●	●	●		●							
Klein	C	5	5	B	●		●		●				●	✓	●*	
Uilkraals	D	4	5	B	●		●	●	●					✓	●	

Summary of the Provisional EcoClassification for estuaries in South Africa's Temperate region continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES: Water			RECOMMENDED MITIGATION MEASURES: Land-use and development						RECOMMENDED MITIGATION MEASURES: Fisheries		
	Present Ecological Status	Importance	Protection Status	Provisional REC	Restore base flows	Restore Floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish
Ratel	A/B	3	5	A/B												
Heuningnes	C/D	5	5	B	●		●	●	●					✓	●	
Klipdrifsfontein	A	3	5	A												
Breë	B	5	5	B	●		●			●			●	✓	●	●
Duiwenhoks	B	5	1	B	●									✓	●	
Goukou	B/C	5	5	B	●		●			●			●	✓	●	●
Gourits	B/C	4	5	B	●	●	●			●				✓	●	
Blinde	B/C	3	1	B/C			●									
Tweekuilen	D/E	4	1	D	●		●									
Gericke	D/E	3	1	D			●									
Hartenbos	D	4	1	C	●	●	●			●						
Klein Brak	B/C	3	1	B/C	●		●	●					●	✓	●	
Groot Brak	D	4	1	C	●	●			●		●		●	✓	●	
Maalgate	B	3	1	B	●											
Gwaing	B	3	1	C			●									
Kaaimans	B	3	5	A/B	●		●									
Wilderness	B/C	5	5	A/B	●		●	●	●						●	●
Swartvlei	B	5	5	B	●				●					✓		
Goukamma	B	4	5	A	●								●		●	
Knysna	B	5	5	B	●								●	✓	●	
Noetsie	B	3	5	A			●									
Piesang	D	4	5	B	●		●		●		●			✓		
Keurbooms	B	5	5	A/B									●	✓		
Matjies	B	3	1	B												
Sout (Oos)	A	3	5	A												
Groot (Wes)	A/B	4	5	A	●										●	
Bloukrans	A	3	5	A												
Lottering	A	3	5	A												
Elandsbos	A	3	5	A												
Storms	A	3	5	A												
Elands	A	3	5	A												
Groot (Oos)	A/B	3	5	A			●									
Tsitsikamma	B	3	5	B			●									
Klipdrif	B	3	1	B			●									

Summary of the Provisional EcoClassification for estuaries in South Africa's Temperate region continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES											
					Water			Land-use and development						Fisheries		
	Present Ecological Status	Importance	Protection Status	Provisional REC	Restore base flows	Restore Floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish
Slang	C	3	1	C			●									
Kromme (Oos)	D	5	5	C	●	●	●						●	✓	●	
Seekoei	D	4	5	B	●		●	●	●					✓		
Kabeljous	C	4	1	C	●									✓		
Gamtoos	B	5	5	B	●		●						●	✓	●	
Van Stadens	B	3	5	A/B	●											
Maitland	B	3	5	B	●											
Baakens	E	3	1	E	●		●									
Papenkuils	E/F	3	1	E/F	●		●									
Swartkops	D	5	5	C	●	●	●			●			●	✓	●*	
Coega (Ngcura)	E	3	1	E						●						
Sundays	C	4	5	B	●								●	✓	●	
Boknes	C	3	1	C												
Bushmans	B	4	5	A	●									✓	●	
Kariega	C	5	5	B	●									✓	●	
Kasuka	A/B	4	1	A/B												
Kowie	B/C	5	1	B	●		●						●	✓	●	
Rufane	C	3	1	C												
Riet	A/B	4	1	A/B												
Kleinemond West	A/B	4	1	A/B												
Kleinemond East	B	4	1	B										✓		
Klein Palmiet	B	3	1	B	●		●									
Great Fish	C	5	5	B/C	●		●						●	✓	●	
Old Womans	C	3	1	C	●		●									
Mpekweni	B	5	1	A/B	●									✓	●	
Mtati	B	5	5	A/B	●									✓		
Mgwalana	B	5	5	A/B	●									✓		
Bira	B	4	5	A/B	●									✓		
Gqutywa	B	4	5	A/B	●											
Ngculura	B	3	1	B	●											
Mtana	A/B	3	1	A/B												
Keiskamma	B	5	5	A/B	●					●		●	●	✓	●	
Ngqinisa	A	3	5	A												
Kiwane	A	3	1	A												

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Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES											
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Tyolomnqa	A/B	4	1	A/B										✓	●	
Shelbertsstroom	B	3	1	B												
Lilyvale	B	3	1	B												
Ross' Creek	A/B	3	1	A/B												
Ncera	A/B	3	5	A/B	●		●									
Mlele	B	3	1	B												
Mcantsi	B	3	1	B												
Gxulu	B	3	1	B												
Goda	A/B	3	5	A/B	●		●									
Hlozi	A/B	3	1	A/B												
Hickman's	B	3	1	B												
Ngqenga	B	3	1	B			●									
Buffalo	D	3	1	D	●										●	
Blind	C/D	3	1	C/D			●									
Hlaze	C	3	1	C	●		●									
Nahoon	C	4	1	B	●	●							●	✓	●	
Qinira	B	4	1	B												
Gqunube	B	4	5	A/B			●			●					●	
Kwelera	A/B	4	5	A/B										✓	●	
Bulura	B	3	1	B											●	
Cunge	A/B	3	1	A/B												
Cintsa	B	3	1	B											●	
Cefane	A/B	4	1	A/B												
Kwenxura	A	3	5	A						●	●				●	
Nyara	A/B	3	1	A												
Mtwendwe (Imtwende)	A	3	1	A												
Haga-Haga	A/B	3	1	A/B												
Mtendwe	A	3	1	A												
Quko	A	3	5	A												
Morgan	B	3	1	B											●	
Cwili	A/B	3	1	A/B												
Great Kei	B/C	5	5	B	●	●				●				✓	●	
Gxara	A/B	3	1	A						●					●	
Ngogwane	A/B	3	1	A/B	●											

Summary of the Provisional EcoClassification for estuaries in South Africa's Temperate region continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES											
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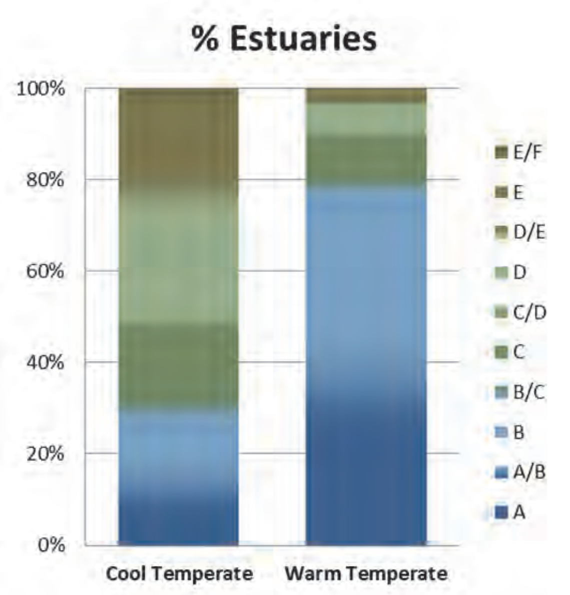
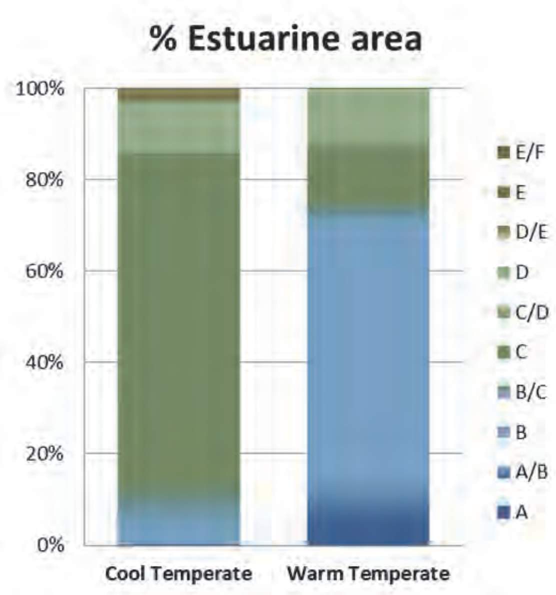
Qolora	A/B	4	1	A/B												
Ncizele	A	3	5	A												
Timba	A/B	3	1	A/B	●											
Kobonqaba	A/B	3	1	A/B	●											
Nxaxo/Ngqusi	A/B	4	5	A/B						●		●		✓	●	
Cebe	A	3	1	A												
Gqunqe	A	3	1	A												
Zalu	A/B	3	1	A/B												
Ngqwara	A/B	3	5	A	●					●						
Sihlontlweni	A	3	1	A												
Nebelele	A	3	1	A												
Qora	A	4	5	A						●					●	
Jujura	A/B	3	1	A	●											
Ngadla	A	3	5	A												
Shixini	A	3	5	A											●	
Beechamwood	A	3	1	A												
Unnamed	A	3	1	A												
Kwa-Goqo	A	3	1	A												
Ku-Nocekedwa	A	3	1	A												
Nqabara/Nqabarana	A	4	5	A						●		●		✓	●	
Ngoma/Kobule	A	3	1	A												
Mendu	A	3	5	A											●	
Mendwana	A	3	5	A											●	
Mbashe	A/B	5	5	A/B	●					●		●		✓	●	

Present Ecological Status

Reflecting on the health assessment of the estuaries in South Africa's Cool- and Warm Temperate regions, the PES show that overall 20% of the systems are considered to be in Category A, 43% in Category B, 27% in Categories C or D, and 10% in Categories E and F. Estuaries in near-natural condition (Categories A or B) are mainly located in the Warm-Temperate region, while systems in the Cool-Temperate region show relatively even distributed across Categories B to E.

The above analysis (based on the number of estuaries) is biased towards the state of the large number of small temporarily open/close estuaries occurring along this stretch of the South African coast. However, analysing results on "estuarine area" (rather than the number of estuaries), most of the estuarine habitat in the Temperate region (67%) is in a C or D Category with only about 2% remaining in a near pristine state (Category A), the latter mainly located in the Warm-Temperate region. The Cool-Temperate region was found to support estuarine habitat mainly in the C and D categories reflecting the large number of degraded and small temporarily open/close systems near coastal urban centres (e.g. Cape Town). In contrast, the Warm-Temperate region was characterised by estuarine habitat in Categories B and C, possibly due to the undeveloped nature of large parts of this region. However, there is a risk of further deterioration if key recommended mitigation measures are delayed.





The above suggests that while a significant number of the estuaries in the Temperate region (63%) are in excellent to good health (Categories A and B), these are generally the small systems in the rural areas with few pressures. The larger systems are predominantly in the fair (C and D) to poor (E and F) categories. This is attributed to higher pressures from their catchments and larger, direct development in their estuary functional zones, as well as fishing pressures. It should also be stressed that these larger systems generally are the more important fish nursery grounds and of higher economic and ecological importance. Although the smaller estuaries tended to be in a better state of health compared to the larger systems, these smaller systems are not as resilient to change, primarily due to their small size and higher residence time brought about by limited tidal exchange. The low resilience of smaller systems is the primary reason for the poor condition of the smaller urban systems. Therefore, only slight increases in the pressures on these small estuaries may result in rapid deterioration in health. In contrast, larger estuaries are more resilient due to strong tidal exchange associated with those systems.

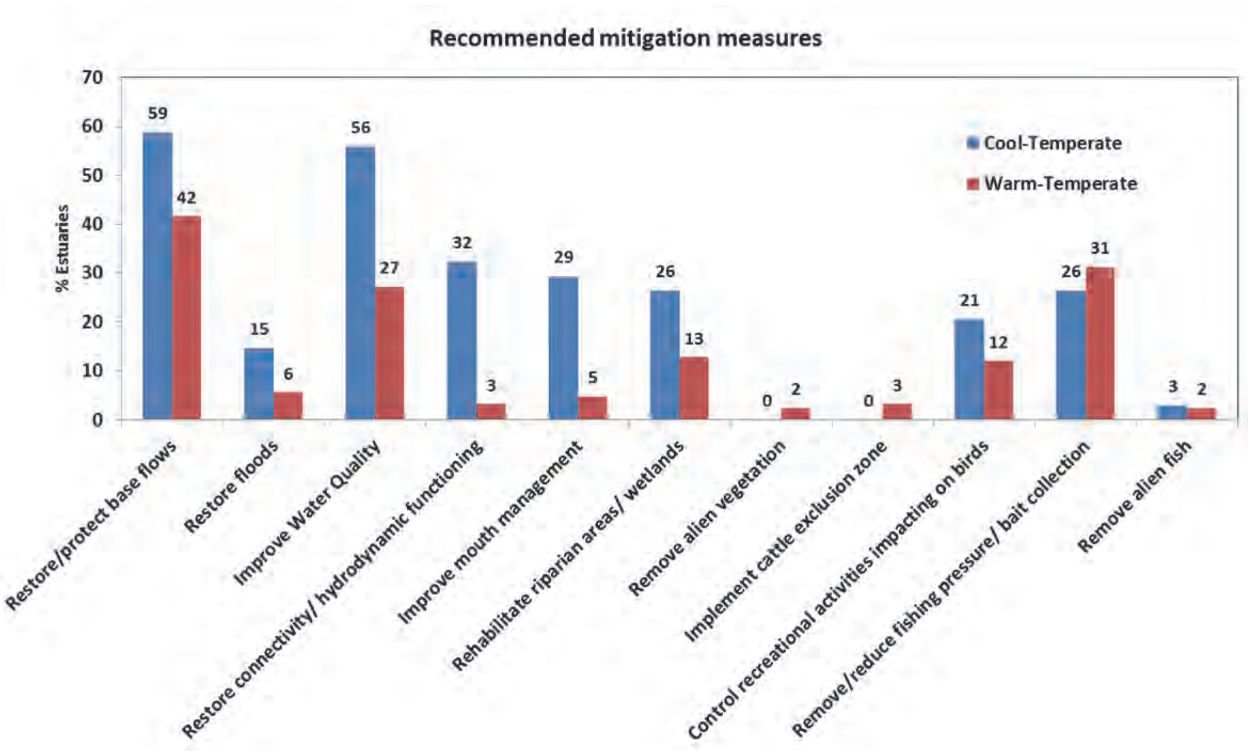
Of specific interest, is that the continuum in estuarine health (as depicted in the straddling categories, e.g. A/B) shows that a large number of systems in the Temperate region are on a trajectory of change, slipping, or have narrowly slipped, into a lower category, A/B (36), B/C (9), C/D (4), D/E (6), E/F (2). The largest grouping comprises the estuaries in the A/B or B/C categories by far. These systems are specifically in need of urgent management intervention to ensure further deterioration to meet the objectives of the provisional EcoClassification.

Estuary Importance

From an estuary importance perspective, 16% (26 systems) of the estuaries in the Temperate region are highly important (= 5), while 19% (31 systems) are rated as important (=4). The remaining 64% (102 systems) are rated as of average to low importance. Further, about 44% (70 systems) of Temperate estuaries are either in formally protected areas or form part of the core set of estuaries required to meet biodiversity targets for the region.

Provisional Recommended Ecological Category and Recommended Mitigation Measures

The Provisional RECs derived for the Temperate Estuaries, show that 36% (58 systems) of estuaries need to improve in health condition in order to achieve overarching biodiversity and related ecosystem services objectives. In the Cool-Temperate region nearly 59% (20 systems) of estuaries require improvement, reflecting both the importance of these aquatic systems along this arid coastline and the severe pressure most of these estuaries are already under. In contrast, only about 30% (38 systems) of estuaries in the Warm-Temperate region require intervention to achieve the Provisional REC. The type of mitigation measures that would be required to meet Provisional RECs are summarised below.



From the water sector perspective, about 28% of estuaries in the Temperate region require some restoration in base flow condition (especially during the low flow period), while 34% needs improvement in water quality. From the land-use and development sector outlook, 9% of systems require increased connectivity with the sea and/or improved hydrological functioning, while 10% requires an improvement in mouth management operations. Nearly 16% of estuaries require rehabilitation of the riparian habitat and/or restoration of floodplain/wetland habitat, while 2% require the removal of alien vegetation. Further, 3% of systems require the implementation of cattle exclusion zones to protect estuarine vegetation (especially mangroves). About 14% of systems require some control of recreational activities, such as boating or hiking, to reduce disturbance to birds. From the fisheries sector perspective, about 26% (42 systems) of estuaries require the reduction/removal of fishing effort (i.e. no-take estuaries, zonation for closed areas, or closed periods), while about 3% (4 systems) of estuaries required the removal of alien fish species to allow for the recovery of indigenous populations.

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SPECIALIST	AFFILIATION	AREA OF RESPONSIBILITY
L. Van Niekerk	CSIR, Stellenbosch	Project leader

The following specialists were part of the study team:

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LIST OF SYMBOLS AND ABBREVIATIONS

BAS	Best Attainable State
CD	Chief Directorate
CMA	Catchment Management Agency
CPUE	Catch-per-unit-effort
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DRP	Dissolved Reactive Phosphate
DRS	Dissolved Reactive Silicate
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EFR	Ecological Flow Requirement
EHI	Estuarine Health Index
EIS	Estuarine Importance Score
EFZ	Estuary Functional Zone
EMP	Estuarine Management Plan
ERC	Ecological Reserve Category
EWR	Ecological Water Requirement
H	High
IDP	Integrated Development Plan
L	Low
M	Medium
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MCM/a	Million Cubic Metres per annum
MLRA	Marine Living Resources Act (No. 18 of 1998)
MPA	Marine Protected Area
MSL	Mean Sea Level
NEMA	National Environmental Management Act (No. 107 of 1998)
NEMP	National Estuarine Management Protocol
NMMU	Nelson Mandela Metropolitan University
NBA	National Biodiversity Assessment
NWA	National Water Act (No. 36 of 1998)
NWRS	National Water Resources Strategies
PES	Present Ecological Status
ppt	Parts per thousand
RDM	Resource Directed Measures
REC	Recommended Ecological Category
REI	River Estuary Interface
RQO	Resource Quality Objectives
SA	South Africa
SDF	Standard Design Flood
VH	Very high
VL	Very low
WMA	Water Management Area

1. INTRODUCTION

1.1 Background

At the interface between land and sea, estuaries form an integral part of the coastal system and support numerous critical ecological processes and functions, which in turn provide important ecosystem services to society. For example, estuaries are nursery areas for many marine invertebrate and fish species of commercial and subsistence importance. While estuaries, from a spatial perspective, comprise a relatively small environmental domain, the coastal system in many ways cannot function without these critical nodes. For example, the collapse of the commercial prawn fishery on the Thukela Banks, brought about by extended closure of the St Lucia Estuary (the nursery grounds), is a case in point.

In South Africa, the National Water Act 36 of 1998 (NWA) mandates the classification of water resources (including estuaries) through the Water Resources Classification process (Dollar *et al*. 2006). This process sets the Management Class (describing the degree of use and desired condition of a water resource); the freshwater quality and quantity allocation (the “Reserve”); and the Resource Quality Objectives for the water resources. A major challenge is the development and implementation of the Water Resources Classification process which lies with South Africa’s diverse range of estuaries. The Classification process needs to take cognisance of the fact that South African estuaries represent a substantial proportion of the country's biological diversity. As a signatory to the International Biodiversity Convention the country is committed to protect its biodiversity. The National Environmental Management: Biodiversity Act 10 of 2004 gives legal status to this commitment. Similarly, to fulfil their mandate of promoting wise use and protection of marine living resources, the Department of Agriculture, Forestry and Fisheries (DAFF) under the Marine Living Resource Act 103 of 1998 (MLRA), have to actively participate in the management of resource utilization in estuaries to protect the nursery grounds of many marine resources. Concerns have been raised that estuaries are disadvantaged under the single catchment classification approach that is currently applied. Within a catchment, an estuary may act as a single “Integrated Unit of Analysis” that competes with the water demands of a number of upstream “Integrated Units of Analysis” in that catchment. Current classification approaches also do not recognise estuarine connectivity, i.e. the regional importance of estuaries along a stretch of coast.

Historical practices of using desktop river methods in determining water requirements for estuaries led to gross underestimations of freshwater flows. Studies conducted by the Ecological Water Requirement (EWR) demonstrated that these systems have a high base flow and flood requirement to maintain connectivity with the sea (open mouth state) and to reset on-going marine sedimentation processes. Some very sensitive estuaries (e.g. estuarine lakes and smaller temporarily open-closed estuaries) may require as much as 90% of their natural MAR to remain functional. As a result, estuaries often form the ‘bottleneck’ for freshwater allocation within the catchment. Recognising this 'bottle-neck' it is crucial that the Water Resource Classification process – and other planning processes – considers this. For example, if an estuary is classified in a higher class than upstream freshwater resource units there are major implications in limiting the potential for water use in the upper catchment. Currently, information on water requirements for estuaries is available for only 15% of South Africa’s estuaries which have been collected over a period of more than ten years as part of EWR studies. In the short-term, therefore, it is unrealistic to rely on the roll-out of EWR studies to inform strategic water resource planning processes. Therefore, unless innovative methods are being developed to realistically reflect the water requirements of estuaries in strategic water resource planning, the biodiversity, and an array of services provides by these ecosystems, may be severely compromised.

1.2 Purpose of this project

Considering the challenges posed to the Water Resources Classification process, the aim of this project was to develop a desktop method for the Provisional EcoClassification (the term used for the Ecological Classification process under the NWA) for estuaries. The method had to provide for a comparative, regional scale assessment of the Present Ecological Status (PES), the ecological importance and protection status, a Provisional Recommended Ecological Category (REC), as well as mitigation measures towards achieving the Provisional REC. This was achieved through the following objectives:

- Develop/refine a stochastic model to determine the degree of freshwater flow modification on a regional scale and apply to the catchments of the Cool- and Warm Temperate biogeographical regions (Appendix B).
- Develop stochastic and rule-based models to assess the hydrodynamic and water quality (abiotic) components for application in the Provisional EcoClassification of estuaries (Appendix C, D and E).
- Develop a desktop method for the Provisional EcoClassification of estuaries from a comparative, regional scale perspective, reconciling the abiotic assessment results (see above), the relative ecological importance of estuaries, as well as the objectives of other biodiversity and socio-economic strategies relevant to estuaries (Chapter 3).
- Apply the desktop method for Provisional EcoClassification to define the ecological health, PES, the ecological importance and protection status, Provisional REC, as well as mitigation measures towards achieving the Provisional REC for the estuaries of the Temperate region (Orange to Mbashe) (Chapters 4 to 7) (while the desktop methods developed here is applicable at the national scale, it is validated as part of this study using the estuaries of the Temperate region).

Note: Ultimately, the Provisional EcoClassification of the Temperate estuaries provided in this study is intended to provide planners with regional-scale knowledge to inform strategic planning processes, at least in the short- to medium-term pending the outcome of more detailed scientific studies. It is not suitable for operational management processes and can therefore not be used for detailed fine-scale planning, such as for approvals of dam developments or waste water treatment work discharges. Those types of assessments still require detailed, site-specific studies (e.g. ecological water requirement and/or environmental impact assessment studies).

1.3 Assumptions and limitations

The following assumptions and limitations should be taken into account:

- The accuracy and confidence of any EWR or EcoClassification study is strongly dependent on the quality of the hydrological information. It should be noted that the hydrology developed as part of this study was done on a regional scale based on readily available data sources. The overall confidence level in the simulated hydrology, therefore, is medium to low, with a particular concern regarding the accuracy of the base flows during the low flow period.
- The hydrology of catchments with a mean annual runoff (MAR) of less than 10 x 10^6 m^3 is inherently difficult to model accurately because of the small volumes involved and the very limited information available to validate the simulated data.
- While stochastic and rule-based models for hydrology and health assessment of the hydrodynamic and water quality (abiotic) components were developed as part of this study, the

health assessment of the biotic components were reliant on available national-scale data sets and collated unpublished data, complemented by expert opinion.

1.4 Report structure

This introductory chapter **(Chapter 1)** provides the background, purpose of the project and the assumptions and limitations. This is followed by a broad overview of the estuaries of the Cool- and Warm Temperate biogeographical regions of South Africa (**Chapter 2: Study Area**). **Chapter 3: Provisional EcoClassification Method for Estuaries** details the desktop method for Provisional EcoClassification in the context of South Africa's official EWR method for estuaries. Specifically it provides details on the application of the Estuary Health Index and the overall approach adopted in setting the PES and Provisional REC.

Moving to the validation of the desktop method on the Temperate estuaries, **Chapter 5: Abiotic characterisation of Temperate estuaries and responses to current pressures** shows the application of the stochastic and rule-based models (where developed as part of this study – see Appendices B, C and D) to assess the health of abiotic components (hydrology, hydrodynamics, physical habitat, water quality) in Temperate estuaries. Also highlighted are the responses of the abiotic components to pressures in the region. **Chapter 6: Biotic characterisation of Temperate estuaries and responses to current pressures** presents the health assessment of the biotic components (microalgae, macrophytes, invertebrates, fish and birds) in the Temperate estuaries, based on available information and expert knowledge, and also evaluates the responses to key driving parameters and pressures in the region. **Chapter 4: The importance of Temperate Estuaries** describes the importance of biodiversity and protection status (conservation importance) of the individual estuaries in the region. This information is used to set the Provisional REC. In addition, this chapter also highlights some of the important estuary nurseries in the country, which become relevant when setting the recommended mitigation measures to achieve the Provisional REC. **Chapter 7: Present Ecological Status** applies the desktop method to the estuaries of the Cool- and Warm-Temperate biogeographical regions to combine the health assessment, conducted in Chapters 5 and 6, to define the PES. **Chapter 8: Provisional Recommended Ecological Category and mitigation measures** uses the PES, as well as the information on the ecological importance and protection status, to define the Provisional REC. Also listed are the recommended mitigation measures towards achieving the Provisional REC for the estuaries in the region.

Finally, **Chapter 9: Conclusions and Recommendations** reflects on the findings of this study, provides a list of future research and monitoring requirements to improve desktop assessments of this nature, as well as additional future benefits of the output from this study.

In addition, this report contains five important appendices, namely:

Appendix A: Physical Characteristics of Temperate Estuaries that lists the key physical characteristics of the Temperate estuaries.

Appendix B: Hydrology Method that provides detail on the methods developed for evaluating change in the hydrology of the region.

Appendix C: Hydrodynamic Desktop Method that summarises the approach taken in evaluating change in the hydrodynamic component

Appendix D: Water Quality Desktop Method: Salinity that describes the approach taken in assessing change in the salinity regime of the Temperate systems.

Appendix E: Water Quality Desktop Method: Nutrient, suspended solids, toxic substances that provides details on the method developed for determining change in the water quality parameters other than salinity (nutrient, suspended solids, toxic substances).

2. STUDY AREA

Estuaries form the interface between land and sea and are strongly influenced by runoff, sediments, wind, wave action, air and water temperatures and constitute some of the most heavily utilised and productive zones on the planet. There are nearly 300 estuaries along the South African coastline that ranges from the Orange River mouth on the West Coast to the Kosi Bay estuarine system on the East Coast. Whitfield (2000) classified South African estuaries into five groups, namely the Permanently Open Estuaries (POEs), Temporarily Open/Closed Estuaries (TOCEs), Estuarine Bays, Estuarine Lakes and River Mouths. Overall TOCEs are the most dominant estuarine type in South Africa with nearly 70% of all estuaries falling within the group (Whitfield *et al*. 2008).

The South African coastline has further been classified into the Cool-Temperate, Warm-Temperate and Subtropical biogeographical regions. Each of these biogeographical regions are characterised by specific rainfall conditions and sea-surface temperatures. Notably the Cool-Temperate region (Orange to Ratel Estuary) is subjected to numerous upwelling events, a feature of the cold Benguela current that flows northwards along the western coastline of South Africa (Shannon 1985; Bolton and Anderson 1997). The Cool-Temperate region mainly receives low winter rainfall and consequently contains the lowest number of estuaries, although most of these are large, permanently open systems.

The Warm-Temperate region (Heuningnes to Mbashe) on the other hand is characterised by TOCEs, which become isolated from the sea by the formation of berms resulting from wave action, long shore sediment deposition, and reduced freshwater inflow. Consequently, these systems are greatly affected by seasonal rainfall events and freshwater abstraction. The Subtropical region is characterised by summer rainfall and has the highest number of estuaries along the South African coastline, which also mainly consists of TOCEs. South Africa's largest estuarine systems also occur within this region, namely the Lake St Lucia and Kosi Bay systems.

Due to variation in climate conditions within the three biogeographical regions, there are large differences in vegetation types (i.e. biomes) between these regions and consequently, human settlement and utilisation varies between these regions. For this reason, the assessment of pressures on, and the health of, these systems will greatly add to the overall management of estuaries and their associated ecosystem goods and services.

This study focuses on the estuaries of the Temperate region (Orange to Mbashe). The geographical boundaries of the study area are shown in Figure 2.1. The natural mean annual runoff (MAR) of the Temperate Estuaries vary between 10 833 x 10^6 m^3 for the Orange Estuary and 0.14 x10^6 m^3 for the Sir Lowry's Pass Estuary (Figure 2.2). The volume of runoff, by global standards, is very low with only 2% of the systems in the region having an inflow higher than 1 000 x10^6 m^3 per annum and only about 8% of the estuaries have an inflow between 100 and 1000 x10^6 m^3. In contrast, 21% of systems in the region have a runoff between 30 and 100 x10^6 m^3, while the majority of the systems (79%) have a runoff less than 30 x10^6 m^3. This dominance of small catchments with low river discharge to the coast is one of the main reasons for the high number of TOCEs along this coastline.

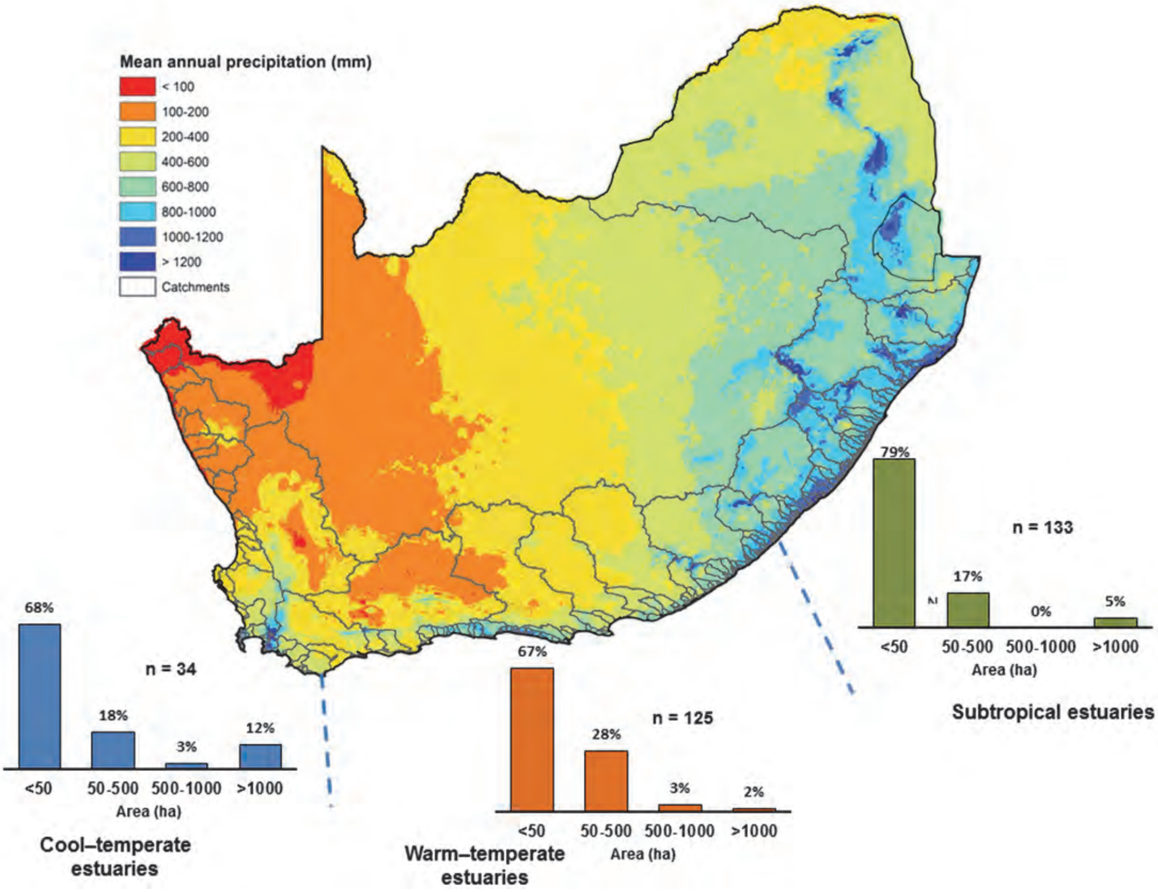

Figure 2.1 Catchment size, biogeographical region and relative size distribution of South Africa's estuaries

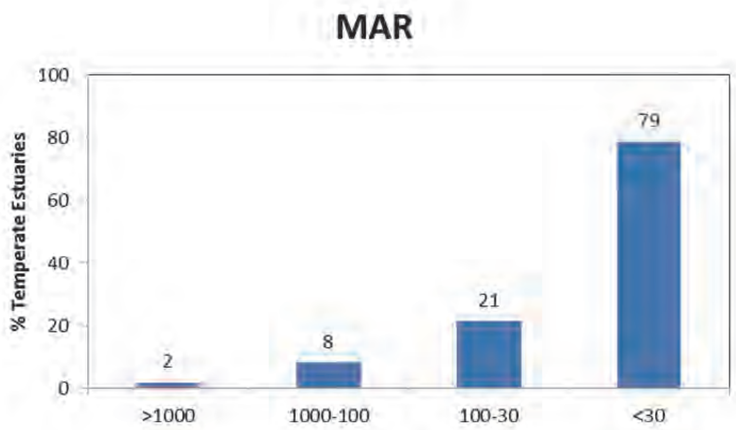

Figure 2.2 Natural Mean Annual Runoff (MAR) distribution entering the Temperate Estuaries

The Cool-Temperate region has fewer, but larger estuaries than the Warm-Temperate region with 12% of systems greater than 1 000 ha in estuarine habitat in contrast to the 2% in the Warm-Temperate region. In both biogeographical regions more than two-thirds of the estuaries are small (less than 50 ha of estuarine habitat). The Warm-Temperate region also has an abundance of medium-sized estuaries: 28% of systems are between 50 and 500 ha, while the Cool-Temperate region supports about 18% of systems between 50 and 500 ha (the larger the estuary, the larger the tidal flows, which in turn assist in maintaining an open connection with the sea).

Only 36% of the estuaries in the Temperate region are estimated to remain open for more than 75% of the time, i.e. have a high degree of connectivity with the sea (Figure 2.3). While about 13% remain open between 75% and 50% of the time. An additional 26% of estuaries remain open between 50% and 25% of the time. Nearly 25% of all systems along this coast are open to the sea for less than 25% of the time.

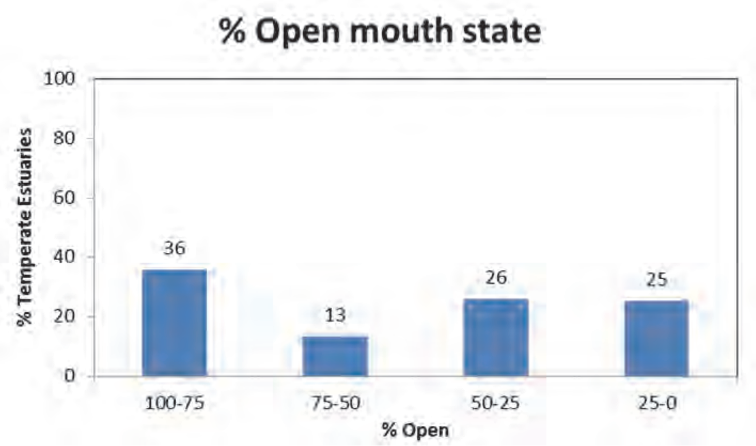

Figure 2.3 Degree of connectivity (% open mouth state) of estuaries in the Temperate region

About 60% of the estuaries in the Temperate region have a “perched” or “constricted” estuary mouth that constricts tidal flows and reduces connectivity with the sea (Figure 2.4). Perched estuaries therefore tend to be more river-dominated in character as the marine influence is limited. Shallow, perched systems tend to lose a substantial portion of their volume during a breaching, with as little as 20% to 30% remaining just after a breaching when the mouth is scoured wide open.

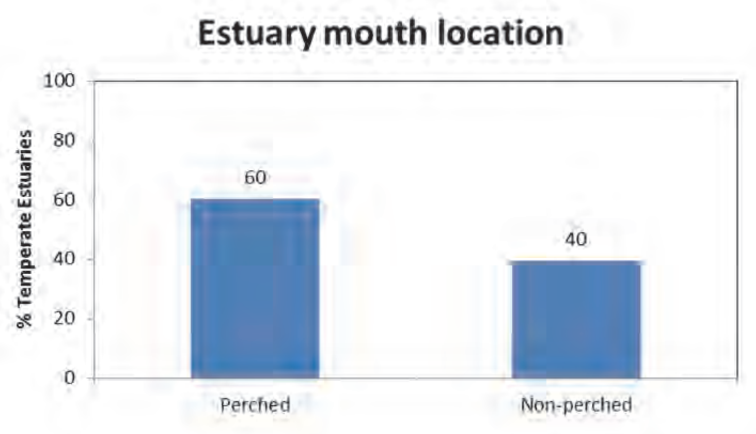

Figure 2.4 Estuary mouth location (perched or non-perched) of estuaries in the Temperate region

3. METHOD FOR PROVISIONAL ECOCLASSIFICATION

3.1 Existing EWR method for estuaries

For consistency, it was decided to align the Provisional EcoClassification method for estuaries – developed as part of this study – with the official EWR method for estuaries. The first EWR method for estuaries was developed soon after the promulgation of the NWA in 1998 and since then has been updated several times (DWAF, 1999; DWAF, 2004; DWAF 2008; Turpie et al. 2013). The estuary method was designed for application at various levels of effort, therefore also adaptable to a desktop level assessment. Initially all the methods for the various water resources (i.e. estuaries, rivers, groundwater and wetlands) followed a set of generic steps. However, over time the suite of methods has been modified incrementally to reflect the unique characteristics and contextual aspects within the various resource types. In essence, the EWR method for estuaries comprises the following main steps:

1. Initiate the study which entails defining the study area, the study team, and the level of study.

2. Define the resource units including the delineation of the geographical boundaries of the resource.

3. Determine the PES that is based on the similarity between an estimated reference condition and the present state and that takes into account specific abiotic and biotic components. The Reference Condition refers to the natural, unimpacted characteristics of an estuary with no or minimal anthropogenic stress. It should reflect undisturbed conditions for hydrological, geomorphological and chemical processes and biological components. This usually requires expert judgement in conjunction with local knowledge and historical data. The Estuarine Health Index is used to set the PES presented which is presented in terms of the classification system of categories A to F. This six category system is applied to all other EWR and EcoClassification methods under the NWA.

4. Determine the ecological importance and protection status of an estuary derived from existing national and/or regional biodiversity and conservation planning projects.

5. Determine the REC defined in terms of the PES and the ecological importance and protection status of an estuary. The REC is set as one of the first four ecological categories (A to D) of the generic classification system and sets the target for protection and management of the resource. This could be the same as the PES, or could be higher if an improvement in resource condition is desired. Criteria for assigning a REC to an estuary include:
    - the sensitivity of the resource to impacts of water use (whether due to ecological sensitivity, or the sensitivity of water users)
    - the importance of the resource, in ecological, social, cultural or economic terms
    - the value of the resource, in ecological, social, cultural or economic terms
    - what can be achieved towards improvement of resource quality, given that not all past impacts may be reversible

6. Quantify the Ecological Water Requirements of the REC, as well as for alternative ecological categories where required.

7. Set the Resource Quality Objectives, including the water quantity and quality parameters for the REC.

In the context of the above, the Provisional EcoClassification process for estuaries – as proposed here – specifically comprises Steps 3, 4 and 5, namely: 1) the definition of the PES (based on change from a reference condition); 2) the description of the ecological importance and protection status, and 3) setting of a Provisional REC. Further recommended mitigation measures to achieve the Provisional REC are included. For the purposes of this study the estuarine functional zone, as defined in the NBA 2011 (Van Niekerk and Turpie, 2012) is used as the geographical boundaries for the estuary resource unit.

3.2 Importance of confidence levels

Beechie *et al*. (2003) emphasise the different types of uncertainty in predictions of ecological processes, including predictive uncertainty, parameter uncertainty, model uncertainty, measurement uncertainty, and natural stochastic variation (inherent random variability). These uncertainties are also relevant to EcoClassification, where qualitative data, expert knowledge and judgement often have to be used due to a lack of empirical information on estuary freshwater requirements in particular. In addition the time frame to obtain such information is usually very limited and do not consider the natural variability and long-term resetting cycles (e.g. floods and droughts) that shape abiotic and biotic processes in estuaries.

The level of available historical data, in combination with the level of effort expended during an assessment, determines the level of confidence of the study. As this study is being conducted at a desktop level on a regional scale, confidence levels are generally varying between low to medium even for estuaries where some historical field data were available. Criteria for the confidence limits attached to statements in this study are shown in Table 3.1.

Table 3.1 Criteria for confidence limits used in this study

Confidence level	Situation	Expressed as percentage
Low	If no data were available for the estuary or similar estuaries	< 40 certainty
Medium	If limited data were available for the estuary or other similar estuaries	40-80% certainty
High	If sufficient data were available for the estuary	> 80% certainty

3.3 Present ecological status

While it was decided to align the Provisional EcoClassification method with South Africa's official EWR method for estuaries, simplification was required for a desktop application at a regional scale. The primary tool used in the EWR method to assess ecological health, and subsequently the PES, is the Estuarine Health Index. The Index considers both abiotic (hydrology, hydrodynamics and mouth condition, water chemistry, sediment processes) and biotic (microalgae, macrophytes, invertebrates, fish and birds) components (Figure 3.1). Both abiotic and biotic components are included because the exact relationships between them are often not well understood and because the biotic responses to specific abiotic parameters generally occur after a lag period (Whitfield *et al*., 2008). For each of the abiotic and biotic components, the health condition is estimated as a percentage (0-100%) of the natural state. Scores are weighted (25% for each abiotic and 20% for each biotic component) and aggregated (50:50) to provide an overall score that reflects the present health of the system as a percentage of that under natural conditions. For this desktop, regional scale assessment methods by which the health status of the individual abiotic and biotic components are being determined was simplified from that used in the official method.

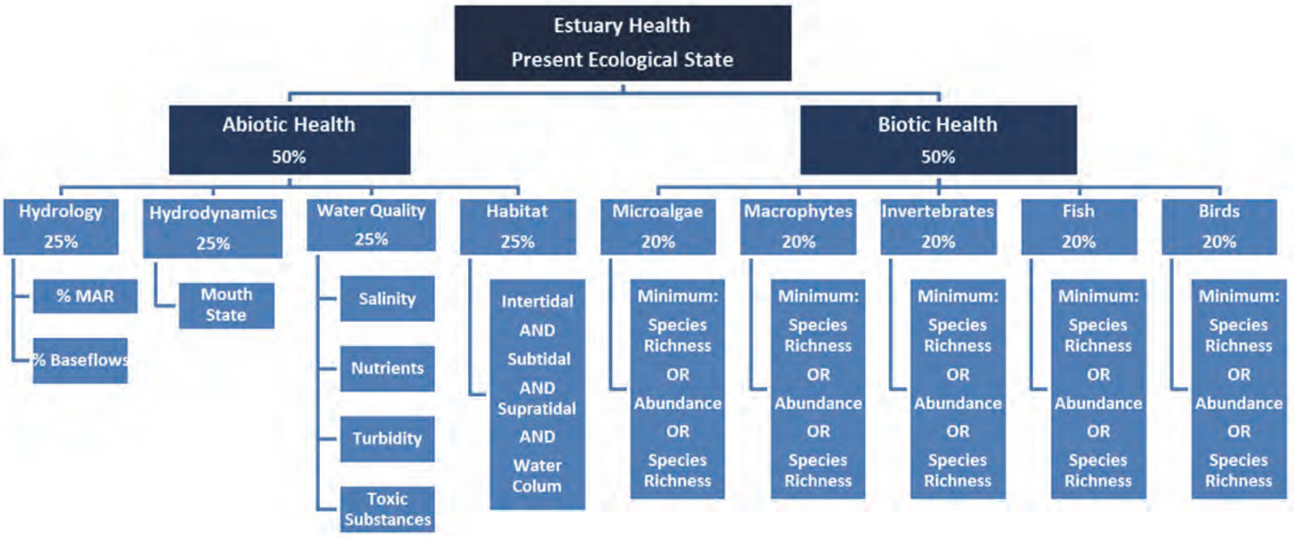

Figure 3.1 **The Estuary Health Index showing the simplifications adopted for the various abiotic and biotic components for this desktop assessment study (in light blue)**

The integrated Estuary Health Index score, in turn, corresponds to an Ecological Category that describes the health using six categories, ranging from natural (A) to critically modified (F) (Table 3.2). It must be emphasised that the A to F scale represents a continuum, and that the boundaries between categories are conceptual points along the continuum. There may therefore be cases where there is uncertainty as to which category a particular estuary belongs, potentially having components that have membership in two categories. To reflect this, straddling categories (±3 from the category scoring range) were therefore introduced in this study, denoted by A/B, B/C, C/D, and so on. The B/C boundary category, for example, is indicated as the light blue to dark green area in Table 3.2. Smaller, more sensitive estuaries tend to degrade rapidly to the lower health Categories (C to F), while the larger, permanently open estuaries demonstrate a degree of resilience and can generally maintain a boundary category as long as pressures are not increased.

In assessing and categorising health, the term “trajectory of change” is used to define a directional change in the condition of abiotic and/or biotic components at the time of the assessment. This is often as a result of a component not yet adapting to the current configuration of influencing factors, e.g. it may still be in a state of flux as a result of a recent water resources development. A trajectory of change can be absent (close to natural or in stable modified state), negative (moving away from reference conditions) or positive (moving back towards natural). Ideally both the direction of change and rate of change need to be highlighted, e.g. short- to medium-term (1-5 years) and long-term (20 years) (Kleynhans and Louw, 2007).

Table 3.2 Estuary health scoring system indicating the relationship between the six Ecological Categories and the loss of ecosystem condition and functionality (adapted from Van Niekerk *et al*. 2013)

Condition (% of pristine)	≥91%	90-75	75 - 61	60 - 41	40-21	≤20
Ecological Category	A Natural	B Largely natural / few changes	C Moderately modified	D Largely modified	E Highly degraded	F Extremely degraded
State	Excellent	Good	Fair		Poor	
Functionality	Retain Process & Pattern		Loss of Process or Pattern		No / Little Process & Pattern	

Continuum	A	A/B	B	B/C	C	C/D	D	D/E	E	E/F	F

Category	Description
A	**Unmodified, or approximates natural condition.** The natural abiotic processes should not be modified. The characteristics of the resource should be determined by unmodifed natural disturbance regimes. There should be no human induced risks to the abiotic and biotic processes and function.
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.
C	**Moderately modified.** A loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
D	**Largely modified.** A large loss of natural habitat, biota and basic ecosystem functions has occurred.
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 system has been modified completely with an almost complete loss of natural abiotic processes and associated biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

Note that ranges for B and C Categories differ with 5% from river and wetland methods to better reflect estuary ecosystem processes and resilience

The EWR method for estuaries requires that a multidisciplinary group of estuarine scientists assess the health of a particular estuary in a workshop setting, based on their collective understanding of the pressures affecting a system and the possible responses of the various components to such pressures. Similarly this desktop method uses available information and expert knowledge in a workshop setting to build a 'mental picture' of the probable natural (reference) states of estuaries and the changes that have occurred under the PES. The following sections discuss the simplified methods for abiotic and biotic components that were developed for this regional scale, desktop EcoClassification process.

3.3.1 Abiotic health assessment methods

As indicated previously, the Estuary Health Index distinguishes between abiotic drivers and biotic responses. The individual drivers and biological responses are referred to as components, while the individual attributes within each component that are assessed (to determine deviation from the expected natural reference condition) are referred to as parameters. The index identifies four abiotic components that should be included in the ecological health assessment for estuaries (Figure 3.1), namely hydrology, hydrodynamics, water quality and physical habitat. The individual assessment methods adopted for each of these components are summarised below.

Hydrology: The hydrology was evaluated on the percentage similarity in the base flow component and MAR using simulated hydrological monthly flow data generated as part of this study (refer to Appendix B for detail). Modelled results were augmented with expert opinion on changes in percentage similarity of median flows, shift in the highest flow month, change in base flow variance, low flow duration, and changes in the high flow onset month. As the data set was generated on a regional scale (i.e. for the Temperate region) the overall confidence is medium/low for changes in MAR but low for changes in base flow. It should be noted that the smaller the catchment the lower the confidence, the reason being that few gauging stations were available near the coast for calibration.

Hydrodynamics: The hydrodynamic method used a simplified water balance model in which the estuary volume between the open mouth state (0.0 m mean sea level) and closed mouth state (2.5-3.5 m mean sea level) were compared with simulated monthly volumes to determine the degree of openness (refer to Appendix C for detail). Modelled results were augmented with expert opinion considering aspects such as mouth protection from coastal conditions and sediment availability. The overall confidence in this component is low.

Water Quality: Shifts in the salinity regime of individual estuaries were evaluated based on statistical models derived from 30 EWR studies for permanently open and temporarily open/closed estuaries (refer to Appendix D for detail). Changes in the other water quality parameters (nutrients, turbidity and toxic substances) were derived from 1) GIS modelling of the catchment (proxy for river condition) and peri-catchment (used as proxy for storm water input) condition; and 2) direct discharges (e.g. waste water treatment works) into the estuaries (refer to Appendix D for detail). A volumetric approach was developed based on the quality of the inflowing water and the fraction it represented of the overall estuary volume. Modifiers were applied to take cognisance of retention as reflected in mouth state. The final water quality component score is weighted: (% Similarity in salinity * 0.4) + (% Similarity in other water quality parameters * 0.6). The overall confidence in this component is low.

Physical Habitat: Change in the physical habitat was evaluated based on changes in the land-use of the surrounding catchment, loss of resetting floods (derived from hydrology component), and direct development and activities in the estuarine functional zone (derived from a visual inspection in Google Earth and personal observations). The overall confidence in this component is medium to low.

3.3.2 Biotic health assessment methods

The Estuary Health Index identifies five biotic components that should be included in the ecological health assessment for estuaries (Figure 3.1), namely microalgae, macrophytes, invertebrates, fish and birds. The individual assessment methods adopted for each of these components are summarised below. For this desktop method, the biotic components were based on an integrative assessment of the degree to which the present species richness, abundance and/or community composition are similar to an estimated reference condition. However, following a precautionary approach, the minimum in similarity of these three parameters should be used if they differed significantly. In most cases the final rating reflects change in the abundance of the various biotic components.

Microalgae: The microalgae health ratings were derived from the change in the following key influencing parameters/components namely: flows, mouth state (as an indicator of change in retention), water quality, and macrophyte composition/abundance (indicative of change in habitat availability for epiphytes). A weighting was applied ((Hydrology * 0.25) + (Mouth State * 0.25) + (Other water quality *

0.40) + (Macrophytes * 0.1)) to produce the overall score. The overall confidence in this component is low.

Macrophytes: The health state of this component was derived from collated unpublished field data, historical observations, a visual inspection of satellite imagery (Google Earth/historical aerial photographs) and expert opinion. In addition, predicted changes in water levels (using mouth state as proxy), water quality and physical habitat were also considered. As some data sets exist on most of the estuaries this component is of a low to medium confidence.

Invertebrates: Similar to Macrophytes the health state of this component is based on collated unpublished field data, historical observations, a visual inspection of satellite imagery (Google Earth) and expert opinion. In addition, predicted changes in flow variability, mouth state, water quality, physical habitat and food availability were key considerations. Very limited data exists on the estuarine invertebrates of the Temperate region. Therefore this component is of very low confidence.

Fish: The fish health was derived from collated regional data sets, unpublished personal data, historical observations, a visual inspection of satellite imagery (Google Earth) and expert opinion. In addition, the predicted changes in cueing factors (e.g. changes in flood regimes), nursery availability (e.g. mouth state), water quality (e.g. salinity regime), habitat structure and food availability were also considered. Fishing pressure – as reflected in catch effort – was estimated separately and used as an aggravating factor. As fish are relatively well studied and regional data sets exist for this component, the overall confidence in this component is higher than most of the other elements of the index.

Birds: The health assessment for birds was estimated from collated regional data sets, unpublished personal data, historical observations, a visual inspection of satellite imagery (Google Earth), and expert opinion. In addition the predicted changes in habitat structure (physical and macrophytes), water levels and food availability were considered. Some historical regional data sets do exist for birds, but as birds are highly mobile (high degree of variability in their numbers) and most of the data sets stem from the 1980s, the overall confidence in this component is relatively low.

3.4 Ecological importance and protection status

In assessing the ecological importance and protection status of estuaries it is most appropriate to consult published national or regional scale assessments rather than deriving these from individual studies. As per the EWR methods the assessment of the ecological importance is based on a number of parameters, namely estuary size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary, taking them into account. National and regional scale assessments of this nature have been conducted by Turpie and Clark (2007) and Turpie *et al*. (2002). Only the functional importance of estuaries is derived individually (usually at the specialist workshops). This aspect is not evaluated in detail in the desktop method.

The National Estuary Biodiversity Plan (Turpie *et al*. 2012) developed a biodiversity plan for the estuaries of South Africa. This plan highlights a core set of priority estuaries for protection in order to achieve national biodiversity targets. The plan assigned partial or full Estuarine Protected Area status to individual systems. This biodiversity plan follows a systematic approach that takes pattern, process and biodiversity persistence into account. While the plan has not explicitly taken social and economic costs and benefits into consideration, it used ecosystem health as a surrogate for the former to some extent. This is because estuaries where the opportunity costs of protection are likely to be high are also likely to be heavily utilised systems that are in a lower state of health.

Lamberth and Turpie (2003) estimate that about 50% of the 160 species of fish that occur in South African estuaries are utilised in fisheries (subsistence, recreational and commercial). At least 60% of these species are considered entirely or partially dependent on estuaries, and are thus likely to be affected by changes in runoff. Important nursery estuaries should therefore also be highlighted as these estuaries often require additional management interventions to assist with achieving biodiversity objectives and fisheries management targets.

3.5 Provisional recommended ecological category and mitigation measures

The EWR method for estuaries derives the REC, from the PES and the ecological importance and protection status of estuaries. A similar approach is adopted for this desktop EcoClassification method. The PES of an estuary defines the minimum Ecological Category for the selection of the Provisional REC, except in the case of estuaries in Categories E and F (Table 3.3). Estuaries in these highly or extremely degraded states should, as a minimum, be improved to reflect an Ecological Category D.

Table 3.3 Relationship between the Present Ecological Status and minimum Ecological Category for consideration as Provisional Recommended Ecological Category

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

The degree to which the Provisional REC needs to be elevated above the PES depends on the level of importance and level of protection/desired protection of a particular estuary (Table 3.4). If the estuary protection status (current or desired) and/or importance are high the aim should be to improve the ecological condition of the system. However, the pressures related to a particular PES should also be considered to determine if improvement is realistic and attainable. This relates to whether the anthropogenic pressures in the catchment and surrounding environs can be addressed and mitigated. If the estuary importance is moderate or low, the aim should be to maintain the ecological status of the system in its PES. Following the rules of the EWR method for estuaries, a Provisional REC below Category D is considered ecologically unacceptable, unless exceptional conditions prevent appropriate mitigation measures from being implemented.

Table 3.4 Criteria recommended for the assignment of the Provisional Recommended Ecological Category, based on the ecological importance and protection status of an estuary

Protection status and importance	Provisional REC	Policy basis
Protected Area Desired Protected Area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health.
Highly important	PES + 1 B or higher	Highly important estuaries should be in an A or B category. If not, improved condition where possible to enhance benefits derived from the estuary.
Important	PES + 1 C or higher	Important estuaries should be in an A, B or C category. If not, improved condition where possible to enhance benefits derived from the estuary.
All other estuaries	PES D or higher	PES to be maintained. No estuaries should be in an E or F category as very little benefits are derived from such a poorly functional estuary, i.e. no/little contribution to biodiversity targets and provision of ecosystem services such as fisheries production.

* BAS = Best Attainable State

The final step in the desktop Provisional EcoClassification method comprises the recommendation of mitigation measures in order to meet the Provisional REC. Where the Provisional REC is higher than the PES, key mitigation measures should be provided to attain the Provisional REC. If the Provisional REC and PES matches, the provision of mitigation measures usually is not required, except where the estuary is considered to be on a downward trajectory of change. Even for estuaries of low importance, Ecological Categories E and F are regarded as unacceptable and mitigation measures must be identified to restore some ecosystem functionality in these systems. Here the aim is not to return the estuary to its pristine state, but to ensure that essential ecosystem services are maintained or reinstated where possible. Key management implications typically associated with various REC categories are listed in Table 3.5 (adapted from the South Africa's EcoClassification applied to freshwater systems – Kleynhans, 1996).

Table 3.5 Key management implications associated with Provisional Recommended Ecological Categories (A to D) (adapted from Kleynhans, 1996)

Provisional REC	Key Management Implication
A	**Unmodified, or approximates natural condition.** *The supply capacity of the resource will not be used.*
B	**Largely natural with few modifications**. *Only a small risk of modifying the natural abiotic processes and exceeding the resource base allowed. The resilience and adaptability of biota must not be compromised.*
C	**Moderately modified**. *A moderate risk of modifying the abiotic processes and exceeding the resource base may occur. Risks to the well-being and survival of intolerant biota (depending on the nature of the disturbance) may increase with some reduction of resilience and adaptability.*
D	**Largely modified**. *Large risk of modifying the abiotic processes and exceeding the resource base may exist. Significant risk to the well-being and survival of intolerant biota depending on the nature of the disturbance may be allowed.*

To provide structure to the recommended mitigation measures as part of the EcoClassification process, these are subdivided into three broad management sectors, namely:

- Water;
- Land-use and development; and
- Fisheries.

This subdivision assists in logically organising and coordinating the cross-sectorial management responses. As part of the identification of mitigation measures, it is crucial to identify important nursery estuaries as these systems often require additional management interventions to achieve biodiversity objectives and fisheries management targets.

4. ABIOTIC CHARACTERISATION AND RESPONSES TO CURRENT PRESSURES

4.1 Hydrology

The hydrological condition of an estuary (Table 4.1) is calculated from the extent to which current inflow patterns resemble those of the reference condition, estimated on the basis of two parameters, (a) general inflow patterns, with a focus on the changes in low flows, and (b) the frequency and magnitude of flood events (refer to Appendix B for details). The relative weighting of these two parameters (60:40) is set according to their assumed importance as drivers in a specific estuary. While this weighting may be altered for a particular system it was felt that for this desktop study the ratio will be kept constant (60:40) throughout unless very specific issues were highlighted that required otherwise. In addition the study provided an indication (descriptive or statistical) of the monthly flows in terms of (Appendix B):

- Magnitude of flow events (% MAR similarity, % Base flow similarity, % Median flow similarity);
- Frequency of flow events (Flood flow variance – not a good indicator if based on monthly flows);
- Duration of flow events (Low flow duration);
- Timing of flow events/seasonality (High flow onset month);
- Rate of change (Change in base flow variance).

Table 4.1 Hydrology condition of South Africa's Temperate estuaries, including the key shifts in hydrological parameters contributing to change

Estuary	Hydrology Condition	MAR (million m^3/a)		% Similarity			Significant change in flow parameter			
		Reference	Present	% MAR similarity	% Base flow similarity	% Median flow similarity	High flow months	Change in base flow variance	Low Flow Duration	High Flow Onset Month
Orange (Gariep)*	D	10 833.0	4 142.9	38			●	●	●	●
Buffels	A/B	9.3	6.7	71	100	100				
Spoeg	A/B	1.1	1.0	97	100	100				
Groen	A	0.5	0.4	98	100	100				
Sout	C	0.8	0.8	95	100	100				●
Olifants	C	1 070.1	715.0	67			●	●		
Jakkalsvlei	E	3.5	2.5	71	0	0		●		
Wadrift	E	13.3	9.8	74	0	0		●		●
Verlorenvlei	E	53.2	40.3	76	0	0		●	●	●
Groot Berg	B/C	916.0	520.4	57			●	●		
Rietvlei/Diep	E	63.3	51.2	81	0	5		●	●	
Sout (Wes)	D/E	31.1	27.5	89	0	37		●	●	
Houtbaai	D/E	15.3	14.5	95	50	73		●		
Wildevoëlvlei	E	2.1	1.8	85	0	50		●		
Bokramspruit	D/E	2.0	1.8	88	0	50		●		
Schuster	C	2.6	2.5	97	40	100		●		
Krom	A/B	7.0	6.8	97	83	86				
Buffels Wes	A	0.5	0.4	80		100				
Elsies	A	0.6	0.5	90		100			●	

Table 4.1 continues/...

Estuary	Hydrology Condition	MAR (million m^3/a)		% Similarity			Significant change in flow parameter			
		Reference	Present	% MAR similarity	% Base flow similarity	% Median flow similarity	High flow months	Change in base flow variance	Low Flow Duration	High Flow Onset Month
Silvermine	D	3.8	3.6	95	20	100		●	●	
Sand	C	21.7	28.0	129	171	183				
Zeekoei	D/E	22.4	26.0	116	147	144				
Eerste	E	6.6	6.6	100	101	107				
Lourens	D	66.3	59.2	89	22	79		●		
Sir Lowry's Pass	C	13.5	21.9	163	488	196		●	●	●
Steenbras	E	33.7	7.8	23	0	0		●	●	●
Rooiels	A	8.6	8.6	100	103	100				
Buffels (Oos)	C	9.7	8.2	84	50	62		●		
Palmiet	C	259.0	198.7	77	99	57	●			●
Bot/Kleinmond	C	97.7	87.4	89	76	80				●
Onrus	F	14.1	10.4	73	71	69				●
Klein	C	55.8	50.5	91	54	76		●		
Uilkraals	E	40.8	29.7	73	0	37		●	●	
Ratel	A/B	4.7	4.4	93	50	67		●	●	
Heuningnes	C	41.6	36.9	89	50	79		●		
Klipdrifsfontein	A	0.2	0.2	97		100				
Breë	C	1 785.0	1 034.0	58			●	●		
Duiwenhoks	D	94.2	72.3	77	36	70			●	
Goukou	D	102.8	77.0	75	60	67				
Gourits	C/D	628.8	446.0	71	27	47	●	●		●
Blinde	C/D	1.3	0.9	70	0	0	●		●	
Tweekuilen	D	35.6	34.4	97	94	97				
Gericke	D	0.3	0.2	89		100				
Hartenbos	C	4.6	2.8	61	63	50	●			
Klein Brak	D	53.4	40.4	76	34	45			●	
Groot Brak	C	41.9	16.3	39	8	7		●	●	
Maalgate	D	38.0	29.9	79	27	48	●	●	●	●
Gwaing	A/B	38.2	35.1	92	81	93	●		●	
Kaaimans	D	35.7	28.8	81	31	67	●	●	●	●
Wilderness	B/C	29.7	25.2	85	26	65		●	●	
Swartvlei	B	83.4	56.7	68	46	58				
Goukamma	A/B	47.8	36.2	76	35	59			●	●
Knysna	A	83.1	68.0	82	69	77				●
Noetsie	A/B	4.4	4.4	100	98	100				●
Piesang	D	5.2	3.4	66	36	55	●			●
Keurbooms	A	98.1	91.5	93	86	89				
Matjies	A	3.4	2.5	75	0	57			●	●
Sout (Oos)	A	5.0	5.0	100	99	100				
Groot (Wes)	B	12.8	11.1	87	61	85				●
Bloukrans	A	40.1	39.3	98	96	98			●	
Lottering	A/B	18.5	16.8	91	85	89				
Elandsbos	A/B	27.2	24.7	91	85	89				
Storms	B	54.1	47.9	89	82	86	●		●	
Elands	A/B	52.2	46.9	90	84	88			●	
Groot (Oos)	A	47.0	44.1	94	90	93				
Tsitsikamma	C	38.9	36.5	94	87	92	●			
Klipdrif	A	19.0	18.6	98	97	97				

Table 4.1 continues/...

Estuary	Hydrology Condition	MAR (million m^3/a)		% Similarity			Significant change in flow parameter			
		Reference	Present	% MAR similarity	% Base flow similarity	% Median flow similarity	High flow months	Change in base flow variance	Low Flow Duration	High Flow Onset Month
Slang	A/B	4.7	4.6	98	93	100				
Krom Oos (Kromme)	E	123.0	37.0	30			●	●	●	●
Seekoei	C/D	17.0	15.9	93	54	78				
Kabeljous	C	11.5	9.1	79	0	25	●			●
Gamtoos	B/C	388.8	265.5	68	25	30				●
Van Stadens	C	17.2	15.6	91	51	81		●		
Maitland	C	12.9	11.7	91	48	75		●		
Baakens	C/D	4.1	3.6	88	35	33				
Papenkuils	C/D	2.9	2.9	99	33	50				
Swartkops	D/E	97.6	79.2	81	1	45		●		
Coega (Ngcura)	D	10.1	8.6	85		100			●	
Sundays	B/C	273.0	260.0	95				●		
Boknes	D/E	14.4	14.4	100		100				
Bushmans	A/B	42.9	40.4	94		50				
Kariega	E	21.7	15.6	72	0	0		●		
Kasuka	A/B	4.3	4.3	99		100				
Kowie	B	31.8	30.3	95	66	85				
Rufane	C/D	1.2	1.1	94		100				
Riet	A/B	2.4	2.3	93		100				
Kleinemond Wes	A	6.0	5.5	91		0				
Kleinemond Oos	A	6.0	2.4	41		0				
Klein Palmiet	A	0.8	0.8	94		100				
Great Fish	B	513.3	463.3	90	199	114				
Old Womans	C	1.1	0.9	85	60	100				
Mpekweni	B/C	2.4	2.1	85	70	50				
Mtati	C	6.0	5.1	85	55	75				
Mgwalana	C	9.7	8.2	84	58	71				
Bira	C	12.0	10.0	83	58	67				
Gqutywa	B	3.5	3.0	84	83	67				
Ngculura	C	0.7	0.6	86	50	100				
Mtana	B	1.1	0.9	84	80	100				
Keiskamma	B	138.9	108.3	78	34	47				
Ngqinisa	A	1.2	1.2	99	100	100				
Kiwane	A	5.3	6.1	115	136	138			●	●
Tyolomnqa	A	1.0	0.8	76	0	0	●	●		
Shelbertsstroom	A/B	0.6	0.6	99	80	100				
Lilyvale	B	1.1	1.0	91	73	100				
Ross' Creek	A	0.6	0.5	99	140	100				
Ncera	A/B	11.0	10.2	93	83	88				
Mlele	B	2.0	1.9	93	76	100				
Mcantsi	A/B	2.8	2.7	93	77	100				
Gxulu	A/B	15.6	14.5	93	82	87				
Goda	A/B	6.2	5.8	93	84	89				
Hlozi	A/B	1.8	1.6	93	83	67			●	
Hickman's	A/B	1.4	1.3	93	90	100				
Ngqenga	A/B	0.4	0.4	93	80	100				
Buffalo	F	96.0	18.7	20	1	0			●	●
Blind	D	0.7	1.1	172	120	100				●

Table 4.1 continues/...

Estuary	Hydrology Condition	MAR (million m^3/a)		% Similarity			Significant change in flow parameter			
		Reference	Present	% MAR similarity	% Base flow similarity	% Median flow similarity	High flow months	Change in base flow variance	Low Flow Duration	High Flow Onset Month
Hlaze	D/E	0.3	0.8	253		100		●	●	●
Nahoon	B/C	39.9	24.8	62	0	0		●		●
Qinira	A	8.4	8.3	98	93	83				
Gqunube	A/B	34.1	32.5	95	88	93				
Kwelera	A/B	34.8	32.8	94	88	92				
Bulura	A	3.7	3.5	94	100	67				
Cunge	A	0.3	0.3	97		100		●		
Cintsa	A/B	4.0	3.8	94	80	100				
Cefane	A/B	3.4	3.2	94	90	100				
Kwenxura	A	16.9	16.6	98	95	92				●
Nyara	A	4.3	4.3	98	85	100				●
Haga-Haga	A	2.2	2.1	98	85	50				●
Mtendwe	A	1.4	1.4	98	110	0				●
Quko	A	17.2	16.9	98	97	92				●
Morgan	A	2.7	2.7	98	110	100				●
Cwili	A	1.2	1.2	98	90	100				●
Great Kei	D/E	954.9	649.3	68	19	36		●		
Gxara	A	3.4	3.4	98	90	100				
Ngogwane	B	0.8	0.8	98	70	100				
Qolora	A	8.9	8.7	98	95	100				
Ncizele	A	1.0	1.0	98	90	100				
Timba	B	0.4	0.4	98	60	100				
Kobonqaba	A	36.2	35.5	98	96	98				
Nxaxo/Ngqusi	A	23.3	22.8	98	96	95				
Cebe	A	5.7	5.6	98	96	100				
Gqunqe	A	7.0	6.8	98	96	86				
Zalu	A	1.7	1.7	98	87	100				
Ngqwara	A	5.2	5.1	98	100	100				
Sihlontlweni	A/B	2.2	2.2	98	85	100				
Nebelele	A/B	1.1	1.0	98	80	0				
Qora	B	78.5	72.0	92	76	85				
Jujura	B	11.3	10.2	91	69	83			●	
Ngadla	A	1.6	1.5	97	87	100				
Shixini	A	42.3	41.0	97	91	93				
Beechamwood	A	0.5	0.5	97	90	100				
Unnamed	A	0.7	0.6	93	75	100				
Kwa-Goqo	A/B	1.0	1.0	97	80	0				
Ku-Nocekedwa	A	1.1	1.1	97	90	100				
Nqabara/Nqabarana	A	76.4	75.9	99	96	100				
Ngoma/Kobule	A	6.3	6.2	98	96	100				
Mendu	A	5.2	5.1	98	99	100				
Mendwana	A	1.4	1.3	98	105	100				
Mbashe	A	801.8	817.7	102	139	113				

About 17% (27 systems) of the Temperate estuaries revealed a significant modification in MAR, while 42% (66 systems) and 35% (56 systems) of estuaries have shown severe alterations in base flows and median flow conditions, respectively (Figure 4.1). Concomitantly, 18% (29 systems) of estuaries had significant shifts in low flow variance, with 18% (29 systems) of estuaries subjected to changes in the low flow duration. Nearly 10% (16 systems) of the estuaries had a change in the number of high flow months, while 20% (32 systems) have shown a shift in the actual onset of the high flow period.

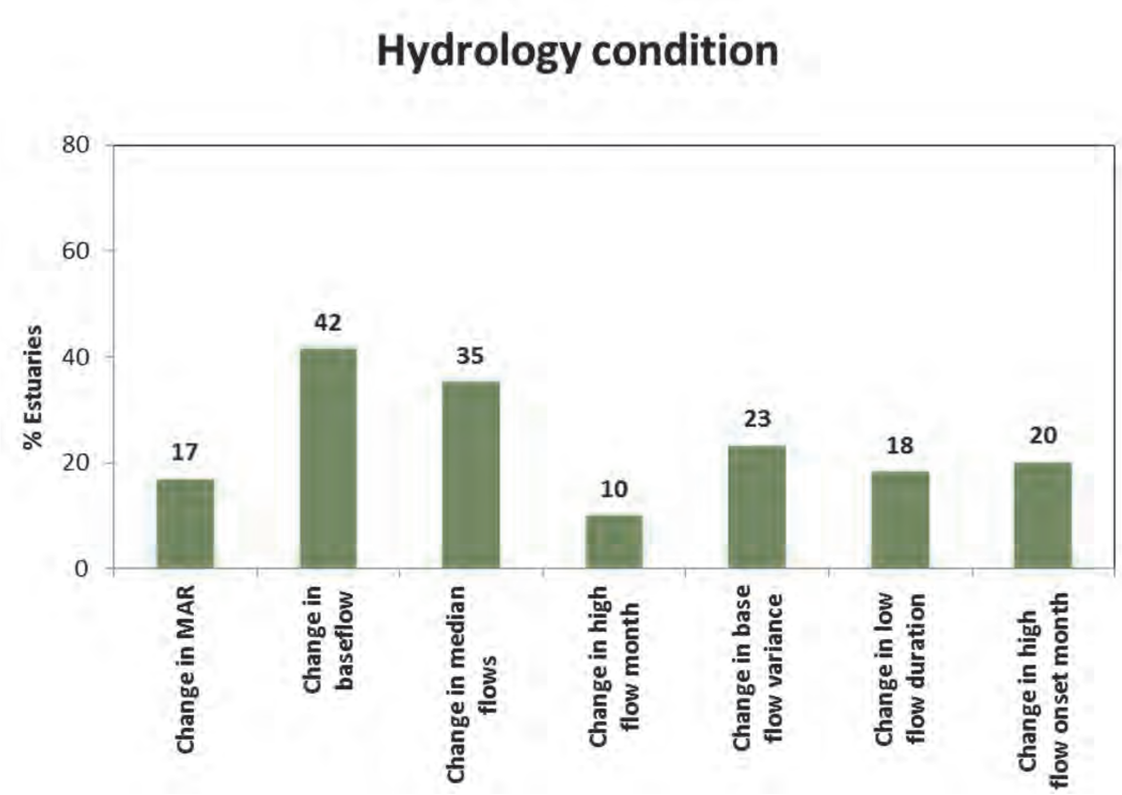

Figure 4.1 Key parameters that influence the hydrology state of the Temperate estuaries

4.2 Hydrodynamics

A range of anthropogenic pressures influence the hydrodynamics (mouth state in particular) of an estuary (Table 4.2), the most important being flow modification.

Table 4.2 Hydrodynamic condition (using mouth state as a proxy) of the Temperate estuaries in South Africa, including the key pressures contributing to modification

Estuary	Hydrodynamic health (mouth state)	Key pressure					
		Flow modification	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth stabilised	Artificial breaching
Orange (Gariep)	C	●	●		●		●
Buffels	B						
Spoeg	A/B						
Groen	A						
Sout	C/D	●	●				
Olifants	A						
Jakkalsvlei	D/E	●	●			●	
Wadrift	E/F	●	●				
Verlorenvlei	C/D	●	●				●
Groot Berg	A/B					●	
Rietvlei/Diep	E	●	●	●	●	●	●
Sout (Wes)	F	●	●	●		●	
Houtbaai	E	●	●		●		
Wildevoëlvlei	D/E	●	●				
Bokramspruit	C/D	●			●		
Schuster	A/B						
Krom	A						
Buffels Wes	A						
Elsies	E/F		●				
Silvermine	E/F	●	●			●	●
Sand	E	●	●	●		●	●
Zeekoei	E	●	●	●		●	
Eerste	E	●	●		●		
Lourens	B						
Sir Lowry's Pass	B						
Steenbras	A						
Rooiels	A						
Buffels (Oos)	B	●					
Palmiet	D	●					
Bot/Kleinmond	C	●					●
Onrus	E	●					
Klein	C/D	●					●
Uilkraals	C	●	●				●
Ratel	A/B						
Heuningnes	D	●					●
Klipdrifsfontein	A						
Breë	A						
Duiwenhoks	A						
Goukou	A						
Gourits	A						
Blinde	B						
Tweekuilen	C/D	●	●		●		
Gericke	C/D	●	●		●		
Hartenbos	D	●	●		●		●
Klein Brak	A/B						
Groot Brak	C/D	●	●		●		●
Maalgate	C	●					

Table 4.2 continues/...

Estuary	Hydrodynamic health (mouth state)	Key pressure					
		Flow modification	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth stabilised	Artificial breaching
Gwaing	B						
Kaaimans	A						
Wilderness	C/D		●			●	●
Swartvlei	B/C		●				●
Goukamma	B						●
Knysna	A						
Noetsie	A/B						
Piesang	D	●					
Keurbooms	A						
Matjies	B/C	●					
Sout (Oos)	A						
Groot (Wes)	A						●
Bloukrans	A						
Lottering	A						
Elandsbos	A						
Storms	A						
Elands	A						
Groot (Oos)	A						
Tsitsikamma	C	●					
Klipdrif	A/B						
Slang	C	●					
Krom Oos (Kromme)	A						
Seekoei	D/E	●	●	●		●	●
Kabeljous	C	●					
Gamtoos	A						
Van Stadens	A/B						
Maitland	A/B						
Baakens	E	●		●		●	
Papenkuils	F	●		●		●	
Swartkops	A/B						
Coega (Ngcura)	F	●		●		●	
Sundays	A						
Boknes	C	●					
Bushmans	A						
Kariega	A						
Kasuka	A						
Kowie	A/B					●	
Rufane	C	●					
Riet	A/B						
Kleinemond Wes	A/B						
Kleinemond Oos	A/B						
Klein Palmiet	A/B						
Great Fish	A/B						
Old Womans	A/B						
Mpekweni	B						
Mtati	B						
Mgwalana	B						
Bira	B						
Gqutywa	B						
Ngculura	B						
Mtana	A/B						

Table 4.2 continues/...

Estuary	Hydrodynamic health (mouth state)	Key pressure					
		Flow modification	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth stabilised	Artificial breaching
Keiskamma	A						
Ngqinisa	A						
Kiwane	A						
Tyolomnqa	A						
Shelbertsstroom	B						
Lilyvale	C						
Ross' Creek	A						
Ncera	A/B						
Mlele	A/B						
Mcantsi	B						
Gxulu	B/C						
Goda	A/B						
Hlozi	A/B						
Hickman's	A/B						
Ngqenga	A/B						
Buffalo	B	●		●		●	
Blind	C	●					
Hlaze	D	●					
Nahoon	A						
Qinira	A/B						
Gqunube	A						
Kwelera	A						
Bulura	A						
Cintsa	A						
Cefane	A/B						
Kwenxura	A						
Nyara	A						
Mtwendwe (Imtwende)	A						
Haga-haga	A						
Mtendwe	A						
Quko	A						
Morgan	A						
Cwili	A/B						
Great Kei	A/B						
Gxara	A						
Ngogwane	A/B						
Qolora	A/B						
Ncizele	B						
Timba	A						
Kobonqaba	A/B						
Nxaxo/Ngqusi	A/B						
Cebe	A						
Gqunqe	A						
Zalu	A						
Ngqwara	A/B						
Sihlontlweni	A						
Nebelele	A						
Qora	A						
Jujura	A						
Ngadla	A/B						
Shixini	A						

Table 4.2 continues/...

Estuary	Hydrodynamic health (mouth state)	Key pressure					
		Flow modification	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth stabilised	Artificial breaching
Beechamwood	A						
Unnamed	A						
Kwa-Goqo	A						
Ku-Nocekedwa	A						
Nqabara/Nqabarana	A						
Ngoma/Kobule	A						
Mendu	A						
Mendwana	A						
Mbashe	A						

Modification in flow contributed to change in about 25% (40 estuaries) of the Temperate estuaries (Figure 4.2). A reduction in base flows generally leads to an increase in mouth closure, while an increase in base flows can lead to more open conditions. Artificial breaching is also seen as a critical modifier of mouth state and was recorded in about 10% (16 systems) of the estuaries. Mouth stabilisations which increase tidal flows, and therefore prevents or retards mouth closure, was noted in about 9% (14 systems) of the estuaries.

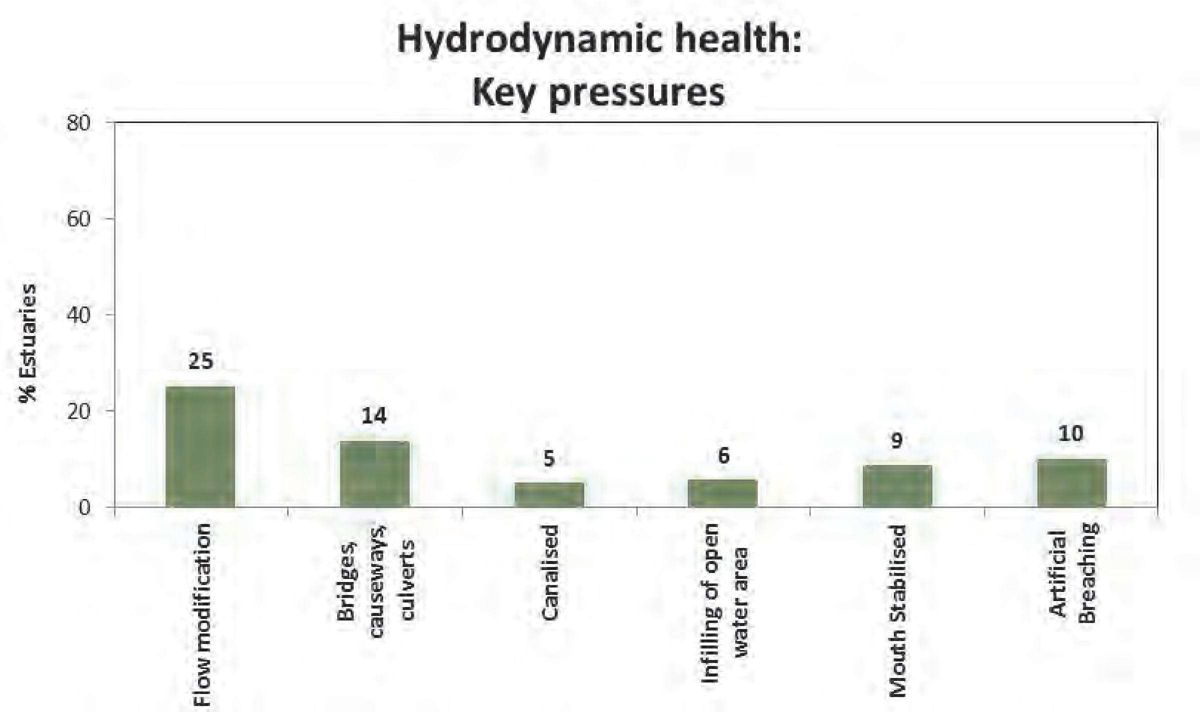

Figure 4.2 Key parameters or pressures that influence the hydrodynamic health state of the Temperate estuaries

Infilling of open water areas – noted in about 6% (9 systems) of the estuaries – reduces tidal flows and leads to increased mouth closure. The construction of bridges, culverts and causeways, which reduces tidal flows have also affected about 14% (22 systems) of estuaries in the region. In contrast, canalisation (5% of estuaries) tends to increase tidal velocities and reduces the occurrence of mouth closure.

4.3 Physical habitat

The physical habitat health state of Temperate estuaries is influenced by a wide range of pressures as illustrated in Table 4.3.

Table 4.3 Physical habitat health state of the Temperate estuaries in South Africa, including the key pressures contributing to modification

Estuary	Physical habitat health	Key Pressure									
		Development/ cultivation in EFZ	Roads, bridges, causeways, culverts	Canalised, levees, revetments	Degraded catchment	Infilling of open water area	Marinas	Harbours	Mining	Salt works	Loss of resetting floods
Orange (Gariep)	B	●	●	●	●	●			●		●
Buffels	C/D	●	●						●		
Spoeg	B		●		●						
Groen	B	●									
Sout	D/E	●	●								
Olifants	B	●	●		●					●	●
Jakkalsvlei	C	●	●		●						
Wadrift	D/E	●	●		●						
Verlorenvlei	C	●	●								
Groot Berg	C/D	●	●	●	●		●	●		●	●
Rietvlei/Diep	E	●	●	●	●	●					
Sout (Wes)	F	●	●	●							
Houtbaai	E	●	●			●					
Wildevoëlvlei	D	●	●								
Bokramspruit	C	●				●					
Schuster	A/B		●								
Krom	A										
Buffels Wes	A										
Elsies	E	●	●								
Silvermine	E	●	●								
Sand	D/E	●	●	●			●				
Zeekoei	E/F	●	●	●							
Eerste	D/E	●	●			●					
Lourens	D	●	●	●		●					
Sir Lowry's Pass	E/F	●	●			●					
Steenbras	A/B										
Rooiels	A/B	●	●			●					
Buffels (Oos)	B		●								
Palmiet	B		●								●
Bot/Kleinmond	A/B	●	●		●						
Onrus	D/E	●									●
Klein	B	●	●								
Uilkraals	C	●	●		●						●

Table 4.3 continues/...

Estuary	Physical habitat health	Key Pressure									
		Development/ cultivation in EFZ	Roads, bridges, causeways, culverts	Canalised, levees, revetments	Degraded catchment	Infilling of open water area	Marinas	Harbours	Mining	Salt works	Loss of resetting floods
Ratel	A										
Heuningnes	B/C	●	●								
Klipdrifsfontein	A										
Breë	A/B	●			●						●
Duiwenhoks	A/B	●	●		●						
Goukou	C	●	●		●						
Gourits	C	●	●		●						●
Blinde	A/B										
Tweekuilen	E	●	●			●					
Gericke	E	●	●			●					
Hartenbos	D	●	●			●					●
Klein Brak	C	●	●		●						
Groot Brak	B	●	●			●					●
Maalgate	A										
Gwaing	A										
Kaaimans	A/B	●	●								
Wilderness	B	●	●								
Swartvlei	A/B	●	●								
Goukamma	A/B	●	●								
Knysna	B	●	●				●				
Noetsie	A										
Piesang	D	●	●								
Keurbooms	A	●	●	●							
Matjies	A										
Sout (Oos)	A										
Groot (Wes)	A/B	●	●								
Bloukrans	A										
Lottering	A										
Elandsbos	A										
Storms	A										
Elands	A										
Groot (Oos)	A										
Tsitsikamma	A										
Klipdrif	A/B	●	●								
Slang	D	●	●								
Krom Oos (Kromme)	C	●	●				●				●
Seekoei	C	●	●	●	●						
Kabeljous	C	●	●		●						
Gamtoos	C	●	●		●						
Van Stadens	A/B	●	●		●						
Maitland	A/B	●	●		●						
Baakens	F	●	●	●							
Papenkuils	F	●	●	●	●						
Swartkops	D	●	●	●	●					●	
Coega (Ngcura)	F	●	●	●	●					●	
Sundays	A/B	●	●		●						
Boknes	A/B	●	●		●						
Bushmans	A/B	●	●		●						
Kariega	B	●	●		●						

Table 4.3 continues/...

Estuary	Physical habitat health	Key Pressure									
		Development/ cultivation in EFZ	Roads, bridges, causeways, culverts	Canalised, levees, revetments	Degraded catchment	Infilling of open water area	Marinas	Harbours	Mining	Salt works	Loss of resetting floods
Kasuka	B	●	●		●						
Kowie	C/D	●	●		●		●				
Rufane	C/D				●						
Riet	A/B	●	●		●						
Kleinemond Wes	A/B	●	●								
Kleinemond Oos	A/B	●	●								
Klein Palmiet	C				●						
Great Fish	A/B	●	●		●						
Old Womans	C	●	●		●						
Mpekweni	B	●	●								
Mtati	A/B		●								
Mgwalana	A/B		●		●						
Bira	A/B	●	●								
Gqutywa	A/B	●			●						
Ngculura	A/B										
Mtana	A										
Keiskamma	C	●	●		●						
Ngqinisa	A				●						
Kiwane	A										
Tyolomnqa	A/B	●	●		●						
Shelbertsstroom	C/D	●	●	●	●						
Lilyvale	A/B	●			●						
Ross' Creek	A/B	●									
Ncera	A/B	●	●								
Mlele	C/D										
Mcantsi	B/C	●									
Gxulu	C	●	●	●	●						
Goda	A/B				●						
Hlozi	A/B				●						
Hickman's	A/B	●									
Ngqenga	C		●								
Buffalo	D/E	●	●	●	●			●			
Blind	C/D	●	●								
Hlaze	A/B		●		●						
Nahoon	A/B	●	●								●
Qinira	C	●			●						
Gqunube	B	●			●						
Kwelera	B	●			●						
Bulura	B	●	●		●						
Cintsa	A/B	●	●		●						
Cefane	C	●	●		●						
Kwenxura	A/B				●						
Nyara	A/B				●						
Mtwendwe (Imtwende)	A/B				●						
Haga-haga	A/B	●			●						
Mtendwe	A/B				●						
Quko	A/B				●						
Morgan	A	●			●						
Cwili	B	●	●		●						

Table 4.3 continues/...

Estuary	Physical habitat health	Key Pressure									
		Development/ cultivation in EFZ	Roads, bridges, causeways, culverts	Canalised, levees, revetments	Degraded catchment	Infilling of open water area	Marinas	Harbours	Mining	Salt works	Loss of resetting floods
Great Kei	**B**	●			●						
Gxara	**C**				●						
Ngogwane	**A**		●		●						
Qolora	**A/B**	●			●						
Ncizele	**A/B**				●						
Timba	**A/B**				●						
Kobonqaba	**A/B**				●						
Nxaxo/Ngqusi	**A/B**	●			●						
Cebe	**B/C**	●			●						
Gqunqe	**A/B**	●			●						
Zalu	**A/B**				●						
Ngqwara	**A/B**	●			●						
Sihlontlweni	**A/B**				●						
Nebelele	**A/B**	●	●		●						
Qora	**A/B**				●						
Jujura	**A/B**				●						
Ngadla	**A/B**				●						
Shixini	**A/B**				●						
Beechamwood	**A/B**		●		●						
Unnamed	**A/B**				●						
Kwa-Goqo	**A/B**				●						
Ku-Nocekedwa	**A/B**				●						
Nqabara/Nqabarana	**A/B**	●			●						
Ngoma/Kobule	**A/B**	●			●						
Mendu	**A/B**	●			●						
Mendwana	**A/B**				●						
Mbashe	**A/B**				●						

In the Temperate region, infrastructure development and cultivation of crops in the estuary functional zone (EFZ) (i.e. below the 5 m contour) is one of the leading causes of degradation/loss of habitat – occurring in 64% (101 systems) of the estuaries (Figure 4.3). Roads and related road infrastructure (e.g. bridges, culverts and causeways) are also prevalent in about 55% (88 systems) of the estuaries leading to loss of connectivity and habitat. Road infrastructure was also one of the leading causes of infilling in 8% of estuaries (12 systems).

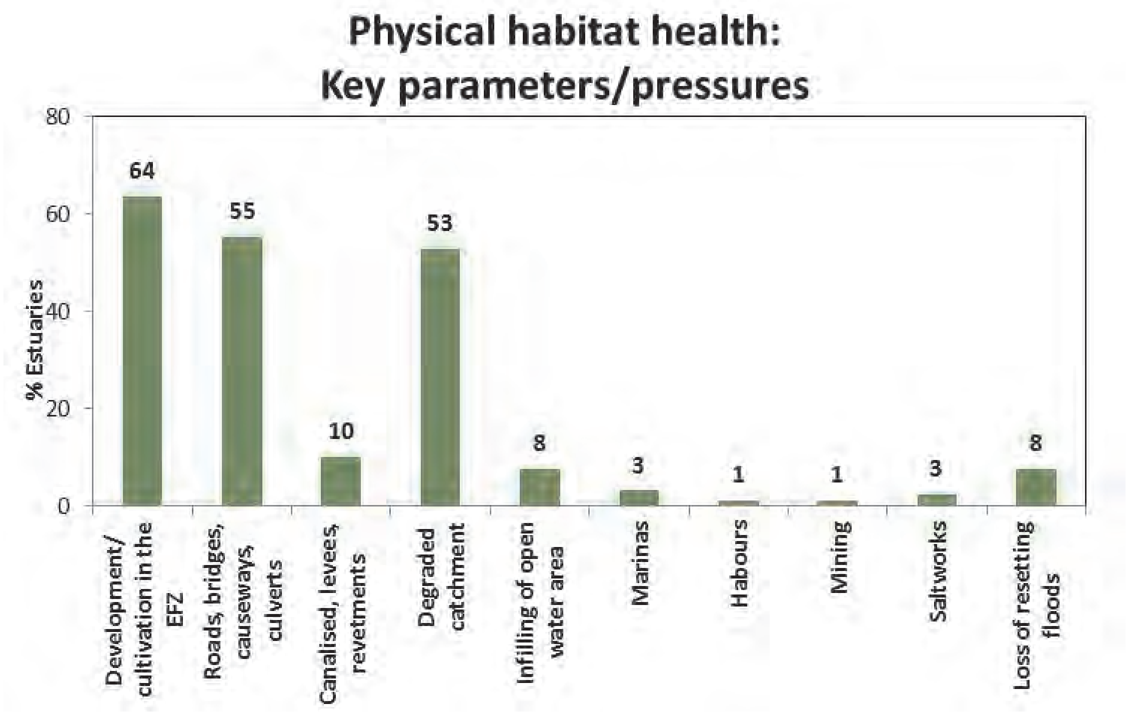

Figure 4.3 Key pressures that influence the physical habitat health of the Temperate estuaries

Poor land-use practices in 53% (84 systems) of the Temperate estuaries are causing increased sedimentation and/or changes in the sediment structure (i.e. mud/sand ratios), which in turn causes loss of water column area and shifts in community structure of biota. While this pressure was especially prevalent along the Wild Coast (former Transkei), where overgrazing and subsistence agriculture is leading to severe land degradation, it was also noted in other large catchments that support significant agricultural activities, e.g. Breede, Goukou, Klein Brak. Loss of major resetting floods in about 8% (12 systems) of estuaries contributed to a long-term shift in physical habitat, leading to more stable systems with less possibility of changes in biotic community structure between events. Canalisation and the construction of levees resulted in habitat changes/loss in about 10% of estuaries (16 systems). Harbour and marina developments impacted on about 1% (2 systems) and 3% (5 systems) of Temperate estuaries respectively. This type of development generally causes significant and irreversible change in physical habitat and a related loss/change in biotic components. Mining activities and salt works in the estuary functional zone impacted on about 1% (2 systems) and 3% (4 systems) respectively.

4.4 Water quality

4.4.1 Salinity

The salinity health condition of estuaries in the Cool- and Warm-Temperate regions of South Africa is summarised in Table 4.4, also listing the key pressures resulting in the change in health.

Table 4.4 The salinity health state of the Temperate estuaries in South Africa, including the key pressures contributing to modification

Estuary	Salinity Health	Key Pressure						
		Flow modification	Change in mouth state	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth Stabilised	Artificial Breaching
Orange (Gariep)	C/D	●	●					
Buffels	A							
Spoeg	A							
Groen	A							
Sout	C	●	●					
Olifants	D	●						
Jakkalsvlei	D	●	●	●			●	
Wadrift	E	●	●	●				
Verlorenvlei	B	●	●	●				●
Groot Berg	C	●					●	
Rietvlei/Diep	E	●	●	●	●	●	●	●
Sout (Wes)	E	●	●	●	●		●	
Houtbaai	C/D	●	●					
Wildevoëlvlei	D/E	●	●					
Bokramspruit	B		●					
Schuster	A							
Krom	A							
Buffels Wes	A							
Elsies	E/F		●	●				
Silvermine	E/F	●	●	●			●	●
Sand	D/E	●	●	●	●		●	●
Zeekoei	E/F	●	●	●			●	
Eerste	E	●	●			●		
Lourens	A/B							
Sir Lowry's Pass	B							
Steenbras	B/C	●						
Rooiels	A							
Buffels (Oos)	B							
Palmiet	B/C		●					
Bot/Kleinmond	A/B		●					●
Onrus	D/E	●	●					●
Klein	C	●	●					●
Uilkraals	C	●	●	●				
Ratel	A							
Heuningnes	D	●	●					●
Klipdrifsfontein	A							
Breë	C/D	●						
Duiwenhoks	B	●						
Goukou	B	●						
Gourits	B/C	●						
Blinde	B	●						
Tweekuilen	C/D	●	●					
Gericke	C/D	●	●					
Hartenbos	C/D	●	●					●
Klein Brak	B	●						

Table 4.4 continues/...

Estuary	Salinity Health	Key Pressure						
		Flow modification	Change in mouth state	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth Stabilised	Artificial Breaching
Groot Brak	C/D	●	●	●				●
Maalgate	A/B	●	●					
Gwaing	B							
Kaaimans	B							
Wilderness	B		●	●				●
Swartvlei	B/C	●	●	●				●
Goukamma	A							
Knysna	A							
Noetsie	B							
Piesang	D	●	●					
Keurbooms	A							
Matjies	B							
Sout (Oos)	A/B							
Groot (Wes)	A							●
Bloukrans	A							
Lottering	A							
Elandsbos	A							
Storms	A							
Elands	A							
Groot (Oos)	A							
Tsitsikamma	C	●	●					
Klipdrif	A							
Slang	A		●					
Krom Oos (Kromme)	E	●						
Seekoei	E	●	●	●			●	
Kabeljous	B		●					
Gamtoos	B							
Van Stadens	B							
Maitland	B							
Baakens	E	●	●		●		●	
Papenkuils	E/F	●	●		●		●	
Swartkops	B							
Coega (Ngcura)	F	●	●		●		●	
Sundays	C							
Boknes	B		●					
Bushmans	A/B							
Kariega	B/C	●						
Kasuka	A							
Kowie	A/B							
Rufane	B		●					
Riet	A/B							
Kleinemond Wes	B							
Kleinemond Oos	A/B							
Klein Palmiet	A/B							
Great Fish	B							
Old Womans	A/B							
Mpekweni	A/B							
Mtati	A/B							

Table 4.4 continues/...

Estuary	Salinity Health	Key Pressure						
		Flow modification	Change in mouth state	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth Stabilised	Artificial Breaching
Mgwalana	A/B							
Bira	A/B							
Gqutywa	A/B							
Ngculura	A/B							
Mtana	A/B							
Keiskamma	C	●						
Ngqinisa	A							
Kiwane	A							
Tyolomnqa	A							
Shelbertsstroom	A/B							
Lilyvale	A/B		●					
Ross' Creek	A							
Ncera	A/B							
Mlele	A/B							
Mcantsi	A/B							
Gxulu	A/B							
Goda	A/B							
Hlozi	A/B							
Hickman's	A/B							
Ngqenga	A/B							
Buffalo	D	●	●		●			
Blind	C	●	●					
Hlaze	D	●						
Nahoon	D	●						
Qinira	A/B							
Gqunube	A							
Kwelera	A							
Bulura	A							
Cintsa	A							
Cefane	A							
Kwenxura	A							
Nyara	A							
Mtwendwe (Imtwende)	A							
Haga-haga	A							
Mtendwe	A							
Quko	A							
Morgan	A							
Cwili	A/B							
Great Kei	A/B							
Gxara	B							
Ngogwane	A							
Qolora	A							
Ncizele	A/B							
Timba	A							
Kobonqaba	A/B							
Nxaxo/Ngqusi	A/B							
Cebe	A							
Gqunqe	A							

Table 4.4 continues/...

Estuary	Salinity Health	Key Pressure						
		Flow modification	Change in mouth state	Bridges, causeways, culverts	Canalised	Infilling of open water area	Mouth Stabilised	Artificial Breaching
Zalu	A							
Ngqwara	A							
Sihlontlweni	A							
Nebelele	A							
Qora	A							
Jujura	A							
Ngadla	A/B							
Shixini	A							
Beechamwood	A							
Unnamed	A							
Kwa-Goqo	A							
Ku-Nocekedwa	A							
Nqabara/Nqabarana	A							
Ngoma/Kobule	A							
Mendu	A							
Mendwana	A							
Mbashe	A							

The salinity regime of an estuary is primarily influenced by its base flows and mouth state. In the Temperate region about 28% (45 systems) of the estuaries showed significant changes in base flows, with the majority of these being a reduction in base flows. Change in the mouth state occurred in about 26% (41 systems) of the estuaries (Figure 4.4). A significant increase in mouth closure reduces connectivity with the sea and generally results in a fresher estuary if base flows have not been reduced to zero. Long-term artificial breaching can lead to infilling of estuarine channels and premature closure, which ultimately result in less seawater penetration – occurring in 8% (13 systems) of estuaries. Bridges, causeways and culverts contributed to reduce tidal influence and seawater penetration in about 9% (14 systems) of the estuaries. While canalisation (4%), infilling of open water areas (1%), and mouth stabilisation (7%) were recorded in a number of systems, they were only included in the salinity rating if their impacts were considered significant.

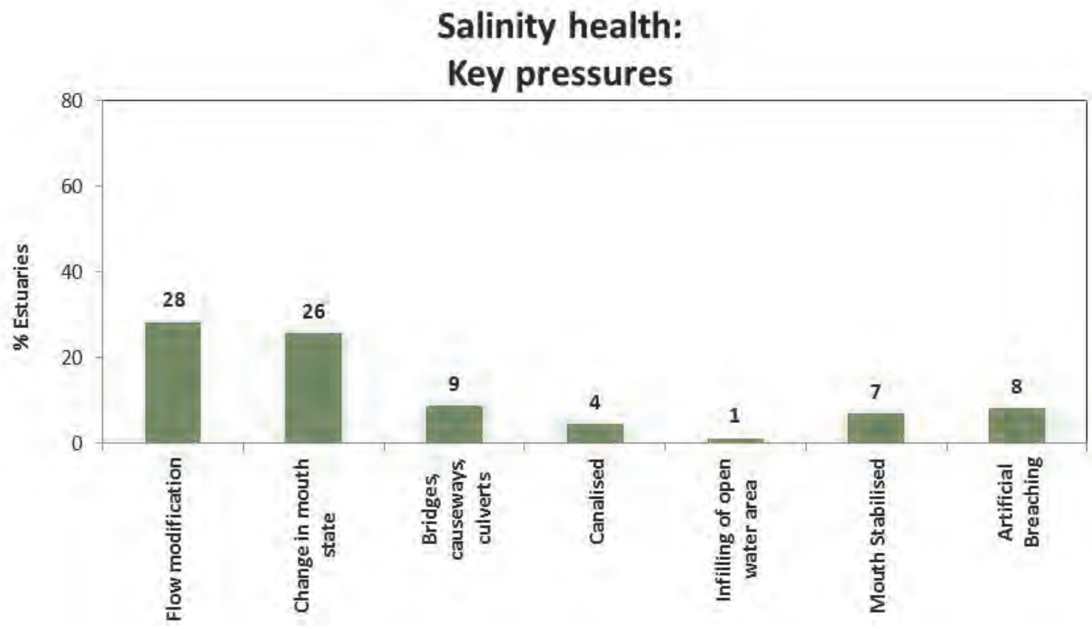

Figure 4.4 Key parameters or pressures that influence the salinity health of the Temperate estuaries

4.4.2 Other Water quality (nutrients, turbidity and toxic substances)

The water quality conditions of estuaries in the Cool- and Warm-Temperate region of South Africa are summarised Table 4.5. The key pressures contributing to modification in these water quality parameters are also indicated.

Table 4.5 Water quality (nutrients, turbidity and toxic substances) health conditions of the Temperate estuaries in South Africa, including the key pressures contributing to modification of water quality

Estuary	WQ Condition	Key Pressure			
		WWTW/ Industrial Effluent	Urban Runoff	Rural Settlement	Formal Agricultural
Orange (Gariep)	C				●
Buffels	B				
Swartlintjies	B				
Spoeg	B				
Groen	B				
Sout	B				
Olifants	C				●
Jakkals	D				●
Wadrift/Langdrift	D				●
Verlorenvlei (lake)	E				●
Berg (Groot)	C	●			●
Rietvlei/Diep	D		●		●
Sout (Wes)	E		●		
Hout Bay (Disa)	F		●		

Table 4.5 continues/...

Estuary	WQ Condition	Key Pressure			
		WWTW/ Industrial Effluent	Urban Runoff	Rural Settlement	Formal Agricultural
Wildevoëlvlei1	D	●	●		
Schuster	A				
Krom	B				
Buffels Wes	B				
Elsies	C		●		
Silvermine	D		●		
Bokramspruit	C		●		
Sand	E		●		
Zeekoe	F	●	●		
Eerste	F	●	●		
Lourens	E	●	●		●
Sir Lowry's	F		●		●
Steenbras	A				
Rooiels	A				
Buffels (Oos)	A				
Palmiet	B				
Bot/Kleinmond (lake)	C	●			●
Onrus	E	●	●		
Klein (lake)	D		●		
Uilkraals	C	●			
Ratel	B				
Heuningnes/Soetendal (lake)	C				●
Klipdrifsfontein	B				
Breede	B				
Duiwenhoks	B				
Goukou	B				
Gourits	B				
Blinde	C				●
Hartenbos	E	●			●
Klein Brak	B	●			●
Groot Brak	D		●		●
Maalgate	C				●
Gwaing	D	●			●
Kaaimans	B				
Wilderness/Touw (lake)	C				●
Swartvlei (Lake)	B				
Goukamma	B				
Knysna	B				
Noetsie	B				
Piesang	C		●		
Keurbooms/Bitou	A				
Matjies	B				
Sout (Oos)	A				
Groot (Wes)	A				
Bloukrans	A				
Lottering	A				
Elandsbos	A				
Storms	A				

Table 4.5 continues/...

Estuary	WQ Condition	Key Pressure			
		WWTW/ Industrial Effluent	Urban Runoff	Rural Settlement	Formal Agricultural
Elands	A				
Groot (Oos)	C				●
Tsitsikamma	C				●
Klipdrif	D				●
Slang	E				●
Kromme (Oos)	A				
Seekoei	D				●
Kabeljous	C				●
Gamtoos	C				●
Van Stadens	B				
Maitland	C		●		●
Baakens	E		●		
Papkuils	F		●		
Swartkops	E		●		
Coega	B				
Sundays	D				●
Boknes	C				●
Bushmans	B				
Kariega	B				
Kasuka	B				
Kowie	B				
Rufane	B				
Riet	B				
Kleinmond Wes	B				
Kleinemond Oos	B				
Klein Palmiet	B				
Great Fish	D			●	
Old Womans	D			●	
Mpekweni	B				
Mtati	B				
Mgwalana	B				
Bira	B				
Gqutywa	B				
Ngculura	B				
Mtana	B				
Keiskamma	C			●	●
Ngqinisa	B				
Kiwane	B				
Tyolomnqa	B				
Shelbertsstroom	C			●	
Lilyvale	B				
Ross creek	B				
Ncera	B				
Mlele	C			●	
Mcantsi	B				
Gxulu	B				
Goda	C			●	
Hlozi	D			●	

Table 4.5 continues/...

Estuary	WQ Condition	Key Pressure			
		WWTW/ Industrial Effluent	Urban Runoff	Rural Settlement	Formal Agricultural
Hickmans	C			●	
Ngqenga	D			●	
Buffalo	C		●		
Blind	F		●		
Hlaze	E		●		
Nahoon	C		●		
Qinira	C		●		
Gqunube	B				
Kwelera	B				
Bulura	B				
Cunge	B				
Cintsa	B				
Cefane	B				
Kwenxura	A				
Nyara	B				
IMtwendwe (Imtwende)	A				
Haga-haga	B				
Mtendwe	A				
Quko	B				
Morgan	B				
Cwili	A				
Great Kei	B				
Gxara	C			●	
Ngogwane	C			●	
Qolora	B				
Ncizele	B				
Timba	B				
Kobonqaba	A				
Nxaxo\ngqusi (Wave crest)	A				
Cebe	B				
Gqunqe	B				
Zalu	B				
Ngqwara	B				
Sihlontlweni	B				
Nebelele	B				
Qora	A				
Jujura	A				
Ngadla	B				
Shixini	A				
Beechamwood	B				
Kwazwelitsha/Kwazwedala	B				
Kwa-goqo	B				
Ku-nocekedwa	B				
Nqabara	A				
Ngoma/Kobule	A				
Mendu	B				
Mendwana	A				
Mbashe	B				

Table 4.5 continues/...

Estuary	WQ Condition	Key Pressure			
		WWTW/ Industrial Effluent	Urban Runoff	Rural Settlement	Formal Agricultural
Ku-Mpenzu	B				
Ku-Bhula/Mbhanyana	A				

Reflecting on the results, formal agriculture is the major factor causing modification of water quality condition in 19% (31 systems) of the Temperate estuaries, followed by urban runoff (17 %, 27 systems), and to a lesser extent WWTWs/Industrial effluent discharges (7%, 11 systems) and rural settlements (7% 11 systems) (Figure 4.5). The latter pressure (rural settlements) is primarily a factor in the Warm-Temperate estuaries of the former Transkei and Ciskei.

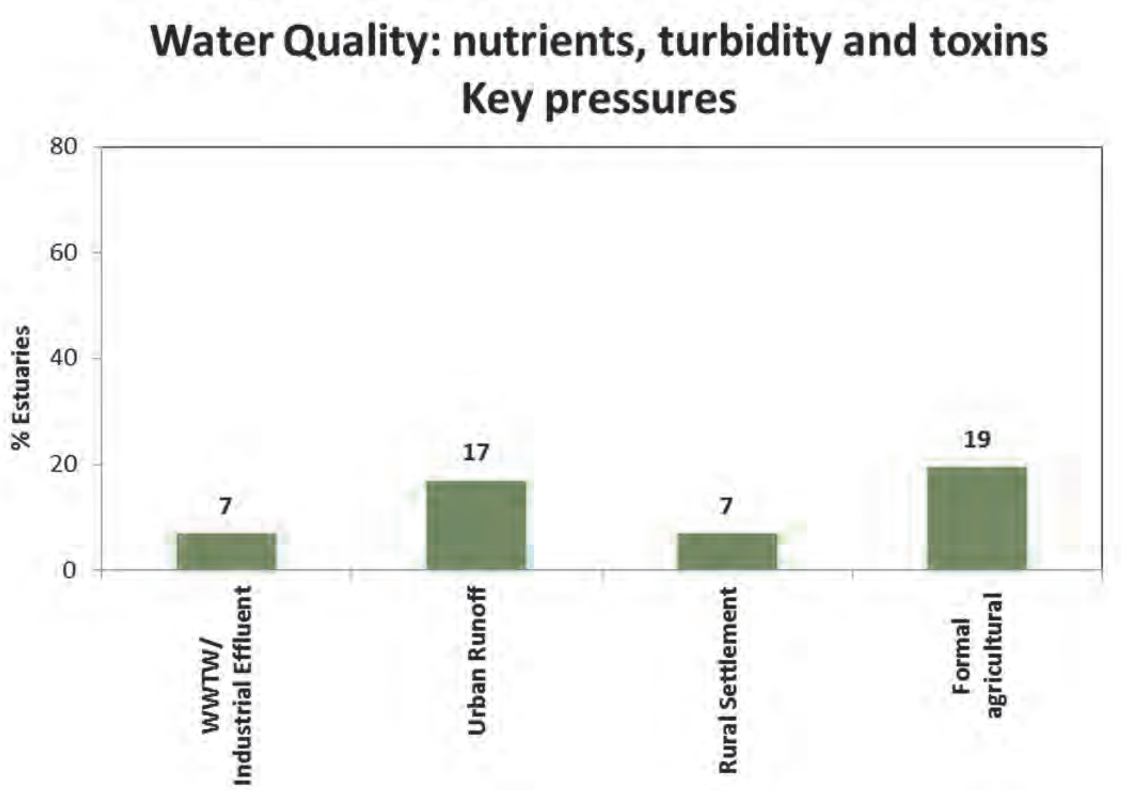

Figure 4.5 Key pressures that influence the water quality health (nutrients, turbidity and toxic substances) of the Temperate estuaries

4.5 Synopsis of abiotic health state

An overview of the abiotic components shows that overall the Cool-Temperate estuaries are in a more modified state than the Warm-Temperate systems (Figure 4.6). The hydrology component especially highlights the degraded state of Cool-Temperate estuaries with only about 20% of the system having a hydrology rating in an A or B Category, which reflects the impact of extensive water resources development in the coastal region and further inland.

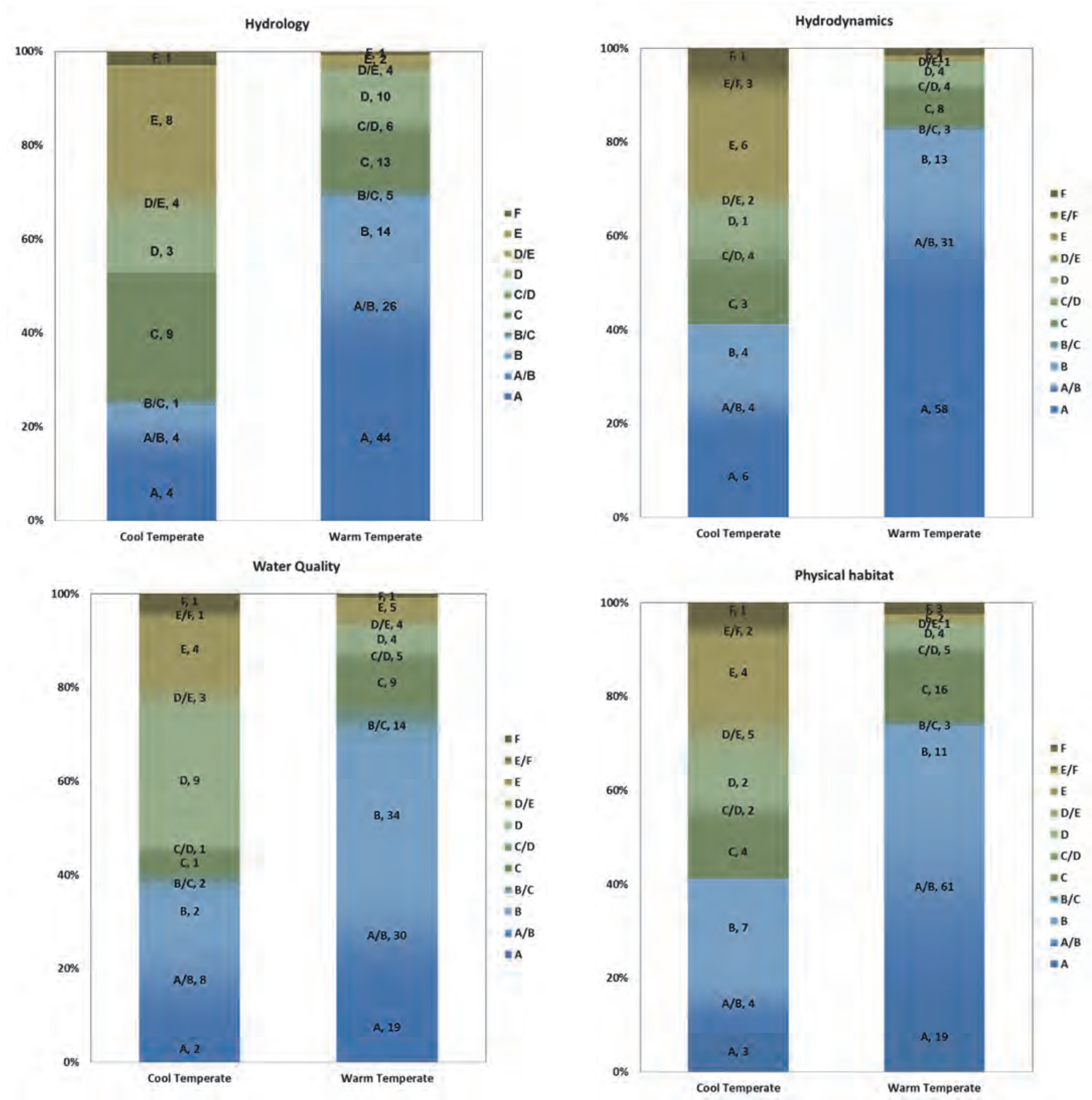

Figure 4.6 Overview of the abiotic health state of the Temperate estuaries

The hydrodynamics component shows an improvement in condition, about 20% and 10% increase in A or B Category systems in the Cool- and Warm-Temperate estuaries respectively, alluding to some resilience in this component, i.e. not all flow modification translate directly into shifts in hydrodynamic condition.

As can be expected, water quality and the physical habitat components showed a relatively similar pattern in condition as a result of coastal development, with a slight increase in degraded systems (from a habitat perspective) in the Warm-Temperate region.

5. BIOTIC CHARACTERISATION AND RESPONSES TO CURRENT PRESSURES

5.1 Microalgae

Microalgae, as primary producers, form the base of food chains in estuaries. The group includes those living in the water column (phytoplankton) and those living on or in exposed intertidal or submerged surfaces (benthic microalgae). Phytoplankton biomass, using chlorophyll *a* as an index, indicates the river-estuary interface zone, a brackish zone in the estuary characterised by high biomass and diversity. As freshwater inflow decreases, the extent of the river-estuary interface zone changes and the flow requirements of the estuary are set based on the acceptable change.

Phytoplankton biomass indicates the nutrient status of an estuary. For example, the Swartkops Estuary in the Eastern Cape Province receives sewage-contaminated freshwater and phytoplankton chlorophyll *a* frequently exceeds 100 $\mu g.l^{-1}$ in the upper reaches, which is typical of a eutrophic system where median chlorophyll *a* is persistently greater than 8 $\mu g.l^{-1}$ (Snow, 2007). Species composition also indicates the nutrient and hydrodynamic status of an estuary (Table 5.1). Dinoflagellates are typically abundant when the estuary is rich in nutrients and stratified. They occur in the middle reaches of an estuary where salinity is >5 ppt whereas cyanophytes (blue-green algae) are common in nutrient-rich water where salinity is <5 ppt.

Table 5.1 Summary of the indicator properties of each of the phytoplankton functional groups

Type	Controlling Factors	References
Chlorophytes	Freshwater conditions; Low residence time (high flow); High N:P, but low Si	Domingues *et al*., 2005; Paerl *et al*., 2006; Barbosa *et al*., 2010; Paerl *et al*., 2010; Domingues *et al*., 2011; Kotsedi *et al*., 2012 Kaselowski & Adams, 2013
Cyanobacteria	High optimum temperature; High nutrient inputs; Low N:P, and low Si High residence time (low flow)	
Diatoms	Present in marine and freshwater; Low residence time (high flow); High N:P ratio, and high Si; Spring and winter blooms	
Dinoflagellates	High residence time (low flow); Stable, stratified conditions; Warm temperatures (spring and summer); High nutrients, but low Si	
Flagellates	High flow conditions; Reduced temperatures; Cosmopolitan distribution along estuaries	

Based on a study of phytoplankton cell size in the Temperate North Atlantic Ocean (Morán *et al*., 2010), there was a definite shift in community structure to smaller phytoplankton, i.e. picophytoplankton, as temperature increased from -0.6ºC to 22ºC. The tiniest members of this phytoplankton group included the cyanobacteria and eukaryotic algae that were less than 2 µm in diameter. Temperature alone was able to explain 73% of the variance in the relative contribution of small cells to total phytoplankton biomass, regardless of trophic status or nutrient loading (Morán *et al*., 2010). Even at a much localised scale the thermal discharge of water from a nuclear power plant in the Gulf of Finland (Ilus and Keskitalo, 2008) supported the shift in community structure to one dominated by cyanobacteria. This suggests that average phytoplankton cell size should decrease and the cyanobacteria should become more dominant from estuaries in the Cool-Temperate zone to those in the Warm-Temperate zone.

The cyanobacteria are also more likely to be more dominant in estuaries in the Warm-Temperate zone, where elevated temperature supports a higher oxygen demand through chemical and biological processes within the sediment. Benthic diatoms are known to respond to salinity and most references describe diatoms as freshwater, brackish or marine species (Bate *et al*., 2013). In addition, diatoms have proven to be useful indicators of trophic status, particularly in freshwater ecosystem studies (Taylor *et al*. 2007). As such, knowledge of diatom ecology is a vital component of estuarine management and it is therefore imperative that they, and phytoplankton, are included in Resource Directed Measures (RDM) studies.

Bate *et al*. (2013) identified 333 diatom taxa in 27 estuaries from the Olifants Estuary in the west to the St Lucia Estuary in the east. Of these, 25 taxa were exclusively found in the Cool-Temperate estuaries (Olifants and Great Berg estuaries), and 124 taxa exclusively found in the 16 Warm-Temperate estuaries. The ratio of the number of diatom taxa per site (cool:warm) was 0.41:0.78, suggesting that there is a far greater variability in Warm-Temperate areas than in Cool-Temperate areas. *Amphora coffeaformis* and *Navicula gregaria* were found in all intertidal and sub-tidal sites, in all reaches of the estuaries studied, and in all Temperate zones making them unsuitable as indicators of environmental conditions. Fourteen other taxa were found in warm and Cool-Temperate zones making them unsuitable as indicators of temperature in South Africa. Further data analysis is required to add species lists from new studies (e.g. Orange River Estuary) to the diatom database, and to develop a list of taxa occurring exclusively in the warm and Cool-Temperate zones. The effect of abiotic characteristics and processes, as well as other biotic components on microalgae is described in Table 5.2.

Table 5.2 Effect of abiotic characteristics and processes, as well as other biotic components on microalgae

Process	Microalgae
Mouth condition (provide temporal implications where applicable)	When the mouth of a temporarily open/closed estuary (TOCE) is open, the conditions within the estuary are similar to a permanently open estuary (POE); i.e. a channel is maintained due to the high volume of water flowing through the system (Whitfield and Bate, 2007). Once the berm at the estuary mouth is breached, there is a major outflow of estuarine water to sea that results in a rapid drop in the water level. This results in previously submerged sand banks becoming exposed for long periods (weeks to years). The exposure of previously inundated sediments has a profound impact on the available microphytobenthic habitat within a TOCE, impacting on higher trophic levels (e.g. providing a food source to intertidal crab species).
Retention times of water masses	Short water retention times favour the dominance of chlorophyte and diatom taxa in the upper and middle reaches of estuaries. Efficient intrusion of marine water in open estuaries replenishes oxygen-rich water in the lower reaches of estuaries, preventing cyanobacteria from becoming dominant. It is important to note that the intrusion of oxygen-poor ground water typically supports cyanobacteria in the microphytobenthos, e.g. a phenomenon observed in the Maaitjies Estuary when the mouth was open.
Flow velocities (e.g. tidal velocities or river inflow velocities)	The effects of river flow on microalgae include nutrient input, which is particularly effective under low flow conditions when residence time of the water column is increased (Whitfield and Bate, 2007). Under high river flow, the phytoplankton is typically dominated by the chlorophytes and diatoms. As river flow decreases, the flagellates become more dominant, and the dinoflagellates become dominant in the middle reaches of estuaries where the water column is stratified, particularly in nutrient-rich water. The water column tends to become dominated by small phytoplankton, the picophytoplankton (<2 µm), when river flow is low. If there is very little exchange of water in the estuary and there is a high oxygen demand, then conditions favour the presence of cyanobacteria in the phytoplankton and in the microphytobenthos.

Table 5.2 continues/...

Process	Microalgae
Total volume and/or estimated volume of different salinity ranges	When a TOCE is breached, the reduction in water level causes a decrease in the volume of water occupied by phytoplankton, limiting the potential area for colonisation of microalgae as well as overall primary production throughout the estuary.
Floods	Large-scale floods are important at scouring accumulated sediment, organic material, and 'old' water from estuaries, effectively resetting the system. The flood itself as well as the improved tidal exchange following the event support the presence of chlorophytes and diatoms in the water column, and provides intertidal habitat for microphytobenthos in TOCEs.
Salinity	Distinct communities containing microalgae, both phytoplankton and microphytobenthos, are present in marine and freshwater environments. The presence of either of these two communities in an estuary is dependent on the hydrodynamics (e.g. tidal intrusion and freshwater flow) within an estuary.
Turbidity	Microalgal primary production is light dependent and an increase in turbidity is likely to inhibit this, resulting in a decrease in the biomass of microalgae.
Dissolved oxygen	Dissolved oxygen is a function of a number of variables including organic loading, water exchange (through river flow or tidal exchange), and the presence of primary producers, etc. If there is a high oxygen demand and poor water exchange then the resulting oxygen-poor environment is likely to support microalgal communities dominated by cyanobacteria.
Nutrients	High nutrient loads in estuaries support high microalgal biomass (median phytoplankton chlorophyll *a* >8 µg.l-1, and median intertidal benthic microalgal chlorophyll *a* >23 mg.m^{-2}). Strong stratification in a nutrient-rich estuary is likely to support a dinoflagellate dominated phytoplankton community. Extended periods of low river flow and tidal exchange in a nutrient-rich estuary will accelerate the process of eutrophication in estuaries, resulting in an organic-rich and oxygen-poor environment that supports a cyanobacteria dominated microalgal community.
Sediment characteristics (including sedimentation)	The accumulation of fine sediment (silts and clays) provides an ideal benthic habitat for epipelic microphytobenthos. This can be a very productive environment supporting a complex food chain (e.g. mobile diatoms, polychaete worms, intertidal crabs, mud prawns, etc.). However, if there is a high organic content then the sediment environment is likely to become anoxic to the sediment surface in extreme cases, and is likely to be dominated by cyanobacteria. The sedimentation of fine sediment is unlikely in environments exposed to strong flow. These environments are typically dominated by coarse sediment, and exposed rocks and boulders providing a suitable habitat for episammic and epilithic microalgal taxa.
Other biotic components	The dominance of microalgae in an estuary is influenced by the presence of other biotic components. In a recently flushed estuary the fast-growing microalgae is perfectly adapted to colonise the environment, with little competition for space and resources. However, with time the higher trophic levels begin to recover and herbivory increases, particularly from the invertebrates, impacting on microalgal biomass. In addition, the presence of macrophytes and macroalgae impact on the microalgae, fringing vegetation and submerged aquatic vegetation provide habitat for epiphytic microalgae (at the expense of epipelic microalgae) but fast growing macroalgae (e.g. *Cladophora glomorata* and *Ulva intestinalis*) compete with microalgae for light and nutrients.

The above information, in turn, was used to estimate the cological health of the microalagae component in Temperate Estuaries. Table 5.2 lists the information together with the key parameters and pressures that contributed to change in the various Temperate estuaries.

Table 5.3 Microalgae health of the Temperate estuaries and the key parameters and/or pressures causing significant modification in health condition.

Estuary	Microalgae health	Key parameters/pressures			
		Flow modification	Change in mouth state	Reduced water quality	Change in macrophyte community
Orange	D/E	●	●	●	●
Buffels	B				●
Spoeg	A/B				
Groen	A/B				
Sout	C	●	●		●
Olifants	C	●		●	●
Jakkalsvlei	D	●	●	●	●
Wadrift	D/E	●	●	●	●
Verlorenvlei	D/E	●	●	●	●
Groot Berg	B/C	●		●	●
Rietvlei/Diep	D/E	●	●	●	●
Sout (Wes)	E	●	●	●	●
Houtbaai	E	●	●	●	●
Wildevoëlvlei	D	●	●	●	●
Bokramspruit	C/D	●	●	●	
Schuster	B	●			
Krom	A				
Buffels Wes	A				
Elsies	C/D		●	●	●
Silvermine	D	●	●	●	●
Sand	D	●	●	●	●
Zeekoei	E	●	●	●	●
Eerste	E	●	●	●	●
Lourens	D	●		●	●
Sir Lowry's Pass	D	●		●	●
Steenbras	B	●			
Rooiels	A				
Buffels (Oos)	B	●			
Palmiet	B/C	●	●	●	●
Bot/Kleinmond	C	●	●	●	
Onrus	E	●	●	●	●
Klein	C/D	●	●	●	
Uilkraals	C/D	●	●	●	●
Ratel	A/B				
Heuningnes	C	●	●	●	●
Klipdrifsfontein	A				
Breë	A/B	●		●	
Duiwenhoks	B	●			
Goukou	B	●			●
Gourits	B	●			●
Blinde	C	●		●	
Tweekuilen	D/E	●	●	●	●
Gericke	D/E	●	●	●	●
Hartenbos	D/E	●	●	●	●
Klein Brak	B/C	●			●
Groot Brak	C/D	●	●	●	●
Maalgate	C	●	●	●	

Table 5.3 continues/...

Estuary	Microalgae health	Key parameters/pressures			
		Flow modification	Change in mouth state	Reduced water quality	Change in macrophyte community
Gwaing	C			●	
Kaaimans	B	●			
Wilderness	B/C		●		
Swartvlei	B		●	●	
Goukamma	A/B				
Knysna	C				
Noetsie	B				
Piesang	C/D	●	●	●	●
Keurbooms	A				
Matjies	A/B				
Sout (Oos)	A/B				
Groot (Wes)	A/B				
Bloukrans	A				
Lottering	A				
Elandsbos	A				
Storms	A				
Elands	A				
Groot (Oos)	B			●	
Tsitsikamma	C	●	●	●	
Klipdrif	C			●	●
Slang	D		●	●	●
Krom Oos (Kromme)	E/F	●		●	●
Seekoei	E	●	●	●	●
Kabeljous	C	●	●	●	●
Gamtoos	B/C	●		●	●
Van Stadens	B	●			
Maitland	B/C	●		●	
Baakens	E	●	●	●	●
Papenkuils	E	●	●	●	●
Swartkops	D	●		●	●
Coega (Ngcura)	D	●	●		●
Sundays	D/E			●	●
Boknes	C	●	●	●	
Bushmans	D				●
Kariega	C	●			●
Kasuka	A/B				
Kowie	B				●
Rufane	B/C	●	●		●
Riet	A/B				
Kleinemond Wes	A/B				
Kleinemond Oos	B				
Klein Palmiet	A/B				●
Great Fish	D			●	
Old Womans	C	●		●	●
Mpekweni	B				
Mtati	B				
Mgwalana	B				
Bira	B				

Table 5.3 continues/...

Estuary	Microalgae health	Key parameters/pressures			
		Flow modification	Change in mouth state	Reduced water quality	Change in macrophyte community
Gqutywa	B				
Ngculura	B				
Mtana	B				
Keiskamma	B				
Ngqinisa	A/B				
Kiwane	A/B				
Tyolomnqa	A				
Shelbertsstroom	B				
Lilyvale	B				
Ross' Creek	A/B				
Ncera	A/B				
Mlele	B				
Mcantsi	B				
Gxulu	B/C				
Goda	B				
Hlozi	B/C				
Hickman's	B/C				
Ngqenga	B/C				
Buffalo	D	●		●	●
Blind	D	●	●	●	
Hlaze	D	●	●	●	
Nahoon	C/D	●		●	●
Qinira	B				
Gqunube	A/B				
Kwelera	A/B				
Bulura	A/B				
Cunge	A/B				
Cintsa	B				
Cefane	A/B				
Kwenxura	A				
Nyara	A				
Mtwendwe (Imtwende)	A				
Haga-Haga	A/B				
Mtendwe	A				
Quko	A				
Morgan	A/B				
Cwili	A				
Great Kei	B/C	●			
Gxara	B			●	
Ngogwane	B			●	
Qolora	A/B				
Ncizele	A/B				
Timba	B				
Kobonqaba	A				
Nxaxo/Ngqusi	A				
Cebe	A/B				
Gqunqe	A				
Zalu	A/B				

Table 5.3 continues/...

Estuary	Microalgae health	Key parameters/pressures			
		Flow modification	Change in mouth state	Reduced water quality	Change in macrophyte community
Ngqwara	A/B				
Sihlontlweni	A				
Nebelele	A/B				
Qora	A				
Jujura	A/B				
Ngadla	A				
Shixini	A				
Beechamwood	A				
Unnamed	A				
Kwa-Goqo	A				
Ku-Nocekedwa	A				
Nqabara	A				
Ngoma/Kobule	A				
Mendu	A				
Mendwana	A				
Mbashe	A/B				

Summarising the microalgae health of the Temperate estuaries, loss in flow were highlighted as the most prevalent factor contributing to the decline in health – highlighted in about 38% (60 systems) of the estuaries (Figure 5.1). Change in mouth state, with related shifts in retention time, was an influencing factor in about 25% (40 systems) of the estuaries in the region. Overall a decline in water quality (i.e. increase nutrient loading) occurred in about 35% (56 systems) of the estuaries. Loss/change in the macrophyte habitat also contributed to the overall microalgae condition in about 31% (50 systems) of Temperate estuaries.

Figure 5.1/...

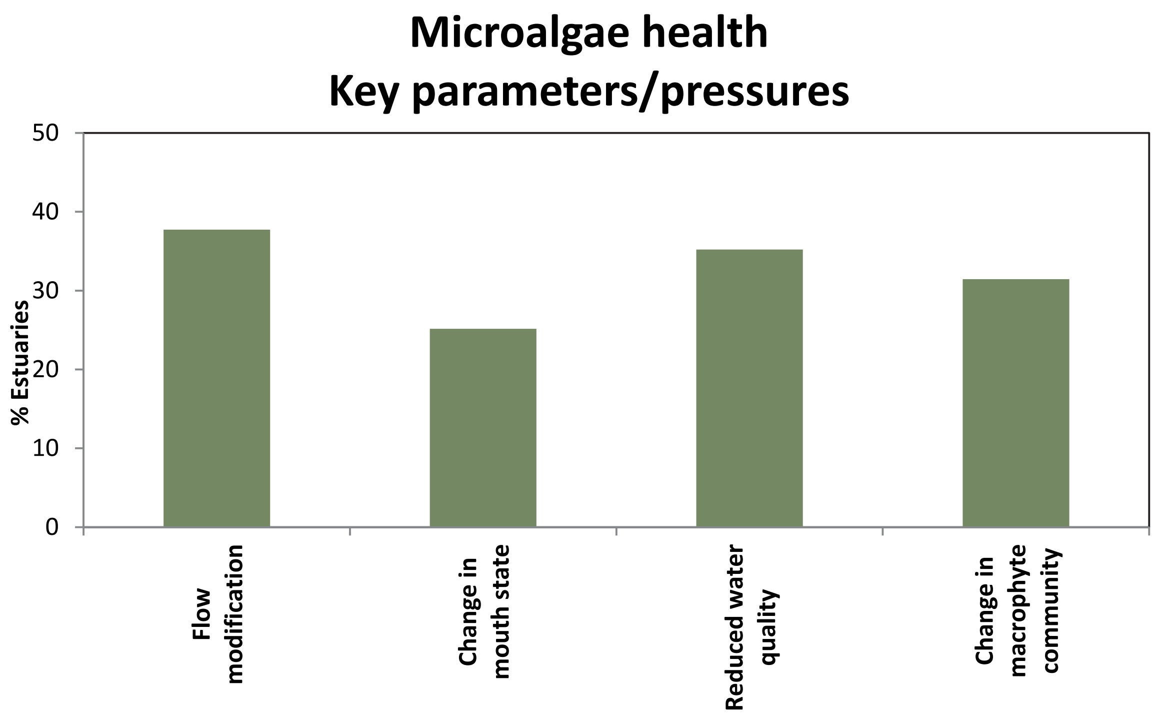

Figure 5.1 Key parameters or pressures that influence microalgae health in the Temperate estuaries

In most cases pressures were more severe in the urban areas or in coastal regions where agricultural activities were concentrated. The Warm-Temperate estuaries of the former Transkei and Ciskei region had the most pristine conditions, while the estuaries around Cape Town, Mossel Bay and Port Elizabeth showed the most severe decline in condition.

5.2 Macrophytes

Table 5.3 described the main habitats and macrophyte groups in South Africa's estuaries. Intertidal and supratidal salt marshes are the dominant macrophyte habitats in Temperate estuaries whereas reeds and sedges are prevalent in subtropical estuaries where there is higher rainfall and runoff. Availability of fine sediment, suitable sediment salinity gradient and some degree of tidal flushing creates ideal habitat for the development of salt marsh in Temperate estuaries. This is unique vegetation consisting mostly of herbaceous halophytes (plants tolerant of salinity). An additional macrophyte habitat is swamp forest that is not included here as it only occurs in subtropical estuaries.

Table 5.4 Macrophyte habitats recorded in the Temperate estuaries (spp. examples in italics)

Habitat type	Defining features, typical/dominant species
Open surface water area	This is the habitat associated with the water column of an estuary and is measured as water surface area. Serves as a possible habitat for phytoplankton.
Sand and mud banks	This habitat provides a possible area for microphytobenthos to inhabit.
Macroalgae	These can be free floating or attached to rocks and other substrates. Filamentous macroalgae often form algal mats and increase in response to nutrient enrichment or calm sheltered conditions when the mouth of an estuary is closed. Typical genera include *Enteromorpha* and *Cladophora*. Many marine species can get washed into an estuary and providing the salinity is high enough, can proliferate. These include *Codium*, *Caulerpa*, *Gracilaria* and *Polysiphonia.*
Submerged macrophytes	Plants that are rooted in both soft subtidal and low intertidal substrata and whose leaves and stems are completely submerged for most states of the tide. Submerged macrophytes tend to occur in permanently open estuaries, particularly eelgrass (*Zostera capensis*) whereas *Ruppia cirrhosa* prefers the less saline and sheltered conditions of TOCEs. *Potamogeton pectinatas* (ribbon weed, fennel pondweed) prefers fresher conditions (salinities below 10) and therefore occurs in closed systems or in the upper reaches of estuaries.
Salt marsh	Salt marsh plants show distinct zonation patterns along tidal inundation and salinity gradients. Zonation is well developed in estuaries with a large tidal range, e.g. Berg, Knysna and Swartkops estuaries. Common genera are *Sarcocornia*, *Salicornia*, *Triglochin*, *Limonium* and *Juncus*. Halophytic grasses such as *Sporobolus virginicus* and *Paspalum* spp. are also present. Intertidal salt marsh occurs below mean high water spring and supratidal salt marsh above this. *Sarcocornia pillansii* is common in the supratidal zone and large stands can occur in estuaries such as the Olifants.
Reeds and sedges	Reeds, sedges and rushes are important in the freshwater and brackish zones of estuaries. Because they are often associated with freshwater input they can be used to identify freshwater seepage sites along estuaries. The dominant species are the common reed *Phragmites australis*, *Schoenoplectus scirpoides* and *Bolboschoenus maritimus.*
Mangroves	Mangroves are trees that establish in the intertidal zone in permanently open estuaries along the east coast of South Africa north of East London where water temperature is usually above 20°C. The white mangrove *Avicennia marina* is the most widespread, followed by *Bruguiera gymnorrhiza* and then *Rhizophora mucronata*.
Floodplain	This is a mostly grassy area which occurs within the 5 m contour line. It also includes dune vegetation at the mouth and riparian vegetation along the middle and upper reaches of the estuary.

Macrophyte habitats provide important ecosystem services such as filtering and detoxification. They cycle nutrients by taking them up and releasing them again through decomposition processes. They provide a nursery for fish and protected habitats for a variety of other organisms. Salt marsh, mangrove and reed & sedge wetlands protect the land from floods and sea storms, and sequester carbon and serve as a source of raw materials for humans. A diversity of macrophyte habitats creates sites desirable for recreation, tourism and research. The effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats are described in Table 5.5.

Table 5.5 Effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats

Process	Macrophytes
Mouth condition (provide temporal implications where applicable)	Open mouth conditions creates intertidal habitat. Salt marsh species occur along a tidal inundation gradient. Closed mouth conditions would promote the growth and proliferation of macroalgae. Prolonged mouth closure could result in the die back of intertidal salt marsh species.
Retention times of water masses	Greater water retention time would provide better opportunities for nutrient uptake by macrophytes thereby favouring their abundance. Low flow conditions could cause the expansion of reeds and sedges into the water channel further reducing flow.
Flow velocities (e.g. tidal velocities or river inflow velocities)	High flow prevents the establishment of large submerged macrophyte beds. Currents less than 0.1 m s^{-1} favour the growth and establishment of submerged macrophytes such as *Stuckenia pectinata* (pondweed).
Total volume and/or estimated volume of different salinity ranges	The longitudinal salinity gradient promotes species richness, different macrophyte habitats are distributed along the length of the estuary, e.g. salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area and preventing the encroachment of reeds and sedges into the main river channel. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal areas. High groundwater level and freshwater flooding maintains suitable moisture conditions for plant growth in salt marshes. Floods are important for resetting the estuary and removing accumulated sediment and macrophyte growth. Floods would also deposit rich organic mud in estuaries and thus floods have an important nitrifying effect.
Salinity	A change in salinity will influence the macrophyte habitats, e.g. reeds and sedges grow better in brackish water whereas salt marsh and sea grass grow better in salinity close to water. Development and runoff can often decrease salinity leading to reed expansion. Reeds and sedges are sensitive to increases in salinity but can survive if their roots and rhizomes are located in salinity less than 20 ppt. However, if freshwater seepage is reduced then it may lead to die back. Freshwater inflow dilutes salts, preventing hypersaline conditions in salt marshes. Rainfall and evaporation on the marsh, groundwater seepage from adjacent land and the salinity of the tidal water that inundates the marsh control the sediment salinity. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal areas.
Turbidity	Increase sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment and distribution. Submerged macrophyte distribution is naturally limited in turbid estuaries, however, catchment degradation can increase silt load.
Dissolved oxygen	Accumulations of macroalgae can reduce the water quality of estuaries, not only by depleting the oxygen in the water column upon decomposition but also causing anoxic sediment conditions when large mats rest on the sediment under low flow conditions.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges). Eutrophication responses are an increase in plant growth, e.g. expansion of reeds, blooms of macroalgae or invasive aquatic floating macrophytes such as *Azolla*. Inorganic nutrients (especially N and P) are known to stimulate the abundance of ephemeral and epiphytic macroalgae. *Ulva* and *Cladophora* often form accumulations due to their filamentous nature and higher nutrient uptake rates than algae with thicker thalli. These accumulations can reduce the water quality of estuaries, by depleting the oxygen in the water column upon decomposition.
Sediment characteristics (including sedimentation)	Catchment degradation and sediment input can lead to unnatural expansion of macrophyte habitats, e.g. reed encroachment into previous open water channel habitats.
Other biotic components	Loss of macrophyte habitat due to invasion by exotic species. Colonisation of disturbed floodplains or estuary margins by invasive plants. Grazing, browsing and trampling by cattle and goats.

As freshwater inflow maintains the structure and function of estuaries, any changes to this will have a negative influence on the macrophytes. Changes in flow velocity and subsequent sedimentation mostly results in macrophytes encroaching into open water areas. Changes in mouth state and water level can cause die back of macrophytes. Salinity influences species richness, biomass and community composition. In an estuary with a longitudinal salinity gradient different macrophytes will be distributed along the gradient. Deterioration in water quality is an increasing problem in South African estuaries. This results in reed expansion, increases in macroalgal blooms and invasive aquatics such as water hyacinth. Floating invasive aquatics frequently occur in the upper reaches of estuaries in response to agricultural return flow.

Most estuarine habitat has been lost due to industrial and residential developments. In many systems agriculture also takes place within the 5 m contour line. The largest habitat loss has occurred in the largest estuaries, e.g. Orange, Berg and Swartkops. However, entire small estuaries have been lost to development, e.g. harbour and salt works in the Coega Estuary and canalisation of the Baakens Estuary.

Grazing and associated trampling by livestock is a common pressure in many estuaries. Browsing by livestock has recently been found to have a major impact on mangroves in rural estuaries in the former Transkei. Hoppe-Speer (2013) noted anthropogenic impacts in 17 estuaries and showed that harvesting of mangrove wood, livestock browsing and trampling and footpaths occurred in more than 70% of the estuaries. Browsing on trees by cattle resulted in a clear browse-line and browsing on propagules mainly by goats reduced mangrove seedling establishment. Mangroves are harvested for building material and fuel wood. Reeds and sedges are also harvested but this activity is more common in subtropical compared to Warm-Temperate estuaries, e.g. *Juncus kraussii* (ncema) and *Phragmites australis* (common reed), are commonly used in KwaZulu-Natal by the local community for mats and basketry.

Alien vegetation can displace estuarine macrophytes. This particularly occurs along the boundaries of estuaries where the Eco tone between the terrestrial and estuarine habitat has been disturbed. In the Temperate estuaries common invasives are *Acacia cyclops*, *Acacia longifolia*, *Acacia mearnsii*, *Lantana camara*, *Solanum americanum* and *Ricinus communis.* Common reed *Phragmites australis* can spread and colonise disturbed Eco tones characterised by low sediment and groundwater conductivity from adjacent development and freshwater runoff.

Other impacts not quantified in this assessment are activities influencing submerged macrophytes such as bait digging, damage by boats and dredging (Adams *et al*. 1999). Sedimentation and subsequent reed expansion has been identified as a separate dominant pressure in KwaZulu-Natal estuaries. For this assessment of Temperate estuaries these changes were considered under physical habitat degradation.

Table 5.6 lists the health state of the macrophyte component in Temperate estuaries, as well as the key parameters and processes that have influenced the condition.

Table 5.6 The macrophyte health state of the Temperate estuaries and the key parameters and/or pressures causing significant modification in health condition

Estuary	Macrophyte Health	Key parameters/pressures							
		Flow velocity	Mouth state & water levels	Salinity	Water quality (other than salinity)	Physical habitat degradation	Grazing	Harvesting	Alien vegetation
Orange	D	●	●	●	●		●		●
Buffels	C/D					●			
Spoeg	A/B								
Groen	A/B					●			
Sout	D	●	●	●		●			
Olifants	C/D	●		●	●		●		
Jakkalsvlei	C/D	●	●	●	●	●			
Wadrift	D/E	●	●	●	●	●			
Verlorenvlei	D	●	●	●	●	●	●		●
Groot Berg	D	●		●	●	●	●		●
Rietvlei/Diep	E	●	●	●	●	●			
Sout (Wes)	F	●	●	●	●	●			
Houtbaai	D/E	●	●	●	●	●			●
Wildevoëlvlei	D	●	●	●	●	●			●
Bokramspruit	A/B	●	●		●	●			
Schuster	A/B	●							
Krom	A								
Buffels Wes	A								
Elsies	E		●	●	●	●			
Silvermine	D/E	●	●	●	●	●			●
Sand	D	●	●	●	●	●			●
Zeekoei	E	●	●	●	●	●			●
Eerste	D/E	●	●	●	●	●			●
Lourens	D	●			●	●			●
Sir Lowry's Pass	E/F	●			●	●			●
Steenbras	A	●							
Rooiels	A/B					●			
Buffels (Oos)	A/B	●							
Palmiet	D	●	●		●				
Bot/Kleinmond	A/B	●	●	●	●				●
Onrus	D/E	●	●	●	●	●			●
Klein	B/C	●	●	●	●				●
Uilkraals	C/D	●	●	●	●	●			●
Ratel	B								●
Heuningnes	C/D	●	●	●	●				●
Klipdrifsfontein	A								
Breë	B	●			●				●
Duiwenhoks	A/B	●							
Goukou	C	●		●		●			●
Gourits	C/D	●		●		●			●
Blinde	A/B	●			●				●
Tweekuilen	D/E	●	●	●	●	●			
Gericke	D	●	●	●	●	●			
Hartenbos	C/D	●	●	●	●	●			●
Klein Brak	C	●				●	●		●
Groot Brak	D/E	●	●	●	●	●			●
Maalgate	A/B	●	●		●				
Gwaing	B				●				●
Kaaimans	A/B	●							
Wilderness	B/C		●			●			
Swartvlei	B/C		●		●	●			

Table 5.6 continues/...

Estuary	Macrophyte Health	Key parameters/pressures							
		Flow velocity	Mouth state & water levels	Salinity	Water quality (other than salinity)	Physical habitat degradation	Grazing	Harvesting	Alien vegetation
Goukamma	A/B				●	●			●
Knysna	B			●		●			
Noetsie	A/B								
Piesang	D	●	●	●	●	●			
Keurbooms	A/B					●			●
Matjies	A/B					●			●
Sout (Oos)	A								
Groot (Wes)	B					●			
Bloukrans	A								
Lottering	A								
Elandsbos	A								
Storms	A								
Elands	A								
Groot (Oos)	A/B				●				
Tsitsikamma	A/B	●	●	●	●				
Klipdrif	C	●			●				
Slang	C/D	●	●		●	●	●		●
Krom Oos (Kromme)	D	●		●	●	●			●
Seekoei	E	●	●	●	●	●			●
Kabeljous	C	●	●		●	●			●
Gamtoos	D	●			●	●			
Van Stadens	B	●							
Maitland	B	●			●				
Baakens	F	●	●	●	●	●			●
Papenkuils	F	●	●	●	●	●			
Swartkops	D/E	●			●	●			●
Coega (Ngcura)	F	●	●	●		●			●
Sundays	D	●		●	●	●			
Boknes	B	●	●		●				
Bushmans	C			●		●			
Kariega	C	●		●		●			
Kasuka	B					●			
Kowie	C/D				●	●			
Rufane	C	●	●			●			●
Riet	A/B								
Kleinemond Wes	A/B					●	●		
Kleinemond Oos	A/B			●		●			
Klein Palmiet	C					●			
Great Fish	B				●				●
Old Womans	C	●			●	●			
Mpekweni	A/B	●					●		
Mtati	A/B	●					●		
Mgwalana	A/B	●					●		●
Bira	A/B	●					●		●
Gqutywa	A/B						●		●
Ngculura	B	●					●		●
Mtana	A								
Keiskamma	C			●	●	●	●		●
Ngqinisa	A/B								
Kiwane	A/B								●
Tyolomnqa	A/B								●
Shelbertsstroom	A/B				●	●			

Table 5.6 continues/...

Estuary	Macrophyte Health	Key parameters/pressures							
		Flow velocity	Mouth state & water levels	Salinity	Water quality (other than salinity)	Physical habitat degradation	Grazing	Harvesting	Alien vegetation
Lilyvale	**A/B**		●						
Ross' Creek	**A/B**								
Ncera	**A/B**								
Mlele	**A/B**					●			
Mcantsi	**B**								
Gxulu	**C**				●	●			
Goda	**A/B**				●				
Hlozi	**A/B**				●				
Hickman's	**A/B**				●				
Ngqenga	**B**				●	●			
Buffalo	**C**	●		●	●	●			
Blind	**B/C**	●	●	●	●	●			
Hlaze	**A/B**	●	●	●	●				
Nahoon	**C**	●		●	●	●			●
Qinira	**B**				●	●			
Gqunube	**B**					●			
Kwelera	**B**					●	●		
Bulura	**B**					●			
Cunge	**A/B**								
Cintsa	**B/C**					●			
Cefane	**A/B**								
Kwenxura	**A/B**								
Nyara	**A**								
Mtwendwe (Imtwende)	**A/B**								
Haga-haga	**A/B**								
Mtendwe	**A/B**								
Quko	**A**								
Morgan	**B**								
Cwili	**A/B**								
Great Kei	**A/B**	●				●	●		
Gxara	**A**				●				
Ngogwane	**A/B**				●				
Qolora	**A/B**					●			
Ncizele	**A/B**								
Timba	**A/B**								
Kobonqaba	**C**						●		
Nxaxo/Ngqusi	**C**						●	●	
Cebe	**A**						●	●	
Gqunqe	**A**						●	●	
Zalu	**A/B**								
Ngqwara	**A/B**								
Sihlontlweni	**A**								
Nebelele	**A**								
Qora	**A/B**								
Jujura	**A**								
Ngadla	**A**								
Shixini	**A/B**								
Beechamwood	**A**								
Unnamed	**A**								
Kwa-Goqo	**A**								
Ku-Nocekedwa	**A**								
Nqabara	**B**						●	●	●

Table 5.6 continues/...

Estuary	Macrophyte Health	Key parameters/pressures							
		Flow velocity	Mouth state & water levels	Salinity	Water quality (other than salinity)	Physical habitat degradation	Grazing	Harvesting	Alien vegetation
Ngoma/Kobule	**A/B**						●	●	
Mendu	**A**								
Mendwana	**A**								
Mbashe	**A/B**						●		

Reviewing the health of the Temperate estuaries, macrophytes indicate that the loss in base flow and/or related flow velocity contributed to a decline in macrophyte condition in about 43% (68 systems) of the estuaries in the region (Figure 5.2). A decline in water quality (i.e. increase nutrient loading) was noted as a key factor in about 42% (66 systems) of the estuaries. An additional key factor in the general decline of a number of estuaries – 45% (71 systems) – was the physical habitat alteration as a result of, e.g. riparian development, mouth canalisation, agricultural activities on the flood plain, roads and road infrastructure.

Change in mouth state, with a related change in water levels was an influencing factor in about 26% (41 systems) of the estuaries in the region. Significant changes in the salinity regime of about 28% (44 systems) of the estuaries also influenced the overall macrophyte community structure.

Pressures that directly contribute to the degradation of macrophyte abundance are grazing in 14% (23 systems), harvesting of reeds/sedges/mangroves in 3% (5 systems) and alien invasive in 29% (49 systems).

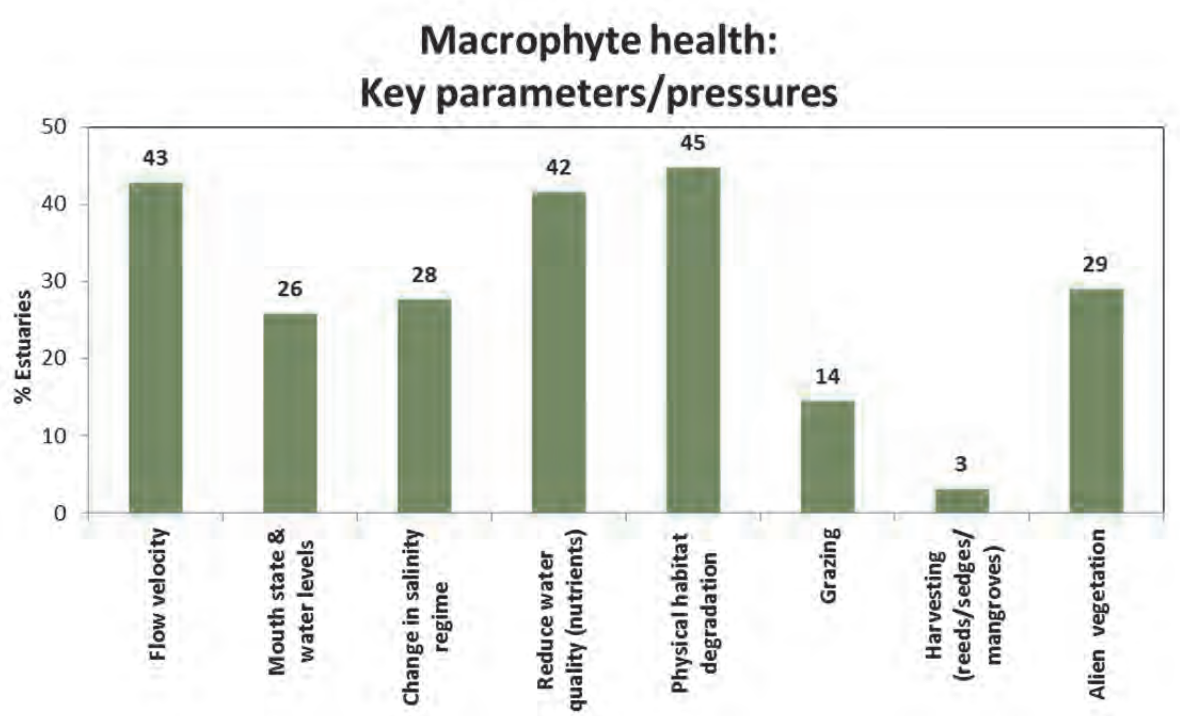

Figure 5.2 Key parameters or pressures that influence the Macrophyte health of the Temperate estuaries

In most cases pressures were more severe in the urban areas or in coastal regions that have major agricultural activities. The Warm-Temperate estuaries of the former Transkei and Ciskei region were in the most pristine condition, while the estuaries around Cape Town, Mossel Bay and Port Elizabeth showed the most severe decline in condition.

5.3 Invertebrates

More than thirty species of intertidal macrofauna are recorded in the lower reaches of the temperate estuaries (Table 5.7). Larger organisms such as sand prawn (*Callianassa kraussi*), mud prawn (*Upogebia africana*) and bloodworm (*Arenicola loveni*) make an important component of estuarine invertebrate populations. Polychaetes are common at all localities, particularly around low and mid-water levels, while small worms, such as *Prionospio sexoculata* were particularly abundant at the upper reaches of most systems. Crabs such as *Dotilla fenestrata* were fairly common at the high tide level. Along the areas Zostera beds occurred while *Paratylodiplax edwardsii* occur around mid-tide at the muddy areas.

Table 5.7 Classification of South African estuarine invertebrate fauna and the parameters influencing their abundance and distribution. POM = Particulate Organic Matter, MPB = Microphytobenthos (Turpie *et al*. 2013)

#	Description	Influencing factors
1	Polychaetes – estuarine resident (e.g. *Ceratoneries keiskama*)	Medium to fine sediments; detritus; other edible invertebrates
2	Polychaetes – marine (e.g. *Arenicola*)	Medium to coarse sediments; detritus; open mouth; saline water
3	Amphipods	Finer sand/mud; shelter; detritus; POM; reduced salinity
4	Isopods	Coarse sediments; higher salinity; dead matter
5	Gastropods – marine dominated species (detritivores, scavengers & predators, e.g. Bullia)	Detritus; open mouth; MPB; higher salinity
6	Gastropods – resident sediment living grazers, detritivores & predators (e.g. *Hydrobia*; *Natica*)	Shelter; submerged macrophytes; MPB; detritus
7	Gastropods – grazers associated with macrophytes	Shelter; submerged macrophytes; MPB
8	Bivalves – estuarine resident	Medium -fine sediments; submerged macrophytes; POM
9	Bivalves – marine (e.g. *Donax/Tellina*)	Med-coarse sediments; open mouth; POM
10	Crabs – resident estuarine (e.g. *Spiroplax)*	Medium -fine sediments; (presence of prawns for *Spiroplax*)
11	Crabs – marine (e.g. *Hymenosoma*)	Open mouth; saline
12	Carids – marine (e.g. *Palaemon*)	Medium -fine sediments; detritus; open mouth; high salinity
13	Carids – resident (e.g. *Betaeus*)	Medium -fine sediments; detritus; submerged macrophytes; prawns (*Betaeus*)
14	Saltmarsh inverts	Saltmarsh
15	Insect larvae	Lower salinities
16	Mud prawns (e.g. *Upogebia*)	Fine sand/mud; open mouth; POM
17	Sand prawns (e.g. *Calianassa*)	Sand; not extended fresh water (>17ppt to breed); POM
18	Zooplankton – marine	Phytoplankton; open mouth
19	Zooplankton estuarine resident	Phytoplankton

The main factors affecting the abundance of the different invertebrate groups found in the Temperate estuaries are summarised in Table 5.8.

Table 5.8 Effect of abiotic characteristics and processes, as well as other biotic components on invertebrate groupings

Factor	Affected categories
Mouth condition (provide temporal implications where applicable)	Mouth closure would benefit the subtidal macrozoobenthos, since the increase in benthic macroalgae would increase food availability. However, the intertidal community (particularly the mud prawn *Upogebia africana* and the marsh crabs) are likely to decline in abundance-biomass as available habitat becomes inundated.
Retention times of water masses	Increased retention times of the water mass would benefit the planktonic assemblage (holoplankton and meroplankton), since loss of larvae through tidal entrainment out of the estuary would be reduced.
Flow velocities (e.g. tidal velocities or river inflow velocities)	As tidal velocities increase, loss of the zooplanktonic forms would increase, particularly among the copepods. Under high flow conditions, entire populations will be lost. Since zooplankton is a key component in the estuarine food web, the ripple effect would impact higher trophic levels directly. Similarly, the benthic assemblage would also be flushed from the system under high flow conditions.
Total volume and/or estimated volume of different salinity ranges	The presence of different salinity zones (0-10, 10-30 and 30-35 approximately) ensures different habitats for organisms. These different zones also lead to increased species richness in the estuary. From a biomass perspective, the larger the 10-30 zone (volume), the higher the biomass of invertebrates present.
Floods	Floods scour accumulated sediments from the estuary, particularly in the lower reaches. Tidal exchange is enhanced and this leads to a resetting of the balance between the three major salinity zones. Because tidal exchange is more dynamic under open mouth conditions, coarser sediments (sand) in the lower estuary particularly are resorted and fine material scoured from these lower reaches near the mouth.
Salinities	The persistence of a full salinity gradient along the length of the estuary is an important characteristic and ensures a range of habitats available to organisms.
Turbidity	Although naturally turbid, benthic organisms particularly become smothered under excessive loads of fine material in the water column.
Dissolved oxygen	Currently not a negative characteristic of the estuary. However, if values fall below approximately 50% of surface saturation, organisms become stressed. Sessile organisms particularly are affected and high mortality can be expected if values begin to fall below the 50% saturation level.
Subtidal, intertidal and supratidal habitat	The availability of these three habitats is an important characteristic of the estuary, increasing species richness and biomass within these zones.
Sediment characteristics (including sedimentation)	A range of sediment types (particularly sand and mud) provides habitat for those organisms that require specific sediment characteristics. Along the estuary (approximately 10-30 salinity range), sediment is probably the single most important environmental variable that structures benthic communities. At the mouth and in the uppermost reaches of the estuary, salinity becomes increasingly important.
Phytoplankton biomass	High phytoplankton biomass leads to increased biomass of invertebrates in the estuary as it is the most important food component in the seston. In the Great Fish, high levels of phytoplankton biomass are sustained, leading to high biomass among the invertebrate community over time.
Benthic microalgae biomass	As above
Zooplankton biomass	A high zooplankton biomass is a feature of the estuary, maintained by a combination of high phytoplankton biomass and a relatively large euryhaline zone (salinity range ~10-30).
Aquatic macrophyte cover	Macrophyte cover is important for the intertidal and supratidal invertebrate community (particularly crabs) as it provides protective habitat and detritus for consumption by the community. Detritus is also exported from the marsh, providing food resources for filter feeders in the estuary water body.
Fish biomass	A high fish biomass leads to high levels of predation on invertebrates, but production levels of the food resources is also high.

Table 5.9 lists the health state of the invertebrate component in Temperate estuaries, as well as the key parameters and processes that have influenced the condition.

Table 5.9 The invertebrate health of the Temperate estuaries and the key parameters and/or pressures causing significant modification in health condition (estuaries rated less than a B Category)

Estuary	Invertebrate Health	Key parameters/pressures								
		Loss of flow variability/base flows	Loss of resetting floods	Mouth state/loss of connectivity	Change in salinity regime	Reduce water quality (oxygen, turbidity, pesticides)	Loss of physical habitat	Change in microalgae community	Change in macrophyte community	Bait collection
Orange	D	●	●	●		●		●	●	●
Buffels	C						●		●	●
Spoeg	B									●
Groen	B									●
Sout	D/E	●		●	●		●	●	●	
Olifants	C	●	●		●	●		●	●	●
Jakkalsvlei	C/D	●		●	●		●	●	●	●
Wadrift	D/E	●		●	●		●	●	●	●
Verlorenvlei	D	●		●			●	●	●	●
Groot Berg	D	●	●		●	●	●		●	●
Rietvlei/Diep	E/F	●		●	●	●	●	●	●	●
Sout (Wes)	F	●		●	●	●	●	●	●	
Houtbaai	E	●		●	●	●	●	●	●	●
Wildevoëlvlei	D	●		●	●	●	●	●	●	●
Bokramspruit	A/B	●		●		●	●	●		
Schuster	A/B									
Krom	A									
Buffels Wes	A									
Elsies	E/F			●	●	●	●	●	●	
Silvermine	E	●		●	●	●	●	●	●	●
Sand	D/E	●		●	●	●	●	●	●	●
Zeekoei	E	●		●	●	●	●	●	●	●
Eerste	E/F	●		●	●	●	●	●	●	●
Lourens	D	●				●	●	●	●	●
Sir Lowry's Pass	F	●				●	●	●	●	●
Steenbras	A		●							●
Rooiels	A/B									●
Buffels (Oos)	A/B									●
Palmiet	C/D	●	●	●		●		●	●	●
Bot/ Kleinmond	B			●	●	●		●		●
Onrus	D/E	●		●	●	●	●	●	●	●
Klein	C	●		●	●	●		●		●
Uilkraals	D	●	●	●	●	●	●	●	●	●
Ratel	B									●
Heuningnes	D	●		●	●			●	●	●
Klipdrifsfontein	A									
Breë	B		●							●
Duiwenhoks	B/C	●								●
Goukou	C	●					●		●	●
Gourits	C	●	●		●		●		●	●
Blinde	B/C	●				●		●		●
Tweekuilen	D/E	●		●	●	●	●	●	●	
Gericke	D/E	●		●	●	●	●	●	●	
Hartenbos	C/D	●	●	●	●	●	●	●	●	●
Klein Brak	B/C	●					●	●	●	●
Groot Brak	D	●	●	●	●	●		●	●	●
Maalgate	D	●		●		●		●		●

Table 5.9 continues/...

Estuary	Invertebrate Health	Key parameters/pressures								
		Loss of flow variability/base flows	Loss of resetting floods	Mouth state/loss of connectivity	Change in salinity regime	Reduce water quality (oxygen, turbidity, pesticides)	Loss of physical habitat	Change in microalgae community	Change in macrophyte community	Bait collection
Gwaing	C					●		●		●
Kaaimans	C	●								●
Wilderness	B			●				●		●
Swartvlei	B									●
Goukamma	A/B									●
Knysna	B/C							●		●
Noetsie	C/D									●
Piesang	D	●		●	●	●	●	●	●	●
Keurbooms	A									●
Matjies	A/B									●
Sout (Oos)	A									●
Groot (Wes)	A/B									●
Bloukrans	A									●
Lottering	A									●
Elandsbos	A									●
Storms	A									
Elands	A									●
Groot (Oos)	A					●				●
Tsitsikamma	B	●		●	●			●		●
Klipdrif	C/D							●	●	●
Slang	D			●			●	●	●	●
Krom Oos (Kromme)	E/F	●	●		●	●	●	●	●	●
Seekoei	E	●	●	●	●	●	●	●	●	●
Kabeljous	C	●		●		●	●	●	●	●
Gamtoos	B	●				●	●	●	●	●
Van Stadens	B	●								●
Maitland	B/C	●				●		●		●
Baakens	F	●		●	●	●	●	●	●	●
Papenkuils	F	●		●	●	●	●	●	●	●
Swartkops	D/E	●	●			●	●	●	●	●
Coega (Ngcura)	F	●		●	●		●	●	●	●
Sundays	D				●			●	●	●
Boknes	C	●		●				●		●
Bushmans	C							●	●	●
Kariega	D	●						●	●	●
Kasuka	A/B									●
Kowie	C/D						●		●	●
Rufane	C	●		●			●	●	●	●
Riet	A/B									●
Kleinemond Wes	A/B									●
Kleinemond Oos	A/B				●					●
Klein Palmiet	C						●		●	●
Great Fish	D							●		●
Old Womans	D	●				●	●	●	●	●
Mpekweni	B	●								●
Mtati	A/B	●								●
Mgwalana	A/B	●								●
Bira	A/B	●								●
Gqutywa	A/B									●

Table 5.9 continues/...

Estuary	Invertebrate Health	Key parameters/pressures								
		Loss of flow variability/base flows	Loss of resetting floods	Mouth state/loss of connectivity	Change in salinity regime	Reduce water quality (oxygen, turbidity, pesticides)	Loss of physical habitat	Change in microalgae community	Change in macrophyte community	Bait collection
Ngculura	A/B	●								
Mtana	A/B									●
Keiskamma	C				●		●		●	●
Ngqinisa	A/B									●
Kiwane	A/B									●
Tyolomnqa	A/B									●
Shelbertsstroom	B						●			●
Lilyvale	B			●						●
Ross' Creek	A/B									●
Ncera	A/B									●
Mlele	A/B						●			●
Mcantsi	B									●
Gxulu	C					●	●	●	●	●
Goda	A/B									●
Hlozi	A/B							●		●
Hickman's	A/B							●		●
Ngqenga	A/B						●	●		
Buffalo	D	●	●		●	●	●	●	●	●
Blind	C	●		●	●	●	●	●		●
Hlaze	C	●		●	●	●		●		●
Nahoon	C/D	●	●		●	●		●	●	●
Qinira	C					●	●			●
Gqunube	B/C									●
Kwelera	B									●
Bulura	B									●
Cunge	A/B									●
Cintsa	A/B						●			●
Cefane	A/B									●
Kwenxura	A/B									●
Nyara	A/B									●
Mtwendwe (Imtwende)	A/B									●
Haga-haga	A/B									●
Mtendwe	A/B									●
Quko	A									●
Morgan	C									●
Cwili	B									●
Great Kei	B/C	●	●				●	●		●
Gxara	A/B									●
Ngogwane	A/B									●
Qolora	A/B									●
Ncizele	A/B									●
Timba	A/B									
Kobonqaba	A/B								●	●
Nxaxo/Ngqusi	B								●	●
Cebe	A									●
Gqunqe	A									●
Zalu	A/B									●
Ngqwara	A/B									●
Sihlontlweni	A									●

Table 5.9 continues/...

Estuary	Invertebrate Health	Loss of flow variability/base flows	Loss of resetting floods	Mouth state/loss of connectivity	Change in salinity regime	Reduce water quality (oxygen, turbidity, pesticides)	Loss of physical habitat	Change in microalgae community	Change in macrophyte community	Bait collection
		Key parameters/pressures								
Nebelele	A									
Qora	A/B									●
Jujura	A/B									●
Ngadla	A									●
Shixini	A									●
Beechamwood	A									
Unnamed	A									
Kwa-Goqo	A									
Ku-Nocekedwa	A									
Nqabara	A/B									●
Ngoma/Kobule	A/B									●
Mendu	A									●
Mendwana	A									
Mbashe	A/B									●

Assessing the invertebrate health of the Temperate estuaries, loss/change in habitat significantly contributed to the decline in overall invertebrate health – 34% (54 systems) of estuaries showed a loss/change of macrophyte habitats, while 31% (50 systems) showed a significant loss of physical habitat (Figure 5.3). Change in mouth state and a related loss of connectivity was an influencing factor for the invertebrates in about 25% (40 systems) of the estuaries in the region.

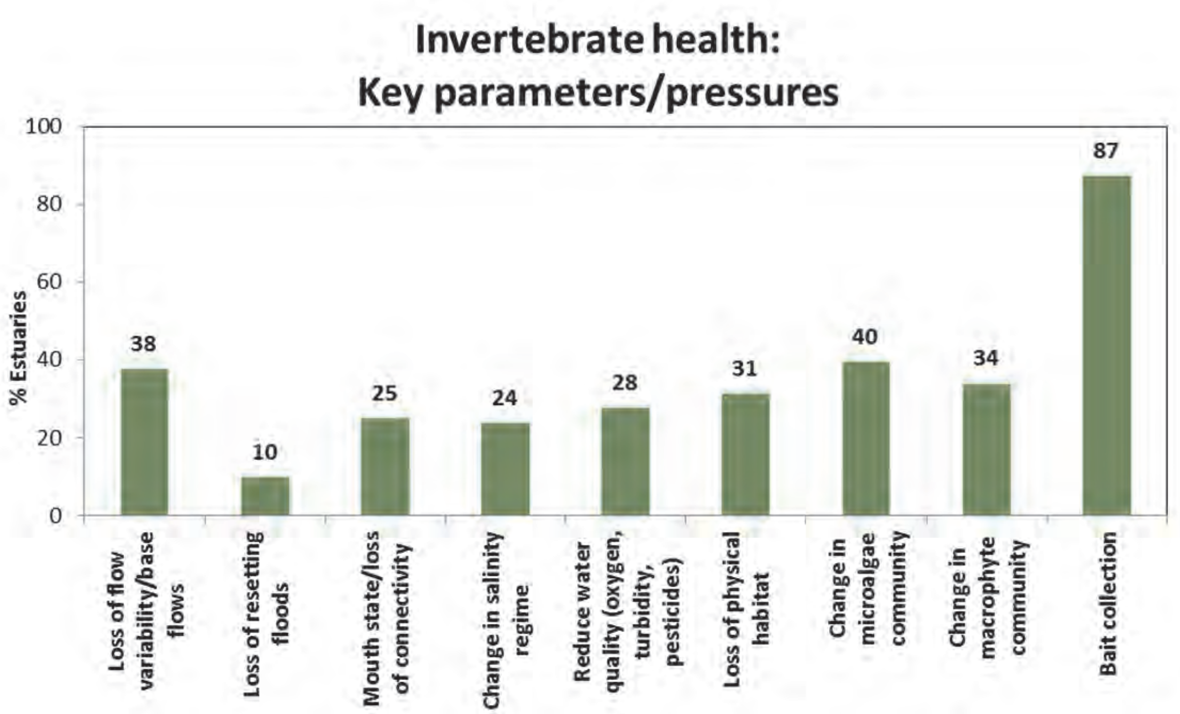

Figure 5.3 Key parameters or pressures that influence the invertebrate health of the Temperate estuaries

Loss in flow variability and/or changes in base flows were highlighted as the reason for the decline in invertebrate health in about 38% (60 systems) of the estuaries, while the loss of resetting floods estimated to be significant for invertebrates in about 10% (16 systems) of the estuaries. Shifts in the salinity regime of about 24% (38 systems) of the estuaries were noted as a possible contributing factor. A decline in water quality (i.e. reduction in oxygen, increase turbidity or presence of toxic substances, e.g. herbicides and pesticides) was noted in about 28% (44 systems) of the estuaries. In addition the loss or change in microalgae abundance in about 40% (63 systems) of estuaries was also a significant factor in the reduction in invertebrate health.

A key pressure that directly contributes to a decline in invertebrate abundance is bait collection which occurred in about 87% of the estuaries (139 systems) in the region. While target species such as sand and mud prawn are relatively resilient in terms of bait collection, habitat destruction and trampling associated with this activity significantly impact on the less reliant target species and critical habitats such as submerged macrophyte beds.

In most cases pressures were more severe in the urban areas or in estuaries that are associated with holiday destinations. The Warm-Temperate estuaries of the former Transkei and Ciskei region were the most pristine in terms of conditions, while the estuaries around Cape Town, Mossel Bay and Port Elizabeth showed the most severe decline in condition. Estuaries that are targeted for recreational fishing generally also showed a related decline in health due to bait collection activities.

5.4 Fish

Estuarine fish diversity in Southern Africa declines south and westwards with few species typical of the tropical and subtropical east coast bioregions occurring on South Africa's Warm-Temperate south-east coast or Cool-temperate west coast (Day 1981, Whitfield 1994, Turpie *et al*. 1999, Whitfield 2005). Conversely, biological and fisheries productivity are highest in the Cool-temperate bioregion and decline eastward in the warm and subtropical bioregions (Lamberth and Turpie 2003). Within each region, fish productivity is higher in permanently open versus temporarily open-closed systems (Harrison and Whitfield 2006) (Table 5.10). Estuarine fish diversity also increases northward into the subtropical and tropical bioregions of the west coast of Sub-Saharan Africa and, in contrast to east coast systems, is strongly influenced by an abundance of freshwater species (Whitfield 2005). Freshwater fish are also a distinct component of the fish assemblages of the Cool-Temperate Orange (47%) and Olifants (21%) estuaries and comprise species mostly endemic to those individual systems (Van Viekerk *et al*. 2013). In addition to this, introduced freshwater species have become dominant in the middle and upper reaches of most estuaries on South Africa's west coast. In contrast to species diversity, the degree of endemism within estuarine fish assemblages increase southward with some species (e.g. Bot River klipvis, *Clinus spatulatus)* confined to one or two systems. This can mostly be attributed to repeated isolation by the northward shift of polar waters and sea level changes during successive glacial periods as well as to the spatial shifts in the transition zones between the three biogeographical regions. These same drivers are largely responsible for distinct populations and behavioural traits in the Cool and Warm-Temperate bioregions (Freon *et al*. 2010). In all, including indigenous freshwater fish, approximately 50 species are associated with estuaries in the Cool-temperate bioregion, more than 100 with those in the Warm-Temperate region and approximately 250 for those in subtropical waters.

Table 5.10 Classification of South African fish fauna according to their dependence on estuaries (adapted from Whitfield 1994)

Category	Description
I Ia Ib	Truly estuarine species, which breed in Southern African estuaries; subdivided as follows: Resident species which have not been recorded breeding in the freshwater or marine environment Resident species which have marine or freshwater breeding populations
II IIa IIb IIc	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on Southern African estuaries; subdivided as follows: a. Juveniles dependant on estuaries as nursery areas b. Juveniles occur mainly in estuaries, but are also found at sea c. Juveniles occur in estuaries but are more abundant at sea
III	Marine species which occur in estuaries in small numbers but are not dependant on these systems
IV	Euryhaline freshwater species that can penetrate estuaries depending on salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems. Includes the following subcategories: a. Indigenous b. Translocated from within Southern Africa c. Alien
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments

The degree of estuarine dependence varies intraspecifically and between assemblages in the different biogeographical regions (Lamberth *et al*. 2008). Some such as silver kob *Argyrosomus inodorus* have no estuary association in the Warm-Temperate bioregion but occur in all predominantly open west coast systems (Lamberth et al. 2008). Similarly, the estuary association of Knysna sand go by *Psammogobius knysnaensis* declining in abundance from east to west and, in the latter region, is mostly confined to the surf-zone. However, this psammophyllic species is more widely distributed within (more sandy) individual systems on the west as opposed to the east coast. Fish that breed in estuaries and/or estuary residents comprise 10%-28% of estuarine fish assemblages on the Cool-Temperate west coast as opposed to 4%-18% for those on the Warm-temperate east coast or 25% for those in the south coast transition zone between the two biogeographical regions. Excluding these species, obligate estuary-dependent marine fish such as white steenbras *Lithognathus lithognathus* comprise only 11% of estuarine fish assemblages in the Cool-Temperate region compared to 22% on the Warm-Temperate east coast. This is most likely a function of the few estuaries and lower probability of recruitment success on the west coast. Including estuary residents, obligate and partially dependent species, up to 48% of Cool-Temperate and 61% of Warm-Temperate estuarine fish assemblages comprise species that have some degree of estuary association.

Approximately 80 species are exploited in South African estuaries (Lamberth and Turpie 2003). Catch diversity increases eastward with 20, 30 and 40 species caught in the Cool-Temperate west coast, south coast transition zone and Warm-Temperate east coast respectively. However, a few taxa, namely mullet Mugilidae, kob *Argyrosomus japonicus*, elf *Pomatomus saltatrix* and spotted grunter *Pomadasys commersonnii* comprise the bulk (>90%) of the catch. Participation in estuarine fisheries ranges from approximately 1000 fishers in the Cool-Temperate bioregion to 10 000-20 000 in the Warm-Temperate region to more than 70 000 in subtropical KZN. Total land mass ranges from 830 t per annum from Cool-Temperate systems, to 1 170 t in the Warm-Temperate region to 755 t in subtropical KZN. Fisheries productivity decreases from 110 $kg.ha^{-1}$ on the Cool-Temperate west coast to 80 $kg.ha^{-1}$ and 60 $kg.ha^{-1}$ on the Warm-temperate and subtropical east coast respectively.

As alluded to the above, estuary size, mouth status and geo-location influence the production and value of individual estuaries. Estuarine biodiversity and fisheries considerations aside, estuaries are also important for nursery and source areas for marine fisheries. Coastwise, estuary-associated species comprise 85% of the catch of the commercial beach-seine and gillnet fisheries and 10% of that of the commercial and recreational boat line fisheries. Accounting for different degrees of estuary-association among fish as well as differences in the value of individual fisheries, it is estimated that estuaries contribute 25% of the value of South African inshore marine fisheries (Lamberth & Turpie 2003). The total value of estuarine fisheries and estuary contribution to marine fisheries is R1.8-2 billion per annum (2014 Rands adapted from Lamberth & Turpie 2003). Key abiotic processes that influence fish health are summarised in Table 5.11.

Table 5.11 Summary of fish responses to abiotic processes and biotic components

Factor	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 & V. Freshwater species
Mouth condition	Resident species proliferate under closed mouth conditions		Abundance and richness of marine migrant communities declines with frequent, aseasonal and prolonged mouth closure.			Increase in abundance at low salinity levels.
Retention times of water masses	Food (zooplankton) abundance for all groups increases with increased retention times. Prolonged mouth closure also favours resident and freshwater species over marine migrants.					
Flow velocities (e.g. tidal velocities or river inflow velocities)	Resident species move upstream when flow velocities increase.	Migrant species exploit tidal currents when migrating into or out of the estuary or when feeding and following the tidal 'front' up the estuary. Eddies accumulate food and provide refugia for both adult and juvenile fish.				Freshwater species can get washed into the estuary by strong river currents.
Total volume and/or estimated volume of different salinity ranges	Increased volume translates to an increase in available habitat for all species, especially those that spend most of their time in the water column. Brackish water habitat is good for resident and estuary associated marine migrants while marine water is good for marine species. High water levels that inundate supratidal areas are positive for juvenile marine fish and small estuarine species.					
Floods	The larvae of resident species are washed into the sea at the onset of floods	Juvenile marine and catadromous species use floodwaters entering the sea as a cue for locating and migrating into estuaries, whereas adults and sub-adults exit during floods or use them to overcome obstacles to move upstream. Major river flooding associated with high sediment loads can cause gill clogging and hypoxia for fish in the estuary. Large aggregations of kob and other fish with preferences for high turbidity often occur immediately adjacent to estuary mouths during floods.				High flow velocities may flush some individuals downstream into the estuary
Salinities	Resident and estuary associated marine species very tolerant of salinities in the range 1-35 PSU.				Tend to stay as close to 35 PSU as possible. Stressed less than 20 PSU.	Highly variable and most prefer asalinity < 10 PSU.
Turbidity	Tolerant of a wide range of turbidity.	Turbidity preferences and tolerances vary among species. High turbidity tolerance (physiological adaptation) among some species affords them refuge and access to a specialist ecological niche.			Generally prefer low turbidity	Tolerant of a wide range of turbidity.
Dissolved oxygen	Most resident and estuary associated marine species become stressed when oxygen drops below 4 mg.l^{-1}. However, surface respiration is an adaptation by most estuarine and freshwater species to overcome hypoxia. Skin respiration is also an adaptation in some species, e.g. mudskippers whereas sole gill-morphology allows survival in hypoxic conditions.				Little tolerance to low oxygen levels/hypoxia.	Surface respiration is an adaptation by some estuarine and freshwater species to overcome hypoxia. Some indigenous species adapted to low oxygen, e.g. air-breathing organs, skin respiration and aestivation, e.g. Galaxiidae.

Table 5.11 continues/...

Factor	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 & V. Freshwater species
Subtidal, intertidal and supratidal habitat	With the obvious exception of mudskippers and to a lesser extent other gobies, blennies & clinids, most fish are confined to the subtidal at low tide but forage in the intertidal during high tide. Intertidal reaches are nonetheless extremely important foraging areas for most fish species. Shallow marginal areas tend to be warmer than deeper channel areas and are thus favourable for metabolic processes. Juveniles and small adults also use shallow water as a predation refuge.					
Other abiotic components (temperature)	Low temperatures can increase the risk of mass mortalities at very low salinities. Sex ratios can be skewed in fish where sex determination is temperature related. Increases in temperature tend to skew towards males, decreases towards females. Consequently, climate change and local scale anthropogenic influences on temperature could have a profound impact on fish populations. Growth rates and gonadal development tend to decrease either side of the optimal temperatures for individual species. Fish move according to their preferred temperature, constraints more in temporarily open/closed than permanently open estuaries.					
Sediment characteristics (including sedimentation)	Individual species preferences are highly variable and often related to preferred food sources. Burying ability and crypsis of some fish (e.g. sole *Heteromycteris capensis*) are governed by sediment characteristics. Some fish are directly and indirectly impacted, e.g. *Psammogobius knysnaensis* are psammophyllic but have commensal/mutual relationships with burrowing invertebrates which are distributed according to their burrowing ability and sediment characteristics.					
Phytoplankton biomass	High phytoplankton production contributes to turbidity in estuaries and probably favours those species with higher turbidity preferences. Phytoplankton is also a food source for filter-feeding fish and invertebrates. Fish also benefit indirectly from proliferation of invertebrates that feed on phytoplankton. Omnivorous filter-feeding fish will out-compete selective feeders during periods of high phytoplankton biomass. Harmful algal blooms in estuaries, usually a result of eutrophication, have a number of direct (toxicity) and indirect (e.g. hypoxia) impacts on fish. Blue-green *Microcystis* blooms, common in SA estuaries, can cause both skin and/or organ lesions in fish resulting in poor health, reduced reproductive success and mortalities. Golden algae *Prymnesium parvum*, an invasive species recorded in Zandvlei, causes fatal gill haemorrhaging and induces abortion and premature spawning in fish.					
Benthic micro-algae biomass	Detritivores, especially mullet, benefit from high microphytobenthos biomass. South African fish biomass in estuaries is dominated by mullet (>60%) and therefore overall fish biomass is largely reflective of benthic algal biomass.					
Zooplankton biomass	Most juvenile fish in estuaries feed on zooplankton. Filter and particulate feeders benefit from increased zooplankton biomass. Many fish species are able to switch between filter and targeted feeding modes to take advantage of dominant zooplanktonic food sources. One caveat is that predatory marine zooplankters (e.g. chaetognaths) may have a devastating impact on recruiting fish larvae. Jellyfish may do the same.					
Aquatic macrophyte cover	Juveniles of most fish species find refuge in littoral macrophyte beds during the daytime but move into open water or to the surface during the night as oxygen levels drop in the littoral zone.					
Benthic invertebrate biomass	Many estuary associated fish species feed on benthic invertebrates and will thus benefit from increases in benthic invertebrate biomass. Burrow associated fish (e.g. gobies) diversity and numbers will vary according to that of benthic invertebrates (e.g. sand prawn).					
Fish biomass	No major piscivorous species in these categories. Most of the fish biomass consists of planktivores and small zoobenthivores. Probably inter and intraspecific competition for space, habitat and food resources though.			Fish biomass dominated by estuary associated marine species that utilise different food chains, e.g. groovy mullet *Liza dumerili* is a detritivore, spotted grunter *Pomadasys commersonnii* a zoobenthivore and dusky kob *Argyrosomus japonicas* a piscivore. The piscivores benefit from the high biomass of estuarine resident and small marine migrants in the estuary.		Introduced freshwater fish may outcompete and eat estuary fish but also result in a substantial increase in biomass, e.g. the sharp tooth catfish *Clarias gariepinus* has invaded the Great Fish system via the Orange River water transfer scheme. Introduced species are usually more tolerant of poor water quality, thereby becoming the dominant fish in some systems.

Table 5.12 provides a summary of the fish health of Temperate estuaries. The table also lists the leading causes of degradation for estuaries rated less than a B Category (i.e. estuaries not in an Excellent or Good state). The level of fishing effort (recreational, subsistence or commercial) is defined as Very high = VH, High = H, Medium = M, Low = L, None = N and estimates of the annual caches per system are provided in tons.

Table 5.12 An overview of the fish health of the Temperate estuaries and the key parameters and/or pressures causing significant modification in health condition (estuaries rated less than a B Category)

Estuary	Fish Health	Key parameters/pressures										
		Loss of flow variability/ base flows	Loss of resetting floods	Change in mouth state/loss of nursery	Salinity	Water quality (oxygen, turbidity, pesticides)	Physical habitat loss	Change in microalgae	Change in macrophyte community	Shift in food source (Invertebrates)	Level of fishing effort (*=gill nets)	Fishing catch-per-unit effort (tons per year)
Orange	D	●	●	●	●	●		●	●	●	L	5.0
Buffels	D			●			●		●	●	L	0.1
Spoeg	B/C										L	0.1
Groen	B/C										L	0.1
Sout	F	●		●	●		●	●	●	●	L	0.1
Olifants	D/E	●	●		●	●		●	●	●	VH*	121
Jakkalsvlei	E	●		●	●	●	●	●	●	●	L	0.1
Wadrift	E	●		●	●	●	●	●	●	●	L	0.1
Verlorenvlei	E	●		●		●	●	●	●	●	M	10.0
Groot Berg	C/D	●	●		●	●	●		●	●	VH*	511
Rietvlei/Diep	F	●	●	●	●	●	●	●	●	●	L	8.0
Sout (Wes)	F	●		●	●	●	●	●	●	●	L	0.1
Houtbaai	F	●		●	●	●	●	●	●	●	L	0.1
Wildevoëlvlei	D	●		●	●	●	●	●	●	●	L	1.0
Bokramspruit	D	●		●		●	●	●			N	0.0
Schuster	A/B	●									N	0.0
Krom	A										N	0.0
Buffels Wes	D										N	0.0
Elsies	F			●	●	●	●	●	●	●	N	0.0
Silvermine	D	●		●	●	●	●	●	●	●	L	0.1
Sand	D	●		●	●	●	●	●	●	●	M	20.0
Zeekoei	E/F	●		●	●	●	●	●	●	●	L	0.1
Eerste	F	●	●	●	●	●	●	●	●	●	L	0.1
Lourens	D	●		●		●	●	●	●	●	L	0.1
Sir Lowry's Pass	E/F	●				●	●	●	●	●	L	0.1
Steenbras	B	●	●								L	1.0
Rooiels	A/B										L	0.1
Buffels (Oos)	A/B	●									L	0.1
Palmiet	B	●		●		●		●	●	●	L	0.2
Bot/Kleinmond	D	●		●	●	●		●	●		VH*	70.0
Onrus	D/E	●	●	●	●	●	●	●	●	●	L	0.1
Klein	C/D	●		●	●	●		●		●	H	80.0
Uilkraals	D	●	●	●	●	●	●	●	●	●	M	2.1
Ratel	A/B										L	0.1
Heuningnes	D	●		●	●	●	●	●	●	●	M	10.0

Table 5.12 continues/...

Estuary	Fish Health	Key parameters/pressures										
		Loss of flow variability/ base flows	Loss of resetting floods	Change in mouth state/loss of nursery	Salinity	Water quality (oxygen, turbidity, pesticides)	Physical habitat loss	Change in microalgae	Change in macrophyte community	Shift in food source (Invertebrates)	Level of fishing effort (*=gill nets)	Fishing catch-per-unit effort (tons per year)
Klipdrifsfontein	A										**N**	0.0
Breë	B	●	●			●					**H**	80.0
Duiwenhoks	C	●									**H**	20.0
Goukou	D	●	●				●		●	●	**H**	13.0
Gourits	C	●	●		●		●		●	●	**H**	20.0
Blinde	E	●				●		●			**L**	0.1
Tweekuilen	D/E	●		●	●	●	●	●	●	●	**L**	0.1
Gericke	E	●		●	●	●	●	●	●	●	**L**	0.1
Hartenbos	D	●	●	●	●	●	●	●	●	●	**L**	2.1
Klein Brak	C/D	●					●	●	●		**M**	10.0
Groot Brak	D/E	●	●	●	●	●		●	●	●	**M**	10.0
Maalgate	A	●		●		●		●		●	**L**	1.0
Gwaing	D					●		●		●	**L**	1.0
Kaaimans	A/B	●								●	**L**	4.0
Wilderness	B/C			●				●	●	●	**H**	170
Swartvlei	B/C			●		●					**L**	170
Goukamma	A/B										**M**	4.1
Knysna	C/D	●			●			●			**H**	70.4
Noetsie	A									●	**L**	0.2
Piesang	C	●		●	●	●	●	●	●	●	**L**	7.2
Keurbooms	B/C										**L**	23.4
Matjies	A					●					**L**	0.1
Sout (Oos)	A/B					●					**L**	0.5
Groot (Wes)	B					●					**M**	5.8
Bloukrans	A/B					●					**L**	1.0
Lottering	A/B					●					**L**	0.2
Elandsbos	A/B					●					**L**	0.2
Storms	A/B					●					**L**	0.1
Elands	A/B					●					**L**	0.1
Groot (Oos)	A/B					●					**L**	0.1
Tsitsikamma	A/B	●		●	●	●		●			**L**	1.8
Klipdrif	D					●		●	●	●	**L**	0.1
Slang	D			●		●	●	●	●	●	**L**	0.1
Krom Oos (Kromme)	D/E	●	●		●	●	●	●	●	●	**H**	22.1
Seekoei	E	●		●	●	●	●	●	●	●	**L**	1.0
Kabeljous	C	●		●		●	●	●	●	●	**L**	2.0
Gamtoos	B/C	●				●	●	●	●		**H**	19.3
Van Stadens	A/B	●									**L**	2.1
Maitland	B/C	●				●		●			**L**	0.1
Baakens	E/F	●		●	●	●	●	●	●	●	**L**	0.1
Papenkuils	F	●	●	●	●	●	●	●	●	●	**L**	0.1
Swartkops	D/E	●	●			●	●	●	●	●	**H**	46.7
Coega (Ngcura)	F	●		●	●		●	●	●	●	**M**	10.0
Sundays	C				●	●		●	●	●	**H**	9.0

Table 5.12 continues/...

Estuary	Fish Health	Key parameters/pressures										
		Loss of flow variability/ base flows	Loss of resetting floods	Change in mouth state/loss of nursery	Salinity	Water quality (oxygen, turbidity, pesticides)	Physical habitat loss	Change in microalgae	Change in macrophyte community	Shift in food source (Invertebrates)	Level of fishing effort (*=gill nets)	Fishing catch-per-unit effort (tons per year)
Boknes	C	●		●		●		●		●	L	0.3
Bushmans	B							●	●	●	H	11.5
Kariega	C/D	●						●	●	●	M	8.0
Kasuka	A/B										L	2.2
Kowie	C						●		●	●	H	6.0
Rufane	C	●		●			●	●	●	●	L	0.1
Riet	A/B										L	0.1
Kleinemond Wes	A/B										L	2.2
Kleinemond Oos	A/B				●						L	2.0
Klein Palmiet	C						●		●	●	L	0.1
Great Fish	C					●		●		●	H	30.0
Old Womans	D	●				●	●	●	●	●	L	0.1
Mpekweni	B	●									M	2.2
Mtati	A/B	●									L	3.0
Mgwalana	A/B	●									L	3.5
Bira	A/B	●									L	8.5
Gqutywa	A/B										L	0.2
Ngculura	C	●									L	0.1
Mtana	A/B										L	2.1
Keiskamma	C/D				●	●	●		●	●	H	66.7
Ngqinisa	B										L	0.1
Kiwane	B										L	2.0
Tyolomnqa	C										H	40.0
Shelbertsstroom	C					●	●				L	0.1
Lilyvale	A/B			●							L	0.1
Ross' Creek	A/B										L	0.1
Ncera	A/B										L	2.3
Mlele	A/B						●				L	0.1
Mcantsi	A/B										L	0.1
Gxulu	B/C					●	●	●	●	●	L	3.2
Goda	A/B					●					L	1.0
Hlozi	A/B					●		●			L	0.1
Hickman's	B/C					●		●			L	0.1
Ngqenga	B/C					●	●	●			L	0.1
Buffalo	D	●	●		●	●	●	●	●	●	H	60.0
Blind	D	●		●	●	●	●	●		●	L	0.1
Hlaze	C	●		●	●	●		●		●	L	0.1
Nahoon	D	●	●		●	●		●	●	●	H	7.4
Qinira	C					●	●			●	M	2.0
Gqunube	C										M	7.7
Kwelera	C										H	8.0
Bulura	C										H	2.0
Cunge	A/B										L	0.1
Cintsa	C						●				M	7.0

Table 5.12 continues/...

Estuary	Fish Health	Key parameters/pressures										
		Loss of flow variability/ base flows	Loss of resetting floods	Change in mouth state/loss of nursery	Salinity	Water quality (oxygen, turbidity, pesticides)	Physical habitat loss	Change in microalgae	Change in macrophyte community	Shift in food source (Invertebrates)	Level of fishing effort (*=gill nets)	Fishing catch-per-unit effort (tons per year)
Cefane	B										**M**	6.2
Kwenxura	B										**M**	7.0
Nyara	A/B										**L**	0.2
Mtwendwe (Imtwende)	A/B										**L**	0.1
Haga-haga	A/B										**L**	1.0
Mtendwe	A/B										**L**	0.1
Quko	A										**L**	3.8
Morgan	C									●	**H**	7.8
Cwili	A/B										**L**	0.1
Great Kei	C/D	●					●	●			**H**	40.0
Gxara	A/B					●					**L**	2.3
Ngogwane	A/B					●					**L**	0.1
Qolora	A/B										**L**	1.7
Ncizele	A/B										**L**	0.1
Timba	A/B										**L**	0.1
Kobonqaba	B								●		**L**	6.0
Nxaxo/Ngqusi	C								●		**H**	9.0
Cebe	A										**L**	2.4
Gqunqe	A										**L**	2.4
Zalu	A/B										**L**	1.5
Ngqwara	A/B										**L**	2.4
Sihlontlweni	A/B										**L**	1.5
Nebelele	A/B										**L**	0.1
Qora	B										**H**	21.0
Jujura	A/B										**L**	1.3
Ngadla	A/B										**L**	1.5
Shixini	B										**M**	5.0
Beechamwood	A/B										**L**	0.1
Unnamed	A/B										**L**	0.1
Kwa-Goqo	A/B										**L**	0.1
Ku-Nocekedwa	A/B										**L**	0.1
Nqabara	A/B										**M**	16.8
Ngoma/Kobule	A/B										**L**	1.0
Mendu	A/B										**M**	2.0
Mendwana	A/B										**M**	0.1
Mbashe	D					●			●		**VH**	25.0

In evaluating fish health of the temperate estuaries, change in food availability, specifically loss of microalgae and invertebrates in 63 (40%) and 61 (38%) of the estuaries respectively, was a key factor in the decline in fish health (Figure 5.4). Deterioration in water quality, i.e. reduced oxygen levels, increased turbidity or presence of toxic substances (e.g. herbicides and pesticides) was evident in 64 (40%) of estuaries.

Loss in flow variability and/or changes in base flows were highlighted as the reasons for the decline in fish health in 65 (41%) of estuaries, while loss of floods associated with juvenile fish recruitment cues were significantly reduced in 18 (11%) systems. Shifts in the salinity regimes of 39 (25%) of estuaries were regarded as significant for fish.

Loss of habitat also contributed to the overall decline in fish health. Fifty (31%) estuaries had experienced significant loss of physical habitat whereas 54 (34%) had lost substantial macrophyte habitat. Change in mouth state, specifically the frequency and duration of mouth closure, and their (spatial and temporal) influence on estuary nursery function, was crucial in 41 (26%) of the estuaries in the region. Overexploitation, a key pressure directly contributing to declines in fish abundance, was considered a concern in 54 (34%) for the estuaries listed.

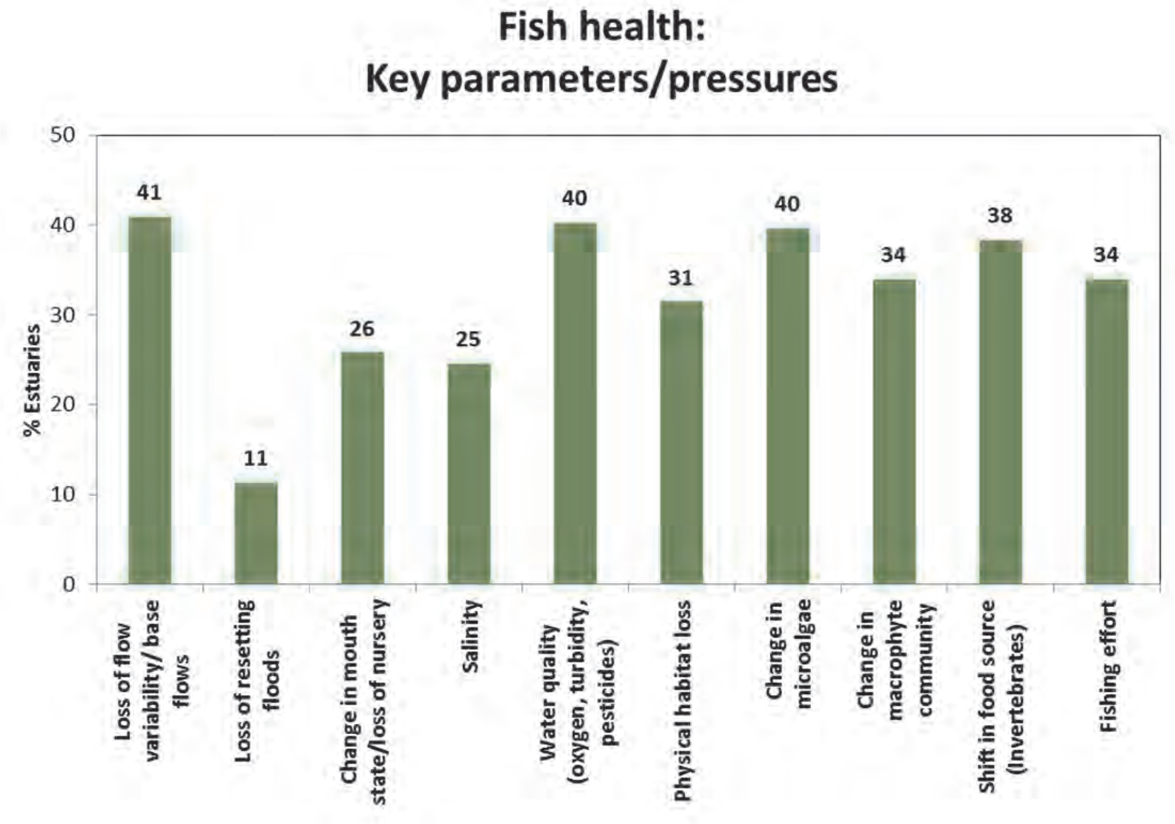

Figure 5.4 Key parameters or pressures influencing the health state of fish in the Temperate estuaries

Total landed mass ranges from 830 t per annum from Cool-Temperate systems, to 1 170 t in the Warm-Temperate region to 755 t in subtropical KwaZulu-Natal. However, these totals are largely reflective of the length of coastline and the number of estuaries in each region. Taking available estuarine area into account, fisheries productivity decreases from 110 $kg.ha^{-1}$ on the Cool-Temperate west coast to 80 $kg.ha^{-1}$ and 60 $kg.ha^{-1}$ on the Warm-Temperate and Subtropical east coast respectively (Figure 5.5). Although fisheries production is reflective of high biological production in the Cool-Temperate region and is higher than elsewhere on South Africa's coastline, at least some of the landed catch biomass can be attributed to the gear used (mostly gillnets) and disproportionally high fishing effort on the few available estuaries there.

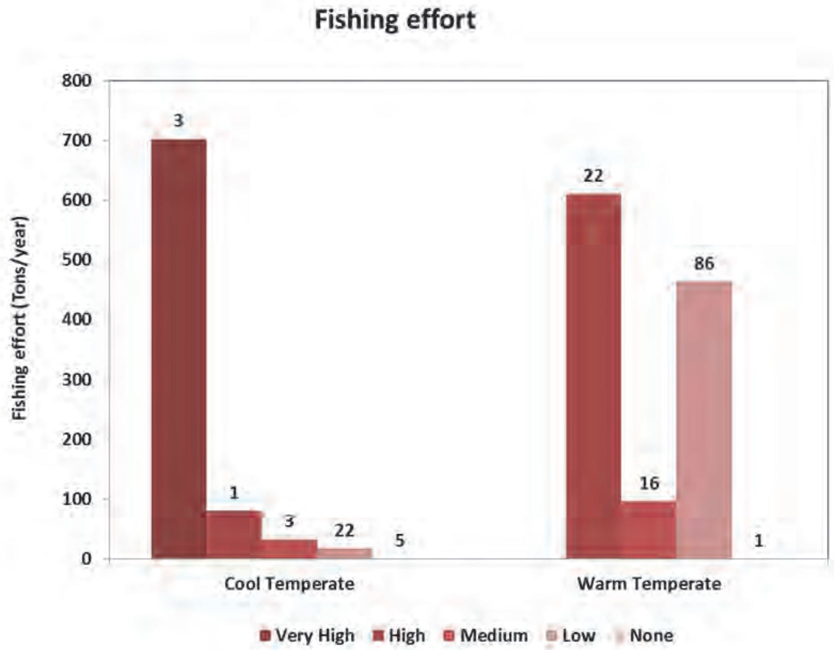

Figure 5.5 Summary of fishing pressure on the Temperate region estuaries expressed as annual catches. The number of estuaries are indicated above each category

Estuary-dependence is regarded as a vulnerable life history characteristic, especially for exploited fish species and a number of anthropogenic stressors in estuaries. Exploited estuary-dependent species such as dusky kob *A. japonicus* and white-steenbras *L. lithognathus,* are also vulnerable with respect to spawning migrations, predictable aggregations, high age at maturity, longevity, residency, and high catchability. In addition, palatability and large size mean that they are in high demand by commercial, recreational and subsistence fishers as well as by the aquaculture industry. Their high catchability is amplified in the confines of estuaries, which in turn suggests that these habitats need to be afforded more protection in compensation.

In most cases pressures were more severe in urban areas or in estuaries associated with holiday destinations. Some of the larger estuaries were subject to very high to high fishing pressure. The Warm-Temperate estuaries of the former Transkei and Ciskei region were the most pristine in condition, while the estuaries in and around the metros of Cape Town, Mossel Bay and Port Elizabeth showed the most severe decline in condition. Overall, the current health and status of most estuarine fish populations is a result of the cumulative pressures of flow, reduction, development and overfishing. Management interventions should reflect this.

5.5 Birds

In addition to being one of the most conspicuous forms of biodiversity in estuaries, birds are thought to play a significant ecological role in these systems, both in terms of the regulation of invertebrate and fish populations, and as an importer of nutrients into some systems. The main groups of birds occurring in South Africa's estuaries are described in Table 5.13. These are divided along taxonomic lines as well as by trophic guild and feeding methods or habitats. The waders, gulls and terns are the most numerous group overall, and tend to be the most common species on the larger estuarine systems, where they occur mainly on the intertidal areas in the lower parts of estuaries (Turpie and Clark 2007). The rest of the groups are associated with the channel areas, and some of them require marginal and bank vegetation. Most of these species are piscivorous, apart from the waterfowl which are predominantly herbivorous or omnivorous. While over 100 waterbird species have been recorded in estuaries, only 33 species were deemed to be dependent on estuaries in the Temperate region (Turpie and Clark 2007). Apart from a slightly higher diversity of species in subtropical areas, the functional groups found in Temperate estuaries are very similar to those of subtropical estuaries in South Africa. The main differences in typical avifauna between the two regions are due to differences in the composition of estuary types.

Table 5.13 Major bird groups found in the Temperate Estuaries and their defining features (Turpie *et al.* 2013)

Bird groups	Defining features, typical/dominant species
Piscivorous cormorants	The estuary supports a few species of pursuit swimming piscivores which catch their prey by following it underwater and therefore prefer deeper water habitat. These include Reed Cormorant, Cape Cormorant, White-breasted Cormorant and African Darter.
Piscivorous wading birds	This group comprises the egrets, herons, ibises and spoonbill. 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. Wading piscivores prefer shallow water up to a certain species dependant wading depth.
Herbivorous waterfowl	This group is dominated by species that tend to occur in lower 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, and all the rallids (e.g. Redknobbed Coot, African Purple Swamphen). Some herbivorous waterfowl such as Egyptian Goose probably feed in terrestrial areas away from the estuary and floodplain as well as in the estuary.
Omnivorous waterfowl	This group comprises ducks which eat a mixture of plant material and invertebrate food such as small crustaceans – Yellow-billed Duck, Cape Teal, Red-billed Teal and Cape Shoveller. Although varying in tolerance, these species are fairly tolerant of more saline conditions.
Benthivorous waders	This group includes all the waders (e.g. Greenshank, Curlew Sandpiper). They are the smallest species on the estuary, and feed on benthic macro-invertebrates in exposed and shallow intertidal areas. Invertebrate-feeding waders forage mainly on exposed sandbanks, mudflats and in the intertidal zone. A few resident species occur such as White-fronted Plover and Black-winged Stilt. Many species of Palaearctic migrants have been recorded on the estuary, often in fairly high numbers.
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. Gulls and terns can be very abundant and use the estuary primarily for roosting.
Piscivorous kingfishers	Three species of kingfishers occur on the estuary in low numbers. They breed and perch on the river banks and prefer areas of open water with overhanging vegetation.
Piscivorous birds of prey	This group includes African Fish Eagle and Osprey. The African Fish Eagle is not confined to a diet of fish, also taking other vertebrates and invertebrates.
Other birds of prey	The Marsh Harrier has been recorded on the estuary in the past, and feeds on small vertebrates such as mice and frogs.

Some of the main flow-related factors to be considered in estimating the bird community under reference conditions and the alternative scenarios are listed in Table 5.14.

Table 5.14 Effect of abiotic characteristics and processes, as well as other biotic components on bird groupings (Source: Turpie *et al*. 2013)

Factor	Cormorants & wading piscivores	Kingfishers & fish-eagle	Waterfowl	Waders, gulls and terns
Mouth condition	Indirectly, through influence on water level and fish		Indirectly, through influence on macrophytes	Mouth closures have negative effect on preferred sandbanks in lower estuary
Salinities			Certain species of waterfowl prefer lower salinities	
Turbidity	Negatively affects visibility for foraging			
Intertidal area				Waders rely mostly on intertidal areas for feeding.
Sediment characteristics (including sedimentation)				Most waders prefer medium to fine sand; a few prefer coarse sand
Primary productivity	Indirectly though influence on food supply			
Submerged macrophytes abundance			Has positive influence on herbivorous waterfowl numbers	
Abundance of reeds and sedges			Has positive influence on some herbivorous waterfowl species	
Abundance of zooplankton			Assumed positive for some omnivorous species	
Benthic invertebrate abundance				Primary food source for invertebrate-feeding waders
Fish biomass	Piscivores will increase with increasing numbers of small to medium-sized fish			

Table 5.15 provides a summary of the bird health of the Temperate estuaries. The table also lists the leading causes of degradation for estuaries rated less than a B Category (i.e. estuaries not in an Excellent or Good state).

Table 5.15 The bird health of the Temperate estuaries and the key parameters and/or pressures causing significant modification in health condition (Estuaries rated less than a B Category).

Estuary	Bird Health	Key parameters/pressures					
		Change in mouth state and water levels	Physical habitat loss	Loss /change of macrophyte habitat	Change in food availability: Invertebrates	Change in food availability: Fish	Recreational activities
Orange	E	●		●	●	●	
Buffels	B/C		●	●	●	●	
Spoeg	A/B						
Groen	A/B						
Sout	D	●	●	●	●	●	
Olifants	A			●	●	●	
Jakkalsvlei	C	●	●	●	●	●	
Wadrift	C/D	●	●	●	●	●	
Verlorenvlei	C	●	●	●	●	●	
Groot Berg	B		●	●	●	●	●
Rietvlei/Diep	D	●	●	●	●	●	●
Sout (Wes)	E/F	●	●	●	●	●	
Houtbaai	D/E	●	●	●	●	●	
Wildevoëlvlei	C/D	●	●	●	●	●	
Bokramspruit	A/B						
Schuster	A/B						
Krom	A						
Buffels Wes	A/B						
Elsies	D	●	●	●	●	●	
Silvermine	D/E	●	●	●	●	●	●
Sand	C/D	●	●	●	●	●	●
Zeekoei	E	●	●	●	●	●	
Eerste	D/E	●	●	●	●	●	
Lourens	C		●	●	●	●	●
Sir Lowry's Pass	E		●	●	●	●	
Steenbras	A						
Rooiels	A/B						
Buffels (Oos)	A/B						
Palmiet	B						
Bot/Kleinmond	B						
Onrus	D/E	●	●	●	●	●	●
Klein	B/C	●			●	●	●
Uilkraals	E	●	●	●	●	●	
Ratel	A/B						
Heuningnes	C	●		●	●	●	●
Klipdrifsfontein	A						
Breë	A/B						
Duiwenhoks	A/B						
Goukou	B						
Gourits	B/C		●	●	●	●	
Blinde	A/B						
Tweekuilen	E/F	●	●	●	●	●	
Gericke	E/F	●	●	●	●	●	
Hartenbos	C	●	●	●	●	●	●
Klein Brak	C		●	●		●	●
Groot Brak	C	●		●	●	●	●

Table 5.15 continues/...

Estuary	Bird Health	Key parameters/pressures					
		Change in mouth state and water levels	Physical habitat loss	Loss /change of macrophyte habitat	Change in food availability: Invertebrates	Change in food availability: Fish	Recreational activities
Maalgate	A						
Gwaing	B						
Kaaimans	A/B						
Wilderness	A/B						
Swartvlei	B/C	●					
Goukamma	A/B						
Knysna	C					●	●
Noetsie	A/B						
Piesang	D	●	●	●	●	●	●
Keurbooms	B						
Matjies	A/B						
Sout (Oos)	A						
Groot (Wes)	A/B						
Bloukrans	A						
Lottering	A						
Elandsbos	A						
Storms	A						
Elands	A						
Groot (Oos)	A/B						
Tsitsikamma	A						
Klipdrif	B						
Slang	C	●	●	●	●	●	
Krom Oos (Kromme)	C		●	●	●	●	●
Seekoei	D/E	●	●	●	●	●	●
Kabeljous	B						
Gamtoos	A/B						
Van Stadens	A/B						
Maitland	A/B						
Baakens	E/F	●	●	●	●	●	
Papenkuils	E/F	●	●	●	●	●	
Swartkops	C		●	●	●	●	●
Coega (Ngcura)	E	●	●	●	●	●	
Sundays	B						
Boknes	A/B						
Bushmans	A/B						
Kariega	B						
Kasuka	A/B						
Kowie	C/D		●	●	●	●	●
Rufane	B						
Riet	A/B						
Kleinemond Wes	A/B						
Kleinemond Oos	A/B						
Klein Palmiet	B/C						
Great Fish	B/C						
Old Womans	B/C						
Mpekweni	A/B						
Mtati	A/B						
Mgwalana	A/B						

Table 5.15 continues/...

Estuary	Bird Health	Key parameters/pressures					
		Change in mouth state and water levels	Physical habitat loss	Loss /change of macrophyte habitat	Change in food availability: Invertebrates	Change in food availability: Fish	Recreational activities
Bira	A/B						
Gqutywa	A/B						
Ngculura	A/B						
Mtana	A/B						
Keiskamma	A/B						
Ngqinisa	A/B						
Kiwane	A/B						
Tyolomnqa	A/B						
Shelbertsstroom	B						
Lilyvale	A/B						
Ross' Creek	A/B						
Ncera	A/B						
Mlele	A/B						
Mcantsi	A/B						
Gxulu	B						
Goda	A						
Hlozi	A						
Hickman's	A/B						
Ngqenga	A/B						
Buffalo	E		●	●	●	●	●
Blind	C/D	●	●		●	●	
Hlaze	C	●			●	●	
Nahoon	C			●	●	●	●
Qinira	C		●		●	●	●
Gqunube	C					●	●
Kwelera	B						
Bulura	B						
Cunge	A/B						
Cintsa	B						
Cefane	A/B						
Kwenxura	A/B						
Nyara	A/B						
Mtwendwe (Imtwende)	A/B						
Haga-haga	A/B						
Mtendwe	A/B						
Quko	A						
Morgan	B						
Cwili	A/B						
Great Kei	B						
Gxara	A/B						
Ngogwane	A/B						
Qolora	A/B						
Ncizele	A						
Timba	A						
Kobonqaba	B						
Nxaxo/Ngqusi	B						
Cebe	A						
Gqunqe	A						

Table 5.15 continues/...

Estuary	Bird Health	Key parameters/pressures					
		Change in mouth state and water levels	Physical habitat loss	Loss /change of macrophyte habitat	Change in food availability: Invertebrates	Change in food availability: Fish	Recreational activities
Zalu	A						
Ngqwara	A						
Sihlontlweni	A						
Nebelele	A						
Qora	A/B						
Jujura	A						
Ngadla	A						
Shixini	A						
Beechamwood	A						
Unnamed	A						
Kwa-Goqo	A						
Ku-Nocekedwa	A						
Nqabara	A						
Ngoma/Kobule	A						
Mendu	A						
Mendwana	A						
Mbashe	A/B						

While the health of bird populations is believed to be relatively good in most of the small estuary systems, the overall health has declined significantly in many of the larger systems, which means that there has been a significant reduction in avifaunal health overall. This is in line with the recent findings of Ryan *et al*. (2012) who observed overall declines in bird numbers along the coast, and Anchor Environmental Consultants (2013) who similarly report significant declines in waterbird numbers at Langebaan Lagoon. In this study, the loss or change in prey species – invertebrates in 42% (26 systems) and fish in 45% (28 systems) of estuaries respectively – was a key factor in the reduction in bird health condition. Loss of habitat – 36 % of estuaries showed significant loss of physical habitat and 39% of estuaries showed change or loss of macrophyte habitats (25 systems) – were also a major factor in the overall decline in health (Figure 5.6).

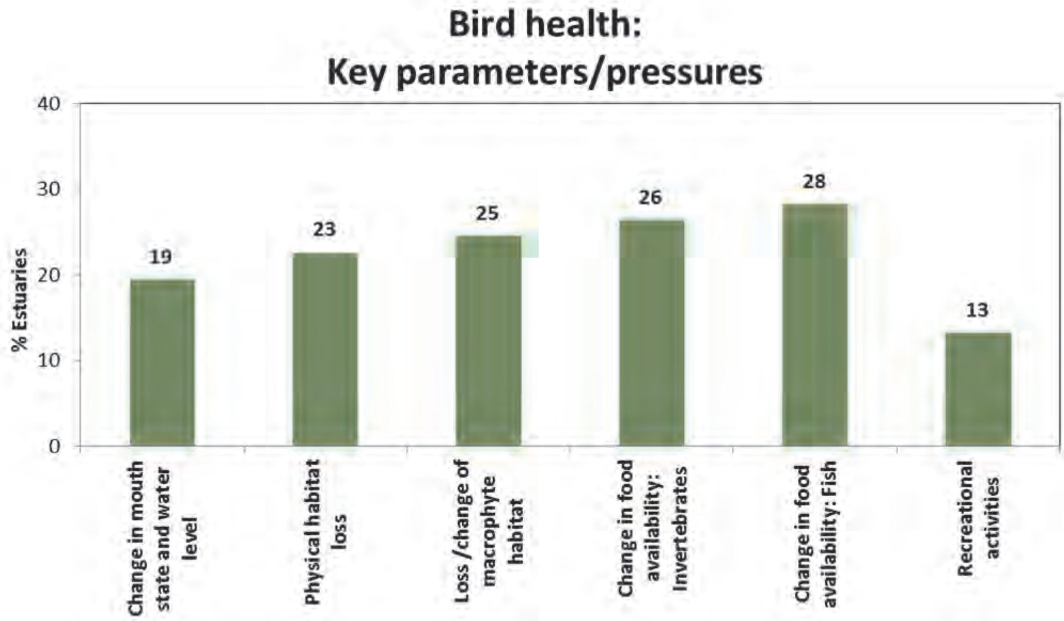

Figure 5.6 Key parameters or pressures that influence the health state of birds in the Temperate estuaries

Change in mouth state and a concomitant change in water levels was an influencing factor in about 19% (31 systems) of the estuaries in the region. A key pressure that directly contributes to a decline in bird numbers is disruptions caused by recreational activities (e.g. skiing, boating, swimming and fishing) that lead to birds being disturbed in feeding, breeding or roosting areas. In most cases the degree of pressure was more severe in the urban areas or in estuaries that are associated with holiday destinations or tourism areas. Although naturally depauperate in terms of avifauna (Turpie *et al*. 2004), the Warm-Temperate estuaries of the former Transkei and Ciskei region were thought to be least impacted, while the estuaries around Cape Town, Mossel Bay and Port Elizabeth showed the most severe declines in condition.

5.6 Synopsis of biotic health assessment

A broad analysis of the biotic components shows that, across the components, the Cool-Temperate estuaries were in a more degraded state than the Warm-Temperate systems (Figure 5.7).

A comparison between the primary producers, microalgae and macrophytes, indicate that roughly 35% and 70% of the plant communities in the Cool- and Warm-Temperate regions are in an A to B category. However, the macrophyte communities include a significant number of severely modified (Category E and F) systems as a result of non-flow related pressures. The number of severely degraded systems from a biotic components perspective increase steadily from microalgae, to macrophyte, through the invertebrates, and ultimately to the fish components, thus reflecting the cumulative effects of flow and non-flow related impacts such as fishing. In contrast, the overall bird component is still in a relatively pristine state with over 40% of systems in the Cool-Temperate and nearly 80% in the Warm-Temperate region still in an A or B Category, thus highlighting the robustness of the bird community to flow changes.

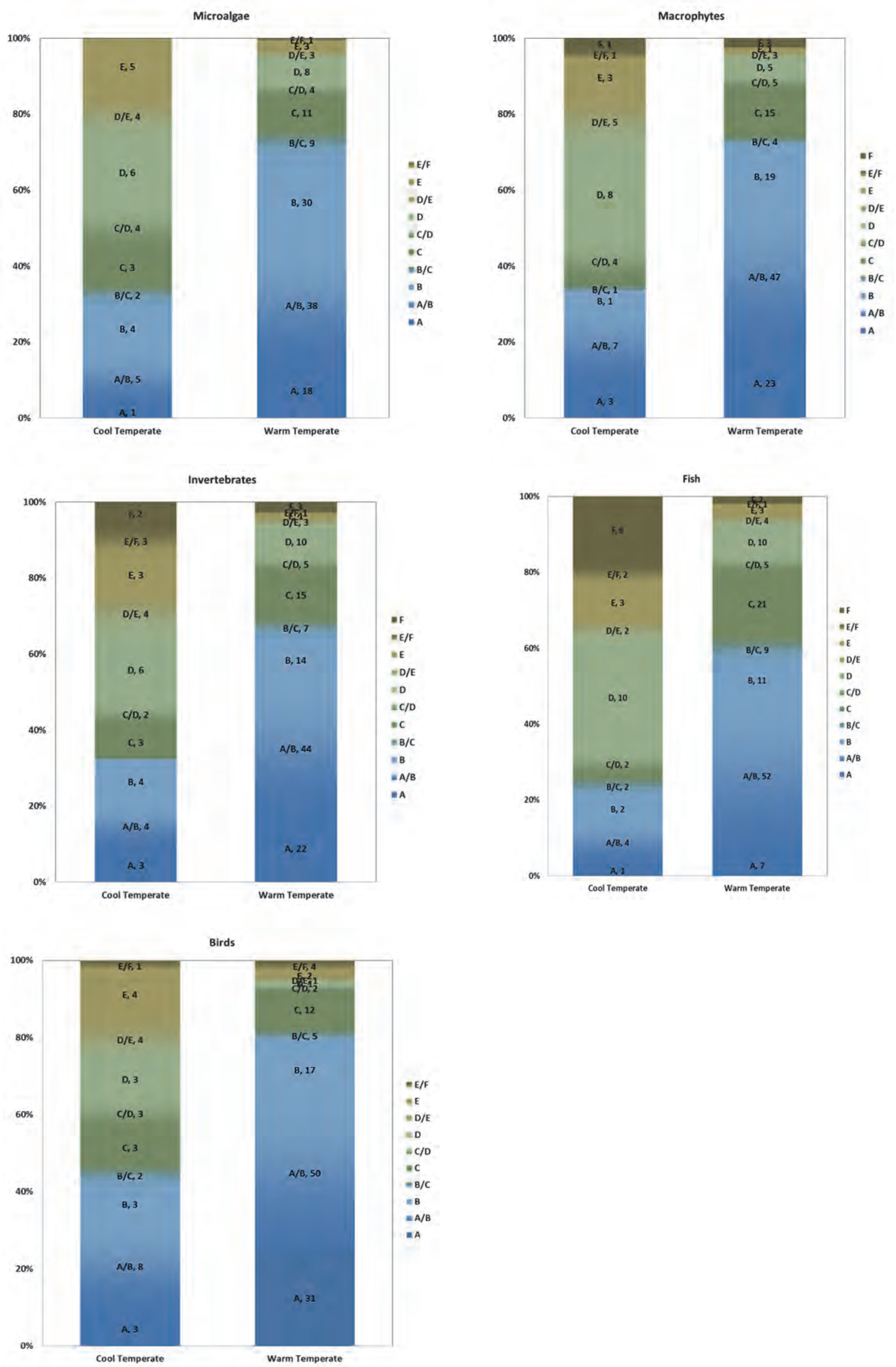

Figure 5.7 Overview of the biotic health state of the Temperate estuaries

6. PRESENT ECOLOGICAL STATUS OF TEMPERATE ESTUARIES

Table 6.1 provides a summary of the overall individual abiotic (hydrology, hydrodynamics, water quality, physical habitat) and biotic (microalgae, macrophytes, invertebrates, fish, birds) ecological health assessment ratings for the Temperate Estuaries estimated using the Estuary Health Index. The PES reflects the average of the abiotic components (habitat health rating) and biotic (biological health rating).

Table 6.1 A summary of the individual abiotic (hydrology, hydrodynamics, water quality, physical habitat) and biotic (microalgae, macrophytes, invertebrate, fish, bird) component categories; the aggregated Habitat and Biotic Health categories and the Present Ecological Status for the Temperate estuaries

Estuary	Hydrology	Mouth State	Water Quality	Physical habitat	Habitat Health Score	Microalgae	Macrophytes	Invertebrates	Fish	Birds	Biological Health Score	PES
Orange	D	C	D	B	C	D/E	D	D	D	E	D	D
Buffels	A/B	B	A/B	C/D	B	B	C/D	C	D	B/C	C	B/C
Spoeg	A/B	A/B	A/B	B	A/B	A/B	A/B	B	B/C	A/B	B	A/B
Groen	A	A	A/B	B	A	A/B	A/B	B	B/C	A/B	A/B	A/B
Sout	C	C/D	B	D/E	C	C	D	D/E	F	D	D	D
Olifants	C	A	D	B	B/C	C	C/D	C	D/E	A	C	C
Jakkalsvlei	E	D/E	D	C	D	D	C/D	C/D	E	C	D	D
Wadrift	E	E/F	D	D/E	E	D/E	D/E	D/E	E	C/D	D	D/E
Verlorenvlei	E	C/D	D	C	D	D/E	D	D	E	C	D	D
Groot Berg	B/C	A/B	D/E	C/D	C	B/C	D	D	C/D	B	C	C
Rietvlei/Diep	E	E	D	E	E	D/E	E	E/F	F	D	E	E
Sout (Wes)	D/E	F	E	F	E	E	F	F	F	E/F	F	E/F
Houtbaai	D/E	E	E	E	E	E	D/E	E	F	D/E	E	E
Wildevoëlvlei	E	D/E	D	D	D	D	D	D	D	C/D	D	D
Bokramspruit	D/E	C/D	B/C	C	C/D	C/D	A/B	A/B	D	A/B	B/C	C
Schuster	C	A/B	A	A/B	B	B	A/B	A/B	A/B	A/B	A/B	A/B
Krom	A/B	A	A/B	A	A	A/B	A	A	A	A	A	A
Buffels Wes	A	A	A/B	A	A	A/B	A	A	D	A/B	B	A/B
Elsies	A	E/F	D	E	D	C/D	E	E/F	F	D	E	D/E
Silvermine	D	E/F	D/E	E	E	D	D/E	E	D	D/E	D	D/E
Sand	C	E	E	D/E	D	D	D	D/E	D	C/D	D	D
Zeekoei	D/E	E	F	E/F	E	E	E	E	E/F	E	E	E
Eerste	E	E	E/F	D/E	E	E	D/E	E/F	F	D/E	E	E
Lourens	D	B	D	D	C/D	D	D	D	D	C	D	C/D
Sir Lowry's Pass	C	B	D/E	E/F	D	D	E/F	F	E/F	E	E	D/E
Steenbras	E	A	A/B	A/B	B	B	A	A	B	A	A	B
Rooiels	A	A	A	A/B	A	A	A/B	A/B	A/B	A/B	A/B	A
Buffels (Oos)	C	B	A/B	B	B	B	A/B	A/B	A/B	A/B	A/B	B
Palmiet	C	D	B/C	B	C	B/C	D	C/D	B	B	C	C
Bot/Kleinmond	C	C	C	A/B	C	C	A/B	B	D	B	B/C	B/C
Onrus	F	E	E	D/E	E	E	D/E	D/E	D/E	D/E	D/E	E
Klein	C	C/D	C/D	B	C	C/D	B/C	C	C/D	B/C	C	C
Uilkraals	E	C	B	C	D	C/D	C/D	D	D	E	D	D
Ratel	A/B	A/B	A/B	A	A/B	A/B	B	B	A/B	A/B	B	A/B
Heuningnes	C	D	C/D	B/C	C	C	C/D	D	D	C	C/D	C/D
Klipdrifsfontein	A	A	A	A	A	A	A	A	A	A	A	A

Table 6.1 continues/...

Estuary	Hydrology	Mouth State	Water Quality	Physical habitat	Habitat Health Score	Microalgae	Macrophytes	Invertebrates	Fish	Birds	Biological Health Score	PES
Breë	C	A	B/C	A/B	B	A/B	B	B	B	A/B	B	B
Duiwenhoks	D	A	B	A/B	B	B	A/B	B/C	C	A/B	B	B
Goukou	D	A	B	C	B/C	B	C	C	D	B	C	B/C
Gourits	C/D	A	B	C	B	B	C/D	C	C	B/C	C	B/C
Blinde	C/D	B	B/C	A/B	B	C	A/B	B/C	E	A/B	B/C	B/C
Tweekuilen	D	C/D	E	E	D	D/E	D/E	D/E	D/E	E/F	D/E	D/E
Gericke	D	C/D	E	E	D	D/E	D	D/E	E	E/F	D/E	D/E
Hartenbos	C	D	D	D	D	D	C/D	C/D	D	C	C/D	D
Klein Brak	D	A/B	B	C	B/C	B/C	C	B/C	C/D	C	C	B/C
Groot Brak	C	C/D	D	B	C	C/D	D/E	D	D/E	C	D	C/D
Maalgate	D	C	B/C	A	B/C	C	A/B	D	A	A	B	B
Gwaing	A/B	B	C	A	B	C	B	C	D	B	C	B
Kaaimans	D	A	B	A/B	B	B	A/B	C	A/B	A/B	B	B
Wilderness	B/C	C/D	B/C	B	B/C	C	B/C	B	B/C	A/B	B	B/C
Swartvlei	B	B/C	B	A/B	B	B	B/C	B	B/C	B/C	B	B
Goukamma	A/B	B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B
Knysna	A	A	B/C	B	A/B	C	B	B/C	C/D	C	C	B
Noetsie	A/B	A/B	B	A	B	B	A/B	C/D	A	A/B	B	B
Piesang	D	D	C/D	D	D	C/D	D	D	C	D	D	D
Keurbooms	A	A	A/B	A	A	A	A/B	A	B/C	B	A/B	A/B
Matjies	A	B/C	B	A	A/B	A/B	A/B	A/B	A	A/B	A/B	A/B
Sout (Oos)	A	A	A/B	A	A	A/B	A	A	A/B	A	A	A
Groot (Wes)	B	A	A	A/B	A/B	A/B	B	A/B	B	A/B	A/B	A/B
Bloukrans	A	A	A	A	A	A	A	A	A/B	A	A	A
Lottering	A/B	A	A	A	A	A	A	A	A/B	A	A	A
Elandsbos	A/B	A	A	A	A	A	A	A	A/B	A	A	A
Storms	B	A	A	A	A	A	A	A	A/B	A	A	A
Elands	A/B	A	A	A	A	A	A	A	A/B	A	A	A
Groot (Oos)	A	A	B	A	A/B	B	A/B	A	A/B	A/B	A/B	A/B
Tsitsikamma	C	C	C	A	B/C	C	A/B	B	A/B	A	A/B	B
Klipdrif	A	A/B	C	A/B	A/B	B/C	C	C/D	D	B	C	B
Slang	A/B	C	C/D	D	C	C/D	C/D	D	D	C	C/D	C
Krom Oos (Kromme)	E	A	E	C	C/D	E/F	D	E/F	D/E	C	D/E	D
Seekoei	C/D	D/E	D/E	C	D	E	E	E	E	D/E	E	D
Kabeljous	C	C	B/C	C	C	C	C	C	C	B	B/C	C
Gamtoos	B/C	A	B/C	C	B	B/C	D	B	B/C	A/B	B/C	B
Van Stadens	C	A/B	B	A/B	B	B	B	B	A/B	A/B	B	B
Maitland	C	A/B	B/C	A/B	B	B/C	B	B/C	B/C	A/B	B	B
Baakens	C/D	E	E	F	E	E	F	F	E/F	E/F	E/F	E
Papenkuils	C/D	F	F	F	E	E	F	F	F	E/F	F	E/F
Swartkops	D/E	A/B	D	D	C/D	D	D/E	D/E	D/E	C	D	D
Coega (Ngcura)	D	F	D	F	E	D	F	F	F	E	E/F	E
Sundays	B/C	A	D/E	A/B	B/C	D/E	D	D	C	B	C/D	C
Boknes	D/E	C	B/C	A/B	C	C	B	C	C	A/B	B/C	C
Bushmans	A/B	A	C	A/B	A/B	D	C	C	B	A/B	B/C	B
Kariega	E	A	B	B	B/C	C	C	D	C/D	B	C	C
Kasuka	A/B	A	A/B	B	A/B	A/B	B	A/B	A/B	A/B	A/B	A/B
Kowie	B	A/B	B	C/D	B	B	C/D	C/D	C	C/D	C	B/C
Rufane	C/D	C	B	C/D	C	B/C	C	C	C	B	B/C	C
Riet	A/B	A/B	B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B

Table 6.1 continues/...

Estuary	Hydrology	Mouth State	Water Quality	Physical habitat	Habitat Health Score	Microalgae	Macrophytes	Invertebrates	Fish	Birds	Biological Health Score	PES
Kleinemond Wes	A	A/B	B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B
Kleinemond Oos	A	A/B	B	A/B	A/B	B	A/B	A/B	A/B	A/B	A/B	A/B
Klein Palmiet	A	A/B	B	C	A/B	A/B	C	C	C	B/C	B/C	B
Great Fish	B	A/B	C/D	A/B	B	D	B	D	C	B/C	C	C
Old Womans	C	A/B	C	C	B/C	C	C	D	D	B/C	C	C
Mpekweni	B/C	B	B	B	B	B	A/B	B	B	A/B	B	B
Mtati	C	B	B	A/B	B	B	A/B	A/B	A/B	A/B	A/B	B
Mgwalana	C	B	B	A/B	B	B	A/B	A/B	A/B	A/B	A/B	B
Bira	C	B	B	A/B	B	B	A/B	A/B	A/B	A/B	A/B	B
Gqutywa	B	B	B	A/B	B	B	A/B	A/B	A/B	A/B	A/B	B
Ngculura	C	B	B	A/B	B	B	B	A/B	C	A/B	B	B
Mtana	B	A/B	B	A	A/B	B	A	A/B	A/B	A/B	A/B	A/B
Keiskamma	B	A	C	C	B	B	C	C	C/D	A/B	B/C	B
Ngqinisa	A	A	A/B	A	A	A/B	A/B	A/B	B	A/B	A/B	A
Kiwane	A	A	A/B	A	A	A/B	A/B	A/B	B	A/B	A/B	A
Tyolomnqa	A	A	A/B	A/B	A/B	A/B	A/B	A/B	C	A/B	A/B	A/B
Shelbertsstroom	A/B	B	B/C	C/D	B	B	A/B	B	C	B	B	B
Lilyvale	B	C	B	A/B	B	B	A/B	B	A/B	A/B	B	B
Ross' Creek	A	A	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B
Ncera	A/B	A/B	B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B
Mlele	B	A/B	B/C	C/D	B	B	A/B	A/B	A/B	A/B	A/B	B
Mcantsi	A/B	B	B	B/C	B	B	B	B	A/B	A/B	B	B
Gxulu	A/B	B/C	B	C	B	B	C	C	B/C	B	B/C	B
Goda	A/B	A/B	B/C	A/B	A/B	B	A/B	A/B	A/B	A	A/B	A/B
Hlozi	A/B	A/B	C	A/B	B	B/C	A/B	A/B	A/B	A	A/B	A/B
Hickman's	A/B	A/B	B/C	A/B	A/B	B	A/B	A/B	B/C	A/B	B	B
Ngqenga	A/B	A/B	C	C	B	B/C	B	A/B	B/C	A/B	B	B
Buffalo	F	B	C/D	D/E	D	D	C	D	D	E	D	D
Blind	D	C	E	C/D	D	D	B/C	C	D	C/D	C/D	C/D
Hlaze	D/E	D	D/E	A/B	D	D	A/B	C	C	C	C	C
Nahoon	B/C	A	D/E	A/B	B/C	C/D	C	C/D	D	C	C	C
Qinira	A	A/B	B/C	C	B	B	B	C	C	C	B/C	B
Gqunube	A/B	A	A/B	B	A/B	A/B	B	B/C	C	C	B	B
Kwelera	A/B	A	A/B	B	A/B	A/B	B	B	C	B	B	A/B
Bulura	A	A	A/B	B	A/B	A/B	B	B	C	B	B	B
Cunge	A	A	A/B	A/B	A	A/B	A/B	A/B	A/B	A/B	A/B	A/B
Cintsa	A/B	A/B	A/B	C	B	B	B/C	A/B	C	B	B	B
Cefane	A/B	A	A/B	A/B	A/B	A/B	A/B	A/B	B	A/B	A/B	A/B
Kwenxura	A	A	A	A/B	A	A	A/B	A/B	B	A/B	A/B	A
Nyara	A	A	A/B	A/B	A/B	A/B	A	A/B	A/B	A/B	A/B	A/B
Mtwendwe (Imtwende)	A	A	A	A/B	A	A	A/B	A/B	A/B	A/B	A/B	A
Haga-haga	A	A	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B
Mtendwe	A	A	A	A/B	A	A	A/B	A/B	A/B	A/B	A/B	A
Quko	A	A	A/B	A	A	A/B	A	A	A	A	A	A
Morgan	A	A/B	B	B	A/B	A/B	B	C	C	B	B	B
Cwili	A	A/B	A	B	A/B	A	A/B	B	A/B	A/B	A/B	A/B
Great Kei	D/E	A	B	C	B/C	B/C	A/B	B/C	C/D	B	B/C	B/C
Gxara	A	A/B	B	A	A/B	B	A	A/B	A/B	A/B	A/B	A/B
Ngogwane	B	A/B	B	A/B	B	B	A/B	A/B	A/B	A/B	A/B	A/B
Qolora	A	B	B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B

Table 6.1 continues/...

Estuary	Hydrology	Mouth State	Water Quality	Physical habitat	Habitat Health Score	Microalgae	Macrophytes	Invertebrates	Fish	Birds	Biological Health Score	PES
Ncizele	A	A	A/B	A/B	A	A/B	A/B	A/B	A/B	A	A/B	A
Timba	B	A/B	B	A/B	A/B	B	A/B	A/B	A/B	A	A/B	A/B
Kobonqaba	A	A/B	A	A/B	A	A	C	A/B	B	B	B	A/B
Nxaxo/Ngqusi	A	A	A	B/C	A	A	C	B	C	B	B	A/B
Cebe	A	A	A/B	A/B	A	A/B	A	A	A	A	A	A
Gqunqe	A	A	A/B	A/B	A	A/B	A	A	A	A	A	A
Zalu	A	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A	A/B	A/B
Ngqwara	A	A	A/B	A/B	A/B	A/B	A/B	A/B	A/B	A	A/B	A/B
Sihlontlweni	A/B	A	A/B	A/B	A/B	A/B	A	A	A/B	A	A	A
Nebelele	A/B	A	A/B	A/B	A/B	A/B	A	A	A/B	A	A	A
Qora	B	A	A	A/B	A/B	A	A/B	A/B	B	A/B	A/B	A
Jujura	B	A/B	A	A/B	A/B	A/B	A	A/B	A/B	A	A/B	A/B
Ngadla	A	A	A/B	A/B	A	A/B	A	A	A/B	A	A	A
Shixini	A	A	A	A/B	A	A	A/B	A	B	A	A/B	A
Beechamwood	A	A	A/B	A/B	A/B	A/B	A	A	A/B	A	A	A
Unnamed	A	A	A/B	A/B	A	A/B	A	A	A/B	A	A	A
Kwa-Goqo	A/B	A	A/B	A/B	A/B	A/B	A	A	A/B	A	A	A
Ku-Nocekedwa	A	A	A/B	A/B	A	A/B	A	A	A/B	A	A	A
Nqabara/Nqabarana	A	A	A	A/B	A	A	B	A/B	A/B	A	A/B	A
Ngoma/Kobule	A	A	A	A/B	A	A	A/B	A/B	A/B	A	A	A
Mendu	A	A	A/B	A/B	A/B	A/B	A	A	A/B	A	A	A
Mendwana	A	A	A	A/B	A	A	A	A	A/B	A	A	A
Mbashe	A	A	A/B	B	A/B	A/B	A/B	A/B	D	A/B	B	A/B

A broad evaluation of distribution of PES in the estuaries of the Temperate region based on the six primary Ecological Categories shows that overall 20% of the systems are considered to be in Category A, 43% in Category B, 27% in Categories C or D, and 10% in Categories E and F (Figure 6.1). Estuaries in near-natural condition (Categories A or B) are mainly located in the Warm-Temperate region, whilst the Cool-Temperate region is characterised by a relatively even distribution of estuaries in Categories B to E. That analysis is biased towards the state of the large number of small TOCEs occurring along the South African coast.

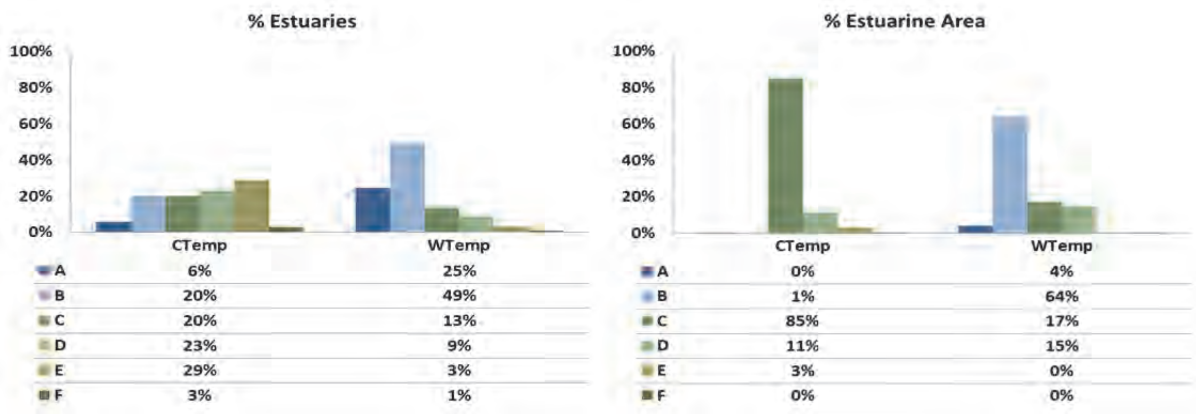

Figure 6.1 A distribution summary of the PES categories of the Temperate estuaries

When analysed according to “estuarine area” rather than the number of estuaries, the majority (~67%) of the estuarine area in the Temperate region is in a C or D Category and only about 2% in a near pristine state (Category A); the latter mainly located in the Warm-Temperate region.

The Cool-Temperate region was found to support estuarine habitat mainly in the C and D categories, especially the small TOCEs near Cape Town and other coastal centres. The Warm-Temperate region, on the other hand was characterised by estuarine habitat in Categories B and C, possibly due to the undeveloped nature of large parts of this zone.

Overall, while a significant number (58%) of the estuaries in the Temperate region are in excellent (Category A) to good health (Category B), these are generally small systems in rural areas with few pressures. On the other hand, the larger systems, which are important as fish nursery grounds and of higher economic and ecological importance, are in a fair (Categories C and D) to poor (Categories E and F) condition due to pressures from the catchment and degradation as a result of direct development in the estuary functional zone. While most of the estuarine habitat in the region is in a good to fair state, there is a risk that the percentage of fair to poor (Categories C and F) estuaries could increase further if appropriate management actions are delayed.

As stressed before, while for practical purposes estuary health is disaggregated into discreet health Categories (A to F), in reality, loss of estuarine functionality happens along a continuum. In estuaries, unlike the terrestrial environment, degradation or loss of habitat seldom means a complete loss of an estuary, e.g. limited examples include canalised and infilled for development. In most cases, degradation means the loss of processes or biological functionality, e.g. the estuarine space is filled with a different salinity condition or different species composition. Generally the physical conditions in estuaries are more dynamic when compared to other aquatic ecosystems, which means that severe degradation of an estuary often comprises a shift from a dynamic to a more stable system. Hence the loss of dynamic function per se is an important indication of declining estuarine health (Van Niekerk, *et al*. 2013).

To reflect this continuum, the estuary health state data generated as part of this study was also disaggregated to a finer scale that shows the straddling categories, e.g. A/B (Figure 6.2).

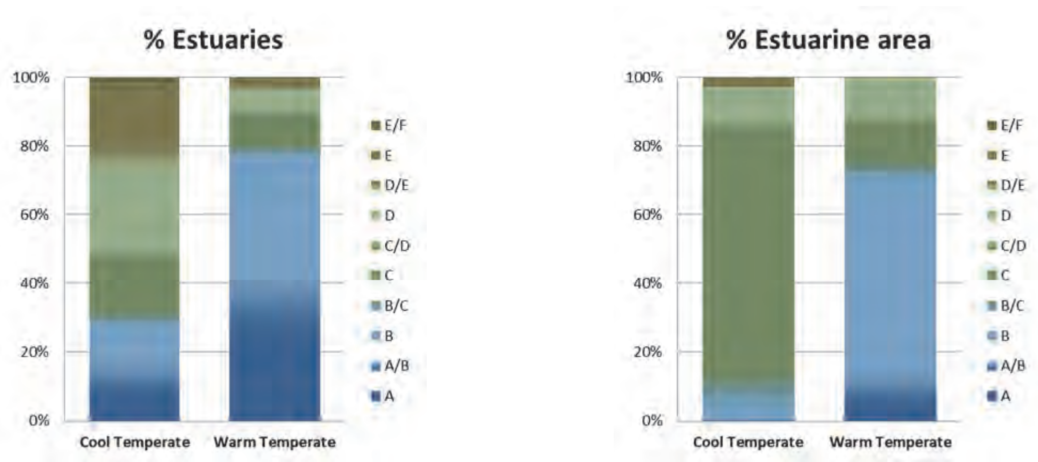

Figure 6.2 A summary of the Present Ecological State of the Temperate estuaries illustrating the continuum in estuary condition of the region

In doing so it becomes clear that a large number of systems are at the cusp of slipping, or have narrowly slipped, into a lower condition: A/B (36), B/C (9), C/D (4), D/E (6), E/F (2). The largest grouping was the estuaries that were in the A/B or B/C categories by far. These systems are in need of urgent management intervention to ensure that their present state is maintained (and provisional REC achieved). It should also be noted that the confidence limits attached to the straddling categories are relatively low as some parameters could only be resolved to the broader primary category range, e.g. water quality. Nevertheless, there is value to be had from indicating the estuaries that are close to tipping into a lower category or can achieve an improved health status with little effort or intervention. Figure 7.2 shows the continuum from near pristine estuaries in a Category A to severely degraded systems in a Category E/F for the Cool-Temperate and Warm-Temperate biogeographical regions. For more detail on individual estuary condition refer to Table 6.1.

Overall, smaller estuaries tend to be in a better state of health because there are fewer pressures on them. However, these systems may not be as resilient to change as large estuaries, primarily due to their small size and higher residence time brought about by limited tidal exchange. This is one of the key reasons for the poor conditions of the urban systems. In contrast, larger estuaries are more heavily affected by catchment and direct pressures (e.g. development in the estuary functional zone and fishing), which lead to degradation and a reduced health status, but are more resilient due to strong tidal exchange associated with this type of system. It should also be stressed that these larger systems generally are important as fish nursery grounds are of higher economic and ecological importance and that there is a considerable risk that the percentage degraded estuaries could increase further if appropriate management actions are delayed.

7. THE IMPORTANCE OF THE TEMPERATE ESTUARIES

7.1 Biodiversity importance

In accordance with the EWR method for Estuaries, the Estuary Importance Score for an estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (DWAF 2008). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition. The scores have been determined for all South African estuaries, apart from functional importance, which is scored by the specialists during EWR workshops. Table 7.1 lists the estuary biodiversity importance rating for the Temperate estuaries (Turpie and Clark 2007, Turpie *et al*. 2002). As per the EWR methods for estuaries, the overall importance score (I) is calculated from the size score (S), habitat importance score (H), zonal type rarity score (Z) and the updated biodiversity importance score (B). In Table 7.1 the EIS for the estuaries of Temperate Region are rated as 3 = "Average Importance" (Score 0-60), 4 = "Important" (score 61-80) or 5 = "High Importance" (Score > 80) to provide an overall indication of their biodiversity importance.

7.2 Protection status and conservation importance

The National Biodiversity Assessment 2011 (Turpie *et al*. 2012) developed a biodiversity plan for the estuaries of South Africa by prioritising and establishing which of them should be assigned partial or full Estuarine Protected Area status. This biodiversity plan followed a systematic approach that took pattern, process and biodiversity persistence into account. While the plan has not explicitly taken social and economic costs and benefits into consideration, it used ecosystem health as a surrogate for the former to some extent. This is because estuaries where the opportunity costs of protection are likely to be high are also likely to be heavily utilised systems that are in a lower state of health.

The plan indicates that on a national scale, 133 estuaries (61 require full protection and 72 require partial protection), including those already protected, would be required to meet biodiversity targets (Turpie *et al*. 2012). Of these, 70 fall within the Temperate region, with a subset of 32 estuaries requiring full protection (Table 7.1 rates national and/or regional priorities[1]= 5), the extent of protection required (Full = full no-take protection, Partial = no-take sanctuary zone), and the recommended proportion of the estuary margin being undeveloped (modified from Turpie *et al*. 2012). Fully protected estuaries are taken to be full no-take areas. Partial protection might involve zonation that includes a no-take area, or it might address other pressures with other types of action. In both these cases, the management objective would be to protect 50% of the biodiversity features of the partially protected estuary. Fully protected and partially protected estuaries can be considered Estuarine Protected Areas, whereas all other estuaries should be designated Estuarine Management Areas. All estuaries require a Management Plan, and these plans should be guided by the results of this assessment. The national priority list provide recommendations regarding the extent of protection required for each estuary, and the recommended extent of the estuary perimeter that should be free from development to an appropriate setback line.

[1] Temperate region biodiversity conservation priorities were developed as part of the Cape Action Plan for the People and the Environment (C.A.P.E.).

Table 7.1 Summary of the importance and Protection Status for the estuaries of the Temperate region (modified from Turpie and Clark 2007, Turpie *et al*. 2012)

Estuary	Estuary Importance						Protection Status (NBA 2011 Biodiversity priority)			
	S	H	Z	B	I	Rating	National and/or CAPE priority	Required extent of protection	Recommended extent of undeveloped margin	Rating
Orange	100	100	90	98	99	5	SA/CAPE	Full	50%	5
Buffels						3				1
Spoeg						3	SA	Full	100%	5
Groen						3				1
Sout						3				1
Olifants	100	100	90	96.5	98	5	SA/CAPE	Partial	50%	5
Jakkalsvlei						3				1
Wadrift						3				1
Verlorenvlei	70	70	60	81.5	72	4	SA	Partial	50%	5
Groot Berg	100	100	90	97.5	98	5	SA/CAPE	Partial	25%	5
Rietvlei/Diep	100	10	60	96	73	4	SA/CAPE	Partial	50%	5
Sout (Wes)						3				1
Houtbaai	10	50	90	42.5	36	3				1
Wildevoëlvlei	80	90	60	86	82	5				1
Bokramspruit	10	10	60	29.5	20	3				1
Schuster	10	10	60	10	15	3				1
Krom	10	10	60	68.5	30	3	SA/CAPE	Full	100%	5
Buffels Wes						3				1
Elsies						3				1
Silvermine	30	50	10	63.5	41	3				1
Sand	90	70	10	91.5	77	4	SA/CAPE	Partial	20%	5
Zeekoei						3				1
Eerste	40	40	10	64.5	43	3	SA/CAPE	Full	75%	5
Lourens	30	30	10	51.5	33	3	SA/CAPE	Full	75%	5
Sir Lowry's Pass	20	20	10	63.5	30	3				1
Steenbras	20	10	20	17.5	17	3				1
Rooiels	40	40	10	65	43	3				1
Buffels (Oos)	50	30	10	73.5	47	3				1
Palmiet	70	60	20	71	63	4	SA/CAPE	Full	50%	5
Bot/Kleinmond	100	100	70	98.5	97	5	SA/CAPE	Partial	50%	5
Onrus	70	60	10	59.5	59	3				1
Klein	100	100	70	100	97	5	SA/CAPE	Partial	50%	5
Uilkraals	80	90	10	82	76	4	SA	Partial	75%	5
Ratel	40	10	10	52	33	3	SA	Full	75%	5
Heuningnes	90	90	20	90.5	83	5	SA/CAPE	Partial	75%	5
Klipdrifsfontein	10	10	10	43.5	18	3	SA/CAPE	Full	75%	5
Breë	100	90	20	89	87	5	SA	Partial	50%	5
Duiwenhoks	100	90	20	76.5	84	5				1
Goukou	90	90	20	79	80	5	SA/CAPE	Partial	50%	5
Gourits	90	60	20	88	75	4	SA/CAPE	Partial	50%	5
Blinde	10	10	10	77.5	27	3				1
Hartenbos	70	60	10	86.5	66	4				1
Klein Brak	80	10	10	69	53	3				1
Groot Brak	90	80	10	79.5	77	4				1
Maalgate	50	10	10	57.5	38	3				1
Gwaing	10	10	10	11.5	10	3				1
Kaaimans	30	10	20	45.5	28	3	SA	Full	50%	5
Wilderness	90	70	70	88	83	5	SA/CAPE	Partial	50%	5
Swartvlei	100	100	70	99.5	97	5	SA/CAPE	Partial	50%	5

Table 7.1 continues/...

Estuary	Estuary Importance						Protection Status (NBA 2011 Biodiversity priority)			
	S	H	Z	B	I	Rating	National and/or CAPE priority	Required extent of protection	Recommended extent of undeveloped margin	Rating
Goukamma	100	40	10	83	72	4	SA/CAPE	Full	75%	5
Knysna	100	100	100	100	100	5	SA/CAPE	Partial	50%	5
Noetsie	30	10	10	51	28	3	CAPE			5
Piesang	80	80	10	72.5	71	4	SA	Partial	50%	5
Keurbooms	100	90	20	95	88	5	SA/CAPE	Partial	50%	5
Matjies	10	10	10	70	25	3				1
Sout (Oos)	70	50	20	67.5	59	3	SA/CAPE	Full	100%	5
Groot (Wes)	70	50	10	83.5	62	4	SA/CAPE	Full	75%	5
Bloukrans	70	10	50	63.5	51	3	SA/CAPE	Full	100%	5
Lottering	50	10	50	25.5	34	3	SA/CAPE	Full	100%	5
Elandsbos	30	10	50	18.5	24	3	SA/CAPE	Full	100%	5
Storms	60	10	50	11.5	34	3	SA/CAPE	Full	100%	5
Elands	10	10	50	11.5	14	3	SA/CAPE	Full	100%	5
Groot (Oos)	10	10	50	11.5	14	3	SA/CAPE	Full	100%	5
Tsitsikamma	10	20	10	45.5	21	3	SA	Full	50%	5
Klipdrif	10	10	10	50.5	20	3				1
Slang	10	0	10	11.5	8	3				1
Krom Oos (Kromme)	100	90	20	95.5	88	5	SA/CAPE	Partial	25%	5
Seekoei	90	80	10	82.5	78	4	SA/CAPE	Partial	25%	5
Kabeljous	90	80	10	84.5	78	4				1
Gamtoos	100	100	20	98.5	92	5	SA/CAPE	Partial	50%	5
Van Stadens	60	30	10	58	47	3	SA/CAPE	Full	50%	5
Maitland	10	70	10	58	37	3	SA/CAPE	Full	75%	5
Baakens						3				1
Papenkuils						3				1
Swartkops	100	100	20	100	92	5	SA/CAPE	Partial	25%	5
Coega (Ngcura)	40	40	10	76.5	46	3				1
Sundays	90	70	20	89	78	4	SA/CAPE	Partial	50%	5
Boknes	60	50	10	72	56	3				1
Bushmans	100	60	20	84.5	78	4	SA/CAPE	Partial	50%	5
Kariega	90	80	20	97	82	5	SA/CAPE	Partial	50%	5
Kasuka	70	70	10	58	61	4				1
Kowie	90	80	20	88.5	80	5				1
Rufane	10	10	10	57.5	22	3				1
Riet	80	80	10	74.5	72	4				1
Kleinemond Wes	80	90	10	71	73	4				1
Kleinemond Oos	70	90	10	84	73	4				1
Klein Palmiet	10	0	10	12	8	3				1
Great Fish	100	100	20	98	92	5	SA/CAPE	Partial	50%	5
Old Womans	60	50	10	76	57	3				1
Mpekweni	90	100	10	92	85	5				1
Mtati	90	100	10	83	83	5	CAPE			5
Mgwalana	90	100	10	79	82	5	SA	Partial	50%	5
Bira	80	70	10	84	72	4	SA	Partial	50%	5
Gqutywa	70	70	10	62	62	4	SA/CAPE	Full	75%	5
Ngculura	20	30	10	61	32	3				1
Mtana	50	70	10	62.5	54	3				1
Keiskamma	100	100	20	97	91	5	SA/CAPE	Partial	50%	5
Ngqinisa	50	60	10	56	50	3	SA	Full	75%	5
Kiwane	60	70	10	53	56	3				1
Tyolomnqa	80	60	10	81	68	4				1
Shelbertsstroom	10	0	10	25	11	3				1

Table 7.1 continues/...

Estuary	Estuary Importance						Protection Status (NBA 2011 Biodiversity priority)			
	S	H	Z	B	I	Rating	National and/or CAPE priority	Required extent of protection	Recommended extent of undeveloped margin	Rating
Lilyvale	20	10	10	19	16	**3**				**1**
Ross' Creek	10	0	10	25	11	**3**				**1**
Ncera	60	50	10	50	50	**3**	SA	Full	75%	**5**
Mlele	20	10	10	19	16	**3**				**1**
Mcantsi	40	20	10	32	30	**3**				**1**
Gxulu	70	50	10	71.5	59	**3**				**1**
Goda	50	30	10	56	43	**3**	CAPE	Full	75%	**5**
Hlozi	10	10	10	39.5	17	**3**				**1**
Hickman's	30	10	10	33.5	24	**3**				**1**
Ngqenga						**3**				**1**
Buffalo	80	40	20	64	60	**3**				**1**
Blind	10	10	10	75	26	**3**				**1**
Hlaze	10	10	10	31.5	15	**3**				**1**
Nahoon	80	60	20	87.5	71	**4**				**1**
Qinira	80	70	10	67.5	67	**4**				**1**
Gqunube	70	50	20	77	62	**4**	SA	Partial	50%	**5**
Kwelera	70	60	20	78	65	**4**	SA	Partial	50%	**5**
Bulura	70	50	10	57.5	56	**3**				**1**
Cunge	10	10	10	18.5	12	**3**				**1**
Cintsa	70	50	10	64.5	58	**3**				**1**
Cefane	80	80	10	60	68	**4**				**1**
Kwenxura	70	50	10	72.5	60	**3**	SA/CAPE	Full	75%	**5**
Nyara	50	40	10	48	43	**3**				**1**
Mtwendwe (Imtwende)						**3**				**1**
Haga-haga	20	20	10	25.5	20	**3**				**1**
Mtendwe	40	40	10	19	32	**3**				**1**
Quko	70	40	10	66.5	56	**3**	SA/CAPE	Full	50%	**5**
Morgan	60	30	10	58	47	**3**				**1**
Cwili	10	10	10	25	14	**3**				**1**
Great Kei	100	70	20	83	80	**5**	SA/CAPE	Partial	50%	**5**
Gxara	60	40	10	49.5	47	**3**				**1**
Ngogwane	40	30	10	54	38	**3**				**1**
Qolora	60	90	10	64	64	**4**				**1**
Ncizele	30	10	10	60.5	31	**3**	SA	Full	75%	**5**
Timba						**3**				**1**
Kobonqaba	60	50	20	57.5	53	**3**				**1**
Nxaxo/Ngqusi	90	80	10	87.5	79	**4**	SA/CAPE	Full	75%	**5**
Cebe	50	40	10	57	45	**3**				**1**
Gqunqe	60	40	10	53	48	**3**				**1**
Zalu	40	20	10	43	33	**3**				**1**
Ngqwara	60	40	10	46.5	47	**3**	SA	Full	75%	**5**
Sihlontlweni	40	20	10	52.5	35	**3**				**1**
Nebelele						**3**				**1**
Qora	80	70	20	82.5	72	**4**	SA/CAPE	Partial	75%	**5**
Jujura	30	10	10	55.5	29	**3**				**1**
Ngadla	50	30	10	43	39	**3**	SA	Full	75%	**5**
Shixini	60	40	20	64	52	**3**	CAPE			**5**
Beechamwood						**3**				**1**
Kwazelitsha/ Kwazwedala						**3**				**1**
Kwa-Goqo						**3**				**1**
Ku-Nocekedwa						**3**				**1**

Table 7.1 continues/...

Estuary	Estuary Importance						Protection Status (NBA 2011 Biodiversity priority)			
	S	H	Z	B	I	Rating	National and/or CAPE priority	Required extent of protection	Recommended extent of undeveloped margin	Rating
Nqabara/Nqabarana	90	70	20	40	66	**4**	SA	Partial	75%	**5**
Ngoma/Kobule	40	40	10	19	32	**3**				**1**
Mendu	60	40	10	39	45	**3**	SA			**5**
Mendwana						**3**	SA			**5**
Mbashe	90	90	30	86	83	**5**	SA/CAPE	Partial	75%	**5**

From an estuary importance perspective, 16% (26 systems) of estuaries in the temperate region are highly important (= 5), while an additional 19% (31 systems) are rated as important (=4). The remaining 64% (102 systems) are judged of average to low importance. In addition, about 44% (70 systems) of Temperate estuaries are either in formally protected areas or from part of the core set of estuaries required to meet biodiversity targets for the region (Turpie et al. 2013).

All estuaries that have a rating of 4 or 5 in the table above require a higher degree of protection and care should be taken with water resource allocation in these catchments to ensure the provision of ecosystem services to society and to maintain/achieve biodiversity objectives.

7.3 Nursery importance

Lamberth and Turpie (2003) estimate that about 50% of the 160 species of fish that occur in South African estuaries are utilised in fisheries (subsistence, recreational and commercial). The total value of estuary fisheries and the contribution of estuary fish to the inshore marine fisheries are about R1.2 billion per annum in 2011 Rands. At least 60% of these species are considered entirely or partially dependent on estuaries, and are thus likely to be affected by changes in runoff.

Although there are close to 300 estuaries along South Africa's coast, the specific habitat requirements of some fish at certain stages of their life may make the choice of juvenile nursery habitat or spawning ground extremely limited. Small juvenile dusky kob *A. japonicus* less than 1-year old prefer the fine sediments of highly turbid estuaries being adapted to find refuge in a "viscous" environment from which other predatory fish are physiologically excluded. This type of habitat comprises less than 5% of the total estuarine area in South Africa. Of the 20 largest catchments in the country, only four rivers – the Mbashe, Great Kei, Mzimvubu and Mtata – have estuaries with the suitable sediment and turbidity characteristics as do an undetermined number of smaller systems such as the Kwelera and Nahoon. For adolescents, the habitat requirements appear to be broader with at least 50% of large and medium size estuaries being suitable nursery environments.

For some species, the level of estuary association appears to vary across biogeographical regions. This may have been selected for at the population level and/or a result of the behavioural and physiological plasticity of the species concerned. For example, on the east and south coast, dusky kob *Argyrosomus japonicus* are obligate estuary-dependent species whereas silver kob *Argyrosomus inodorus* are not and never enter estuaries there. On the cool west coast where the Warm-Temperate *A. japonicus* do not occur, *A. inodorus* utilise the Orange and other estuaries, probably for feeding or as a warm-water refuge. The Angolan dusky kob *A. coronus* occurs in the sea on the Cool-Temperate west coast, until the Warm-

Temperate Cunene, where it is dominant in estuaries and *A. inodorus* no longer occur (Lamberth *et al*. 2008).

White steenbras *Lithognathus lithognathus* occur from the Orange Estuary to the Warm-Temperate/subtropical transition zone on the east coast. There is an annual spawning migration to this bioregion transition zone, spawning occurring late July to September on the fluvial fans off selected estuary mouths. These fluvial fans appear to be limited with the Mbashe as the only confirmed spawning area and the Mtata, Mzimvubu and Great Kei as the only other systems having similar catchment and sediment characteristics. If *L. Lithognathus* are restricted to spawning on these few fluvial fans, the entire South African spawning habitat may be less than 50 hectares. Historically, there may have also been a west coast spawning population with the Orange having a suitable fluvial fan. Intensive beach-seine and gillnet fishing over the last 100 years may have seen this population become extinct or indiscernible.

With the overexploitation and collapse of dusky kob and white steenbras, spotted grunter *Pomadasys commersonnii* have become the most important species in terms of landed biomass in estuaries from Cape Agulhas eastward. This has been accompanied and perhaps facilitated by life history adjustments, range expansion and stock separation into at least two populations in its historical and new distribution. Its historical core distribution was from Warm-Temperate Algoa Bay to subtropical KwaZulu-Natal northward. The new distribution extends into the Breede and Heuningnes estuaries in the Warm-Cool Temperate biogeographical region transition zone. Four decades ago this species was rare in catches in the Breede region but a massive increase in abundance indicates accelerated range expansion over the past twenty years or so. Until 10-15 years ago, the bulk of the adult population in the new distribution would migrate northward in winter for spring spawning in sub-tropical waters. Since then, most of these spotted grunter are non-migratory, remaining in the south all year round with peak spawning in late summer and autumn and stock separation has effectively occurred. Climate change components, most importantly the freshwater flow, appear to be the biggest drivers of this shift but persistence is probably also due to the described life history changes as well as to overfishing of potential competitors and predators of spotted grunter in its new range. Furthermore, spotted grunter are overexploited in their historical range due to massive increases in estuarine fishing effort and shifts in targeting toward this species. Conversely, the population in the new range is "underexploited" in that, typical of newly protected or "invasive" populations, it is currently above equilibrium and the surplus sustaining catches, this despite high levels of fishing effort. However, intensive fishing will inevitably lead to very brief stability between the under- and overexploited states.

Acoustic telemetry studies of spotted grunter (and other species) indicate a high level of connectivity between estuaries within a biogeographical region. Range expansion would not have occurred were it not for the connectivity between grunter populations or the acceptable health of the estuaries in its new distribution. In turn, relatively poor health (including unavailability) of many subtropical systems may also have aided spotted grunter's shift southward. In all, the health of multiple individual systems needs to be ensured to maintain the connectivity between them.

Zambezi (bull) sharks, *Carcharhinus leucas*, are a large predatory shark species commonly occurring in coastal waters of Warm-Temperate, tropical and subtropical seas, occurring from Kosi to the Breede Estuary on the southwest coast. Zambezi sharks are taken as by-catch in fisheries throughout their range, and are increasingly targeted for the shark fin market and trophy fishing industry. Combined with increasing human induced degradation of critical habitats, Zambezi shark populations are becoming locally depleted in many areas. The species is currently listed as Near Threatened by the IUCN Red List.

It is one of few shark species physiologically capable of inhabiting salt- and freshwater systems, and is thought to utilise estuarine systems and freshwater rivers as pupping and nursery grounds. As such, estuaries are considered critical habitat for Zambezi sharks. Recent evidence suggests that, in certain parts of their distribution, Zambezi sharks exhibit philopatry to estuarine and river systems although the degree and nature of philopatry remain unknown. Studies utilising satellite technology and acoustic telemetry have also demonstrated this species can undertake large-scale migrations, moving several thousand kilometres in a relatively short timeframe. Based on the physic-chemical and physical characteristics of South Africa's estuaries – and therefore suitability for Zambezi sharks – it is indicative that several major river systems may be suitable habitat, including the Breede, Gouritz, Gamtoos, Sundays, Great Fish, Great Kei, Mtata and Mbashe. Although several of these systems may not be used for reproductive purposes, they should be considered critical habitat for ensuring the health of Zambezi shark populations in South Africa.

Table 7.2 provides a summary of the Temperate Region important nursery areas. All estuaries larger than 100 ha in total habitat were included in the list. In addition, some smaller estuaries with known endemic fish or invertebrate species, e.g. East Kleinmond that is the prime nursery for the Estuarine Pipefish, were also incorporated. Confirmed importance is indicated by an ●, while ●? indicates unconfirmed status but likely as estuary and catchment characteristics indicate suitable habitat. About 26% (42 systems) of estuaries in the Temperate region are important nurseries for fish and therefore play an important role in the recovery of overexploited and collapsed fish stocks.

Table 7.2/...

Table 7.2 A summary of the Temperate region's very important nursery estuaries (adapted from Van Niekerk and Turpie 2012)

Estuary	Biodiversity	Kob species	Steenbras (spawning grounds)	Spotted grunter	Zambezi sharks
Orange (Gariep)	●	●			
Buffels	●				
Olifants	●	●			
Groot Berg	●	●			
Rietvlei/Diep	●				
Wildevoëlvlei	●				
Sand	●				
Bot/Kleinmond	●	●			
Klein	●	●			
Uilkraals	●				
Heuningnes	●	●		●	
Breede	●	●		●	●?
Duiwenhoks	●	●		●	
Goukou	●	●		●	
Gouritz	●	●		●	●?
Klein Brak	●	●		●	
Groot Brak	●	●		●	
Swartvlei	●			●	
Knysna	●	●		●	●?
Keurbooms	●	●		●	
Kromme	●	●		●	
Seekoei	●			●	
Kabeljous	●	●		●	
Gamtoos	●	●		●	●?
Swartkops	●	●		●	
Sundays	●	●		●	●?
Bushmans	●	●		●	
Kariega	●	●		●	●?
Kowie	●	●		●	
East Kleinemonde	●	●		●	
Great Fish	●	●		●	●?
Mpekweni	●	●		●	
Mtata	●			●	
Mgwalana	●			●	
Bira	●			●	
Keiskamma	●	●	●?	●	●?
Tyolomnqa	●	●	●?	●	
Nahoon		●		●	
Kwelera		●		●	
Great Kei	●	●	●?	●	●?
Nxaxo/Ngqusi	●			●	
Nqabara/Nqabarana	●			●	
Mbashe	●	●	●	●	●?

8. PROVISIONAL RECOMMENDED ECOLOGICAL CATEGORY AND MITIGATION MEASURES

The previous two chapters assessed the PES (Chapter 6) and the ecological importance and protection status (Chapter 7) of the Temperate estuaries. Following the method adopted from the EWR method for estuaries (refer to Chapter 3), the Provisional EcoClassification of the Temperate Estuaries was guided by the PES that sets the minimum REC, except for systems in Categories E and F (which needs to be improved to category D, at least) (Table 3.3). The degree to which the REC needs to be elevated above the PES is determined by the **importance** and **protection status** of a particular estuary (Table 3.4). Using this method, the Provisional RECs for the Temperate estuaries were derived at a specialist workshop. Table 8.1 presents an overall summary of the Provisional EcoClassification results for the Temperate estuaries, including the Provisional REC.

In addition, Table 8.1 indicates the recommended mitigation measures for each estuary, where considered necessary to achieve the Provisional REC. The mitigation measures are grouped into three broad management sectors relating to water, land-use and development, and fisheries, to assist with the coordination of cross-sectorial responses and ultimately to ensure that the overarching objective of the EcoClassification is achieved. Important nursery estuaries are also highlighted as these estuaries often require additional management interventions to assist with achieving biodiversity objectives and fisheries management targets. The successful implementation of the key fisheries related mitigation measures, in turn, would support the achievement of the EcoClassification of the Temperate Estuaries.

Overall, 36% (58 systems) of the estuaries in the Temperate region need to improve in health condition to achieve overarching biodiversity and related ecosystem services objectives. In the Cool-Temperate region nearly 59% (20 systems) of estuaries require some improvement. This is a reflection of both the importance of these aquatic systems along an arid coastline and the severe pressure most of these estuaries are under. In contrast, only about 30% (38 systems) in the Warm-Temperate region require some intervention to achieve the recommended health condition.

A summary of the results is provided in Table 8.2 below. Listed are the PES, importance and protection status, and Provisional REC for each estuary. Results derived from previous EWR studies are highlighted in blue text (these were not reassessed as part of this desktop assessment unless experts were concerned with change in estuary condition since the study). Estuary Importance is rated as 3 = “Average Importance” (Score 0-60), 4 = “Important” (score 61-80) or 5 = “High Importance” (Score > 80). Priority estuaries identified in the South African National Estuary Biodiversity Plan are allocated a rating of 5 for protection status. Finally, the table lists the recommended mitigation measures to achieve the Provisional REC. These are organised in the various management sectors, namely water, land-use and development, and fisheries. Estuaries in which gillnetting needs to be addressed is marked with an *.

Table 8.1 Summary of the Provisional EcoClassification for estuaries in South Africa's Temperate region.

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Orange (Gariep)	D	5	5	C	●	●	●	●		●				✓	●		
Buffels	B/C	3	1	B/C					●					✓			
Spoeg	A/B	3	5	A	●												
Groen	A/B	3	1	A	●												
Sout	D	3	1	D													
Olifants	C	5	5	B	●	●	●			●				✓	●*		Remove gillnets from system
Jakkalsvlei	D	3	1	D	●		●		●								
Wadrift	D/E	3	1	D	●		●	●		●							Increase culverts below bridge
Verlorenvlei	D	4	5	C	●		●	●							●*	●	Increase connectivity with sea (e.g. bridge culverts); remove gillnets from system
Groot Berg	C	5	5	C	●	●				●			●	✓	●*		Remove gillnets from system
Rietvlei/Diep	E	4	5	D	●		●	●		●				✓	●		
Sout (Wes)	E/F	3	1	E			●										
Disa (Houtbaai)	E	3	1	D			●						●				
Wildevoëlvlei	D	5	1	C			●	●		●				✓			
Bokramspruit	C	3	1	C													
Schuster	A/B	3	1	A/B													
Krom	A	3	5	A													

Table 8.1 continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Buffels Wes	A/B	3	1	A/B													
Elsies	D/E	3	1	D				●		●							
Silvermine	D/E	3	1	D	●		●	●	●				●				**Improve water quality (e.g. runoff from golf course)**
Sand	D	4	5	D	●		●	●	●	●			●	✓	●		**Increase intertidal areas through rehabilitation/restoration project**
Zeekoei	E	3	1	E	●		●	●	●				●				
Eerste	E	3	5	D	●		●	●	●	●							
Lourens	C/D	3	5	C	●		●										**Improve water quality (e.g. herbicides and pesticides from golf course)**
Sir Lowry's Pass	D/E	3	1	D			●										
Steenbras	B	3	1	B	●												
Rooiels	A	3	1	A													
Buffels (Oos)	B	3	1	B													
Palmiet	C	4	5	B	●	●											
Bot/Kleinmond	C	5	5	B/C	●		●		●				●	✓	●*		**Remove gillnets from system**
Onrus	E	3	1	D	●	●	●		●								**Control reed growth**
Klein	C	5	5	B	●		●		●				●	✓	●*		**Remove gillnets from system**
Uilkraals	D	4	5	B	●		●	●	●					✓	●		
Ratel	A/B	3	5	A/B													

Table 8.1 continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Heuningnes	C/D	5	5	B	●		●	●	●					✓	●		
Klipdrifsfontein	A	3	5	A													
Breë	B	5	5	B	●		●			●			●	✓	●	●	
Duiwenhoks	B	5	1	B	●									✓	●		
Goukou	B/C	5	5	B	●		●			●			●	✓	●	●	
Gourits	B/C	4	5	B	●	●	●			●				✓	●		
Blinde	B/C	3	1	B/C			●										
Tweekuilen	D/E	4	1	D	●		●										Restore some estuarine functionality
Gericke	D/E	3	1	D			●										Restore some estuarine functionality
Hartenbos	D	4	1	C	●	●	●			●							
Klein Brak	B/C	3	1	B/C	●		●	●					●	✓	●		
Groot Brak	D	4	1	C	●	●			●		●		●	✓	●		
Maalgate	B	3	1	B	●												
Gwaing	B	3	1	C			●										
Kaaimans	B	3	5	A/B	●		●										
Wilderness	B/C	5	5	A/B	●		●	●	●						●	●	
Swartvlei	B	5	5	B	●				●					✓			
Goukamma	B	4	5	A	●								●		●		

Table 8.1 continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Knysna	B	5	5	B	●								●	✓	●		
Noetsie	B	3	5	A			●										
Piesang	D	4	5	B	●		●		●		●			✓			Remove desalination plant from estuary functional zone
Keurbooms	B	5	5	A/B									●	✓			
Matjies	B	3	1	B													
Sout (Oos)	A	3	5	A													
Groot (Wes)	A/B	4	5	A	●										●		
Bloukrans	A	3	5	A													
Lottering	A	3	5	A													
Elandsbos	A	3	5	A													
Storms	A	3	5	A													
Elands	A	3	5	A													
Groot (Oos)	A/B	3	5	A			●										
Tsitsikamma	B	3	5	B			●										
Klipdrif	B	3	1	B			●										
Slang	C	3	1	C			●										
Kromme (Oos)	D	5	5	C	●	●	●						●	✓	●		
Seekoei	D	4	5	B	●		●	●	●					✓			

Table 8.1 continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES: Water			Land-use and development						Fisheries			Additional Comment
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	
Kabeljous	C	4	1	C	●									✓			No more dam development as it reduces opportunities for breaching
Gamtoos	B	5	5	B	●		●						●	✓	●		
Van Stadens	B	3	5	A/B	●												
Maitland	B	3	5	B	●												
Baakens	E	3	1	E	●		●										
Papenkuils	E/F	3	1	E/F	●		●										
Swartkops	D	5	5	C	●	●	●			●			●	✓	●*		Remove gillnets from system
Coega (Ngcura)	E	3	1	E						●							Develop engineering solutions to restore/improve estuarine functionality, redesign saltmarshes to ensure a more natural flow from river into harbour
Sundays	C	4	5	B	●								●	✓	●		
Boknes	C	3	1	C													
Bushmans	B	4	5	A	●									✓	●		
Kariega	C	5	5	B	●									✓	●		
Kasuka	A/B	4	1	A/B													
Kowie	B/C	5	1	B	●		●						●	✓	●		
Rufane	C	3	1	C													
Riet	A/B	4	1	A/B													

Table 8.1 continues/…

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Kleinemond West	A/B	4	1	A/B													
Kleinemond East	B	4	1	B										✓			
Klein Palmiet	B	3	1	B	●		●										Strong trajectory downwards. This system can degrade to a D very easily.
Great Fish	C	5	5	B/C	●		●						●	✓	●		
Old Womans	C	3	1	C	●		●										Improve water quality, e.g. stop spraying of pesticides on Golf Course fairways
Mpekweni	B	5	1	A/B	●									✓	●		
Mtati	B	5	5	A/B	●									✓			
Mgwalana	B	5	5	A/B	●									✓			
Bira	B	4	5	A/B	●									✓			
Gqutywa	B	4	5	A/B	●												
Ngculura	B	3	1	B	●												
Mtana	A/B	3	1	A/B													
Keiskamma	B	5	5	A/B	●					●		●	●	✓	●		
Ngqinisa	A	3	5	A													
Kiwane	A	3	1	A													
Tyolomnqa	A/B	4	1	A/B										✓	●		
Shelbertsstroom	B	3	1	B													

Table 8.1 continues/…

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Lilyvale	B	3	1	B													
Ross' Creek	A/B	3	1	A/B													
Ncera	A/B	3	5	A/B	●		●										
Mlele	B	3	1	B													
Mcantsi	B	3	1	B													
Gxulu	B	3	1	B													
Goda	A/B	3	5	A/B	●		●										
Hlozi	A/B	3	1	A/B													
Hickman's	B	3	1	B													
Ngqenga	B	3	1	B			●										
Buffalo	D	3	1	D	●										●		
Blind	C/D	3	1	C/D			●										
Hlaze	C	3	1	C	●		●										
Nahoon	C	4	1	B	●	●							●	✓	●		
Qinira	B	4	1	B													
Gqunube	B	4	5	A/B			●			●					●		Improve/establish storm water management
Kwelera	A/B	4	5	A/B										✓	●		
Bulura	B	3	1	B											●		

Table 8.1 continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Cunge	A/B	3	1	A/B													
Cintsa	B	3	1	B											●		
Cefane	A/B	4	1	A/B													
Kwenxura	A	3	5	A						●	●				●		Institute setback lines for development
Nyara	A/B	3	1	A													
Mtwendwe (Imtwende)(Imtwende)	A	3	1	A													
Haga-haga	A/B	3	1	A/B													
Mtendwe	A	3	1	A													
Quko	A	3	5	A													
Morgan	B	3	1	B											●		
Cwili	A/B	3	1	A/B													
Great Kei	B/C	5	5	B	●	●				●				✓	●		
Gxara	A/B	3	1	A						●					●		
Ngogwane	A/B	3	1	A/B	●												
Qolora	A/B	4	1	A/B													
Ncizele	A	3	5	A													
Timba	A/B	3	1	A/B	●												
Kobonqaba	A/B	3	1	A/B	●												During extended drought illegal

Table 8.1 continues/…

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
																	/uncontrolled abstraction removed/reduced base flows. Loss of base flows led to mouth closure causing die-off of mangroves.
Nxaxo/Ngqusi	A/B	4	5	A/B						●		●		✓	●		
Cebe	A	3	1	A													These system should be targeted for protection/conservation
Gqunqe	A	3	1	A													These system should be targeted for protection/conservation
Zalu	A/B	3	1	A/B													
Ngqwara	A/B	3	5	A	●					●							Restore floodplain area between the two arms.
Sihlontlweni	A	3	1	A													
Nebelele	A	3	1	A													
Qora	A	4	5	A						●					●		
Jujura	A/B	3	1	A	●												
Ngadla	A	3	5	A													
Shixini	A	3	5	A											●		
Beechamwood	A	3	1	A													
Unnamed	A	3	1	A													
Kwa-Goqo	A	3	1	A													

Table 8.1 continues/...

Estuary	PROVISIONAL ECOCLASSIFICATION				RECOMMENDED MITIGATION MEASURES												
					Water			Land-use and development						Fisheries			
	PES	Biodiversity Importance	Protection Status	Provisional REC	Restore base flows	Restore floods	Improve Water Quality	Restore connectivity/ hydrological functioning	Improve mouth management	Rehabilitate riparian areas/ wetlands	Remove alien vegetation	Implement cattle exclusion zone	Control recreational activities impacting on birds	Important nurseries	Remove/reduce fishing pressure/ bait collection	Remove alien fish	Additional Comment
Ku-Nocekedwa	A	3	1	A													
Nqabara/Nqabarana	A	4	5	A						●		●		✓	●		
Ngoma/Kobule	A	3	1	A													
Mendu	A	3	5	A											●		
Mendwana	A	3	5	A											●		
Mbashe	A/B	5	5	A/B	●					●		●		✓	●		

An overview of the extent of mitigation required in the Cool- and Warm-Temperate regions respectively, is summarised in Figure 8.1.

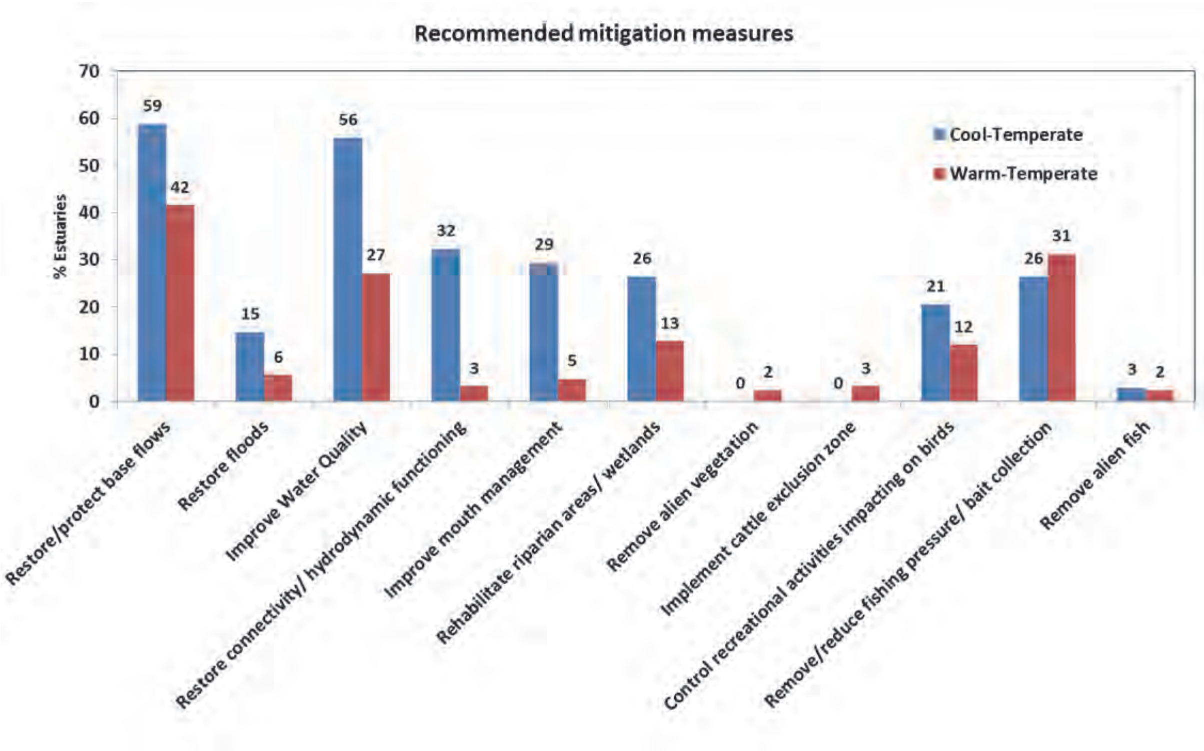

Figure 8.1 Overview of the distribution of key mitigation measures required to achieve the Provisional Recommended Ecological Categories for the estuaries of the Temperate region

From the water sector perspective, about 45% (72 systems) of estuaries require some restoration or protection of base flow conditions (especially during the low flow period), while 33% (53 systems) needs improvement in water quality. From land-use and development sector outlook, 9% (15 systems) of systems require increased connectivity with the sea and/or improved hydrodynamics exchange, while 10% (16 systems) requires an improvement in how the mouth is being managed.

Nearly 16% (25 systems) of estuaries highlighted the need for rehabilitation of the riparian habitat and/or restoration of floodplain/wetland habitat, while 2% (3 systems) requires the removal of alien vegetation. An additional 3% (4 systems) of systems require the implementations of cattle exclusion zones to protect estuarine vegetation (especially mangroves). About 14% (22 systems) of systems require some control of recreational activities, such as boating or hiking, to reduce disturbance of birds. From the fisheries sector perspective, about 30% (48 systems) of estuaries require the reduction/removal of fishing effort (i.e. no-take estuaries, zonation for closed areas, or closed periods), while about 3% (4 systems) of estuaries required the removal of alien fish species to allow for the recovery of indigenous populations.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

This study set out to develop a desktop method for the Provisional EcoClassification for estuaries to inform the National Water Resources Classification process, among others. The method had to provide for a comparative, regional scale assessment of the Present Ecological Status (PES), the ecological importance and protection status, the Provisional Recommended Ecological Category (REC), as well as mitigation measures towards achieving the Provisional REC.

To assess the degree of freshwater flow modification on a regional scale, an existing model was refined and applied to the catchments of the Cool- and Warm-Temperate biogeographical regions draining into estuaries. These simulated median monthly flow data sets for the reference condition and present state provided the base data for the Provisional EcoClassification of the region. In order to improve the assessment of abiotic components in estuaries at a regional scale, stochastic and rule-based models were developed for the assessment of the hydrodynamic and water quality components. These methods provided simplified approaches to populate the Estuarine Health Index that was used to define the PES at regional scales. Finally, the above was incorporated into a desktop method for the Provisional EcoClassification of estuaries, aligned with the existing EWR method for estuaries developed under the NWA. This desktop method reconciled the abiotic and biotic health assessment results, the relative ecological importance and protection status of estuaries, as well as the objectives of other biodiversity and socio-economic strategies relevant to estuaries into a Provisional EcoClassification system.

The desktop method was then applied to the estuaries in the Cool- and Warm-Temperate regions of South Africa. First, the ecological health of individual abiotic and biotic components was assessed for the estuaries at a regional scale in order to derive the PES. This was followed by an assessment of the ecological importance and protection status of the Temperate Estuaries. Finally, the Provisional REC was determined for each estuary in the Temperate region, as well as mitigation measures towards achieving the Provisional REC for these estuaries.

This study therefore provides a desktop method for the Provisional EcoClassification of estuaries. Its application to the Temperate estuaries provides planners with regional-scale knowledge to inform strategic planning processes, at least in the short- to medium-term pending the outcome of more detailed scientific studies. However, these results are not suitable for detailed, fine-scale planning, such as approvals of dam development or approvals of discharges from wastewater treatment works. Such studies still require detailed site-specific scientific studies, e.g. detailed EWR studies or Environmental Impact Assessment studies.

9.2 Recommended research priorities

The following research priorities, related to the improvement of the confidence of future regional desktop assessments to inform regional health assessment and/or **strategic planning processes** relevant for estuaries, are recommended:

- **Develop desktop biotic assessment models:** Similar to the abiotic models developed as part of this study, develop desktop methods for regional health assessment of biotic components. A model has already been proposed (as part of this study) for microalgae, but health assessments for macrophytes, invertebrates, fish and birds are still largely based on expert opinion. Such models would assist in quantifying some of the understanding of estuary functioning explicitly.

- **Investigate the use of the desktop health assessment models as prediction tools.** The stochastic and rule-based models develop for abiotic boitci components as part of this study, show great potential as a prediction tool to be applied in a "forecasting mode" to investigate regional scale change, e.g. climate change or far-future water resource development scenarios. This potential should be investigated further.

- **Importance of the smaller and/or ephemeral outlets:** This study again emphasised that more than 60 micro-estuaries and small outlets are still excluded from estuarine planning frameworks (at present deemed non-functional estuarine systems) (see Van Niekerk and Turpie 2012 for a full list), i.e. representative of significant biological activity (Harrison *et al*. 2000). This exclusion leaves them unprotected from any inappropriate future water resource and/or coastal development. However, as these systems are very small it is highly unlikely that they will ever be assessed on an individual basis, i.e. as part of a formal EWR study. It is therefore recommended that a separate research study be undertaken to demarcate these smaller or more ephemeral outlets, to investigate their ecological importance, and finally integrate them into current planning frameworks, such as EcoClassification processes.

- **Nursery function for exploited and collapsed fish species:** Recent studies have indicated that while most estuaries serve as nurseries, some of the more sediment rich systems are associated with "sediment deltas" in the near-shore marine environment. These areas serve as nurseries for some species that have collapsed stocks. It is of the utmost importance that such systems are identified and their nursery function quantified to ensure sustainable resource utilisation into the future. As fishing pressure escalates along the coast it is envisaged that key nurseries may require additional rules to guide the setting of the REC and the range of proposed mitigation measures to improve estuary health.

- **Connectivity and regional importance:** Estuarine ecosystems are not independent and isolated from other ecosystems. Rather, estuaries form part of a local, regional, national and global ecosystem network through either a direct connection via water flows (the transport of nutrients, detritus, larvae, plankton, etc.) or indirectly via the movement of estuarine fauna. Hence, a disturbance to a specific estuary may be reflected in effects on adjacent systems and/or on ecosystems remote from that estuary. Unfortunately, although there is ample evidence of the regional interaction and interdependence between especially the estuaries, little quantification has been conducted in South Africa on the connectivity between systems and how to incorporate "knock-on effects" of neighbouring systems' health into regional desktop assessments (as this study), EWR studies and biodiversity plans. Where a coast comprises a large number of small systems (e.g. Wild Coast) the collective is frequently more important than the individual systems but little concrete science exist to support this.

- **Investigate status of invasive species in estuaries:** With the exception of plants and freshwater fish, very little is known about invasive species in South Africa's estuaries. There is an urgent need to understand the potential environmental impact of invasive species on both ecosystem function and the value derived from estuaries. This will assist in refining future health estimates of estuary condition and the setting of mitigation measures. Included is a need for a census on the occurrence of invasive alien species in different estuaries, including all invasive species (i.e. freshwater, marine and estuarine).

9.3 Recommendations for data acquisition and monitoring

The following data acquisition and/or monitoring activities, related to the improvement of the confidence of future regional desktop assessments to inform regional health assessment and/or **strategic planning processes** relevant for estuaries, are recommended:

- **Expand on the national DWA monitoring programme collecting data on river inflow and water quality at the head of all estuaries.** The DWA is urged to increase the present coverage to include systems under significant pressure (PES = C to F) and a selection of representative pristine sites (e.g. nearly permanently closed small TOCEs). The river inflow data is needed to calibrate and refine the desktop hydrodynamic model for predicting mouth state, while the river water quality data is needed to tighter couple land-use activities to estuary water quality.

- **Expand on the national DWA monitoring programme recording water levels (and mouth state) in estuaries.** There are long-term datasets available on only about 10% of the estuaries in the Temperate region. The DWA is urged to increase the present coverage to include systems under significant pressure (PES = C to F) and a selection of representative pristine sites (e.g. nearly permanently closed small TOCEs). The data is needed to calibrate and refine the desktop hydrodynamic model for predicting mouth state.

- **Regular update of the regional/national simulated monthly flow data set for estuaries.** The simulated river flow data generated as part of this study project needs to be updated on an annual basis (at a minimum with each update of the national hydrology, e.g. WR2005). This is required to provide the context to historical and current studies reliant on river inflow in the absence of measured river inflow data. Future updates of this data set will also form the basis for future reviews and expansion of the EcoClassification conducted as part of this study.

- **Resolve the future updates of the national land cover data into more categories.** Land cover information provides valuable insight into the quality of runoff entering estuaries from the catchment. Unfortunately, the datasets evaluated in this study suffers from some weaknesses. The 2000 land cover for South Africa used in this study had a high resolution in the number of classes (49) that could be coupled to specific land-use impact, but its accuracy in terms of spatial resolution is poor. While the more resent updates (e.g. 2009 South African National Biodiversity Institute) more accurately reflect spatial land-use change, it has insufficient classes (<10) to assist with predicting the impact of catchment practices on estuary water quality. Ideally, the limited set of land cover types should be resolved into more classes to provide greater land-use cover detail adjacent to estuaries in order to improve the accuracy in deriving water quality in river inflow to estuaries.

- **Mapping the topography and bathemetry of South Africa's estuaries:** Historical cross-sectional survey data are available for less than a third of the estuaries in the country. In most cases these data are over 20 years old. Most planning processes (e.g. EWR studies, Estuary Management Plans, setback lines, spatial development plans) are of low confidence as they lack this basic information. Assessment of change (sedimentation, erosion sensitivity to flow modifications, structural developments) is therefore mostly inferred from hydrological and pressure data. Improved planning and assessments urgently require a significant effort to address these basic data requirements. Detailed, systematic topographical and bathymetrical surveys therefore are needed for all estuaries. Lidar data recently collected on the estuary functional zone for a large number of estuaries will go a long way to address this gap in data, but research is required on the accuracy and potential use of this data set. Volumetric data flowing from such surveys would go a long way to improve the application of the desktop methods for water quality and mouth state (hydrodynamics) developed as part of this study.

- **Sediment data:** Very little information is available on the sediment structure of the Temperate estuaries. This is a significant data gap as grain size distribution and the mud/sand ratios influence biodiversity patterns significantly. The lack of sediment information also makes it very difficult to assess environmental change in relation to some of the major pressures such as dam development and sand mining. The collation of a national set of sediment grain size data would assist greatly in developing predictive models for habitat responses and invertebrates to flow changes.

- **Taxonomic surveys of plants in all South African estuaries:** Taxonomic revision of salt marsh species is required so that macrophyte species lists and GIS spatial data can be updated for all estuaries. This is especially important where data are older than 10 years. This would include field surveys to ground truth the data. Such data in turn would be used to improve on desktop health estimates and the building of desktop biotic assessment models.

- **Taxonomic surveys of the invertebrates in all South African estuaries:** There is no detailed national dataset for South African estuarine invertebrates which compromise the quality of any regional health assessment conducted on these systems. Limited invertebrate data were collated at a national scale more than a decade ago but little effort has been made to address this since then. Future desktop assessments and biodiversity plans cannot be refined properly without addressing this gap in knowledge in a systematic manner.

- **National/regional surveys of the fish and bird fauna of estuaries:** National/regional scale surveys on fish and birds in all South African estuaries were last carried out in the early 1990s. These surveys urgently need to be repeated in a coordinated effort that is comparable with the earlier surveys. Such data would assist in building regional scale prediction models and verify existing desktop estimates of estuary health.

9.4 Potential future benefits

The Provisional EcoClassification of estuaries developed as part of this study (both the desktop method and its application to the Temperate estuaries) will not only inform the Water Resources Classification process, but also other strategic assessment and planning processes such as:

- The Provisional EcoClassification of the Temperate region can assist DWA with prioritising their efforts in rolling out detailed EWR studies, e.g. based on the degree of pressure on the individual estuaries and the need to improve the condition for a number of systems. In addition, the results from this study provides clarity on the key pressures that drives change in an estuary, e.g. whether it relates to modification in flow or deterioration in water quality (mandated of DWA) or whether the pressures fall within the mandate of other departments (e.g. fisheries a DAFF mandate).

- The revised estuary health assessment data of the Temperate estuaries resulting from this study can be used to update the "Estuary Ecosystem Status" and "Protection Level Status" indicators in the next edition of the National Biodiversity Assessment: Estuaries Component (2015-2017). The revised health assessment data can also be used to update national and regional biodiversity planning processes, such as the National Estuary Biodiversity Plan, as health state is one of the selection criteria for conservation (Turpie *et al*. 2013).

- The output from this study can also be used by municipalities in the Temperate region to inform their local planning processes, such as the District and Local Municipal Integrated Development Plans and Spatial Development Frameworks (required under the Municipal Systems Act of 2000). Especially useful to them is the identification and impact of current land-use and development practices in and around the estuaries. In addition, the recommended mitigation measures that can be undertaken at a local level, e.g. increased connectivity with the sea and the need to manage artificial breaching more effectively, become useful. This information will also be useful in the development of individual Estuary Management Plans (as required by the National Estuarine Management Protocol under the National Environmental Management Integrated Coastal Management Act No. 24 of 2008).

- Finally, the outputs of this study can be used in the prefeasibility phases of Strategic Environmental Assessments (SEAs) and Environmental Impact Assessment (EIA) involving estuaries to assess the large-scale activities such as heavy mineral sand mining and construction freeways.

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APPENDICES

APPENDIX A: PHYSICAL CHARACTERISTICS OF TEMPERATE ESTUARIES

NAME	X-Coordinate	Y-Coordinate	Bio-geographical Region	Open water (ha)	Estimated estuary volume (m^3)	Perched /Con-stricted (1=Y; 0=N)	%Open (1=100-75; 2=75-50; 3=50-25; 4=25-0)
Orange (Gariep)	16° 27' 28.0943"	28° 38' 8.6783"	CTemp	474	11854400	0	1
Buffels	17° 3'2.26"	29° 40' 38.17"	CTemp	5	48673	0	4
Spoeg	17° 21' 31.4280"	30° 28' 21.691"	CTemp	2	19889	0	4
Groen	17° 34' 35.6268"	30° 50' 48.472"	CTemp	15	146261	0	4
Sout	17° 50' 54.2831"	31° 14' 41.207"	CTemp	28	281292	0	4
Olifants	18° 11' 13.6283"	31° 42' 3.7583"	CTemp	335	10062405	0	1
Jakkalsvlei	18° 18' 48.2976"	32° 5' 4.70759"	CTemp	3	33392	0	4
Wadrift	18° 19' 30.9719"	32° 12' 16.509"	CTemp	64	638945	0	4
Verlorenvlei	18° 19' 59.4263"	32° 18' 57.319"	CTemp	1361	40815300	1	4
Groot Berg	18° 8' 37.9860"	32° 46' 11.096"	CTemp	667	20024580	0	1
Rietvlei/Diep	18° 28' 55.7148"	33° 53' 23.654"	CTemp	224	3359317	0	1
Sout (Wes)	18° 28' 17.7095"	33° 54' 28.925"	CTemp	36	360876	0	2
Houtbaai	18° 21' 16.2000"	34° 2' 47.0075"	CTemp	1	1768	0	2
Wildevoëlvlei	18° 20' 35.8332"	34° 7' 38.6796"	CTemp	32	850335	1	1
Bokramspruit	18° 19' 57.6335"	34° 8' 3.65999"	CTemp	0	4326	0	1
Schuster	18° 22' 15.2651"	34° 12' 7.3619"	CTemp	1	6457	0	1
Krom	18° 22' 42.2436"	34° 13' 51.391"	CTemp	7	67786	1	3
Buffels Wes	18° 27' 42.4151"	34° 19' 5.6532"	CTemp	2	3000	0	3
Elsies	18° 25' 53.3495"	34° 9' 37.5083"	CTemp	3	3000	0	3
Silvermine	18° 26' 20.1227"	34° 7' 57.9467"	CTemp	0	3620	1	3
Sand	18° 28' 35.4000"	34° 6' 22.9823"	CTemp	96	1924180	1	3
Zeekoei	18° 30' 17.7623"	34° 5' 54.3083"	CTemp	292	5837660	1	1
Eerste	18° 45' 13.4028"	34° 4' 43.7771"	CTemp	12	180107	1	1
Lourens	18° 48' 39.0347"	34° 6' 0.18719"	CTemp	2	21027	1	1
Sir Lowry's Pass	18° 51' 53.6220"	34° 9' 20.0160"	CTemp	0	638	1	2
Steenbras	18° 49' 9.88319"	34° 11' 41.348"	CTemp	1	8645	0	1
Rooiels	18° 49' 15.7620"	34° 17' 44.786"	CTemp	2	27333	0	1
Buffels (Oos)	18° 49' 46.3259"	34° 20' 20.209"	CTemp	2	16452	1	2
Palmiet	18° 59' 38.9075"	34° 20' 43.584"	CTemp	13	268344	1	1
Bot/Kleinmond	19° 5.' 49.6751"	34° 22' 6.3516"	CTemp	1272	31364000	0	4
Onrus	19° 10' 43.2912"	34° 25' 7.1472"	CTemp	3	28462	1	3
Klein	19° 17' 53.3723"	34° 25' 14.354"	CTemp	1153	34590600	0	3
Uilkraals	19° 24' 27.4859"	34° 36' 27.176"	CTemp	49	489356	0	2
Ratel	19° 44' 47.4216"	34° 46' 15.668"	CTemp	1	12867	1	2
Heuningnes	20° 7' 9.28560"	34° 42' 53.244"	WTemp	1475	29499200	0	1
Klipdrifsfontein	20° 43' 52.7951"	34° 27' 6.8616"	WTemp	0	4487	1	4
Breë	20° 50' 43.1951"	34° 24' 26.762"	WTemp	1171	35134200	0	1
Duiwenhoks	21° 0' 4.25520"	34° 21' 54.107"	WTemp	111	2762775	0	1
Goukou	21° 25' 24.6972"	34° 22' 42.067"	WTemp	125	3123425	0	1
Gourits	21° 53' 9.25440"	34° 20' 43.227"	WTemp	324	6474800	0	1
Blinde	22° 0' 46.6092"	34° 12' 39.060"	WTemp	2	18821	1	4
Tweekuilen	22° 6'42.11"	34° 9'5.51"	WTemp	10	3000	1	4
Gericke	22° 6'37.50"	34° 8'38.35"	WTemp	10	3000	1	4
Hartenbos	22° 7' 32.8152"	34° 6' 54.4032"	WTemp	31	311801	1	4
Klein Brak	22° 8' 54.9096"	34° 5' 34.5480"	WTemp	91	1829896	0	1
Groot Brak	22° 14' 21.4511"	34° 3' 26.1144"	WTemp	63	1265840	0	3
Maalgate	22° 21' 15.9803"	34° 3' 15.8039"	WTemp	14	282770	1	3
Gwaing	22° 26' 2.90039"	34° 3' 23.2883"	WTemp	5	90757	0	1
Kaaimans	22° 33' 25.4015"	33° 59' 52.130"	WTemp	9	189229	0	1
Wilderness	22° 34' 52.0571"	33° 59' 44.728"	WTemp	512	10248140	1	4
Swartvlei	22° 47' 46.5215"	34° 1' 53.4576"	WTemp	1185	76887814	0	2
Goukamma	22° 56' 56.8859"	34° 4' 37.7795"	WTemp	46	927668	0	1
Knysna	23° 3' 41.2308"	34° 4' 57.7416"	WTemp	1022	40876800	0	1
Noetsie	23° 7' 44.9543"	34° 4' 49.0872"	WTemp	6	55259	1	3
Piesang	23° 22' 43.5431"	34° 3' 37.6740"	WTemp	5	50519	1	2

Appendix A continues/...

NAME	X-Coordinate	Y-Coordinate	Bio-geographical Region	Open water (ha)	Estimated estuary volume (m^3)	Perched /Con-stricted (1=Y; 0=N)	%Open (1=100-75; 2=75-50; 3=50-25; 4=25-0)
Keurbooms	23° 22' 41.4732"	34° 2' 59.4599"	WTemp	311	9334470	0	1
Matjies	23° 28' 12.6552"	34° 0' 7.07399"	WTemp	1	10925	1	2
Sout (Oos)	23° 32' 11.5548"	33° 59' 22.207"	WTemp	6	86628	1	1
Groot (Wes)	23° 34' 9.04799"	33° 58' 54.411"	WTemp	29	573072	1	2
Bloukrans	23° 38' 50.8884"	33° 58' 46.721"	WTemp	2	32309	0	1
Lottering	23° 44' 9.41999"	33° 59' 43.836"	WTemp	2	15743	0	1
Elandsbos	23° 46' 4.59120"	34° 0' 12.6467"	WTemp	2	15506	0	1
Storms	23° 54' 10.7568"	34° 1' 15.5064"	WTemp	2	49760	0	1
Elands	24° 4' 44.7096"	34° 2' 38.3387"	WTemp	5	92639	0	1
Groot (Oos)	24° 11' 42.0683"	34° 3' 35.6219"	WTemp	8	166662	0	2
Tsitsikamma	24° 26' 17.9736"	34° 8' 8.13480"	WTemp	14	138452	1	2
Klipdrif	24° 38' 13.3764"	34° 10' 20.521"	WTemp	2	8967	0	4
Slang	24° 39' 13.3271"	34° 10' 26.864"	WTemp	2	11332	0	4
Krom Oos (Kromme)	24° 50' 33.8208"	34° 8' 34.6811"	WTemp	275	8255370	0	1
Seekoei	24° 54' 38.6748"	34° 5' 12.0119"	WTemp	70	1048890	1	3
Kabeljous	24° 55' 57.0108"	34° 0' 31.7051"	WTemp	72	722335	1	4
Gamtoos	25° 2' 4.97040"	33° 58' 13.529"	WTemp	233	6994710	0	1
Van Stadens	25° 13' 13.2455"	33° 58' 13.994"	WTemp	17	171219	1	3
Maitland	25° 17' 31.0271"	33° 59' 16.933"	WTemp	4	41857	0	3
Baakens	25° 37' 48.0468"	33° 57' 49.427"	WTemp	2	16817	0	1
Papenkuils	25° 36' 49.9896"	33° 55' 2.2548"	WTemp	2	20885	1	1
Swartkops	25° 37' 58.9619"	33° 51' 58.481"	WTemp	428	12842790	0	1
Coega (Ngcura)	25° 41' 26.6604"	33° 47' 43.368"	WTemp	60	602548	0	4
Sundays	25° 51' 13.4100"	33° 43' 18.609"	WTemp	163	4890210	0	1
Boknes	26° 35' 10.5396"	33° 43' 37.822"	WTemp	14	143447	1	4
Bushmans	26° 39' 49.0392"	33° 41' 41.697"	WTemp	166	4968180	0	1
Kariega	26° 41' 11.0364"	33° 40' 57.975"	WTemp	107	3220710	0	1
Kasuka	26° 44' 7.07280"	33° 39' 14.741"	WTemp	23	225170	1	4
Kowie	26° 54' 5.88240"	33° 36' 13.053"	WTemp	146	4382580	0	1
Rufane	26° 56' 8.97719"	33° 34' 50.995"	WTemp	1	16670	0	3
Riet	27° 0' 49.8671"	33° 33' 40.330"	WTemp	3	32417	1	4
Kleinemond Wes	27° 2' 46.1471"	33° 32' 28.845"	WTemp	36	359560	1	4
Kleinemond Oos	27° 2' 57.5699"	33° 32' 20.493"	WTemp	31	314568	1	3
Klein Palmiet	27° 7' 30.5795"	33° 30' 25.257"	WTemp	0	4145	0	4
Great Fish	27° 8' 26.4624"	33° 29' 42.820"	WTemp	137	4095840	0	1
Old Womans	27° 8' 53.0520"	33° 28' 57.975"	WTemp	5	47984	1	4
Mpekweni	27° 13' 52.2336"	33° 26' 16.843"	WTemp	30	302195	1	4
Mtati	27° 15' 32.6591"	33° 25' 22.360"	WTemp	50	501134	1	4
Mgwalana	27° 16' 27.1704"	33° 24' 46.886"	WTemp	53	530821	1	3
Bira	27° 19' 33.7116"	33° 23' 1.5360"	WTemp	74	738213	1	4
Gqutywa	27° 21' 29.0844"	27° 21' 29.084"	WTemp	42	421739	1	4
Ngculura	27° 22' 4.49760"	33° 21' 29.077"	WTemp	1	3000	0	3
Mtana	27° 25' 55.7940"	33° 19' 6.9779"	WTemp	13	134750	1	4
Keiskamma	27° 29' 28.4388"	33° 16' 53.328"	WTemp	183	5477820	0	1
Ngqinisa	27° 31' 40.5696"	33° 15' 9.8603"	WTemp	11	106488	1	4
Kiwane	27° 32' 35.4012"	33° 14' 53.887"	WTemp	34	336783	1	4
Tyolomnqa	27° 35' 0.31560"	33° 13' 32.779"	WTemp	97	1934058	0	3
Shelbertsstroom	27° 36' 56.3903"	33° 12' 25.527"	WTemp	0	2442	0	1
Lilyvale	27° 38' 12.8723"	33° 11' 34.270"	WTemp	1	12102	0	2
Ross' Creek	27° 39' 27.6192"	33° 10' 36.325"	WTemp	1	11775	1	3
Ncera	27° 40' 5.54160"	33° 10' 12.417"	WTemp	21	212538	1	3
Mlele	27° 40' 47.8631"	33° 9' 34.963"	WTemp	4	40028	1	3
Mcantsi	27° 42' 7.11719"	33° 8.' 43.832"	WTemp	3	34963	1	2
Gxulu	27° 43' 53.3675"	33° 7' 8.0579"	WTemp	34	341301	1	3
Goda	27° 46' 30.1188"	33° 6' 3.9239"	WTemp	14	135263	1	3
Hlozi	27° 48' 42.7788"	33° 5' 8.1491"	WTemp	3	29805	0	2
Hickman's	27° 50' 22.8767"	33° 4' 14.984"	WTemp	3	25288	1	2
Ngqenga	27° 51' 53.5968"	33° 3' 22.7988"	WTemp	0	3000	0	2
Buffalo	27° 54' 58.7448"	33° 1' 36.476"	WTemp	102	4075160	0	1
Blind	27° 55' 39.6983"	27° 55' 39.698"	WTemp	1	5653	0	1

Appendix A continues/...

NAME	X-Coordinate	Y-Coordinate	Bio-geographical Region	Open water (ha)	Estimated estuary volume (m^3)	Perched /Con-stricted (1=Y; 0=N)	%Open (1=100-75; 2=75-50; 3=50-25; 4=25-0)
Hlaze	27º 56' 57.6816"	32º 59' 21.231"	WTemp	1	5092	0	1
Nahoon	27º 57' 6.13439"	32º 59' 11.176"	WTemp	58	1744134	0	1
Qinira	27º 57' 53.3987"	32º 58' 27.130"	WTemp	25	247395	1	3
Gqunube	28º 2' 5.63639"	32º 56' 1.9535"	WTemp	63	1251718	0	1
Kwelera	28º 4' 37.2072"	32º 54' 26.495"	WTemp	36	727072	0	1
Bulura	28º 5' 36.2076"	32º 53' 28.805"	WTemp	24	237756	0	4
Cunge	28º 6' 37.5263"	32º 51' 39.157"	WTemp	0	1600	0	2
Cintsa	28º 7' 1.35839"	32º 49' 53.155"	WTemp	26	259313	1	4
Cefane	28º 8.' 13.5528"	32º 48' 34.070"	WTemp	33	328330	1	4
Kwenxura	28º 9' 5.71680"	32º 47' 55.589"	WTemp	38	378980	1	3
Nyara	28º 10' 55.2611"	32º 47' 6.8279"	WTemp	11	112650	1	3
Mtwendwe (Imtwende)	28º 14' 13.1135"	32º 46' 12.133"	WTemp	0	4535	0	2
Haga-haga	28º 17' 9.04920"	32º 44' 26.836"	WTemp	3	33618	0	3
Mtendwe	28º 18' 34.3367"	32º 43' 32.303"	WTemp	0	4336	0	1
Quko	28º 20' 38.5691"	32º 42' 30.949"	WTemp	43	432567	0	3
Morgan	28º 22' 25.4531"	32º 41' 27.214"	WTemp	24	243065	1	4
Cwili	28º 23' 9.47040"	32º 40' 47.593"	WTemp	1	6917	0	2
Great Kei	28º 23' 56.8679"	32º 39' 58.168"	WTemp	226	4513680	0	1
Gxara	28° 24'45.07"	32°39'30.25"	WTemp	21	210189	1	4
Ngogwane	28° 25'17.91"	32°38'55.31"	WTemp	3	30805	1	4
Qolora	28° 26'5.79"	32°37'47.70"	WTemp	11	113092	1	2
Ncizele	28°26'16.68"	32°37'42.50"	WTemp	1	14411	0	3
Timba	28° 26'45.16"	32°37'31.65"	WTemp	0	3000	0	3
Kobonqaba	28º 29' 25.2924"	32º 36' 28.209"	WTemp	37	746938	0	1
Nxaxo/Ngqusi	28º 31' 34.5323"	32º 35' 5.0315"	WTemp	31	311558	0	3
Cebe	28º 35' 8.97719"	32º 31' 16.273"	WTemp	22	219883	1	3
Gqunqe	28º 35' 22.2396"	32º 31' 7.6836"	WTemp	22	219062	0	3
Zalu	28º 36' 11.2572"	32º 30' 9.5183"	WTemp	9	93445	1	3
Ngqwara	28º 36' 50.6016"	32º 29' 39.138"	WTemp	22	219927	1	3
Sihlontlweni	28º 38' 41.3627"	32º 28' 52.957"	WTemp	9	88489	0	3
Nebelele	28º 39' 21.3480"	32º 27' 45.575"	WTemp	1	3000	0	4
Qora	28º 40' 24.4740"	32º 26' 46.932"	WTemp	53	1054658	0	1
Jujura	28º 41' 38.2596"	32º 25' 51.960"	WTemp	6	63047	0	1
Ngadla	28º 42' 31.2515"	32º 25' 6.0599"	WTemp	9	86656	0	4
Shixini	28º 43' 31.8467"	32º 24' 11.163"	WTemp	25	496208	0	1
Beechamwood	28º 45' 7.48439"	32º 22' 29.492"	WTemp	1	3000	0	3
Kwazlelitsha/Kwa zwedala	28º 45' 29.4371"	32º 22' 12.151"	WTemp	3	3000	0	3
Kwa-Goqo	28º 45' 41.4539"	32º 21' 59.050"	WTemp	6	3000	0	3
Ku-Nocekedwa	28º 46' 40.0655"	32º 20' 55.766"	WTemp	2	3000	0	3
Nqabara/Nqabara na	28º 47' 25.1915"	32º 20' 22.970"	WTemp	73	1461952	0	1
Ngoma/Kobule	28º 50' 14.3195"	32º 18' 4.1868"	WTemp	13	127834	0	3
Mendu	28º 52' 40.0332"	32º 16' 51.297"	WTemp	26	262778	0	4
Mendwana	28º 53' 3.25679"	32º 16' 8.1336"	WTemp	3	3000	0	1
Mbashe	28º 54' 6.84359"	32º 14' 59.946"	SubTrop	135	2693480	0	1

APPENDIX B: HYDROLOGY METHOD

Background

There is an urgent need to assess the changes in runoff to the estuaries of South Africa from the Reference condition (natural) to Present State. This runoff data is necessary to determine the present health status of South Africa's estuaries, on a national scale, as part of a national Estuarine Health Assessment.

Changes in the runoff to estuaries is required for the more than 300 individual catchments (see Appendix A) that feed into the functional estuaries around the coast of South Africa. Estimating the Reference and Present hydrology for any estuary requires the modelling of the entire catchment of the estuary. In the unlikely event that an estuary's catchment lies in only one quaternary catchment, this exercise would be fairly simple since hydrology and water use information is readily available at quaternary scale. However, should an estuary's catchment be large, for example, the Orange River estuary, the estimation of the reference and present hydrology becomes a massive task since it would entail accumulating data on water use, reservoirs transfers in and out and forestry for about 1 000 quaternary catchments. At the other end of the scale, many estuaries have catchments which occupy only a small portion of a quaternary catchment. In this case the hydrology and water use information for the quaternary catchment will need to be scaled in an intelligent and consistent manner.

Clearly, from the above discussion, the estimation of reference and present hydrology for all 280 estuaries in South Africa is not a trivial exercise and in order to achieve this within a reasonable time and budget requires innovation. This first report of project K5/2187 describes the methodology that has been developed to tackle this problem.

Before commencing with model development, existing models were evaluated for this task of modelling all the estuaries in South Africa. There are four options that were evaluated, the Water Resources Yield Model (DWAF,. 1998), WRSM2000 (Middleton and Baily, 2008), WSAM (Schulze and Watson, 2002), and the Water Resources Modelling Platform (Mallory *et al*, 2011).

The water resources yield model

The Water Resources Yield Model (DWAF, 1998), developed and maintained by the Department of Water Affairs, has been set up for many of the major basins in South Africa. The intention is therefore to use these model setups wherever they are available, i.e. where they have modelled the whole catchment down to the estuary. A list of these model setups is given in Table B.1. The only missing component with existing Water Resources Yield Model setups is that these models do not have a function to produce cumulative natural flow time series. This can be overcome by developing an application to use the hydrological data and compute this separately.

Table B.1 WRYM model setups applicable to estuaries

Catchment	Client	PSP
Orange	Orasecom	WRP
Mhlthuze	DWA	WRP
Thukela	DWA	WRP
Mgeni	DWA	WRP
Umzimkulu	DWA	WRP
Umkomaaz	DWA	BKS
Breede	DWA	Aurecon
Berg	DWA	Aurecon

While the above list of models only accounts for 8 out of the 280 estuaries, it covers more than half of the catchment areas to be modelled by including the Orange catchment.

WRSM2000

As part of the WR 2005 project (Middleton and Bailey, 2008) to update the hydrology for the whole of South Africa, the WRSM2000 model setups were updated for the whole country. These could be used to generate natural hydrology and, with some effort, also present hydrology. One of the problems to be overcome is that WRSM2000 model setups have historic water use data and not present day water use data. Hence, any WRSM2000 model run using the existing setup would not produce stationery records. In order to produce a stationery record, all the water use time series would need to be changed to present day time series. This would be a big task.

WRSM200 is however a source of national water use data. Most importantly, it contains estimated irrigated areas in each quaternary catchment. This will be used to estimate irrigation use at a quaternary scale.

WSAM

The WSAM model (Schulze and Watson, 2002) was developed to support the National Water Resources Strategy. It is a tool which can quickly carry out water balances at a quaternary scale for the whole country. The two shortcomings of WSAM are that firstly, it only produces results in terms of Mean Annual Runoff (MAR) and does not produce time series as required for this estuaries project. The second shortcoming is that the model's data base has not been kept up to date. It seems it was last updated in about 2006.

The Water Resources Modelling Platform

The Water Resources Modelling Platform (WReMP), developed largely by IWR Water Resources with input from the Institute of Water Research and the University of Pretoria, is similar to WRYM in that it is a time series simulation model. It can therefore produce the reference and present day time series required of this Estuaries project. The main motivation for the development of WReMP was to develop a Windows based water resources model. At the time of it development of WRYM was a DOS based model and many practitioners still use WRYM in DOS mode.

The advantage of WReMP over WRYM for this particular application of modelling all the estuaries in South Africa is that this model has been structured to interface with databases referenced to South Africa quaternary catchments. It is therefore relatively simple to set up models simply by indicating the quaternary catchments included in the setup and the relationship between these setups. The other major advantage is that IWR Water Resources are the custodians to the WReMP source code and can therefore adapt the model to meet specific applications.

In addition to the above, there are numerous existing WReMP setups which can be used to model reference and present day hydrology. These are listed in Table B.2.

Table B.2 Existing WReMP setups

Catchment	Client
Mfolozi	Isimangaliso Wetland Park
Durban Bay	Durban Metro
Amanzimtoti	Durban Metro
Umvongo	Umgeni Water
Mbokotwini	Durban Metro
All T and S region catchment	DWA: Stream flow reduction
Keiskamma	DWA: NWRP
Buffalo	DWA: NWRP
Nahoon	DWA: NWRP
Knysna	DWA: NWRP
Krom	DWA: NWRP
Swartvlei	DWA: NWRP
Bushmans	DWA: NWRP
Bot	DWA: NWRP
Groot Brak	DWA: NWRP
Uilenkraal	DWA: NWRP
Buffels Rivier	DWA: NWRP

Recommended models

The recommended approach is to use existing WRYM and WReMP model setups where available. Catchments that have not been modelled in the past will be setup using WReMP. The following section describes the process to be used to streamline the setting up of this model.

Model setups for reconnaissance level hydrological modelling of inflows into estuaries

There are several distinct steps required in order to set up a water resources model. These are as follows:

- Determine the connectivity of the quaternary catchments
- Source the reference hydrology for all these catchments (natural flow, evaporation, rainfall)
- Include all significant dams in the model
- Include water use in the model
- Include streamflow reduction due to commercial afforestation and alien invasive vegetation in the model

The automation of these steps is described in the following sections.

Determining the connectivity of quaternary catchment making up the estuary catchment

One of the more onerous tasks in setting up most models is determining the connectivity between catchments and capturing this in a format that can be interpreted numerically. Fortunately, the connectivity of South Africa quaternary catchments has already been determined by Prof Hughes of the Institute of Water Research. This is in a simple format listing which quaternary catchment lies downstream of each quaternary. This is a practical approach since there can be only one catchment downstream of each catchment (see example below in Table B.3).

Table B.3 Example of Quaternary catchment connectivity as described by Hughes

R10A	R10B
R10B	R10C
R10C	R10D
R10D	R10E
R10E	R10J
R10F	R10G
R10G	R10H
R10H	R10J
R10J	R10K
R10K	R10L
R10L	R10M
R10M	OUT

WReMP has a more complex structure to describe the connectivity of catchments since, as a water resources model, it needs to take into account transfers of water from one catchment to the next. An Example of a WReMP connectivity setup is shown in Figure B.1.

System Definition

Add node | Insert Node | Delete Node | Number of channels

Node no	Node name	IN 1	IN 2	IN 3	IN 4	IN 5	IN 6	IN 7	IN 8	OUT 1	OUT 2	OUT 3	OUT 4	OUT 5	OUT 6	OUT 7	OUT 8
1	R10A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	R10B	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
3	R10C	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
4	R10D	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
5	R10E	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
6	R10F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
7	R10G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
8	R10H	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
9	R10J	5	6	8	0	0	0	0	0	0	0	0	0	0	0	0	9
10	R10K	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
11	R10L	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
12	R10M	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12

Figure B.1 WReMP System definition table

This shows how at each node in the system (a catchment in this case would be represented by a node) can have up to 8 inflows and 8 outflows. The connectivity shown in Table B.2 is therefore described in WReMP as the Out 8 channel which flows into the downstream node. This is shown as a systems diagram in Figure B.2.

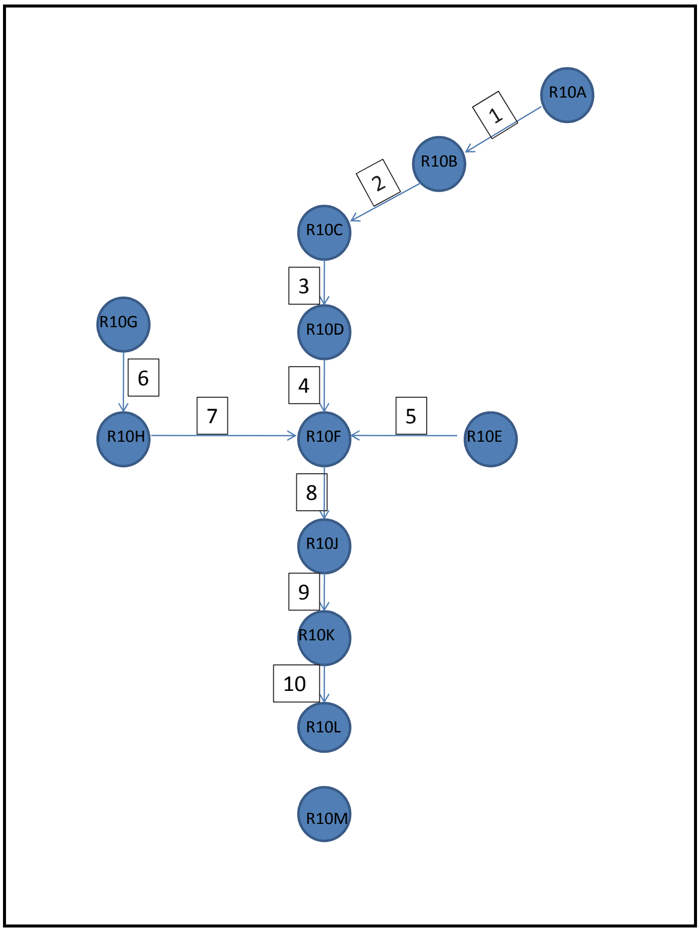


Figure B.2 System Diagram

The first step in streamlining the model setup procedure is therefore to convert the Hughes connectivity to the WReMP system definition. This is not a trivial exercise since the starting point for modelling an estuary is the downstream node, so the modelling process needs to proceed upstream and explore all branches. In order to make this process as intuitive as possible for the model user, the user is offered a drop down list, firstly of primary catchments, from which a list of quaternary catchments is derived. The user selects the quaternary catchment which represents the most downstream catchment in the system to be modelled. See Figure B.3.

Source reference hydrology

The convenience of using quaternary catchments is that in South Africa most hydrological data is referenced to the quaternary catchments. Hence, if the quaternary catchments upstream of the estuary are known the hydrological data can be automatically sourced. This is dealt with by the WReMP by storing all the WR2005 natural runoff flow and rainfall time series in a directory named WR2005. During model setup, the user is prompted to identify the quaternary catchment associated with the node or catchment. This need not necessarily be the same as the node name. Figure B.4 and B.5 show the process of capturing the hydrological data automatically.

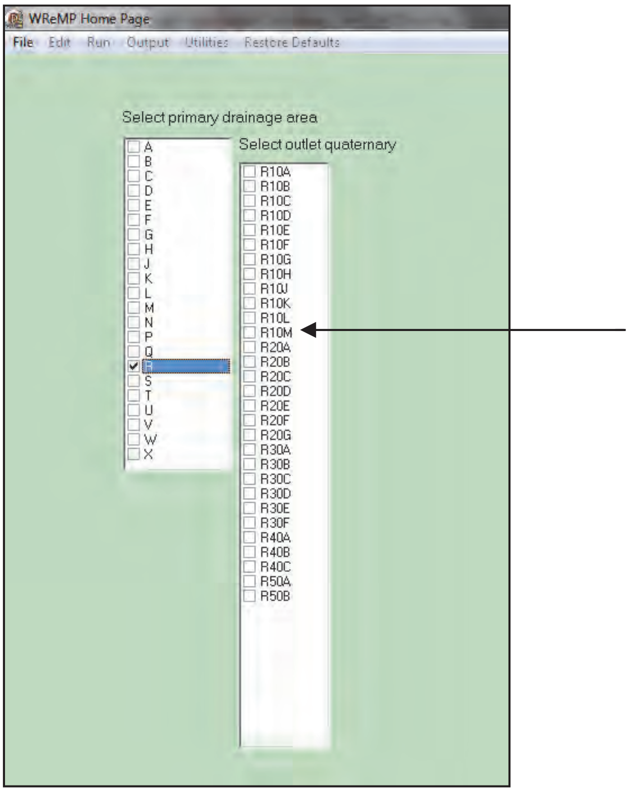


Figure B.3 Estuary selection process

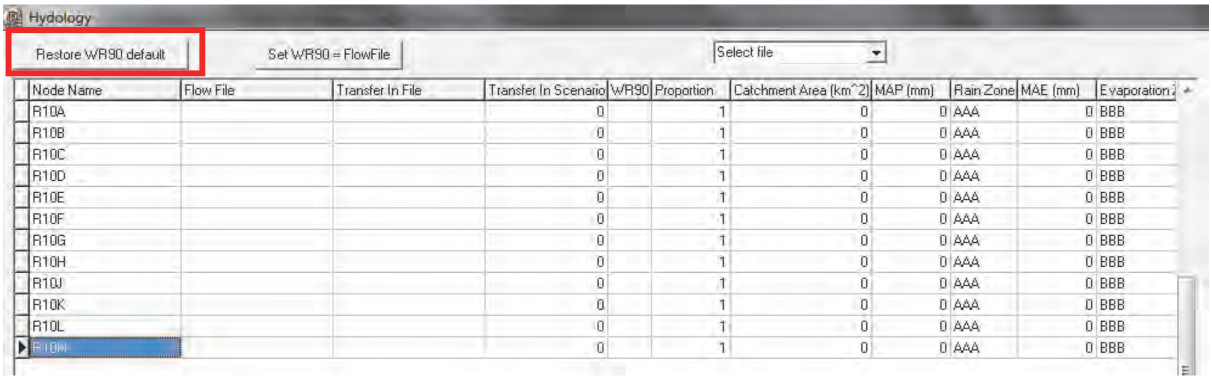


Figure B.4 Hydrological data capture screen (unpopulated)

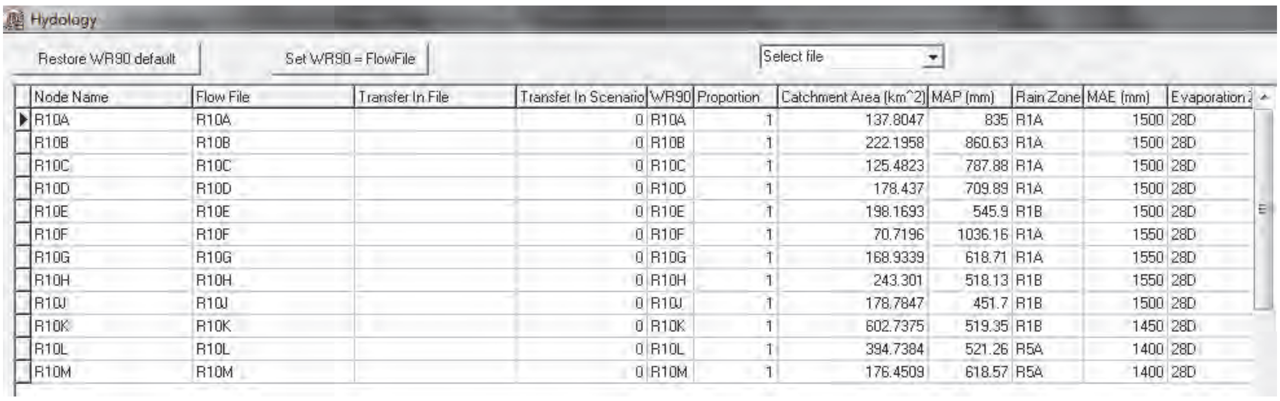


Figure B.5 Hydrological data capture (populated)

Procedures such as 'Restore WR90 Default' reference the quaternary names obtained from the process which identifies the quaternary catchments within the estuary catchment and uses this to populate the hydrology table with rainfall, evaporation zone and rainfall zone. The next step in the process is to read the incremental flow files, the rainfall files and the monthly evaporation data.

Include significant dams in the process

Dams in a catchment – even if they are not used for their intended purpose of water supply – change the natural or reference hydrology in two ways. Firstly, water that would have flowed downstream is stored in the dam and hence the advent of spring floods are delayed and attenuated. Also, in almost all areas of South Africa, potential evaporation exceeds rainfall. Hence there is a net water loss from the surface of dam. In order to model present day hydrology, it is important to include all significant dams located in an estuary's catchment. Typically this would be a long and arduous task, but through the development of a dam database, referenced to quaternary catchments, this process has been automated.

Figure B.6 shows an extract of the National dam database for the R10 secondary catchment while Figure B.7 shows the WReMP model screen for capturing this data.

Database Desktop
File Edit View Table Record Tools Window Help

Table : C:\WReMP\Data\DamsSA.DB

DamsSA	Quat	Name	Major Dam Capacity	Major Dam Area	Dead Storage	Major Dam Factor	Minor Dam Capacity	Minor Dam Area	Minor Dam Factor	Farm dam proportion
1328	R10A	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1329	R10B	SANDILEDAM	27.50	1.84	0.00	0.00	14.68	1.04	0.00	40.00
1330	R10C	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1331	R10D	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1332	R10E	DEBE DAM (CISKEI)	6.00	0.80	0.00	0.00	0.00	0.00	0.00	40.00
1333	R10F	0	0.00	0.00	0.00	0.00	0.09	0.02	0.00	5.00
1334	R10G	BINFIELDPARKDAM-CISKEI	36.83	2.60	0.00	0.00	1.79	0.30	0.00	45.00
1335	R10H	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1336	R10J	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1337	R10K	0	0.00	0.00	0.00	0.00	1.18	0.06	0.00	5.00
1338	R10L	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1339	R10M	0	0.00	0.00	0.00	0.00	0.14	0.00	0.00	5.00

Figure B.6 Extract from the National Dam database

frmDams

Restore defaults

Node numbe	Node name	Full supply capaci	Full supply ar	Dead storage	Power
1	R10A	0	0	0	0
2	R10B	27.5	1.84	0	0.6
3	R10C	0	0	0	0
4	R10D	0	0	0	0
5	R10E	6.0	0.80	0	0.6
6	R10F	0	0	0	0
7	R10G	36.83	2.60	0	0.6
8	R10H	0	0	0	0
9	R10J	0	0	0	0
10	R10K	0	0	0	0
11	R10L	0	0	0	0
12	R10M	0	0	0	0

Figure B.7 Dam capture screen

The evaporation from the surface of dams is dependent on several factors. Rainfall and evaporation are obviously important factors but so is the surface area, which will fluctuate from month to month. It is therefore important to model the change in surface area with the change in storage. WReMP deals with this in the same way as the WRSM 2000 model using the relationship:

$$Area = a \times Storage^{b} \qquad Eqn\ [1]$$

Where **a** and **b** are constants which can only be determined accurately if the dam basin has been surveyed. All the larger dams in South Africa have been surveyed and the parameters **a** and **b** have been determined. In the absence of a surveyed dam, a good default value for **b** is 0.6.

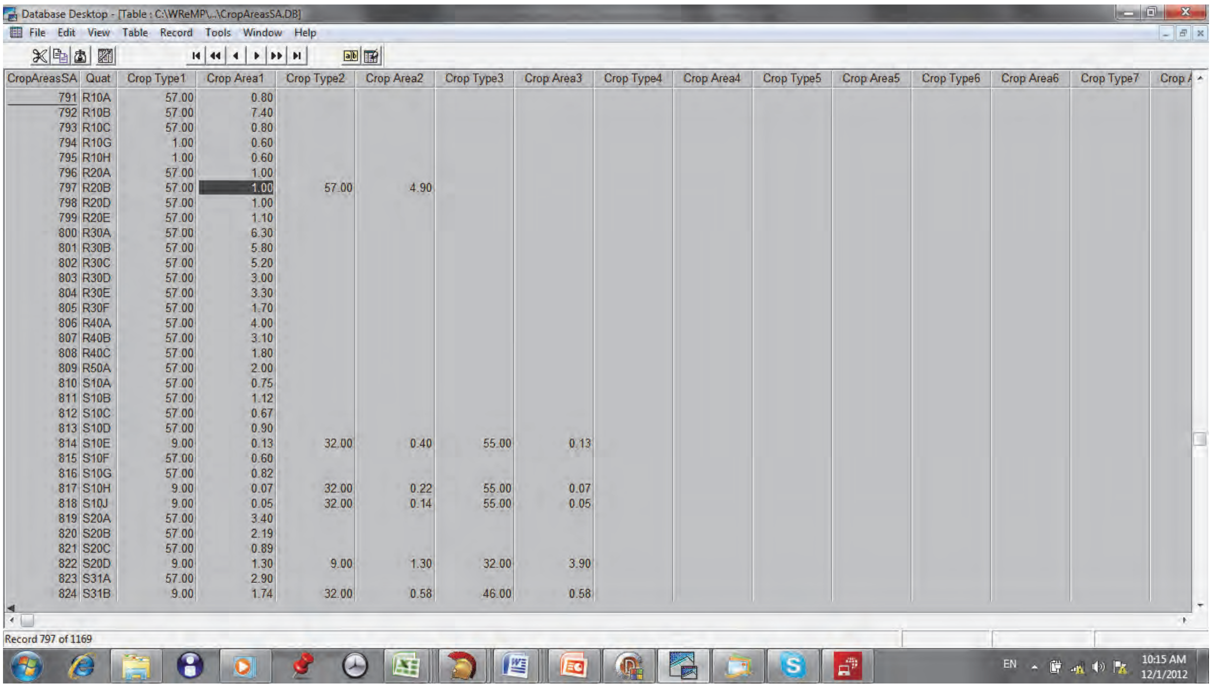
Including water use in the model

Perhaps the most tedious task in setting up a water resources model is to source reliable information on water use within the catchment under consideration and capturing this as time series. This task has been streamlined in WReMP by creating two databases, one for irrigation, the other for all other water use as well as transfers in and out of the quaternary catchments. These databases are also referenced to quaternary catchments.

Irrigation water use

Water use by irrigators is complex in that it depends on several factors such as the type of crops grown and the climatic conditions, especially rainfall and evapo-transpiration. As part of the preparation for the first edition of the National Water Resources Strategy (DWAF, 2004), data was nationally collected on the type and areas of crops grown in each quaternary catchment. While the crop areas are probably out of date, the crop types will not have changed significantly. This database will therefore be updated as part of this project using the areas from the WR2005 project.

An extract of the crop database is shown in Figure B.8.



CropAreasSA	Quat	Crop Type1	Crop Area1	Crop Type2	Crop Area2	Crop Type3	Crop Area3	Crop Type4	Crop Area4	Crop Type5	Crop Area5	Crop Type6	Crop Area6	Crop Type7	Crop A
791	R10A	57.00	0.80												
792	R10B	57.00	7.40												
793	R10C	57.00	0.80												
794	R10G	1.00	0.60												
795	R10H	1.00	0.60												
796	R20A	57.00	1.00												
797	R20B	57.00	1.00	57.00	4.90										
798	R20D	57.00	1.00												
799	R20E	57.00	1.10												
800	R30A	57.00	6.30												
801	R30B	57.00	5.80												
802	R30C	57.00	5.20												
803	R30D	57.00	3.00												
804	R30E	57.00	3.30												
805	R30F	57.00	1.70												
806	R40A	57.00	4.00												
807	R40B	57.00	3.10												
808	R40C	57.00	1.80												
809	R50A	57.00	2.00												
810	S10A	57.00	0.75												
811	S10B	57.00	1.12												
812	S10C	57.00	0.67												
813	S10D	57.00	0.90												
814	S10E	9.00	0.13	32.00	0.40	55.00	0.13								
815	S10F	57.00	0.60												
816	S10G	57.00	0.82												
817	S10H	9.00	0.07	32.00	0.22	55.00	0.07								
818	S10J	9.00	0.05	32.00	0.14	55.00	0.05								
819	S20A	57.00	3.40												
820	S20B	57.00	2.19												
821	S20C	57.00	0.89												
822	S20D	9.00	1.30	9.00	1.30	32.00	3.90								
823	S31A	57.00	2.90												
824	S31B	9.00	1.74	32.00	0.58	46.00	0.58								

Figure B.8 Crop area database

The irrigation database supports up to ten different crop types within each quaternary catchment with the crop type referenced to a crop number. The crop number in turn is referenced to a crop factor database which contains approximately 60 difference crop types. Irrigation water requirement time series are then calculated at a monthly time step using the widely accepted equation given below:

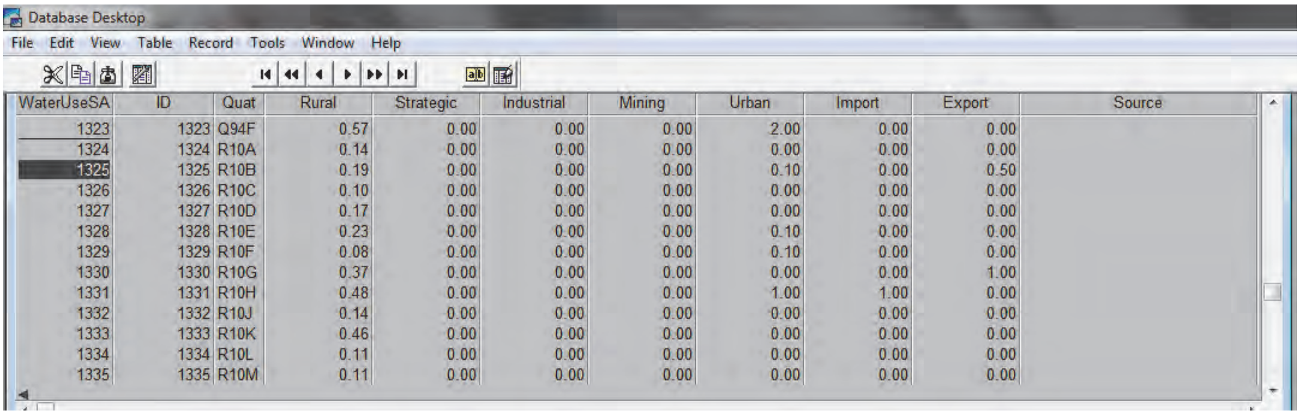
$$Requirement_i = \underline{(Evap_i - Rainfall_i) \times CropFactor_i} \qquad \text{Eqn (2)}$$

(1 – Efficiency)

Where i refers to the time step, which in the case of WReMP, is monthly. The requirement is therefore calculated for every month.

All other water use

All other water use is assumed to be independent of climatic conditions can be simplified into an annual average demand. An extract of this database for the R10 secondary catchment is shown in Figure B.9. This database was however developed during the development of water balances for the first edition of the National Water Resources Strategy (DWAF, 2004) and the data contained in the database is now out of date. The intention is to update the domestic use part of this database (as part of this estuaries project) using DWA's recently completed All Towns Reconciliation Strategies studies. Updated irrigation area will be sourced from the WR2005 study, completed in 2007.



WaterUseSA	ID	Quat	Rural	Strategic	Industrial	Mining	Urban	Import	Export	Source
1323	1323	Q94F	0.57	0.00	0.00	0.00	2.00	0.00	0.00	
1324	1324	R10A	0.14	0.00	0.00	0.00	0.00	0.00	0.00	
1325	1325	R10B	0.19	0.00	0.00	0.00	0.10	0.00	0.50	
1326	1326	R10C	0.10	0.00	0.00	0.00	0.00	0.00	0.00	
1327	1327	R10D	0.17	0.00	0.00	0.00	0.00	0.00	0.00	
1328	1328	R10E	0.23	0.00	0.00	0.00	0.10	0.00	0.00	
1329	1329	R10F	0.08	0.00	0.00	0.00	0.10	0.00	0.00	
1330	1330	R10G	0.37	0.00	0.00	0.00	0.00	0.00	1.00	
1331	1331	R10H	0.48	0.00	0.00	0.00	1.00	1.00	0.00	
1332	1332	R10J	0.14	0.00	0.00	0.00	0.00	0.00	0.00	
1333	1333	R10K	0.46	0.00	0.00	0.00	0.00	0.00	0.00	
1334	1334	R10L	0.11	0.00	0.00	0.00	0.00	0.00	0.00	
1335	1335	R10M	0.11	0.00	0.00	0.00	0.00	0.00	0.00	

Figure B.9 National Water Use Database (Original source: WSAM)

Stream-flow reduction

It is a well-established fact that exotic forests and invasive alien vegetation reduce the natural runoff from the catchment in which they are located. A considerable amount of research has gone into quantifying this stream-flow reduction and the methodologies have been incorporated into WReMP linked to databases of areas of forestry plantations and invasive alien plants.

The method used for the forestry is that described by Mallory and Hughes (2011) while invasive alien vegetation is dealt with using the method described by Mallory *et al*. (2011). Examples of the Forestry and Invasive Alien Database are shown in Figure B.10 and Figure B.11.

Conclusions and recommendations

The estimation of reference and present hydrology for all estuaries in South Africa requires the modelling of the catchments upstream of the estuaries. While producing natural hydrology is relatively simple, present day hydrology requires estimates of all water use upstream of every estuary.

Database Desktop - [Table : C:\WReMP\...\ForestrySA.DB]

ForestrySA	ID	QUAT	EUCS	PINE	WATTLE	SOURCE
1324	1,324.00	R10A	0.00	11.34	0.00	Landsat2000+ Licences
1325	1,325.00	R10B	0.00	14.26	0.00	Landsat2000+ Licences
1326	1,326.00	R10C	0.00	6.94	0.00	Landsat2000+ Licences
1327	1,327.00	R10D	0.00	4.11	0.00	Landsat2000+ Licences
1328	1,328.00	R10E	0.00	1.98	0.00	Landsat2000+ Licences
1329	1,329.00	R10F	0.00	29.36	1.34	Landsat2000+ Licences
1330	1,330.00	R10G	0.00	1.37	0.00	Landsat2000+ Licences
1331	1,331.00	R10H	0.00	2.12	0.00	Landsat2000+ Licences
1332	1,332.00	R10J	0.00	0.59	0.00	Landsat2000+ Licences
1333	1,333.00	R10K	1.15	0.00	0.00	Landsat2000+ Licences
1334	1,334.00	R10L	0.03	0.00	0.00	Landsat2000+ Licences
1335	1,335.00	R10M	0.26	0.15	0.00	Landsat2000+ Licences
1336	1,336.00	R20A	1.50	28.80	0.00	Landsat2000+ Licences
1337	1,337.00	R20B	1.74	5.59	0.00	Landsat2000+ Licences
1338	1,338.00	R20C	0.00	1.67	0.00	Landsat2000+ Licences
1339	1,339.00	R20D	0.00	0.46	0.00	Landsat2000+ Licences
1340	1,340.00	R20E	1.68	3.49	0.19	Landsat2000+ Licences

Figure B.10 Forestry database

Database Desktop - [Table : C:\WReMP\...\AlienVeg.DB]

AlienVeg	Node	Hydro	Area	WR90	Upland	Riparian
1	R10A	R10A	137.80	R10A	4.09	0.00
2	R10B	R10B	222.20	R10B	8.76	0.00
3	R10C	R10C	125.48	R10C	15.06	0.00
4	R10D	R10D	178.44	R10D	4.00	0.00
5	R10E	R10E	198.17	R10E	0.63	0.00
6	R10F	R10F	70.72	R10F	0.93	0.00
7	R10G	R10G	168.93	R10G	18.60	0.00
8	R10H	R10H	243.30	R10H	0.48	0.08
9	R10J	R10J	178.78	R10J	1.44	0.00
10	R10K	R10K	602.74	R10K	1.04	0.96
11	R10L	R10L	394.74	R10L	20.39	0.46
12	R10M	R10M	176.45	R10M	0.29	0.11

Figure B.11 Alien Vegetation database

This estuaries study will firstly use whatever existing model setups are available. There are several existing WRYM and WReMP setups, mostly in the larger catchments, that will make a significant contribution to the estuaries project. The remaining estuaries will be setup using a system of databases of water use, stream-flow reduction and dams, all referenced to quaternary hydrology. Model setups can then be automated within WReMP and the software to do this has been developed and tested as part of this study.

First and foremost, existing models were sourced where they were available. Secondly, information on catchment developments was obtained from readily available sources. The third strategy was to populate a water resource and water use database which is cross-referenced to quaternary catchments so as to automate model setups. This database was incorporated into the Water Resources Modelling Platform which is the modelling tool being used where existing models are not available (Mallory et al. 2011).

The preliminary application of the methodology applied both existing models as well as the Water Resources Modelling Platform (WReMP).

Results are presented in the following format:

- Natural Mean Annual Runoff;
- Present Day Mean Annual Runoff;
- Percentage change in Mean Annual Runoff, referred to as MAR Similarity;
- Natural and present day base flow (defined as the 25th percentile);
- Percentage change in base flow, referred to as Base flow similarity;
- Median flow (natural and present day);
- The month in which the maximum flows occurs;
- The month in which the minimum flow occurs;
- Flood variance for both natural and present day flow, defined as the 95th percentile over the 25th percentile;
- Base flow variance for both natural and present day flow, defined as the 75th percentile over the 25th percentile;
- The duration of low flow, which was defined as the number of months from when the mean monthly flow drops below 6% of the MAR to the minimum flow month. This was determined for both natural and present day conditions;
- The month in which high flows commence was defined as the first month after the minimum flow month in which the monthly flow exceeds the mean monthly flow. This was determined for both natural and present day conditions;
- Coefficient of variability, defined as average monthly flow minus median monthly flow divided by the median monthly flow; and
- An assessment of whether the flow is bimodal or not, that is, two wet periods and two dry periods.

For example, the Mdlotane Estuary is located in KwaZulu-Natal north of Durban (see Figure B.12). The natural MAR is 6.0 million m^3/annum, which is similar to the present. The base flow remains unchanged.

Figure B.12 The Mdlotane Estuary on the KwaZulu-Natal coast

The monthly flow distribution and flow duration curves are shown in Figure B.13 and Figure B.14.

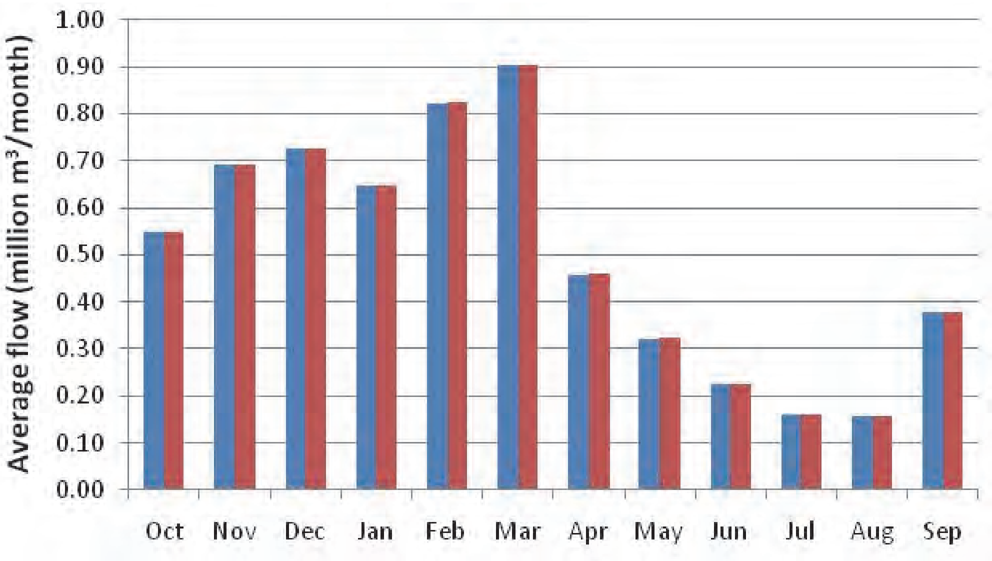


Figure B.13 Monthly distribution of flow into the Mdlotane Estuary for natural (blue) and present state (red)

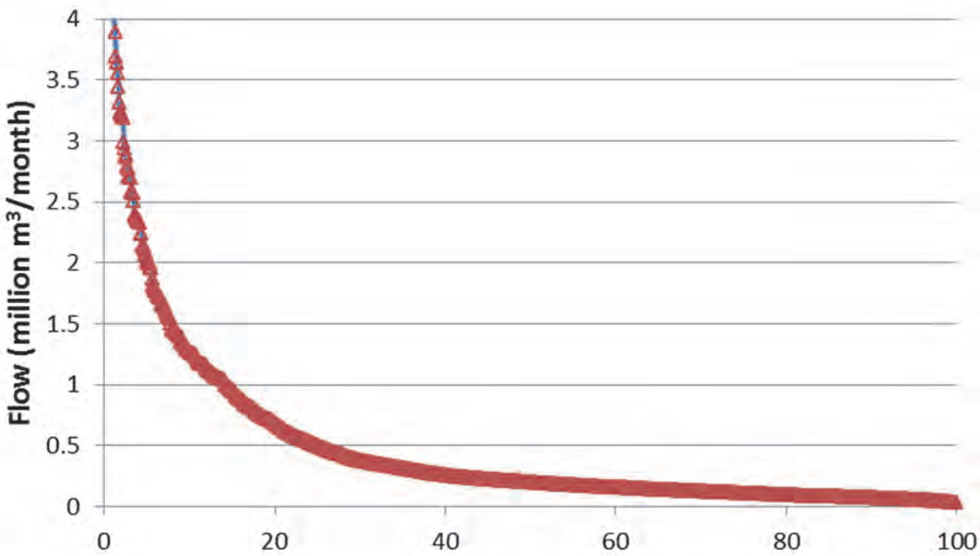


Figure B.14 Duration curves of flow into the Mdlotane Estuary

Table B.4 provides a summary of the model outputs and a range of flow indicators generated as part of this study:

- Reference condition MAR;
- Present state MAR;
- Median flows (m^3/s);
- Base flows (m^3/s);
- Maximum Flows (m^3/s);
- Highest flow month;

- Flood variance;
- Base flow variance;
- Low flow duration (months);
- High flow onset month;
- Coefficient of variability; and
- Nature of flow distribution.

Table B.4 Simulated Reference condition (NAT) and Present state (PD) MAR, median flows (m^3/s), Base flows (m^3/s), Maximum flows (m^3/s), highest flow month, flood variance, base flow variance, low flow duration (months), high flow onset month, coefficient of variability and nature of flow distribution.

Estuary	Catchment area (km^2)	MAR_{nat} (million m^3/a)	MAR_{pd} (million m^3/a)	Median Flows $_{Nat}$ (m^3/s)	Median flows $_{pd}$ (m^3/s)	Base Flow $_{nat}$ (m^3/s)	Base flow $_{pd}$ (m^3/s)	Max Flow Mont $_{nat}$	Max Flow Month $_{pd}$	Flood Variance $_{nat}$	Flood Variance ^{pd}	Base Flow Variance$_{(nat}$	Base Flow Variance ^{pd}	Low Flow Duration $_{nat}$	Low Flow Duration $_{pd}$	High Flow Onset Month $_{nat}$	High Flow Onset month$_{pd}$	Coeff variability $_{nat}$	Coeff variability$_{pd}$	BiModal?
Buffels	9 767.4	9.3	6.7	0.0	0.0	0.0	0.0	9	9					7	7	8	8		0.0	Yes
Spoeg	1 423.9	1.1	1.0	0.0	0.0	0.0	0.0	9	9					6	6	7	7		0.0	No
Groen	4 686.9	0.5	0.4	0.0	0.0	0.0	0.0	9	9					6	6	8	8	44.6	56.0	Yes
Sout	1 420.0	0.8	0.8	0.0	0.0	0.0	0.0	9	9					6	6	8	7	38.9	41.0	No
Jakkalsvlei	425.3	3.5	2.5	0.0	0.0	0.0	0.0	9	9	112.0		14.0		7	7	8	8	69.2	0.0	No
Wadrift	741.3	13.3	9.8	0.1	0.0	0.0	0.0	9	9	87.0		7.5		7	7	8	9	87.4	0.0	No
Verlorenvlei	1 873.4	53.2	40.3	0.4	0.0	0.1	0.0	11	11	77.7		12.4		6	7	9	8	48.3	0.0	No
Rietvlei/Diep	1 508.9	63.3	51.2	0.7	0.0	0.1	0.0	11	11	80.6		23.4		6	7	9	9	36.7	790.1	No
Sout (Wes)	267.9	31.1	27.5	0.4	0.1	0.1	0.0	11	11	40.2		8.3		7	6	9	9	33.2	89.2	No
Houtbaai	36.3	15.3	14.5	0.1	0.1	0.0	0.0	10	10	91.3	186.0	28.5	51.7	7	7	9	9	51.6	68.3	No
Wildevoëlvlei	12.7	2.1	1.8	0.0	0.0	0.0	0.0	11	11	87.0		17.0		7	7	9	9	41.7	67.9	No
Bokramspruit	12.0	2.0	1.8	0.0	0.0	0.0	0.0	11	11	82.0		16.0		7	7	9	9	39.2	76.4	No
Schuster	15.4	2.6	2.5	0.0	0.0	0.0	0.0	11	11	52.5	129.9	10.5	25.1	7	7	9	9	41.9	45.0	No
Krom	41.7	7.0	6.8	0.1	0.1	0.0	0.0	11	11	71.5	84.9	14.3	16.7	7	7	9	9	40.1	42.2	No
Buffels Wes	2.8	0.5	0.4	0.0	0.0	0.0	0.0	11	11					7	7	9	9	44.5	90.0	No
Elsies	3.6	0.6	0.5	0.0	0.0	0.0	0.0	11	11					7	8	9	9	58.4	98.0	No
Silvermine	22.4	3.8	3.6	0.0	0.0	0.0	0.0	11	11	76.5	375.8	15.0	72.3	7	6	9	9	40.7	49.1	No
Sand	93.8	21.7	28.0	0.2	0.3	0.1	0.1	11	11	60.7	41.6	14.8	11.4	7	7	9	9	46.1	24.5	No
Zeekoei	96.3	22.4	26.0	0.2	0.3	0.1	0.1	11	11	58.5	44.0	14.2	11.2	7	7	9	9	46.6	32.4	Yes
Eerste	176.0	6.6	6.6	0.2	0.2	0.1	0.1	11	11	7.2	7.2	3.5	3.5	4	4	8	8	15.6	15.4	No
Lourens	120.8	66.3	59.2	1.4	1.1	0.3	0.1	11	11	20.7	94.0	10.3	44.5	6	6	8	8	16.9	21.7	No
Sir Lowry's Pass	43.7	13.5	21.9	0.3	0.6	0.1	0.3	11	11	19.6	5.1	10.4	3.0	6	5	9	8	17.2	8.4	No
Steenbras	72.4	33.7	7.8	0.7	0.0	0.2	0.0	11	11	18.0		8.9		6	7	9	10	16.9	0.0	No
Rooiels	21.0	8.6	8.6	0.2	0.2	0.1	0.1	11	11	18.3	17.6	9.2	8.9	6	6	9	9	16.6	16.8	No

Table B.4 continues/...

Estuary	Catchment area (km^2)	MAR_{nat} (million m^3/a)	MAR_{pd} (million m^3/a)	Median Flows $_{Nat}$ (m^3/s)	Median flows $_{pd}$ (m^3/s)	Base Flow $_{nat}$ (m^3/s)	Base flow $_{pd}$ (m^3/s)	Max Flow Mont $_{nat}$	Max Flow Month $_{pd}$	Flood Variance $_{nat}$	Flood Variance ^{pd}	Base Flow Variance$_{(nat}$	Base Flow Variance ^{pd}	Low Flow Duration $_{nat}$	Low Flow Duration $_{pd}$	High Flow Onset Month $_{nat}$	High Flow Onset month$_{pd}$	Coeff variability $_{nat}$	Coeff variability$_{pd}$	BiModal?
Buffels (Oos)	23.6	9.7	8.2	0.2	0.1	0.1	0.0	11	11	17.5	33.1	8.9	15.0	6	6	9	9	17.0	27.5	No
Palmiet	471.0	259.0	198.7	5.5	3.1	1.1	1.1	10	11	23.9	19.7	12.2	9.3	6	6	8	9	17.3	30.8	Yes
Bot/Kleinmond	906.9	97.7	87.4	1.2	0.9	0.3	0.2	11	11	42.8	50.2	10.8	12.5	6	6	8	9	31.5	39.3	No
Onrus	55.5	14.1	10.4	0.1	0.1	0.0	0.0	11	11	78.7	82.2	19.3	18.0	6	6	8	9	40.5	60.3	No
Klein	785.1	55.8	50.5	0.6	0.4	0.2	0.1	11	11	58.4	100.1	10.4	16.4	5	5	9	9	37.7	50.2	No
Uilkraals	355.8	40.8	29.7	0.4	0.2	0.1	0.0	11	11	74.2		19.7		4	5	8	8	35.8	96.2	No
Ratel	124.7	4.7	4.4	0.1	0.0	0.0	0.0	11	11	41.8	82.0	9.5	17.5	4	5	7	7	30.2	41.6	No
Heuningnes	1 784.6	41.6	36.9	0.6	0.5	0.2	0.1	11	11	30.1	56.7	8.4	14.8	4	4	7	7	26.9	34.4	No
Klipdrifsfontein	15.9	0.2	0.2	0.0	0.0	0.0	0.0	11	11		19.8		4.3	3	3	7	7	23.0	33.3	Yes
Duiwenhoks	1 138.6	94.2	72.3	2.0	1.4	1.0	0.4	11	11	8.7	20.7	3.6	8.2	2	3	7	7	16.8	24.5	Yes
Goukou	1 345.7	102.8	77.0	2.3	1.5	1.2	0.7	1	1	8.0	11.1	3.2	4.2	2	2	6	6	16.5	25.2	Yes
Gourits	45 135.0	628.8	446.0	8.2	3.8	3.6	1.0	2	7	23.6	70.8	5.6	13.6	1	1	2	6	28.5	62.2	Yes
Blinde	36.7	1.3	0.9	0.0	0.0	0.0	0.0	2	11	23.0		4.5		2	3	6	6	30.2	0.0	Yes
Tweekuilen	30.1	35.6	34.4	0.6	0.6	0.4	0.4	11	11	9.2	9.5	2.6	2.6	3	3	11	11	21.7	22.6	Yes
Gericke	7.7	0.3	0.2	0.0	0.0	0.0	0.0	2	2					2	2	6	6	24.4	49.8	
Hartenbos	170.0	4.6	2.8	0.0	0.0	0.0	0.0	2	12	45.3	46.1	6.5	5.2	2	2	11	11	41.1	83.2	Yes
Klein Brak	514.3	53.4	40.4	0.8	0.4	0.4	0.1	2	2	18.7	49.1	5.1	10.0	1	2	11	11	24.2	54.0	Yes
Groot Brak	168.9	41.9	16.3	0.7	0.1	0.3	0.0	2	2	14.9	116.3	5.2	12.9	2	1	12	12	21.0	321.6	Yes
Maalgate	185.3	38.0	29.9	0.4	0.2	0.2	0.1	6	2	27.6	95.0	7.3	19.9	2	1	12	11	32.3	67.4	Yes
Gwaing	123.3	38.2	35.1	0.7	0.6	0.4	0.3	6	1	12.0	14.7	4.2	4.8	2	1	11	11	21.1	22.8	Yes
Kaaimans	132.7	35.7	28.8	0.7	0.5	0.4	0.1	2	1	9.1	28.8	3.8	10.6	2	1	12	11	17.8	26.9	Yes
Wilderness	167.3	29.7	25.2	0.4	0.2	0.2	0.0	6	6	26.1	93.8	6.4	19.9	2	1	11	11	30.2	46.8	Yes
Swartvlei	398.4	83.4	56.7	1.6	0.9	0.8	0.4	1	1	11.0	18.1	4.0	5.7	1	1	11	11	19.0	33.5	Yes
Goukamma	388.9	47.8	36.2	0.9	0.5	0.4	0.2	1	1	12.0	30.6	4.1	8.6	2	1	11	6	20.1	35.0	Yes
Knysna	381.4	83.1	68.0	1.8	1.4	1.1	0.7	1	1	7.4	9.5	3.1	3.7	2	2	8	11	16.4	21.5	Yes
Noetsie	39.4	4.4	4.4	0.1	0.1	0.1	0.1	1	1	6.7	6.8	2.5	2.6	3	3	8	11	16.5	16.7	No
Piesang	47.2	5.2	3.4	0.1	0.1	0.1	0.0	1	12	6.7	14.3	2.5	4.8	3	3	11	8	16.9	30.5	Yes

Table B.4 continues/...

Estuary	**Catchment area (km^2)**	**MAR_{nat} (million m^3/a)**	**MAR_{pd} (million m^3/a)**	**Median Flows $_{Nat}$ (m^3/s)**	**Median flows $_{pd}$ (m^3/s)**	**Base Flow $_{nat}$ (m^3/s)**	**Base flow $_{pd}$ (m^3/s)**	**Max Flow Mont $_{nat}$**	**Max Flow Month $_{pd}$**	**Flood Variance $_{nat}$**	**Flood Variance ^{pd}**	**Base Flow Variance($_{nat}$**	**Base Flow Variance ^{pd}**	**Low Flow Duration $_{nat}$**	**Low Flow Duration $_{pd}$**	**High Flow Onset Month $_{nat}$**	**High Flow Onset month$_{pd}$**	**Coeff variability $_{nat}$**	**Coeff variability$_{pd}$**	**BiModal?**
Keurbooms	1 132.0	98.1	91.5	2.1	1.8	1.3	1.1	1	1	7.3	8.3	2.8	3.0	3	3	8	8	17.3	19.5	No
Matjies	23.5	3.4	2.5	0.1	0.0	0.0	0.0	12	12	7.4		3.0		4	5	11	8	16.9	32.0	No
Sout (Oos)	34.3	5.0	5.0	0.1	0.1	0.1	0.1	12	12	7.4	7.4	3.0	3.0	4	4	11	11	16.8	16.9	No
Groot (Wes)	88.0	12.8	11.1	0.3	0.2	0.2	0.1	12	12	7.4	11.7	3.0	4.6	4	4	11	10	17.0	20.7	Yes
Bloukrans	88.2	40.1	39.3	0.8	0.8	0.4	0.4	12	12	10.5	10.8	4.2	4.3	0	1	6	6	17.5	18.0	Yes
Lottering	146.0	18.5	16.8	0.5	0.4	0.3	0.2	12	12	6.4	7.1	3.0	3.2	1	1	11	11	14.9	17.0	Yes
Elandsbos	146.0	27.2	24.7	0.7	0.6	0.4	0.3	12	12	6.4	7.1	3.0	3.2	1	1	11	11	15.0	17.0	Yes
Storms	208.0	54.1	47.9	1.3	1.1	0.8	0.6	12	1	6.4	7.1	3.0	3.2	0	1	11	11	15.0	17.6	Yes
Elands	189.0	52.2	46.9	1.2	1.1	0.7	0.6	12	12	7.1	7.8	3.1	3.3	0	1	11	11	15.6	18.0	Yes
Groot (Oos)	176.0	47.0	44.1	1.1	1.0	0.6	0.5	11	11	7.2	7.7	3.5	3.7	4	4	8	8	15.4	16.7	No
Tsitsikamma	266.0	38.9	36.5	0.9	0.8	0.4	0.4	12	11	8.4	9.3	3.9	4.3	4	4	8	8	16.4	18.0	No
Klipdrif	221.0	19.0	18.6	0.4	0.4	0.2	0.2	11	11	12.2	12.3	4.7	4.8	2	2	8	8	18.8	19.3	No
Slang	221.0	4.7	4.6	0.1	0.1	0.0	0.0	11	11	11.7	12.4	4.6	4.8	2	2	8	8	18.6	19.4	No
Seekoei	250.0	17.0	15.9	0.2	0.1	0.1	0.1	11	11	25.6	46.1	4.6	7.9	3	3	10	10	36.0	44.5	No
Kabeljous	286.0	11.5	9.1	0.1	0.0	0.1	0.0	12	11	23.2		4.6		3	3	11	10	34.9	142.6	Yes
Gamtoos	34 816.0	388.8	265.5	4.7	1.4	2.3	0.6	6	6	23.7	77.1	4.8	9.5	1	1	11	5	30.8	106.1	Yes
Van Stadens	308.0	17.2	15.6	0.2	0.1	0.1	0.0	11	11	45.2	84.3	11.4	20.4	3	3	8	8	40.9	51.6	No
Maitland	308.0	12.9	11.7	0.1	0.1	0.0	0.0	11	11	43.1	84.5	10.9	20.4	3	3	8	8	41.9	51.7	No
Baakens	362.0	4.1	3.6	0.0	0.0	0.0	0.0	12	12	28.7	79.0	2.8	6.2	2	2	6	6	50.4	107.2	Yes
Papenkuils	362.0	2.9	2.9	0.0	0.0	0.0	0.0	12	12	30.8	103.9	3.0	7.9	2	2	6	6	57.4	111.2	No
Swartkops	1 395.0	97.6	79.2	0.6	0.3	0.3	0.0	12	12	60.0	7 784.2	7.3	725.6	2	2	6	6	57.5	126.4	Yes
Coega (Ngcura)	565.0	10.1	8.6	0.0	0.0	0.0	0.0	12	12					2	3	11	11		0.0	Yes
Boknes	422.0	14.4	14.4	0.0	0.0	0.0	0.0	12	12					2	2	6	6	179.5	186.5	Yes
Bushmans	2 785.0	42.9	40.4	0.1	0.0	0.0	0.0	12	12					2	2	6	6	266.9	475.2	Yes
Kariega	647.0	21.7	15.6	0.1	0.0	0.0	0.0	12	12	104.6		9.9		2	2	6	6	102.3	0.0	Yes
Kasuka	342.0	4.3	4.3	0.0	0.0	0.0	0.0	12	12					2	2	6	6	214.0	357.3	Yes
Kowie	918.0	31.8	30.3	0.1	0.1	0.1	0.0	12	12	81.8	120.5	7.7	10.2	2	2	6	6	89.9	108.7	Yes

Table B.4 continues/...

Estuary	Catchment area (km^2)	MAR_{nat} (million m^3/a)	MAR_{pd} (million m^3/a)	Median Flows $_{Nat}$ (m^3/s)	Median flows $_{pd}$ (m^3/s)	Base Flow $_{nat}$ (m^3/s)	Base flow $_{pd}$ (m^3/s)	Max Flow Mont $_{nat}$	Max Flow Month $_{pd}$	Flood Variance $_{nat}$	Flood Variance ^{pd}	Base Flow Variance$_{(nat}$	Base Flow Variance ^{pd}	Low Flow Duration $_{nat}$	Low Flow Duration $_{pd}$	High Flow Onset Month $_{nat}$	High Flow Onset month$_{pd}$	Coeff variability $_{nat}$	Coeff variability$_{pd}$	BiModal?
Rufane	246.0	1.2	1.1	0.0	0.0	0.0	0.0	12	12					2	2	6	6	118.8	598.1	Yes
Riet	246.0	2.4	2.3	0.0	0.0	0.0	0.0	12	12					2	2	6	6	240.8	1 208.2	Yes
Kleinemond Wes	246.0	6.0	5.5	0.0	0.0	0.0	0.0	12	12					2	2	6	6	199.0	998.9	Yes
Kleinemond Oos	246.0	6.0	2.4	0.0	0.0	0.0	0.0	12	12					2	2	6	6	199.0	1 998.8	Yes
Klein Palmiet	246.0	0.8	0.8	0.0	0.0	0.0	0.0	12	12					2	2	6	6		0.0	Yes
Great Fish	30 243.0	513.3	463.3	4.2	4.8	1.7	3.4	6	6	42.8	17.4	8.1	3.2	5	5	2	2	45.8	40.1	Yes
Old Womans	22.9	1.1	0.9	0.0	0.0	0.0	0.0	2	2	34.0	48.7	6.0	7.8	2	2	6	6	54.7	73.3	Yes
Mpekweni	50.0	2.4	2.1	0.0	0.0	0.0	0.0	2	2	36.5	45.7	6.0	7.4	2	2	6	6	60.0	70.8	Yes
Mtati	123.4	6.0	5.1	0.0	0.0	0.0	0.0	2	2	30.2	47.9	5.0	7.7	2	2	6	6	53.8	72.5	Yes
Mgwalana	198.7	9.7	8.2	0.1	0.1	0.0	0.0	2	2	32.4	48.9	5.4	7.8	2	2	6	6	52.9	72.5	Yes
Bira	253.2	12.0	10.0	0.1	0.1	0.1	0.0	2	2	29.5	43.2	5.2	7.2	2	2	6	6	51.2	70.5	Yes
Gqutywa	74.4	3.5	3.0	0.0	0.0	0.0	0.0	2	2	34.7	35.5	6.0	6.1	2	2	6	6	49.3	66.8	Yes
Ngculura	13.6	0.7	0.6	0.0	0.0	0.0	0.0	2	2	19.0	32.8	3.0	5.8	2	2	6	6	63.7	63.7	Yes
Mtana	22.4	1.1	0.9	0.0	0.0	0.0	0.0	2	2	31.0	33.5	6.0	5.8	2	2	6	6	52.2	65.5	Yes
Keiskamma	2 699.1	138.9	108.3	1.9	0.9	1.0	0.4	6	6	16.9	44.5	3.9	8.5	2	2	1	1	27.3	59.7	Yes
Ngqinisa	11.7	1.2	1.2	0.0	0.0	0.0	0.0	2	2	10.3	10.2	2.7	2.6	3	3	7	7	22.6	23.1	Yes
Kiwane	53.1	5.3	6.1	0.1	0.1	0.1	0.1	2	2	9.9	7.8	2.5	2.3	3	2	7	6	23.1	17.9	Yes
Tyolomnqa	419.4	1.0	0.8	0.0	0.0	0.0	0.0	2	11	38.0		7.0		2	2	6	6	33.3	0.0	Yes
Shelbertsstroom	6.2	0.6	0.6	0.0	0.0	0.0	0.0	2	2	8.0	10.1	2.0	2.6	3	3	7	7	19.8	23.0	Yes
Lilyvale	11.0	1.1	1.0	0.0	0.0	0.0	0.0	2	2	9.7	12.0	2.3	3.1	3	3	7	7	21.1	26.7	Yes
Ross' Creek	5.4	0.6	0.5	0.0	0.0	0.0	0.0	2	2	14.0	10.1	4.0	2.6	3	3	7	7	26.5	22.9	Yes
Ncera	80.3	11.0	10.2	0.2	0.1	0.1	0.1	2	2	14.1	15.8	2.9	3.2	3	3	6	6	25.2	28.4	Yes
Mlele	14.5	2.0	1.9	0.0	0.0	0.0	0.0	2	2	12.8	15.7	2.6	3.2	3	3	6	6	23.9	28.3	Yes
Mcantsi	20.8	2.8	2.7	0.0	0.0	0.0	0.0	2	2	13.0	15.7	2.7	3.2	3	3	6	6	24.8	28.2	Yes
Gxulu	114.2	15.6	14.5	0.2	0.2	0.1	0.1	2	2	13.8	15.8	2.8	3.2	3	3	6	6	25.4	28.4	Yes
Goda	45.2	6.2	5.8	0.1	0.1	0.1	0.1	2	2	14.1	15.8	2.9	3.2	3	3	6	6	25.9	28.5	Yes
Hlozi	12.8	1.8	1.6	0.0	0.0	0.0	0.0	2	2	14.0	15.8	2.8	3.2	3	2	6	6	24.0	28.6	Yes

Table B.4 continues/...

Estuary	Catchment area (km^2)	MAR_{nat} (million m^3/a)	MAR_{pd} (million m^3/a)	Median Flows $_{Nat}$ (m^3/s)	Median flows $_{pd}$ (m^3/s)	Base Flow $_{nat}$ (m^3/s)	Base flow $_{pd}$ (m^3/s)	Max Flow Mont $_{nat}$	Max Flow Month $_{pd}$	Flood Variance $_{nat}$	Flood Variance ^{pd}	Base Flow Variance$_{(nat}$	Base Flow Variance ^{pd}	Low Flow Duration $_{nat}$	Low Flow Duration $_{pd}$	High Flow Onset Month $_{nat}$	High Flow Onset month$_{pd}$	Coeff variability $_{nat}$	Coeff variability$_{pd}$	BiModal?
Hickman's	10.4	1.4	1.3	0.0	0.0	0.0	0.0	2	2	15.3	15.8	3.0	3.2	3	3	6	6	27.5	28.7	Yes
Ngqenga	3.2	0.4	0.4	0.0	0.0	0.0	0.0	2	2	14.0	16.3	3.0	3.3	3	3	6	6	20.6	27.8	Yes
Buffalo	1 292.2	96.0	18.7	1.0	0.0	0.5	0.0	2	2	25.4	655.4	5.3	8.0	3	1	1	2	36.4	4 800.6	No
Blind	5.6	0.7	1.1	0.0	0.0	0.0	0.0	2	2	26.0	31.3	4.0	8.3	3	3	12	1	64.0	15.7	Yes
Hlaze	2.8	0.3	0.8	0.0	0.0	0.0	0.0	2	2		31.5		9.6	3	4	12	1	30.5	8.3	Yes
Nahoon	585.6	39.9	24.8	0.2	0.0	0.1	0.0	2	2	91.6		6.7		2	2	11	6	103.9	0.0	Yes
Qinira	72.7	8.4	8.3	0.1	0.1	0.0	0.0	2	2	47.4	50.7	7.7	8.2	3	3	12	12	55.3	58.9	Yes
Gqunube	650.7	34.1	32.5	0.3	0.3	0.2	0.1	2	2	26.4	28.8	4.2	4.5	2	2	11	11	47.7	52.2	Yes
Kwelera	387.3	34.8	32.8	0.2	0.2	0.1	0.1	2	2	42.4	45.8	6.5	6.8	3	3	11	11	54.3	59.7	Yes
Bulura	41.4	3.7	3.5	0.0	0.0	0.0	0.0	2	2	47.0	44.7	7.3	6.6	3	3	11	11	52.3	59.1	Yes
Cunge	3.6	0.3	0.3	0.0	0.0	0.0	0.0	2	2		39.3		5.7	3	3	11	11	30.8	62.6	Yes
Cintsa	44.4	4.0	3.8	0.0	0.0	0.0	0.0	2	2	37.5	44.8	5.8	6.6	3	3	11	11	56.0	58.6	Yes
Cefane	37.7	3.4	3.2	0.0	0.0	0.0	0.0	2	2	42.7	45.2	6.7	6.7	3	3	11	11	55.6	58.6	Yes
Kwenxura	144.1	16.9	16.6	0.1	0.1	0.1	0.1	2	2	45.7	47.5	7.3	7.5	3	3	11	1	55.3	56.8	Yes
Nyara	37.0	4.3	4.3	0.0	0.0	0.0	0.0	2	2	41.0	47.8	6.5	7.5	3	3	11	1	53.2	56.9	Yes
Haga-haga	18.2	2.2	2.1	0.0	0.0	0.0	0.0	2	2	40.5	47.2	6.5	7.4	3	3	11	1	52.6	57.0	Yes
Mtendwe	12.1	1.4	1.4	0.0	0.0	0.0	0.0	2	2	53.0	48.0	9.0	7.6	3	3	11	1	46.1	57.9	Yes
Quko	146.6	17.2	16.9	0.1	0.1	0.1	0.1	2	2	46.5	47.3	7.4	7.5	3	3	11	1	54.4	56.9	Yes
Morgan	23.6	2.7	2.7	0.0	0.0	0.0	0.0	2	2	52.0	46.7	8.5	7.4	3	3	11	1	53.9	57.4	Yes
Cwili	10.0	1.2	1.2	0.0	0.0	0.0	0.0	2	2	45.0	49.0	7.0	7.7	3	3	11	1	57.9	57.9	Yes
Great Kei	20 543.1	954.9	649.3	10.0	3.7	4.7	0.9	6	6	29.7	121.1	6.3	19.6	5	5	2	2	35.6	99.4	Yes
Gxara	30.6	3.4	3.4	0.0	0.0	0.0	0.0	6	6	19.1	21.2	2.4	2.6	2	2	6	6	33.4	34.9	Yes
Ngogwane	7.0	0.8	0.8	0.0	0.0	0.0	0.0	6	6	15.5	21.8	2.0	2.7	2	2	6	6	38.3	34.7	Yes
Qolora	79.3	8.9	8.7	0.1	0.1	0.1	0.1	6	6	20.4	21.3	2.6	2.6	2	2	6	6	33.2	34.7	Yes
Ncizele	8.9	1.0	1.0	0.0	0.0	0.0	0.0	6	6	19.5	21.5	2.5	2.7	2	2	6	6	32.4	34.8	Yes
Timba	3.1	0.4	0.4	0.0	0.0	0.0	0.0	6	6	14.0	22.7	2.0	2.8	2	2	6	6	34.2	34.2	Yes
Kobonqaba	321.9	36.2	35.5	0.4	0.4	0.3	0.3	6	6	20.4	21.3	2.6	2.6	2	2	6	6	33.8	34.8	Yes

Table B.4 continues/...

Estuary	Catchment area (km^2)	MAR_{nat} (million m^3/a)	MAR_{pd} (million m^3/a)	Median Flows $_{Nat}$ (m^3/s)	Median flows $_{pd}$ (m^3/s)	Base Flow $_{nat}$ (m^3/s)	Base flow $_{pd}$ (m^3/s)	Max Flow Mont $_{nat}$	Max Flow Month $_{pd}$	Flood Variance $_{nat}$	Flood Variance ^{pd}	Base Flow Variance$_{(nat}$	Base Flow Variance ^{pd}	Low Flow Duration $_{nat}$	Low Flow Duration $_{pd}$	High Flow Onset Month $_{nat}$	High Flow Onset month$_{pd}$	Coeff variability $_{nat}$	Coeff variability$_{pd}$	BiModal?
Nxaxo/Ngqusi	134.0	23.3	22.8	0.2	0.2	0.1	0.1	6	6	24.7	25.4	4.2	4.2	1	1	1	1	39.8	41.2	Yes
Cebe	32.7	5.7	5.6	0.1	0.1	0.0	0.0	6	6	24.8	25.5	4.2	4.2	1	1	1	1	39.6	41.1	Yes
Gqunqe	40.0	7.0	6.8	0.1	0.1	0.0	0.0	6	6	24.8	25.3	4.2	4.2	1	1	1	1	39.9	41.2	Yes
Zalu	9.7	1.7	1.7	0.0	0.0	0.0	0.0	6	6	22.0	25.1	3.7	4.2	1	1	1	1	41.3	41.3	Yes
Ngqwara	30.2	5.2	5.1	0.1	0.1	0.0	0.0	6	6	25.8	25.3	4.4	4.2	1	1	1	1	39.3	41.3	Yes
Sihlontlweni	12.7	2.2	2.2	0.0	0.0	0.0	0.0	6	6	21.8	25.1	3.8	4.2	1	1	1	1	43.2	41.5	Yes
Nebelele	6.1	1.1	1.0	0.0	0.0	0.0	0.0	6	6	20.5	25.4	3.5	4.2	1	1	1	1	34.1	41.1	Yes
Qora	705.2	78.5	72.0	0.9	0.8	0.6	0.5	6	6	19.7	24.8	2.8	3.3	2	2	6	6	33.3	39.2	Yes
Jujura	83.3	11.3	10.2	0.1	0.1	0.1	0.1	6	6	20.1	28.9	2.9	3.8	1	2	6	6	35.4	44.3	Yes
Ngadla	11.7	1.6	1.5	0.0	0.0	0.0	0.0	6	6	19.3	22.1	2.7	3.1	1	1	6	6	38.0	38.0	Yes
Shixini	315.6	42.3	41.0	0.5	0.4	0.3	0.3	6	6	20.5	22.1	2.9	3.1	1	1	6	6	35.4	37.7	Yes
Beechamwood	4.1	0.5	0.5	0.0	0.0	0.0	0.0	6	6	20.0	22.1	3.0	3.1	1	1	6	6	53.0	37.6	Yes
Unnamed	5.2	0.7	0.6	0.0	0.0	0.0	0.0	6	6	11.0	14.0	2.5	3.3	5	5	2	2	21.5	25.0	Yes
Kwa-Goqo	7.3	1.0	1.0	0.0	0.0	0.0	0.0	6	6	18.5	22.6	2.5	3.2	1	1	6	6	31.8	38.4	Yes
Ku-Nocekedwa	8.1	1.1	1.1	0.0	0.0	0.0	0.0	6	6	20.0	22.2	3.0	3.1	1	1	6	6	35.1	37.6	Yes
Nqabara/Nqabarana	648.0	76.4	75.9	0.8	0.8	0.6	0.5	6	6	18.3	18.7	3.6	3.7	1	1	6	6	33.9	33.9	Yes
Ngoma/Kobule	34.7	6.3	6.2	0.1	0.1	0.0	0.0	6	6	24.3	25.0	4.3	4.4	1	1	1	1	38.4	40.7	Yes
Mendu	28.5	5.2	5.1	0.1	0.1	0.0	0.0	6	6	25.0	25.1	4.5	4.4	1	1	1	1	38.9	40.8	Yes
Mendwana	7.5	1.4	1.3	0.0	0.0	0.0	0.0	6	6	26.0	24.6	4.5	4.4	1	1	1	1	44.0	41.2	Yes
Mbashe	6 067.0	801.8	817.7	10.1	11.4	4.8	6.6	6	6	22.8	15.8	6.1	4.4	5	5	2	2	29.5	26.1	No

APPENDIX C: HYDRODYNAMIC DESKTOP METHOD

Background

Predictive tools to assess physical processes in estuaries may vary from simple empirical relationships, through one-dimensional (1D) hydrodynamic/water quality models to fully 3D hydrodynamic/water quality models such as the DELFT3D suite of numerical models. The most appropriate modelling technique or model needs to be selected based on the purpose of the model, data availability and the confidence level required (Van Ballegooyen et al. 2004). Detailed assessments typically require higher levels of confidence, which is associated with complex 2D or 3D modelling, while low confidence strategic assessments may only require simple statistical relationships or water balance modelling.

Water balance models (also called box models) were developed to evaluate the response of different hydrological parameters under a variety of hydrological conditions. Water balance models are used to simplify estuarine hydrodynamic processes in order to assess the through-flow, or lack thereof, of material in a system. This type of model is ideal for determining mouth state and is presently applied in most estuarine water resources studies.

In spite of the relatively simple concept of water balance equation, specific considerations are needed for proper application. This section will provide a summary of the simplified water balance mode model being used for the estuary health assessment.

Elements of a water balance model

Usually temporarily open/closed estuaries will remain closed until their basins fill up to a level equal to the height of the sand berm across their mouths. Any additional water added to an estuary basin after this will cause mouth breaching. The foremost assumption in the development of a water balance model is therefore that breaching will occur when the Water Level (*WL*) in the estuary basin equals, or is greater than the height of the berm (B_h). This results in an algebraic inequality which states that a breach occurs if:

$$WL(t) \geq B_h(t)$$

The volume of water in an estuary at a particular time (*t)* can be described as the sum of the various volumes entering and/or leaving the system by different means, as well as the previous volume of water in the estuary (i.e. at time *t-1*). This procedure which accounts for the quantity of water in an estuary is known as the water volume balance (e.g. Smakhtin, 2004).

Potentially flows entering an estuary include: the inflow from the river, V_{inflow}; precipitation directly onto the estuary's surface (V_{precip}); the volume of seawater entering the estuary over the berm through wave action ($V_{overwash}$); the volume of water entering through anthropogenic influences ($V_{artificial}$); and the volume of water directly entering through the ground (V_{ground}). Potentially outflows from an estuary include: evaporation from the estuary's surface (V_{evap}); the volume of water that seeps through the berm from the estuary ($V_{seepage}$); the volume of water exiting through anthropogenic influences ($V_{artificial}$); and the volume of water exiting through the ground as seepage (V_{ground}).

Figure C.1 provides a graphic representation of the water volume balance in a closed estuary.
The equation for the **Volume of water** in the estuary at time *t*, is thus given as:

$$V_t = V_{t-1} + V_{inflow} + V_{precip} + V_{evap} + V_{seepage} + V_{overwash} + V_{artificial} + V_{ground}$$

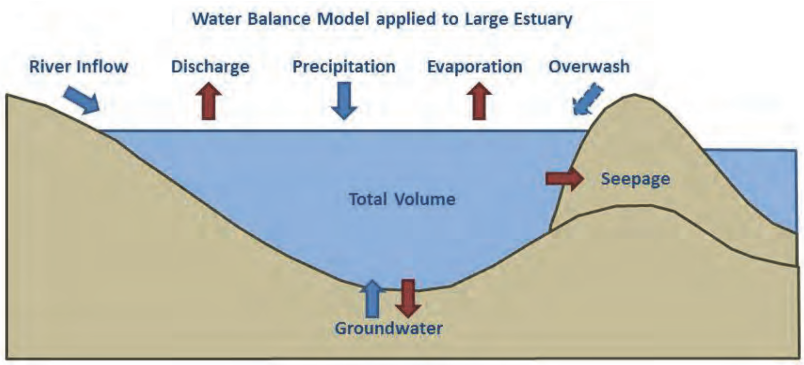


Figure C.1 Schematic illustration of a water balance model for a temporarily closed estuary

Ideally to apply a water balance model to an estuary the following data is required:

- ***Inflow data:*** Data on river inflow into an estuary is crucial for correlating river flow to the state of the mouth (as reflected by water level recordings), particularly in temporarily open/closed estuaries.
- ***Bathymetric data and berm heights:*** To calculate the volume of the estuary under various tidal regimes, datum referenced cross section data (depth measurements to mean sea level) is required at regular intervals along the length of the system as far as tidal influence can be detected. This includes observations on the sand berm near the estuary mouth.
- ***Mouth Observations:*** Where possible, continuous water level recorders should be installed or daily mouth observations should be logged at temporarily open/closed estuaries, particularly in systems where a semi-closed mouth phase sometimes exists.
- ***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).
- ***Wave Conditions:*** Information on wave conditions (as reflected by the direction and amplitude of the waves) can be used to correlate mouth closure with possible storms at sea.
- ***Salinity data must be collected at regular depth intervals along the length of an estuary.*** Sampling should cover all the salinity regimes. For temporarily open/closed systems, a stable closed phase must be sampled as well as a stable open phase.

Unfortunately, for most South African estuaries this data is lacking, thus requiring a simplification of the classic water balance model for a national or regional scale desktop assessment.

Simplification of water balance model for the national health assessment

Studies have shown that for most temporarily open/closed estuaries (75% are smaller than 50 ha in size) V_{inflow} is usually the dominant natural factor that causes the mouth to breach (Van Niekerk et al. 2012). Monthly river inflow (V_{inflow}) simulated as part of this study for Reference and Present Conditions provide an indication in the shifts in river inflow on a catchment scale.

In most temporarily open/closed estuaries the direct rainfall contribution (V_{precip}) and evaporation (V_{evap}) is negligible compared with river inflow (V_{inflow}) because of their small sizes (Van Niekerk *et al*. 2012). These parameters are therefore generally not included in a simplified water model. However, they may need to be for estuaries with large surface areas or systems that remain closed for extended periods, for example estuarine lakes such as St Lucia or Swartvlei.

Unless information is available on significant direct abstraction or discharges, $V_{artificial}$ will be neglected in the water balance calculation. Data on the quantity of water entering or leaving the estuary via the sub-surface flow (V_{ground}) are generally also not available, but in most small to medium size estuaries, the parameter can also be treated as negligible compared to river inflow (V_{inflow}) in the water balance calculation (Van Niekerk et al. 2012). For the purposes of the development of a standardised water balance model for the desktop assessment, $V_{overwash}$ will be ignored to simplify model development.

In summary, in most of the Temperate temporarily open/closed estuaries, river inflow is the dominating water balance factor (Van Niekerk et al. 2012). This relationship can be calculated or determined through correlating mouth conditions with river inflow. For most systems the classic water balance model can be reduced to a simple exceeding relationship, i.e. if inflow exceeds the volume of the estuary it will be open. Where the total volume of the system is estimated as the open water area of the system multiplied by the height (depth) of water needed to fill it to breaching level, i.e. the difference between the breaching level and the closing water level.

$$V = Area(H_{breach} - H_{closed})$$

On a high energy coastline, closure will occur within less than a month of flow decreasing below the estimated flow needed to maintain open mouth conditions, while at a more protected estuary mouth, closure may only occur after a few months. The rate of closure will not be considered as part of this desktop assessment.

Adaptations of the water balance modelling approach for temporarily open/closed estuaries in South Africa can be schematised as illustrated in Figure C.2.

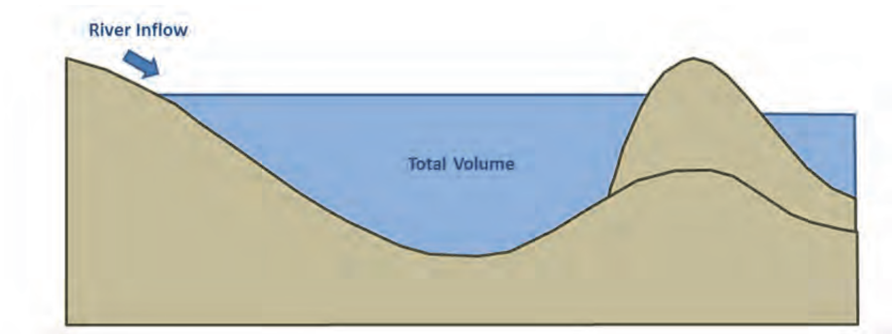


Figure C.2 A schematic illustration of the desktop application of the water balance model

Area

For the majority of estuaries the open water area (ha) will be estimated from the mouth to the 5 m mean sea level (MSL) contour – demarcated as the estuary functional zone in Van Niekerk and Turpie (2012). In temporarily open/closed estuaries, open surface area can vary significantly between observations, depending on the water level and associated degree of back-flooding. Unfortunately, only one standardised data set exists for estuarine open water area along the entire coast (Van Niekerk and Turpie 2012), which will inject a degree of uncertainty around the surface area calculations. This data set was reviewed and refined for this study.

Height

The height at which breaching of a specific estuary will occur is the result of the duration of the closed state, wave action in the mouth region, together with sufficient sediment availability. For this study breaching levels for the Temperate estuaries were assumed at 2.5 to 3.0 m MSL (e.g. Great Brak Estuary). Mouth closure is assumed to occur between 0.5 and 1.0 m MSL.

Maximum volume required to maintain an open mouth state

In theory, the maximum volume required to maintain an open mouth state in the Temperate region is the estuary open water area multiplied by about 1.5 to 2.0 m. In reality localised parameters (e.g. significant tidal flows, high degree of protection from wave energy, lack of sediment) assist in maintaining an open mouth state and a specific estuary may require significantly less water flow to maintain an open mouth state.

To identify the key relationships that maintain an open mouth state from a flow perspective, historical EWR studies on temporarily open estuaries were summarised in terms of their open water area, the maximum volume needed to breach an estuary, and the flow rate/monthly volume below which an estuary is likely to close (Table C.1). In addition a monthly flushing ratio (monthly volume/estuary volume) was defined to normalise the required flow rate to the dimensions of a specific estuary.

In evaluating the monthly flushing ratio for individual system it becomes clear that larger estuaries require less water to remain open than the small systems. This is because large estuaries have significant tidal flows which assist in maintaining open mouth conditions. Most of the estuaries show an ability to remain open as long as the estimated maximum volume required is provided 1 to 5 times a month. The 80th percentile value indicated that a replacement volume of 5.8 times is required if a breaching level between 2.5 and 3.0 m MSL is assumed (Table C.1). The high flushing ratios associated with some of the smaller systems were attributed to low confidence in the simulated flow data, open water areas and degree of open conditions.

Therefore, for this study it was assumed that if the monthly flow volume simulated for the Reference and Present Conditions exceeded the estuary breaching volume between 1 and 5 times a month, the estuary mouth will remain open. The degree of similarity in hydrodynamics was rated based on the total occurrence of closed mouth state from the Reference to the Present Condition.

This output of the model was then verified in a workshop environment and moderated by expert opinion if localised features or pressures were recoded (e.g. high degree of protection against wave action, stabilised mouth, artificial breaching).

Table C.1 A summary of the estuary open water area, the maximum volume needed to breach the estuary, the flow rate/monthly volume below which an estuary is likely to close, and the monthly flushing ratio (estuary volume/monthly volume) as defined in historical EWR studies for temporarily open/closed estuaries.

Estuary	%Open (1=100-75; 2=75-50; 3=50-25; 4=25-0)	Open water area (ha)	Estuary volume needed to breach (m^3)	Flow rate (m^3/s)	Monthly volume (m^3)	Monthly flushing ratio ($Est_{Vol}/Monthly_{Vol}$)
Orange (Gariep)	1	474.18	7 112 640	5.00	12 960 000	1.82
Tugela/Thukela	1	334.85	5 022 735	2.00	5 184 000	1.03
Mgeni	1	84.54	1 268 156	0.03	77 760	0.06
Seekoei	3	69.93	1 048 889	-	3 000 000	2.86
Groot Brak	3	63.29	949 380	-	500 000	0.53
Goukamma	1	46.38	695 751	0.50	1 296 000	1.86
Mdloti	3	28.46	426 955	0.30	777 600	1.82
Tsitsikamma	2	13.85	207 678	0.05	129 600	0.62
Palmiet	1	13.42	201 258	0.05	129 600	0.64
Mhlanga	3	11.21	168 126	0.40	1 036 800	6.17
Mbokodweni	1	8.75	131 274	0.20	518 400	3.95
Zotsha	1	8.54	128 031	0.07	181 440	1.42
Tongati	1	3.66	54 972	0.60	1 555 200	28.29
Little Manzimtoti	2	2.58	38 665	0.03	77 760	2.01
Matjies	2	1.09	16 388	0.03	77 760	4.74
Siyaya	4	0.91	13 677	0.30	777 600	56.85
Kleinemond Oos	3	0.41	6217	-	300 000	48.25

APPENDIX D: WATER QUALITY DESKTOP METHOD: SALINITY

Background

The saline regime of an estuary is regulated by tidal amplitude, river inflow and the bathymetry (size and shape) of an estuary (Prandle 2009). The salinity distribution and structure may be altered by flow modification (reduction in flow leads to increase penetration and an increase in flow to reduce penetration); anthropogenic actions such as dredging (deepening of estuary increasing salinity penetration); the construction of causeways and bridges (preventing/reducing salinity penetration); and artificial breaching (increasing or decreasing duration of open mouth state). Changes in the salinity distribution may have implications for water geochemistry, sedimentation (e.g. flocculation zone may change) or the dispersal of pollutants.

Due to the high variance in river inflow patterns, the dynamic nature of the tides and the effect of localised bathymetry; it is difficult to accurately predict salinity intrusion for a specific estuary. Ideally, enough continuous river inflow and salinity records would exist to allow for an estuary-specific correlation model to be developed or a numerical model to be calibrated. Unfortunately in South Africa's data poor environment this is very seldom achievable, as continuous flow records, long-term salinity measurements, and accurate bathymetry data are a rarity.

Desktop method

This study has therefore taken a statistical approach in developing a salinity prediction model for the Temperate estuaries. Historical EWR studies were scrutinised and the various "salinity states" associated with a range of river flow rates summarised for the permanently open estuaries (Table D.1) and temporarily open/closed estuaries (D.2). The aim was to tease out the occurrence of the three dominant salinity states:

1. Marine
2. Brackish (mixed)
3. Freshwater

Table D.1 A summary of salinity states and associated flow ranges defined in historical EWR studies for permanently open estuaries.

Estuary	Openwater area (ha)	Flow rates (m^3/s) associated with salinity states		
		Marine	Brackish*	Fresh
Olifants	335	2	11.0	20
Groot Berg	667	1	13.0	25
Breë	1171	3	11.5	20
Knysna	1022	2	6.0	10
Keurbooms	311	0.5	5.3	10
Sout (Oos)	6	0.05	0.5	1
Krom Oos (Kromme)	275	1	4.5	8
Sundays	163	0.5	7.8	15
Bushmans	166	0.3	2.7	5
Nahoon	58	0.5	2.8	5
Mtata	60	0.5	5.3	10

*Defined as the mean flow range between the Marine and Freshwater dominated salinity state

Table D.2 A summary of salinity states and associated flow ranges defined in historical EWR studies for temporarily open/closed estuaries.

Estuary	Openwater area (ha)	Flow rates (m^3/s) associated with salinity states				
		Closed	Semi-closed	Marine	Transition	Fresh
Orange	474.2	5		5	20	50
Tugela/Thukela	334.8	2	5	5	30	30
Palmiet	13.4	0.05	1	10	20	20
Goukamma	46.4	0.5		0.8	5	5
Groot Brak	63.3	0.2		0.4	2	2
Matjies	1.1	0.03		0.3		
Tsitsikamma	13.8	0.05	0.4	0.4		
Mngazi	82.2	0.05	0.05	0.2		20
Little Manzimtoti	2.6	0.03	0.06	0.06		0.3
Mngeni	85	1		1	3	10
Mbokodweni	8.8	0.2	0.4	0.7		
Mhlanga	11.2	0.4	0.5	5		2
Mdloti	28.5	0.2				5
Tongati	3.7	0.4		0.6		5
Siyaya	0.9	0.3		0.3		
iZotsha	9	0.07		0.07		1

The associated flow ranges for the various salinity states was evaluated against a range of the estuary's physical parameters, e.g. openwater area, estuary volume, and estuary flushing/turnover rate. The strongest relationship was found with estuary open water area. This was attributed to the fact that estuarine openwater area is a good proxy for the degree of tidal exchange. In a few highly stratified estuaries (systems with a layered salinity structure) the relationship between salinity structure and flow correlated better with estuary volume. However, overall open water area was taken as a better predictor of the flow rate at which a dominant salinity regime would occur since few estuaries in South Africa are permanently stratified, the bathymetry data are lacking to predict which systems are likely to develop stratification as a dominant feature, and estuary volume data were of a poor quality at a regional scale.

Overall a very strong correlation was found between openwater area and flows for the Freshwater and Marine dominated sates in the permanently open systems (see Figure D.1) – a function of their generally well-mixed, tidally dominated hydrodynamics. A less clear relationship was found for the large number of temporarily open/closed systems (see Figure D.2). This high degree of variance was attributed to the high variance in open water areas between the open and closed state, the influence of coastal parameters (e.g. degree of protection from wave action), and the rounding-up of river inflow ranges associated with states to reflect uncertainty in a precautionary approach.

The abovementioned relationships were applied using the openwater area of individual estuaries as the predictor of the associated flow ranges that will drive a salinity state. The total occurrences of this flow range were then identified in the simulated monthly flow data set generated as part of this study. The occurrence of these dominant salinity states were calculated for both the Reference and Present Condition and the degree of similarity determined on the shifts in states. Only the percentage occurrence of the Marine and Freshwater dominated states needed to be estimated from the simulated monthly flow data set, as the transitional brackish/mixed state could be calculated as the remainder, e.g. if an estuary is on average three months in the Freshwater dominated state and another three months in the Marine dominated state it will be in a Brackish/mixed salinity state for six months of the year, i.e. 12-(3 +3) = 6.

This output of the model was then verified in a workshop environment and moderated by expert opinion if localised pressures were recorded (e.g. stabilised mouth, causeways, bridges, artificial breaching).

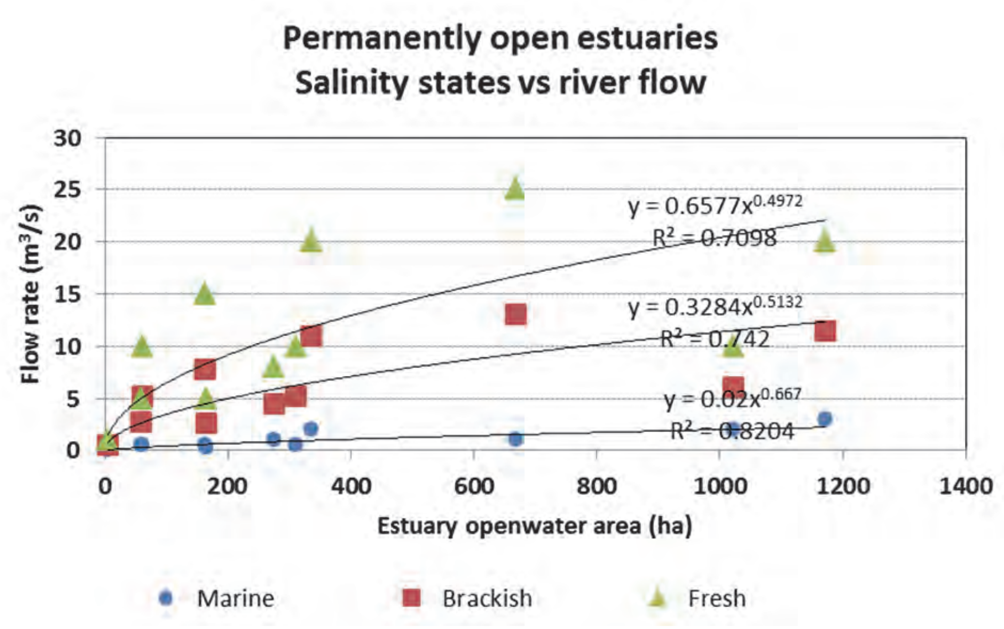


Figure D.1 Relationship between estuary openwater area and salinity states for permanently open estuaries

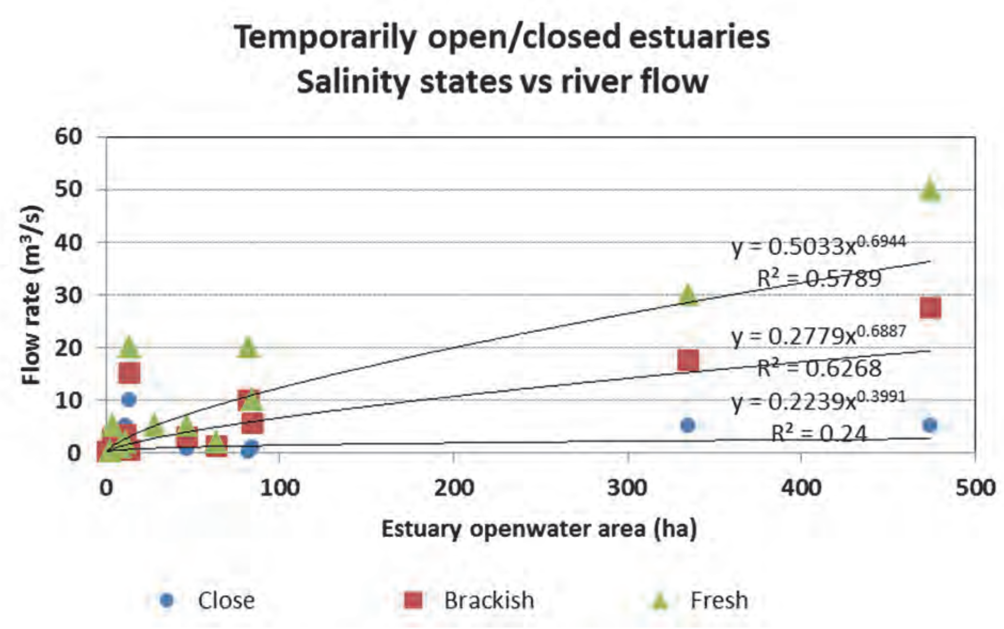


Figure D.2 Relationship between estuary openwater area and salinity states for temporarily open/closed estuaries

APPENDIX E: WATER QUALITY DESKTOP METHOD: NUTRIENTS, TURBIDITY AND TOXIC SUBSTANCES

Several water quality related studies have been conducted on South African estuaries (as reviewed for example, in Allanson and Baird (1999) and Taljaard *et al*., [2009]), but in most instances studies did not address water quality condition ("health") per se, rather they investigated specific characteristics or processes. Except for systems for which EWR studies have been conducted (Table E1), detailed measurements and information to assess the **water quality condition other than salinity** (*hereafter referred to as WQ condition*) in South Africa's approximately 300 estuaries, at a regional or national scale, remains scarce.

One of the aims of this study, therefore, was to investigate the possibility of developing a desktop method to assess WQ condition of estuaries in a data poor environment. The method, as far as possible, had to be aligned with the approach adopted in the Estuarine Health Index (EHI) applied in the EWR method for South Africa's estuaries (DWA 2013) so as to create continuity between this desktop method and the official method. Numerous factors influence the WQ in estuaries (Galbraith & Burns 2007; Moss 1998; Elliott and Sorrell 2002). Typically the two main water sources, namely catchment runoff (river inflow) and seawater, have the dominant influence. In addition, runoff from areas along the banks of an estuary (here referred to as the peri-catchment), as well as *in situ* physical, biogeochemical and biological processes influencing the water quality dynamics, can also play a significant role.

Key factors influencing the WQ of runoff entering estuaries from river inflow (and peri-catchments) include the geomorphology, climate and land-use in the catchment. In addition, the size and slope of the catchment, precipitation, wind, temperature, erosion, vegetation and soil structure all play a role. Furthermore, land-use management (e.g. in agriculture, forestry and urban areas) can also play a role in the quality of water. Influences from such anthropogenic activities is superimposed on an underlying gradient in parent geological material, soil type, topography, and other features of the natural catchment. Nutrient and sediment measurements often show that land-use overrides natural features, particularly in agricultural areas (Johnson *et al*. 1997). Natural factors may be of primary importance when anthropogenic influences are minor, or when such influences are widespread and fairly uniform across the study region. However studies have shown that when anthropogenic and natural gradients covary and only anthropogenic land-use is assessed, the influence attributed to land-use modification can be overestimated (Allan 2004).

For the purposes of this study, **land-use** is considered the most dominant driver for modification of WQ in estuaries, as a result of catchment (or peri-catchments) runoff, in particular **agriculture and forestry, and urbanisation.** Agriculture and forest land-use degrades streams by increasing diffuse inputs of pollutants, impacting riparian and stream channel habitat, and altering flows (Allan 2004). For example agricultural practices such as land clearance, irrigation, drainage, pesticide use, soil enrichment (fertilising) and animal waste affect the quality and quantity of drainage water entering rivers. However, streams do exhibit some resilience to such influences, where river quality usually remains in good condition until the extent of agriculture is relatively high, more than 30%-50% (Allan 2004).

Table E.1 Water quality condition (reflecting similarity between Reference condition and Present state) extracted from EWR studies conducted on estuaries

Estuary	DIN/DIP	SS/Turbidity	DO	Toxic Substances	Overall*	WQ Score
Orange	80	90	80	90	**83**	**B**
Olifants	50	80	80	80	**61**	**C**
Great Berg	36	85	83	80	**54**	**D**
Palmiet	74	91	85	90	**80**	**B**
Bot	57	89	75	85	**67**	**C**
Uilkraals	36	99	91	90	**58**	**D**
Breede	80	80	100	90	**84**	**B**
Great Brak	45	58	71	70	**53**	**D**
Swartvlei	90	80	94	90	**84**	**B**
Goukamma	82	87	92	90	**85**	**B**
Knysna	80	59	93	90	**70**	**C**
Keurbooms	88	95	99	95	**91**	**A**
Sout	90	90	95	-	**91**	**A**
Matjies	85	85	85	-	**85**	**B**
Kromme	33	33	70	100	**46**	**D**
Seekoei	54	52	100	80	**62**	**C**
Sundays	17	58	72	70	**36**	**E**
East Kleinemonde	70	95	85	80	**76**	**B**
Nahoon	80	80	100	50	**64**	**C**
Umtata	25	25	80	80	**39**	**E**
Umzimvubu	68	98	100	90	**79**	**B**
iZotsha	46	95	77	70	**59**	**D**
Umzimkulu	80	92	99	80	**84**	**B**
Little Amanzimtoti	30	50	10	60	**24**	**E**
Umngeni	21	66	64	60	**37**	**E**
Umhlanga	40	70	60	60	**49**	**D**
Mdloti	10	40	40	30	**20**	**F**
Tongati	10	40	20	30	**18**	**F**
Thukela	70	50	80	100	**63**	**C**
St Lucia	75	95	90	80	**80**	**B**

***WQ condition = [min (DIN/DIP; SS; DO; Toxic substances) + weighted mean (DIN/DIP; SS; DO; Toxic)]/2**

The influence of various land-use activities on WQ – and variability thereof – is demonstrated in Tables E.2a-E.2c, for dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP) and total suspended solids (TSS), respectively. Studies on river quality from catchments of varying agricultural land-use showed that nitrogen (e.g. DIN) supply was greatest from dairy farming, with a lower level of nitrogen supply from catchments of low intensity pastoral grazing, native forest and/or pine plantations. Phosphorus (e.g. DIP) supply was highest in catchments of erodable pasture land on slopes, with less from land-used for dairy farming, low intensity pastoral grazing, and forestry (Galbraith and Burns 2007; Elliott and Sorrell 2002). Galbraith & Burns (2007) also found in their studies that physical and chemical measures influencing nutrient input related positively to the extent and degree of land cover modification, and inversely to the size and slope of the catchment, and the area of the water body.

Table E.2a Dissolved inorganic nitrogen (DIN) concentrations measured in runoff from various land-use types derived from available literature. The associated geomorphology or urban developments is also shown for most land-use types

Land-use type	Place	Geomorphology	DIN (µg/l)	Reference
Forest (28) Grassland (66) Rocks (6)	Empangeni (SA)		107	Simpson (1991)
Natural Forest	New Zealand	Sand- and siltstone	115	Ouinn & Stroud (2002)
Grassland & natural forest (100)	Thukela (SA)		125	Simpson (1991)
Forest (5) Plantation (7) Grassland (77) Rocks (13) Subsistence farm (3)	Empangeni (SA)		256	Simpson (1991)
Pasture	New Zealand	Sand- and siltstone	264	Ouinn & Stroud (2002)
Timber (57) Scrub & Veld (32) Small holding (11)	Natal midlands (SA)		362	Simpson (1991)
Natural: Forest & Shrub	California (USA)	Sedimentary/Igneous	380	Yoon & Stein (2008)
Pine	New Zealand	Sand- and siltstone	459	Ouinn & Stroud (2002)
Urban: commercial (weighted mean)	Pinetown (SA)	Built-up	488	Simpson & Kemp (1982)
Cropland (57) Forest (35) Pasture (8)	Pennsylvania(USA)	Silt loams	581	Poinke *et al.* (1999)
Timber (77) Scrub & Veld (23)	Natal midlands (SA)		610	Simpson (1991)
Forestland (95)	Pennsylvania (USA)	Sandstone	710	Poinke & Urban (1985)
Urban: Residential (51) commercial (19) light industry (19) (weighted mean)	Pinetown (SA)	Built-up	824	Simpson & Stone (1988)
Urban: Residential (74) Commercial & light industry (17) Undeveloped (9)	Michigan (USA)	Built-up	1098	Schmidt & Spencer (19886
Cropland (67)	Pennsylvania (USA)	Shale	1320	Poinke & Urban (1985)
Cropland (73)	Pennsylvania (USA)	Siltstone	4650	Poinke & Urban (1985)
Feedlot (100)	Thukela (SA)		6846	Simpson (1991)

Table E.2b Dissolved inorganic P (DIP) concentrations measured in runoff from various land-use types derived from available literature. The associated geomorphology or urban developments is also shown for most land-use types

Land-use type	Place	Geomorphology	DIP/ Soluble P (µg/l)	Reference
Forestland (95)	Pennsylvania (USA)	Sandstone	7	Poinke & Urban (1985)
Forest (28) Grassland (66) Rocks (6)	Empangeni (SA)		10	Simpson (1991)
Pasture	New Zealand	Sand- and siltstone	10	Ouinn & Stroud (2002)
Cropland (67)	Pennsylvania (USA)	Shale	12	Poinke & Urban (1985)
Cropland (57) Forest (35) Pasture (8)	Pennsylvania(USA)	Silt loams	12	Poinke *et al.* (1999)
Plantation (77) Scrub & Veld (23)	Natal midlands (SA)		17	Simpson (1991)
Forest (5) Plantation (7) Grassland (77) Rocks (13) Subsistence farm (3)	Empangeni (SA)		17	Simpson (1991)
Plantation	New Zealand	Sand- and siltstone	23	Ouinn & Stroud (2002)
Natural Forest	New Zealand	Sand- and siltstone	24	Ouinn & Stroud (2002)
Plantation (57) Scrub & Veld (32) Small holding (11)	Natal midlands (SA)		26	Simpson (1991)
Grassland & Natural Forest (100)	Thukela (SA)		35	Simpson (1991)
Natural: Forest & Shrub	California (USA)	Sedimentary/Igneous	40	Yoon & Stein (2008)
Cropland (73)	Pennsylvania (USA)	Siltstone	45	Poinke & Urban (1985)
Urban: commercial (weighted mean)	Pinetown (SA)	Built-up	47	Simpson & Kemp (1982)
Urban: Residential (51) commercial (19) light industry (19) (weighted mean)	Pinetown (SA)	Built-up	96	Simpson & Stone (1988)
Urban: Residential (74) Commercial & light industry (17) Undeveloped (9)	Michigan (USA)	Built-up	121	Schmidt & Spencer (1986)
Feedlot (100)	Thukela (SA)		4474	Simpson (1991)

Table E.2c Total suspended solids (TSS) and turbidity levels measured in runoff from various land-use types derived from available literature. The associated geomorphology or urban developments is also shown for most land-use types

Land-use type	Place	Geomorphology	Total Suspended Solids (Mg/L)	Turbidity (Ntu)	Reference
Natural Forest	New Zealand	Sand- and siltstone	5	9	Ouinn & Stroud (2002)
Pine	New Zealand	Sand- and siltstone	12	11	Ouinn & Stroud (2002)
Pasture	New Zealand	Sand- and siltstone	21	25	Ouinn & Stroud (2002)
Plantation (57) Scrub & Veld (32) Small holding (11)	Natal midlands (SA)		56	30	Simpson (1991)
Forest (28) Grassland (66) Rocks (6)	Empangeni (SA)		75	9	Simpson (1991)
Urban: Residential (74) Commercial & light industry (17) Undeveloped (9)	Michigan (USA)	Built-up	77	25	Schmidt & Spencer (1986)
Natural: Forest & Shrub	California (USA)	Sedimentary/Igneous	98	-	Yoon & Stein (2008)
Plantation (77) Scrub & Veld (23)	Natal midlands (SA)		118	47	Simpson (1991)
Urban: commercial (weighted mean)	Pinetown (SA)	Built-up	125	-	Simpson & Kemp (1982)
Forest (5) Plantation (7) Grassland (77) Rocks (13) Subsistence farm (3)	Empangeni (SA)		126	24	Simpson (1991)
Urban: Residential (51) commercial (19) light industry (19) (weighted mean)	Pinetown (SA)	Built-up	250	-	Simpson & Stone (1988)
Feedlot (100)	Thukela (SA)		332	44	Simpson (1991)
Natural: Grassland & Forest (100)	Thukela (SA)		437	208	Simpson (1991)

Landscape metrics, particularly the proportion of agriculture in the catchment and forest in the riparian zone, was found to explain 65-84% of the variation in nitrogen, dissolved phosphorus, and suspended sediments yields (Jones *et al*. 2001). Urbanisation in catchments has a marked influence on runoff quality into water resources (Simpson 1986). Pollutants in runoff from urbanised areas include excess inorganic nutrients, organic matter, suspended solids, toxic metals, hydrocarbons, pesticides and human pathogens (Tables E.2a-c). Sources of urban pollution include atmospheric fall-outs (e.g. exhaust fumes and atmospheric waste discharges) and runoff from catchment material (e.g. street surfaces, buildings, parking areas and pavements). Further urbanisation generally increases runoff volumes and peak flow rates because of increased impervious areas, reduction in natural storage and the introduction of hydraulically more efficient drainage systems. As a result urbanisation of catchments not only greatly increases pollution loads to water resources (i.e. larger runoff and high pollutant concentrations), but also the manner in which runoff is delivered will enhance erosion, dislodgement and entrainment of pollutants.

Another major source of WQ modification in South African estuaries is piped discharges (or point source discharges) mainly from **Wastewater Treatment Works** (WWTWs). Historically, licenses for the discharge of municipal waste water to any freshwater resource has to meet at least the general effluent standards (or in some instances special standards) as specified in of the General Authorisation in terms of Section 39 of the National Water Act (No 36 of 1998) (NWA) (Government Gazette No. 26187, 26 March 2004). For the purposes of this study, the quality as specified in the 'general standards' will be used as proxy from the input quality from WWTWs. Such quality standards are presented in Table E.3.

Table E.3 General and special standards as specified for inorganic nutrients and TSS in General Authorisation under the NWA

Parameter	General Standard	Special Standard
Suspended solids (mg/ℓ)	10	2
Total ammonia-N (mg/ℓ)	6	2
Nitrate-N (mg/ℓ)	15	1.5
DIN (mg/ℓ)	21	3.5
DIP (mg/ℓ)	10	1 (median) 2.5 (max)

Estimating WQ condition

Studies have been undertaken to estimate river water quality from land-use, e.g. Stein *et al.* (2002) adopted an index approach for assessing anthropogenic river disturbance. The method is based on the assumption that (a) the intensity and extent of human activities within the catchment and (b) in-stream structures that alter the flow regime can provide surrogate indicators of the extent of disturbance of natural river processes. Furthermore, their method assumed that the degree to which the hydrological, geomorphological and biological processes have altered water quality forms a continuum from severely degraded to near-pristine (Stein *et al*. 2002). The method distinguishes between direct changes to the flow regime and indirect anthropogenic changes in the catchment. In the case of catchment disturbance four major factors were considered: (1) land-use activity; (2) settlements and structures; (3) infrastructure; and (4) extractive industries and other point sources of pollution. Weighted scores reflect both the spatial extent and potential magnitude of impact from the disturbance and, in the case of point sources, proximity to the stream. Stein *et al.* (2002) adopted an index approach because it was more easily understood by, and communicated to, a wide range of stakeholders and because it reflected the qualitative nature of the information. In their method pollution (or water quality) was implicitly included as a contributor to change, but it did not define the specific contribution of changes in catchment water quality water per se.

Another example is presented by Malan *et al*. (2003) using a simple flow-concentration modelling approach based on solute rating curves for inclusion in determination of the ecological Reserve studies for rivers in South Africa. The method entails the collation of available concentration and flow data for eco-regions of uniform water quality – most suitably applied on an individual catchment scale as these relationship as often place-based. Mean monthly discharge (stream flow) values and median monthly concentration values for each variable (C) were then correlated to derive relationships. Using this approach WQ could then be derived from flow patterns. Flow-concentration modelling was found to be most useful for total dissolved solids, individual salts and ions and other conservative constituents, but is not suitable for simulation of dissolved oxygen or temperature. Nutrient concentrations also often exhibit considerable scatter when plotted against flow – presumably a consequence of various other influencing processes (e.g. microbial conversion between chemical forms, adsorption/desorption from sediment particles, uptake by the biota).

The aim of this study was to investigate a desktop assessment method to assess estuary condition (in this case WQ condition) aligned with the official EWR methods for estuaries (DWA 2008). In the official EWR method WQ condition is defined in terms of the Estuarine Health Index (EHI). The rationale and approach adopted in the development of the EHI is discussed in detail in DWAF (2008). In essence the EHI defines WQ condition as the degree of similarity between the reference condition and present state in terms of the following parameters, namely:

- Nutrients (dissolved inorganic nitrogen – DIN and dissolved inorganic phosphate – DIP);
- Dissolved oxygen;
- Suspended solids (turbidity); and
- Toxic substances.

In assessing the WQ condition of an estuary typical abiotic states – each linked to a specific river inflow range – is first determined. Then each of these states is characterised in term the concentrations of the four WQ parameters, both under the reference condition and present state. Shifts in the occurrence of the various states from reference to present and shifts in WQ concentrations are then used to determine similarity using Czekanowski's similarity index (WRC 2013):

$$\sum(min(ref,pres) \ \ (\sum ref + \sum pres)/2$$

Finally, the similarity scores of the four WQ parameters are combined to provide the **WQ condition** of the estuary as follows:

$$[min\ (DIN/DIP;\ SS;\ DO;\ Toxic) + weighted\ mean\ (DIN/DIP;\ SS;\ DO;\ Toxic)]/2.$$

The official EHI, therefore require *in situ* concentration data on various water quality parameters in the estuary. In terms of assessing WQ condition for estuaries at a desktop level on a regional scale, lack of WQ data is the major constraint.

To remove complexity, the number of WQ parameters used was therefore reduced to three parameters for the desktop assessment, namely:

- Nutrients
- Turbidity
- Toxic substances.

Dissolved oxygen (the other WQ parameter included in the EHI) is predominantly influenced by *in situ* processes within the estuary such as organic accumulation, retention, stratification and water depth. As a result, it becomes extremely difficult to sensibly derive oxygen levels within an estuary primarily on the character of sources. For this reason, it was excluded in this phase of the investigation into a systematic approach to derive estuary WQ condition.

The following section describes the method applied in assessing WQ condition as part of this desktop assessment.

Method Description

Ideally, the WQ condition of an estuary should be determined by assessing modification *in situ* concentration measurements from reference to present. However, such data is not readily available for South African estuaries. An alternative approach therefore had to be investigated. A box model approach was considered using source inputs that predominantly affect WQ condition in estuaries, namely (Figure E.1):

- River inflow (e.g. from primary river catchment) into the estuary
- Diffuse runoff (e.g. from peri-catchment) entering along the banks of the estuary.
- Point sources (e.g. WWTW effluent) discharged directly into estuaries

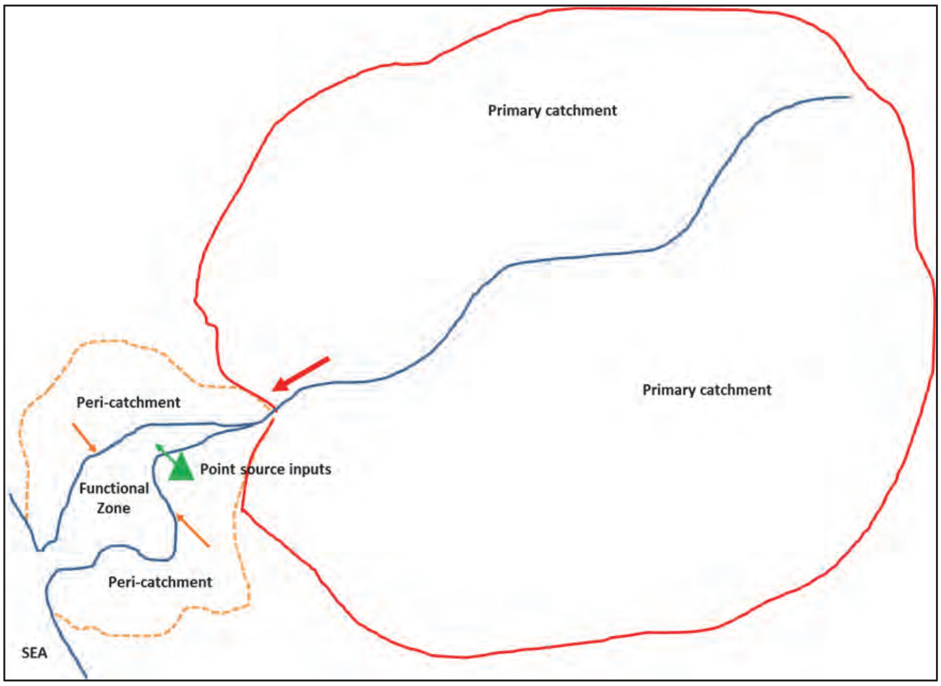


Figure E.1 A schematic illustration of source inputs applied for this desktop water balance model

For the purposes of this study, river inflow was derived from the primary catchment of the system, while diffuse runoff entering from the banks of the estuary was defined as the peri-catchment, i.e. the area 500 m landward of the 5 m MSL contour. Detailed data on water quality concentrations from all these source inputs were not available. Therefore present water quality for river inflow (primary catchment) and diffuse runoff from the bank (peri-catchment) were derived from land-use types. Land-use cover in South Africa is categorised into a number of land-use types. Land-use practices strongly influence water quality in diffuse runoff. Therefore, using a rating system (Table E.4) similar to that applied in the EHI of the official EWR methods (DWAF 2008), each land-use type was allocated a WQ rating for the three selected parameters, relative to the reference (where reference WQ rating equals "1"). The overall WQ rating for a specific land-use type was then equated to the maximum WQ rating of the three parameters as illustrated in Table E.5.

Table E.4 WQ rating categories (similar to the EHI) applied in this desktop assessment

A	1	91-100	Unmodified, natural
B	2	76-90	Largely natural with few modifications
C	3	61-75	Moderately modified
D	4	41-60	Largely modified
E	5	21-40	Highly modified
F	6	0-20	Extremely degraded

The WQ ratings of various land-use types in a specific catchment were then used to derive a WQ rating for river inflow (primary catchment) and diffuse runoff from along the estuary banks (peri-catchment), weighted by area. Recognising some of the limitations of the land-use cover data (e.g. outdated or inappropriate resolution), WQ ratings of the various catchments were verified at a specialist workshop. Where necessary the WQ ratings were adjusted based on expert judgement.

In the case of WWTWs, nutrients are typically the parameter that is most modified from reference (at least equally, but usually more than the other two parameters). Most WWTWs operate on either general or special limits (Table E.3) where thresholds for dissolved inorganic nitrogen (DIN) are 21 mg/ℓ and 3.5 mg/ℓ, respectively. With natural DIN concentrations in estuaries typically ranging between 0.05 mg/ℓ and 0.15 mg/ℓ, these thresholds represent a large modification from reference to present. Similarly, general and special limits for dissolved inorganic P (DIP) are 10 mg/ℓ and 1 mg/ℓ, respectively, while concentrations in estuaries naturally ranging between 0.01 and 0.02 mg/ℓ. As a result a default WQ rating of "6" was assumed for WWTWs.

While the sea is an important source of water to an estuary, it was assumed (for the purposes of this desktop assessment) that water quality associated with seawater inflow did not change markedly from reference, or at least not as much compared with modification in water quality in inflows from catchments, peri-catchments and WWTWs. This assumption was based on similar findings in the EWR studies conducted previously on estuaries.

For each estuary, WQ ratings were calculated for river inflow (derived from primary catchment land-use), diffuse inflow from along its banks (derived from peri-catchment land-use) and, where applicable WWTW inflows (allocated default WQ ratings of "6") (Table E.5).

The resultant influence of specific source inputs on the estuary's water quality were calculated using their WQ rating and the **daily volume** from the source relative to the estuary's volume. The average daily volume for river inflow was calculated by dividing the **present** mean annual runoff (MAR) of the primary catchment by 365 (number of days in the year). The average daily volume of diffuse runoff from the banks was calculated from the peri-catchment area as follows:

$$\text{Average daily volume}_{\text{diffuse runoff from banks}} = \text{Area}_{\text{peri-catchment}} / \text{Area}_{\text{primary catchment}} * \text{MAR}_{\text{present}}$$

The average daily volume for WWTWs was obtained from the Western Cape Province Green Drop Report (DWA 2012).

Table E.5 Land-use categories and associated WQ ratings

PROPOSED CATEGORY	LAND-USE TYPE	NUTRIENTS	SS	TOXIC SUBSTANCES	WQ Rating
Natural	Forest (indigenous)	1	1	1	1
Natural	Woodland (previously termed Forest and Woodland)	1	1	1	1
Natural	Thicket, Bushland, Bush Clumps, High Fynbos	1	1	1	1
Natural	Shrubland and Low Fynbos	1	1	1	1
Natural	Herbland	1	1	1	1
Natural	Unimproved (natural) Grassland	1	1	1	1
Irrigated pastures	Improved Grassland	4	1	3	4
Plantations	Forest Plantations (Eucalyptus spp)	1	1	1	1
Plantations	Forest Plantations (Pine spp)	1	1	1	1
Plantations	Forest Plantations (Acacia spp)	1	1	1	1
Plantations	Forest Plantations (Other / mixed spp)	1	1	1	1
Plantations	Forest Plantations (clearfelled)	1	3	1	3
Waterbodies - natural or dams (Mallor	Waterbodies	1	1	1	1
Wetlands	Wetlands	1	1	1	1
Natural	Bare Rock and Soil (natural)	1	1	1	1
Erosion	Bare Rock and Soil (erosion : dongas / gullies)	1	4	1	4
Erosion	Bare Rock and Soil (erosion : sheet)	1	4	1	4
Degraded	Degraded Forest & Woodland	1	3	1	3
Degraded	Degraded Thicket, Bushland, etc	1	3	1	3
Degraded	Degraded Shrubland and Low Fynbos	1	3	1	3
Degraded	Degraded Herbland	1	3	1	3
Degraded	Degraded Unimproved (natural) Grassland	3	3	1	3
Irrigated, perennial (orchards, vines)	Cultivated, permanent, commercial, irrigated	4	3	4	4
Dryland, perennial (orchards, vines)	Cultivated, permanent, commercial, dryland	1	3	1	3
Irrigated, sugarcane	Cultivated, permanent, commercial, sugarcane	4	4	4	4
Irrigated, annual (vegetables)	Cultivated, temporary, commercial, irrigated	4	4	4	4
Dryland, annual (wheat, maize)	Cultivated, temporary, commercial, dryland	1	3	3	3
Dryland, annual (wheat, maize)	Cultivated, temporary, subsistence, dryland	1	4	1	4
Irrigated, annual (vegetables)	Cultivated, temporary, subsistence, irrigated	3	4	1	4
Residential formal	Urban / Built-up (residential)	6	1	3	6
Residential dense rural	Urban / Built-up (rural cluster)	3	3	3	3
Residential formal	Urban / Built-up (residential, formal suburbs)	6	1	3	6
Residential formal	Urban / Built-up (residential, flatland)	6	1	3	6
Residential formal	Urban / Built-up (residential, mixed)	6	1	3	6
Residential formal	Urban / Built-up (residential, hostels)	6	1	3	6
Residential formal	Urban / Built-up (residential, formal township)	6	1	3	6
Residential informal	Urban / Built-up (residential, informal township)	6	6	1	6
Residential informal	Urban / Built-up (residential, informal squatter camp)	6	6	1	6
Smallholdings	Urban / Built-up (smallholdings, woodland)	1	1	1	1
Smallholdings	Urban / Built-up (smallholdings, thicket, bushland)	1	1	1	1
Smallholdings	Urban / Built-up (smallholdings, shrubland)	1	1	1	1
Smallholdings	Urban / Built-up (smallholdings, grassland)	1	1	1	1
Commercial	Urban / Built-up, (commercial, mercantile)	3	1	3	3
Commercial	Urban / Built-up, (commercial, education, health, IT)	3	1	3	3
Industrial heavy	Urban / Built-up, (industrial / transport : heavy)	3	1	6	6
Industrial light	Urban / Built-up, (industrial / transport : light)	3	1	6	6
Mining subsurface	Mines & Quarries (underground / subsurface mining)	1	1	1	1
Mining surface	Mines & Quarries (surface-based mining)	3	4	4	4
Mining surface	Mines & Quarries (mine tailings, waste dumps)	3	4	4	4

The relative volume fraction was calculated as $\text{Volume}_{\text{estuary}}/\text{Volume}_{\text{inflow.}}$ Volume fractions greater >1 indicated a high influence on estuary WQ and a ratio <0.25 indicated a low influence on estuary WQ. The influence of each input on **WQ in the estuary** was then derived from the WQ rating of the input source and its volume fraction using the matrix below:

Volume fraction: Estuary volume/Daily inflow volume	WQ rating of Inflow 1	2	3	4	5	6
> 1	1	2	3	4	5	6
1-0.75	1	2	3	4	5	6
0.75-0.5	1	2	3	4	5	6
0.5-0.25	1	1	2	3	4	5
0.25-0.025	1	1	1	2	3	4
0.025-0.0025	1	1	1	1	2	3
<0.0025	1	1	1	1	1	2
<0.00025	1	1	1	1	1	1

This matrix accounted for the effect of seawater intrusion into systems where the volume fraction was <0.5. Here the assumption was that on average a significant proportion of the estuary was still flushed with "clean' seawater and that this had to be accounted for. However, in the case of perched estuaries (where tidal flushing is usually relative small) with volume fractions <0.5, the resultant estuary WQ assumed the WQ rating allocated to the source input.

The **resultant WQ in the estuary** was then equated to the maximum WQ rating of inflows (Table E.5). Finally, the frequency of mouth opening/closure was taking into account to define the **WQ condition in the estuary** as follows:

Percentage mouth open	Resultant WQ Estuary 1	2	3	4	5	6
1: 100-75	1	2	3	4	5	6
2: 75-50	1	2	3	5	6	6
3: 50-25	2	3	4	5	6	6
4: 25-0	2	3	4	5	6	6

Here the assumption was that estuaries closing for extended periods (e.g. more than 50% of the time) provide sufficient residence time for *in situ* processes to further modify water quality. To verify the results from the above approach, the WQ conditon allocated to 35 estuaries as part of EWR studies were compared with the WQ conditon derived from this method. The correlation was very good, revealing an r^2 = 0.89 (Figure E.2).

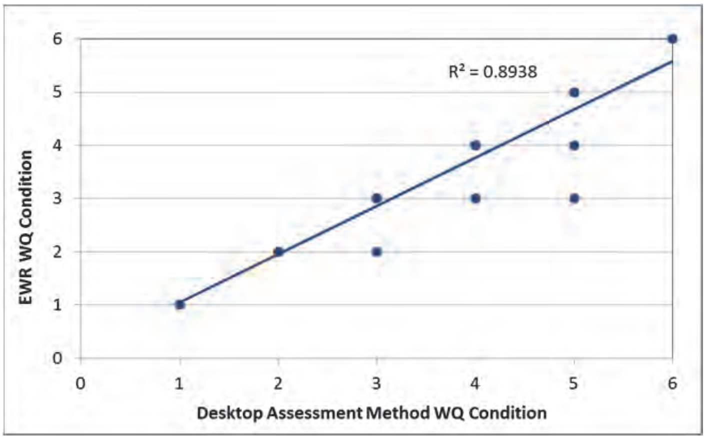


Figure E.2 Comparison between WQ condition (EWR studies) versus WQ condition (this desktop assessment method)

Table E.6 Determination of WQ condition in the Temperate estuaries of South Africa

NAME	WQ condition	Resultant WQ Estuary	Perched (1=Y; 0=N)	%Open (1=100-75; 2=75-50; 3=50-25; 4=25-0)	POINT SOURCE DISCHARGES (e.g. WWTWs)				DIFFUSE SOURCES ALONG BANKS			RIVER INFLOW		
					WQ Estuary	WQ rating	Volume fraction	Name	WQ Estuary	WQ rating	Volume fraction	WQ Estuary	WQ rating	Volume fraction
Orange (Gariep)	C	3	0	1			0.00000		1	1	0.0000	3	3	0.9575
Buffels	B	1	0	4			0.00000		1	3	0.0450	1	1	0.3749
Swartlintjies	B	1	0	4			0.00000		1	1	0.0004	1	1	0.1863
Spoeg	B	1	0	4			0.00000		1	1	0.0000	1	1	0.0244
Groen	B	1	0	4			0.00000		1	1	0.0000	1	1	0.0083
Sout	B	1	0	4			0.00000		1	1	0.0003	1	1	0.0146
Olifants	C	3	0	1	1	6	0.00004	Lutzville	1	3	0.0002	3	5	0.1947
Jakkals	D	3	0	4			0.00000		1	2	0.0008	3	5	0.2053
Wadrift\Langdrift	D	3	0	4			0.00000		1	2	0.0005	3	5	0.0419
Verlorenvlei (lake)	E	4	1	4			0.00000		1	2	0.0000	4	4	0.0027
Berg (Groot)	C	3	0	1	3	6	0.00649	Fish factory	1	2	0.0006	3	5	0.0712
Rietvlei/Diep	D	4	0	1	3	6	0.01314	Potsdam	1	5	0.0004	4	6	0.0417
Sout (Wes)	E	4	0	2			0.00000		1	5	0.0021	4	6	0.2089
Hout Bay (Disa)	F	6	0	2			0.00000		5	5	0.6332	6	6	22.6324
Wildevoelvlei	D	4	1	1	3	6	0.01105	Wildevoelvlei	1	2	0.0004	4	4	0.0058
Schuster	A	1	0	1			0.00000		1	3	0.0688	1	1	1.0543
Krom	B	1	1	3			0.00000		1	1	0.0109	1	1	0.2752
Buffels Wes	B	1	0	3			0.00000		1	1	0.0208	1	1	0.3324
Elsies	C	2	0	3			0.00000		1	3	0.0301	2	3	0.4877
Silvermine	D	3	1	3			0.00000		1	3	0.1623	3	3	2.6941
Bokramspruit	C	3	0	1			0.00000		1	1	0.0000	3	3	1.1235
Sand	E	4	1	3			0.00000		1	4	0.0030	4	4	0.0282
Zeekoe	F	6	1	1	3	6	0.02361	Cape Flats	2	6	0.0014	6	6	0.0096
Eerste	F	6	1	1	5	6	0.30257	Macassar	1	4	0.0098	6	6	1.3247
Lourens	E	5	1	1			0.00000		4	5	0.3639	5	5	7.7077
Sir Lowry's	F	5	1	2			0.00000		2	5	0.0065	5	5	0.6227
Steenbras	A	1	0	1			0.00000		1	1	0.0909	1	1	8.3504
Rooiels	A	1	0	1			0.00000		1	3	0.0662	1	1	0.8665
Buffels (Oos)	A	1	1	2			0.00000		1	3	0.0003	1	1	1.5641
Palmiet	B	2	1	1			0.00000		1	1	0.0531	2	2	1.6713
Bot/Kleinmond (lake)	C	2	1	4	1	6	0.00003	Hawston	1	2	0.0002	2	2	0.0076
Onrus	E	4	1	3			0.00000		1	4	0.0219	4	4	0.7061
Klein (lake)	D	3	1	3	1	6	0.00001	Standord	1	2	0.0001	3	3	0.0040
Uilkraals	C	3	0	2	3	6	0.00000	Sewage inflow bridge	1	1	0.0035	1	1	0.1646
Ratel	B	1	1	4			0.00000		1	1	0.0138	1	1	0.9963
Heuningnes/Soetendal (la	C	3	1	1			0.00000		1	2	0.0001	3	3	0.0034
Klipdrifsfontein	B	1	1	4			0.00000		1	1	0.0054	1	1	0.1423
Breede	B	2	0	1			0.00000		1	2	0.0005	2	4	0.0806
Duiwenhoks	B	2	0	1			0.00000		1	3	0.0010	2	4	0.0717
Goukou	B	2	0	1	2	6	0.00070	Stilbaai	1	2	0.0008	2	4	0.0676
Gourits	B	2	0	1			0.00000		1	3	0.0001	2	4	0.1887
Blinde	C	2	1	4			0.00000		1	1	0.0034	2	2	0.1275
Hartenbos	E	4	1	4	4	6	0.02575	Hartenbos	1	4	0.0008	3	3	0.0248
Klein Brak	B	2	0	1	1	6	0.00005	Friemersheim	1	2	0.0017	2	4	0.0604
Groot Brak	D	3	0	4			0.00000		2	6	0.0014	3	5	0.0352
Maalgate	C	2	1	3			0.00000		1	2	0.0018	2	2	0.1549
Gwaing	D	4	0	1	4	6	0.08739	Gwaing	1	2	0.0175	4	4	0.9855
Kaaimans	B	2	0	1			0.00000		1	1	0.0094	2	3	0.4167
Wilderness/Touw (lake)	C	2	1	4			0.00000		1	2	0.0007	2	2	0.0067
Swartvlei (Lake)	B	2	1	2			0.00000		1	2	0.0001	2	2	0.0020
Goukamma	B	2	0	1			0.00000		1	1	0.0076	2	4	0.1441
Knysna	B	2	0	1	1	6	0.00014	Knysna	2	6	0.0002	1	1	0.0046
Noetsie	B	1	1	3			0.00000		1	1	0.0106	1	1	0.2163
Piesang	C	3	1	2			0.00000		1	4	0.0143	3	3	0.1856
Keurbooms/Bitou	A	1	0	1			0.00000		1	2	0.0011	1	1	0.0631
Matjies	B	2	1	2			0.00000		1	1	0.0350	2	2	1.0708
Sout (Oos)	A	1	1	1			0.00000		1	1	0.0179	1	1	0.3194
Groot (Wes)	A	1	1	2			0.00000		1	1	0.0025	1	1	0.0532
Bloukrans	A	1	0	1			0.00000		1	1	0.0478	1	1	3.3317
Lottering	A	1	0	1			0.00000		1	1	0.0388	1	1	2.9269
Elandsbos	A	1	0	1			0.00000		1	1	0.0797	1	1	4.3589
Storms	A	1	0	1			0.00000		1	1	0.0294	1	1	2.6346
Elands	A	1	0	1			0.00000		1	1	0.0241	1	1	1.3869
Groot (Oos)	C	3	0	2			0.00000		1	2	0.0183	3	3	0.7253
Tsitsikamma	C	3	1	2			0.00000		1	1	0.0076	3	3	0.2634
Klipdrif	D	3	0	4			0.00000		1	1	0.0598	3	3	5.6771
Slang	E	4	0	4			0.00000		1	2	0.0599	4	4	1.1069
Kromme (Oos)	A	1	0	1			0.00000		1	3	0.0002	1	3	0.0123
Seekoei	D	3	1	3			0.00000		1	4	0.0014	3	3	0.0297
Kabeljous	C	2	1	4			0.00000		1	1	0.0015	2	2	0.0369
Gamtoos	C	3	0	1			0.00000		1	5	0.0001	3	5	0.1040
Van Stadens	B	1	1	4			0.00000		1	1	0.0088	1	1	0.2501
Maitland	C	2	0	4			0.00000		1	1	0.0121	2	2	0.7654
Baakens	E	5	0	1			0.00000		2	5	0.0161	5	5	0.5862
Papkuils	F	6	1	1			0.00000		2	6	0.0008	6	6	0.3791
Swartkops	E	5	0	1			0.00000		5		0.0002	3	6	0.0169
Coega	B	1	0	4			0.00000		1	1	0.0006	1	1	0.0392

NAME	WQ condition	Resultant WQ Estuary	Perched (1=Y; 0=N)	%Open (1=100-75; 2=75-50; 3=50-25; 4=25-0)	POINT SOURCE DISCHARGES (e.g. WWTWs) WQ Estuary	WQ rating	Volume fraction	Name	DIFFUSE SOURCES ALONG BANKS WQ Estuary	WQ rating	Volume fraction	RIVER INFLOW WQ Estuary	WQ rating	Volume fraction
Sundays	D	4	0	1			0.00000		1	2	0.0002	4	6	0.1457
Boknes	C	2	1	4			0.00000		1	2	0.0040	2	2	0.2746
Bushmans	B	2	0	1	2	6	0.00040	Boesmans River Mouth	1	1	0.0002	1	1	0.0203
Kariega	B	2	0	1	2	6	0.00031	Kenton on sea	1	2	0.0003	1	1	0.0133
Kasuka	B	1	1	4			0.00000		1	1	0.0028	1	1	0.0519
Kowie	B	2	0	1	2	6	0.00041	Port Alfred	1	2	0.0005	1	1	0.0190
Rufane	B	1	0	4			0.00000		1	1	0.0061	1	1	0.1842
Riet	B	1	1	4			0.00000		1	1	0.0072	1	1	0.1900
Kleinmond Wes	B	1	1	4			0.00000		1	1	0.0027	1	1	0.0416
Kleinemond Oos	B	1	1	3			0.00000		1	1	0.0000	1	1	0.0239
Klein Palmiet	B	1	0	4			0.00000		1	1	0.0262	1	1	0.5063
Great Fish	D	4	0	1			0.00000		1	1	0.0002	4	5	0.3099
Old Womans	D	3	1	4			0.00000		3		0.0033	1	1	0.0538
Mpekweni	B	1	1	4			0.00000		1	1	0.0011	1	1	0.0187
Mtati	B	1	1	4			0.00000		1	1	0.0014	1	1	0.0278
Mgwalana	B	1	1	4			0.00000		1	1	0.0017	1	1	0.0423
Bira	B	1	1	3			0.00000		1	1	0.0015	1	1	0.0370
Gqutywa	B	1	1	4			0.00000		1	1	0.0012	1	1	0.0193
Ngculura	B	1	1	4			0.00000		1	1	0.0196	1	1	0.5068
Mtana	B	1	1	4			0.00000		1	1	0.0024	1	1	0.0182
Keiskamma	C	3	0	1			0.00000		3		0.0006	1	3	0.0542
Ngqinisa	B	1	1	4			0.00000		1	1	0.0036	1	1	0.0302
Kiwane	B	1	1	4			0.00000		1	1	0.0031	1	1	0.0431
Tyolomnqa	B	1	0	3			0.00000		1	2	0.0018	1	2	0.0489
Shelbertsstroom	C	3	0	2			0.00000		3	5	0.1089	2	2	0.6968
Lilyvale	B	1	0	3			0.00000		1	2	0.0373	1	2	0.2273
Ross creek	B	1	1	4			0.00000		1	1	0.0272	1	1	0.1263
Ncera	B	2	1	2			0.00000		1	1	0.0083	2	2	0.1320
Mlele	C	2	1	3			0.00000		1	1	0.0111	2	2	0.1271
Mcantsi	B	2	1	2			0.00000		1	2	0.0167	2	2	0.2073
Gxulu	B	2	1	2			0.00000		1	1	0.0042	2	2	0.1164
Goda	C	2	1	3			0.00000		1	2	0.0051	2	2	0.1167
Hlozi	D	3	1	3			0.00000		1	2	0.0185	3	3	0.1496
Hickmans	C	3	1	2			0.00000		1	2	0.0070	3	3	0.1438
Ngqenga	D	3	1	3			0.00000		1	1	0.0173	3	3	0.3689
Buffalo	C	3	0	1			0.00000		2	6	0.0001	3	6	0.0126
Blind	F	5	1	4			0.00000		1	2	0.0627	5	5	0.5428
Hlaze	E	4	1	2			0.00000		1	3	0.0810	4	4	0.4294
Nahoon	C	3	0	1			0.00000		1	4	0.0005	3	5	0.0426
Qinira	C	2	0	3			0.00000		1	3	0.0043	2	4	0.0919
Gqunube	B	2	0	1			0.00000		1	2	0.0009	2	4	0.0702
Kwelera	B	2	0	1			0.00000		1	1	0.0021	2	4	0.1236
Bulura	B	2	1	2			0.00000		1	1	0.0046	2	2	0.0405
Cunge	B	1	1	4			0.00000		1	1	0.0611	1	1	0.5292
Cintsa	B	1	1	4			0.00000		1	2	0.0043	1	1	0.0398
Cefane	B	1	1	4			0.00000		1	1	0.0027	1	1	0.0267
Kwenxura	A	1	1	2			0.00000		1	1	0.0033	1	1	0.1198
Nyara	B	1	1	3			0.00000		1	1	0.0045	1	1	0.1035
Imtwendwe	A	1	1	2			0.00000		1	1	0.0107	1	1	0.6325
Haga-haga	B	1	1	4			0.00000		1	1	0.0148	1	1	0.1715
Mtendwe	A	1	1	2			0.00000		1	1	0.1025	1	1	0.8751
Quko	B	1	0	3			0.00000		1	1	0.0028	1	1	0.1068
Morgan	B	1	1	4			0.00000		1	2	0.0031	1	1	0.0303
Cwili	A	1	1	2			0.00000		1	2	0.0615	1	1	0.4575
Great Kei	B	2	0	1			0.00015		1	1	0.0004	2	3	0.3941
Gxara	C	2	1	3			0.00000		1	1	0.0045	2	2	0.0440
Ngogwane	C	2	1	4			0.00000		1	2	0.0180	2	2	0.0687
Qolora	B	2	1	2			0.00000		1	2	0.0073	2	2	0.2115
Ncizele	B	2	1	2			0.00000		1	1	0.0202	2	2	0.1863
Timba	B	1	1	3			0.00000		1	1	0.0004	1	1	0.3160
Kobonqaba	A	1	0	1			0.00000		1	2	0.0023	1	2	0.1303
Nxaxo\ngqusi (Wave cres	A	1	0	1			0.00000		1	1	0.0106	1	2	0.2005
Cebe	B	1	1	3			0.00000		1	1	0.0072	1	1	0.0695
Gqunqe	B	1	0	3			0.00000		1	1	0.0063	1	2	0.0853
Zalu	B	1	1	3			0.00000		1	1	0.0109	1	1	0.0486
Ngqwara	B	1	1	3			0.00000		1	2	0.0062	1	1	0.0640
Sihlontlweni/gcin	B	1	0	3			0.00000		1	1	0.0062	1	1	0.0670
Nebelele	B	1	0	3			0.00000		1	2	0.0657	1	1	0.9434
Qora	A	1	0	1			0.00000		1	1	0.0020	1	1	0.1870
Jujura	A	1	1	1			0.00000		1	1	0.0137	1	1	0.4466
Ngadla	B	1	1	4			0.00000		1	1	0.0067	1	1	0.0478
Shixini	A	1	1	1			0.00000		1	1	0.0027	1	1	0.2264
Beechamwood	B	1	1	3			0.00000		1	1	0.0163	1	1	0.4795
Kwazwelitsha/Kwazweda	B	1	1	3			0.00000		1	1	0.0169	1	1	0.5233
Kwa-goqo	B	1	1	3			0.00000		1	1	0.0271	1	1	0.8712
Ku-nocekedwa	B	1	1	3			0.00000		1	1	0.0447	1	1	0.9589
Nqabara	A	1	0	1			0.00000		1	1	0.0033	1	2	0.1422
Ngoma/Kobule	A	1	1	2			0.00000		1	1	0.0124	1	1	0.1322
Mendu	B	1	0	4			0.00000		1	1	0.0038	1	1	0.0530
Mendwana	A	1	0	1			0.00000		1	1	0.0321	1	1	1.2100
Mbashe	B	2	0	1			0.00000		1	1	0.0026	2	2	0.8317
Ku-Mpenzu	B	1	1	3			0.00000		1	1	0.0164	1	1	0.0615
Ku-Bhula/Mbhanyana	A	1	1	2			0.00000		1	1	0.0105	1	1	0.2159