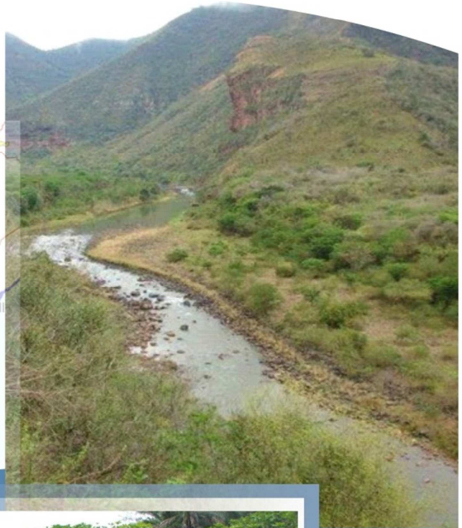
REPORT NO: RDM/WMA11/00/CON/CLA/0614

CLASSIFICATION OF WATER RESOURCES AND DETERMINATION OF THE COMPREHENSIVE RESERVE AND RESOURCE QUALITY OBJECTIVES IN THE MVOTI TO UMZIMKULU WATER MANAGEMENT AREA

PROJECT NUMBER: WP 10679

VOLUME 2C: SUPPORTING INFORMATION ON THE DETERMINATION OF WATER RESOURCE CLASSES -MHLALI (U30E) ESTUARY EWR AND ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS



DECEMBER 2014

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

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CLASSIFICATION OF WATER RESOURCES AND DETERMINATION OF THE COMPREHENSIVE RESERVE AND RESOURCE QUALITY OBJECTIVES IN THE MVOTI TO UMZIMKULU WATER MANAGEMENT AREA

VOLUME 2C: SUPPORTING INFORMATION ON THE DETERMINATION OF WATER RESOURCE CLASSES – MHLALI (U30E) ESTUARY EWR AND ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

Report Number: RDM/WMA11/00/CON/CLA/0614

APRIL 2015

REFERENCE

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Department of Water and Sanitation, South Africa, April 2015. Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: Volume 2c: Supporting Information on the Determination of Water Resource Classes –Mhlali (U30E) Estuary EWR and Ecological Consequences of Operational Scenarios Prepared by: CSIR for Rivers for Africa eFlows Consulting PTY Ltd. DWA Report: RDM/WMA11/00/CON/CLA/0614.

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2	Report Number: RDM/WMA11/00/CON/CLA/0113	Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: **Status Quo assessment, IUA delineation and Biophysical Node identification**
3	Report Number: RDM/WMA11/00/CON/CLA/0213	Classification of Water Resources and Determination of the Comprehensive Reserve and Resource Quality Objectives in the Mvoti to Umzimkulu Water Management Area: **River Resource Units and EWR sites**
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DEPARTMENT OF WATER AFFAIRS AND SANITATION
CHIEF DIRECTORATE: WATER ECOSYSTEMS

CLASSIFICATION OF WATER RESOURCES AND DETERMINATION OF THE COMPREHENSIVE RESERVE AND RESOURCE QUALITY OBJECTIVES IN THE MVOTI TO UMZIMKULU WATER MANAGEMENT AREA

VOLUME 2C: SUPPORTING INFORMATION ON THE DETERMINATION OF WATER RESOURCE CLASSES –MHLALI (U30E) ESTUARY EWR AND ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

Approved for RFA by:

…………………………………….. **……………………………………..**

Delana Louw Date
Project Manager

DEPARTMENT OF WATER AND SANITATION (DWS)
Approved for DWS by:

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Chief Director: Water Ecosystems Date

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REPORT SCHEDULE

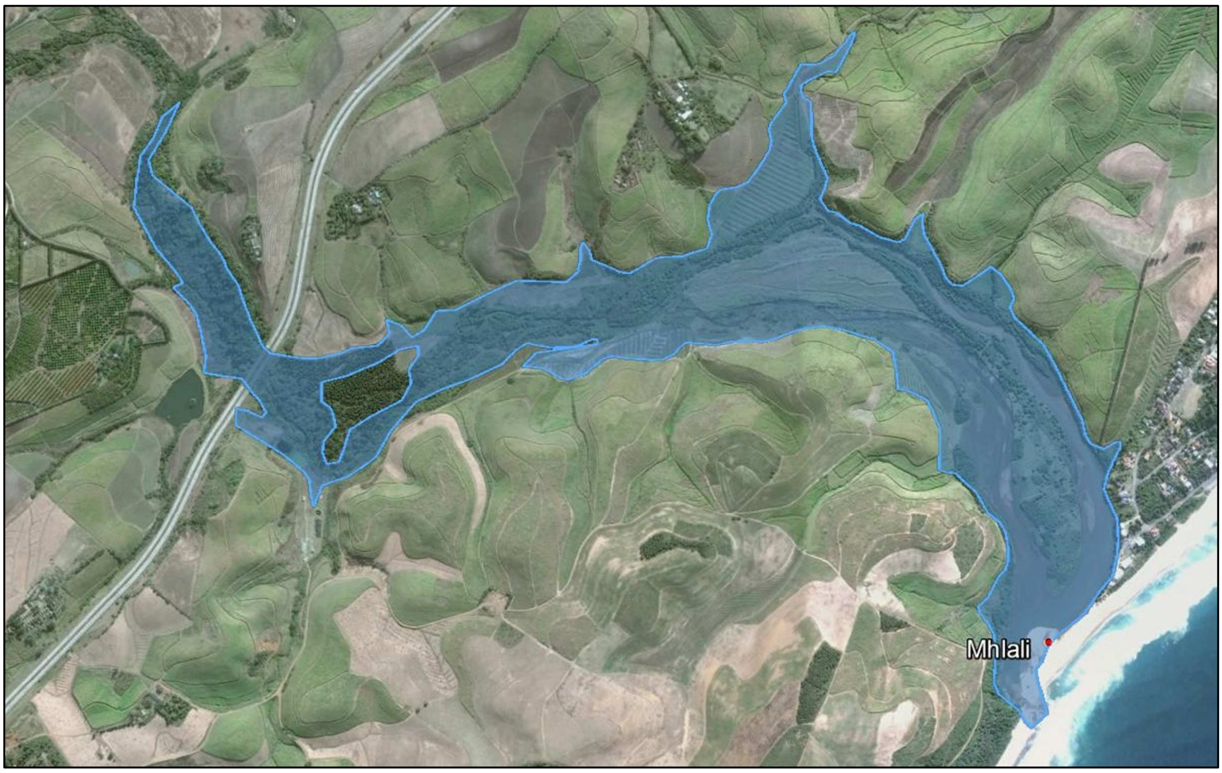
Version	Date
First draft	December 2014
Second draft	April 2015
Final	September 2015

EXECUTIVE SUMMARY

STUDY AREA

The mouth of the Mhlali River is approximately 68 km north of Durban. The Mhlali Estuary is classified as a *"Temporarily open/closed"* type estuary as it mouth closes from time to time depending on river inflow (Whitfield 1992). For the purposes of this Ecological Water Requirement (EWR) study, the geographical boundaries of the estuary are defined as follows:

Downstream boundary:	Estuary mouth 29°27'41.37"S 31°16'37.04"E
Upstream boundary:	29°26'40.83"S 31°14'58.85"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank



Geographical boundaries of the Mhlali Estuary based on the Estuary Functional Zone

PRESENT ECOLOGICAL STATE

The scores allocated to the various abiotic and biotic health parameters for the Mhlali Estuary and the overall Present Ecological Status (PES) for the system are calculated by Estuarine Health Index (EHI) (see below). The Mhlali Estuary present state was estimated to be 57 (i.e. 57% similar to natural condition), which translates into a PES of Category D. The PES is mostly attributed to the following factors:

- Increase in nutrient input as a result of Waste Water Treatment Works (WWTW) and poor catchments practises, causing excessive growth of reed and aquatic invasive plants in intertidal and subtidal habitats.
- Significant loss of habitat in the Estuary Functional Zone as a result of sugar cane farming; and
- Artificial breaching of the estuary mouth at lower than natural levels.

The Mhlali Estuary is on a steep trajectory downwards as significant further deterioration in estuary health is anticipated once the Shakaskraal WWTW runs at full capacity and the Tinley Manor WWTW (planned for 2015) discharges into the estuary. See Chapter 7 for more detail.

Estuarine Health Score for the Mhlali Estuary

Variable	Estuarine health score		
	Overall	**Excluding flow related pressures**	**Conf***
Hydrology	62	62	Low
Hydrodynamics and mouth condition	80	80	Low
Water quality	62.2	62.2	Low
Physical habitat alteration	60	98	Low
Habitat health score	**66**	**76**	
Microalgae	50	100	Low
Macrophytes	51	90	Low/medium
Invertebrates	40	88	Low
Fish	60	92	Low
Birds	40	92	Low
Biotic health score	**48**	**92**	
ESTUARY HEALTH SCORE	**57**	**84**	
PRESENT ECOLOGICAL STATE (PES)	**D**	**B**	
OVERALL CONFIDENCE	**Low**	**Low**	

* Confidence

RELATIVE CONTRIBUTION OF FLOW AND NON-FLOW RELATED IMPACTS ON HEALTH

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 84, which would raise the PES to a B Category. This suggests that non-flow impacts have played a significant role in the degradation of the estuary to a D, but that flow-related impacts are also one of the main causes of degradation. **The highest priority is to address is the quality of influent water**. Of the non-flow-related impacts, water quality problem as a result of the high nutrient load associated with the WWTWs and poor catchments practises was found to be the most important factor that influenced the health of the system. The excess nutrients in the inflowing water increased plant growth and loss of open intertidal and riparian habitat (e.g. sand and mudbanks that use to be important bird habitats). Low oxygen events that is associated with high nutrient and organic inputs reduce invertebrate abundance to 40% of Reference Conditions and prevents the system from functioning as an effective fish nursery. Thus in turn, reducing food availability to birds.

Another key non-flow related pressure was the **loss of riparian area due to sugarcane farming** in the Estuary Functional Zone, causing loss in estuary habitat and loss of a buffer area against human disturbance.

ESTUARY IMPORTANCE

The Estuary Importance Score (EIS) takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (see below). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. The scores have been determined for all

South African estuaries, apart from functional importance, which is scored by the specialists in the workshop. Historically the Mhlali supported a very good diversity of fish species. This is reduced under present day conditions. Although the Mhlali is a relatively small system located on a section of coast with a relative abundance of estuaries, the nature of the system (bathymetry, mouth dynamics and resulting salinity regimes over different states) renders its nursery potential good. From a functional importance perspective, it can be considered of medium nursery value for estuarine associated fish species in the region.

The EIS for the Mhlali Estuary, is estimated to be 63, i.e., the estuary is rated as “Important”.

Estuarine Importance scores for the Mhlali Estuary

Criterion	Weight	Score
Estuary Size	15	60
Zonal Rarity Type	10	10
Habitat Diversity	25	90
Biodiversity Importance	25	80
Functional Importance	25	70
Weighted Estuary Importance Score		**63**

RECOMMENDED ECOLOGICAL CATEGORY

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary.

Estuary protection status and importance, and the basis for assigning a REC

Protection status and importance	REC	Policy basis
Protected area	**A or BAS***	**Protected and desired protected areas should be restored to and maintained in the best possible state of health.**
Desired Protected Area		
Highly important	**PES + 1, min B**	**Highly important estuaries should be in an A or B Category.**
Important	PES + 1, min C	Important estuaries should be in an A, B or C Category.
Of low to average importance	PES, min D	Estuaries to remain in a D Category.

* Best Attainable State

The PES for the Mhlali Estuary is a D, with a sharp downwards trajectory. The Mhlali Estuary is rated as “Important” from a biodiversity perspective and should therefore be in a C Category.

In addition, the system also forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets as defined in the National Estuaries Biodiversity Plan and the National Biodiversity Assessment (NBA) 2011. The NBA 2011 recommends that the minimum Category for the Mhlali be a B, that the system be a granted partial no-take protection, and that 50% of the estuary margin be undeveloped.

Based on the above and the reversibility of impacts, the Recommended Ecological Category for the Mhlali Estuary is a B Category.

ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

The proposed scenarios for the Mhlali estuary are summarised below:

Summary of flow scenarios

Scenarios	Description	MAR[1] (10^6 m^3)	% Remaining
Reference	Natural Flow	56.31	100
Present	Present day (+WWTW: Shakaskraal (0.8 Ml/d))	51.55	92
Scenario 1	Present, but without input from WWTW	51.26	91
Scenario 2	Present day (WWTW: Shakaskraal (1.6 Ml/d) + Tinley Manor (6 Ml/d))	54.03	96
Scenario 3	Abstraction + WWTW (WWTW: Shakaskraal (1.6 Ml/d) + Tinley Manor (6 Ml/d))	46.94	83
Scenario 4	WWTW at full capacity (1.6 Ml/d + 18Ml/d)	58.41	104
Scenario 5	Present minus WWTW, including remedial actions: rehab of flood plain, removal of old weir, no artificial breaching, no sugar cane farming in the Estuary Functional zone	51.26	91

1 Mean Annual Runoff

The estuary is currently in a D Category. An evaluation of the four scenarios provided the following insights:

- Under Scenario 1 the Mhlali Estuary will improve slightly in health to a C Category, as a result of improved water quality. This scenario represents the recent past before the various current and planned WWTW came on line.
- While, under Scenario 2 the estuary will deteriorate further in health by about 3% as a result of deteriorating water quality conditions.
- Under Scenario 3 the estuary will deteriorate significantly, by about 15 % as a result of severely deteriorating water quality conditions and reduce in river flow. Under this scenario treated effluent become the dominant source of freshwater to the system under low to average inflow conditions.
- Under Scenario 4 the estuary will also deteriorate significantly, by about 14%, as a result of severely deteriorating water quality conditions and an increase in freshwater inflow associated with the maximum discharges to the system.

None of the scenarios (1 to 4) achieved the REC for the Mhlali Estuary. Therefore an additional scenario, Scenario 5, was conducted. Scenario 5 is based on the freshwater inflow simulated for Scenario 1 in conjunction with the following management interventions:

- Reduce the nutrient input from the WWTW and catchment to control growth of reeds and aquatic invasive plants;
- Remove the sugarcane from the Estuary Functional Zone (below 5 m contour) to allow for a buffer against human disturbance and the development of a transitional vegetation ecotone between estuarine and terrestrial ecosystems;
- Removal of vegetation from main river channel in upper reaches, including invasive aliens plants and strands of eucalypts (using CoastCare programme);
- Ensure that the estuary is not artificial breached; and
- Remove the old saltwater weir from middle reaches of system.

Scenario 5 achieved the REC of a B.

EHI score and corresponding Ecological Categories under the different runoff scenarios

Variable	Weight	Scenario Group						
		Present	1	2	3	4	5	Conf
Hydrology	25	62	72	97	65	73	72	Low
Hydrodynamics and mouth condition	25	80	80	87	70	93	80	Low
Water quality	25	62.2	74	49	42	47	74	Low
Physical habitat alteration	25	60	60	61	59	63	73	Low
Habitat health score		**66**	**71**	**74**	**59**	**55**	**75**	Low
Microalgae	20	50	55	20	20	20	70	Low
Macrophytes	20	51	53	49	40	48	70	Low
Invertebrates	20	40	45	30	20	30	80	Low
Fish	20	60	60	40	30	30	70	Low
Birds	20	40	45	30	20	25	60	Low
BIOTIC HEALTH SCORE		**48**	**52**	**34**	**26**	**31**	**70**	**Low**
ESTUARY HEALTH SCORE		**57**	**62**	**54**	**42**	**43**	**72**	**Low**
ECOLOGICAL STATUS		**D**	**C**	**D**	**D**	**D**	**B**	

OVERALL CONFIDENCE

The confidence levels of the assessment were low for most of the abiotic and biotic components. The overall confidence of the study was therefore LOW.

In terms of the abiotic components, it was not possible to define and characterise the three abiotic states for this system with high/medium confidence, mainly because long-term continuous mouth state/water level data and river inflow records were not available. Water quality data was also not available for river inflow near the head of the estuary. Very limited information was available on the biotic components of the system.

However, while the study may be of low confidence regarding key aspects driving component scores (e.g. the precise river flow rate at which the Mhlali Estuary mouth closes, the absolute number of fish species occurring in the system), the study team were of **HIGH confidence that the current nutrient levels in the inflowing water, far exceed the assimilative capacity of this small estuary (nutrient levels were estimated from general effluent standard concentrations and recorded waste water inflow).**

It can also be stated with **HIGH confidence that the system is on a DOWNWARDS trajectory of change**. Similarly, while the study team have of low confidence in the absolute PES score, they are of **HIGH confidence that the proposed future WWTW discharge scenarios will further degrade the system significantly into a lower Category D**. It is even possible that the system may even degrade to an E Category.

ECOLOGICAL FLOW REQUIREMENTS

The **'recommended Ecological Flow Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the Recommended Ecological Category (REC). Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. Based on this assessment, we have ascertained that the REC for the Mhlali Estuary is a Category B.

The flow requirements for the estuary are based on Scenario 5 (similar to Scenario 1) and are summarised below:

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	12.92	17.08	16.38	17.46	19.97	26.62	12.01	5.80	20.45	6.22	1.01	28.77
99	12.45	13.49	14.03	15.76	17.38	23.93	11.05	5.64	5.21	1.81	0.80	7.37
90	1.99	6.31	5.59	6.59	11.11	7.91	4.59	2.15	0.53	0.37	0.38	0.50
80	1.05	3.19	3.69	4.81	7.72	5.19	2.60	0.68	0.29	0.23	0.18	0.30
70	0.52	2.19	2.40	3.44	4.12	3.75	1.64	0.42	0.19	0.07	0.10	0.23
60	0.42	1.01	1.65	2.59	2.78	2.41	0.86	0.30	0.11	0.06	0.08	0.15
50	0.32	0.63	1.06	1.73	2.10	1.53	0.59	0.21	0.07	0.06	0.06	0.08
40	0.24	0.44	0.62	0.91	1.25	0.91	0.42	0.15	0.06	0.06	0.05	0.07
30	0.15	0.34	0.45	0.56	0.64	0.55	0.31	0.11	0.06	0.05	0.04	0.05
20	0.08	0.24	0.33	0.39	0.50	0.33	0.21	0.08	0.05	0.04	0.04	0.05
10	0.06	0.10	0.14	0.26	0.24	0.17	0.08	0.07	0.04	0.04	0.04	0.04
1	0.04	0.05	0.06	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03
0.1	0.04	0.04	0.05	0.06	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02

The following management interventions are required to attain a B Category:

- Reduce the nutrient input from the WWTW and catchment to control growth of reeds and aquatic invasive plants.
- Remove the sugarcane from the Estuary Functional Zone (below 5 m contour) to allow for a buffer against human disturbance and the development of a transitional vegetation ecotone between estuarine and terrestrial ecosystems.
- Removal of vegetation from main river channel in upper reaches, including invasive aliens plants and strands of eucalypts (using CoastCare programme).
- Ensure that the estuary is not artificial breached; and
- Remove the old saltwater weir from middle reaches of system.

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ACRONYMS AND ABBREVIATIONS

BAS	Best Attainable State
CD: WE	Chief Directorate: Water Ecosystems
CSIR	Centre of Scientific and Industrial Research
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphate
DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EFZ	Estuary Functional Zone
EHI	Estuarine Health Index
EIA	Environmental Impact Assessment
EIS	Estuarine Importance Score
EWR	Ecological Water Requirement
H	High
HPLC	High Performance Liquid Chromatography
L	Low
M	Medium
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MPB	microphytobenthos
MSL	Mean Sea Level
NBA	National Biodiversity Assessment
NWA	National Water Act (1998)
PES	Present Ecological State
PSD	Particle size Distribution
PSU	Practical Salinity Units
REC	Recommended Ecological Category
REI	River Estuary Interface
RQO	Resource Quality Objective
WMA	Water Management Area
WWTW	Waste Water Treatment Works

1 INTRODUCTION

1.1 BACKGROUND

There is an urgency to ensure that water resources in the Mvoti to Umzimkulu Water Management Area (WMA) are able to sustain their level of uses and be maintained at their desired states. The determination of the Water Resource Classes of the significant water resources in Mvoti to Umzimkulu WMA will ensure that the desired condition of the water resources, and conversely, the degree to which they can be utilised is maintained and adequately managed within the economic, social and ecological goals of the water users (DWA, 2011). The Chief Directorate: Water Ecosystems (CD:WE) of the Department of Water and Sanitation (DWS) initiated a study during 2012 for the provision of professional services to undertake the Comprehensive Reserve, classify all significant water resources and determine the Resource Quality Objectives (RQOs) in the Mvoti to Umzimkulu WMA.

The objective of this task was to describe and document the EWR and scenario consequences for the Mhlali estuary. The output of this task will serve as input to the RQO, implementation, monitoring and Legal Notice.

1.2 INTEGRATED STEPS APPLIED IN THIS STUDY

The integrated steps for the National Water Classification System, the Reserve and RQOs (DWA, 2012) are supplied in Table 1.1.

Table 1.1 Integrated study steps

Step	Description
1	Delineate the units of analysis and Resource Units, and describe the status quo of the water resource(s) (completed).
2	Initiation of stakeholder process and catchment visioning (on-going).
3	Quantify the Ecological Water Requirements and changes in non-water quality ecosystem.
4	**Identification and evaluate scenarios within the Integrated Water Resource Management process.**
5	**Evaluate the scenarios with stakeholders and determine Water Resource Classes.**
6	Develop draft RQOs and numerical limits.
7	Gazette and implement the class configuration and RQOs.

This task forms ***part*** of Step 3 and 4, i.e. the determination of EWRs and consequences of scenarios.

1.3 ECOLOGICAL WATER REQUIREMENT METHOD FOR ESTUARIES

Methods to determine the environmental flow requirement of estuaries were established soon after the promulgation of the National Water Act (NWA) in 1998. The so-called “Preliminary Reserve Method” involves setting a Recommended Ecological Category (REC) (i.e. desired state), recommended Ecological Reserve (i.e. flow allocation to achieve the desired state) and recommended RQOs for a resource on the basis of its present health status and its ecological importance. (see Volume 2a for a more detailed description of the method).

1.4 DEFINITION OF CONFIDENCE LEVELS

The level of available historical data in combination with the level of effort expended during the assessment determines the level of confidence of the study. Three levels of study have been recognised in the past in terms of the effort expended during the assessment – rapid, intermediate and comprehensive. In this study, effort lay somewhere between intermediate and comprehensive study, in that some field data collection was carried out, but the long-term river inflow data needed to bench mark the abiotic processes were not available. Nevertheless, as a result of the availability of historical data and the relative uncomplicated nature of the estuarine processes meant that we expected the confidence of the study to be low. This is a situation that can only be remedied with some comprehensive and long term data collection on the system. Criteria for the confidence limits attached to statements in this study are:

Confidence level	Situation
Low	Limited data available
Medium	Reasonable data available
High	Good data available

1.5 ASSUMPTIONS AND LIMITATIONS FOR THIS STUDY

The accuracy and confidence of an Estuarine Ecological Water Requirements (EWR) study is strongly dependent on the quality of the hydrology. The overall confidence in the hydrology supplied to the estuarine study team is of a medium level, with a particular concern regarding the accuracy of the simulated base flows during the low flow period into the estuary.

1.6 STRUCTURE OF THIS REPORT

The report is structured as follows:

Chapter 1: Introduction
An overview of EWR methods and confidence of the study is provided.

Chapter 2: Background Information
This Chapter summarises important background information related to the hydrological characteristics, catchment characteristics and land-use, as well as human pressures affecting the estuary.

Chapter 3: Delineation of Estuary
The geographical boundaries of the study area, as well as the zoning and typical abiotic states adopted for this estuary, are defined.

Chapter 4: Ecological Baseline and Health Assessment
This chapter provides a baseline ecological and health assessment of the estuary. It describes each of the abiotic and biotic aspects of the estuary - from hydrology to birds – describing an understanding of the present situation and estimation of the reference condition. The health state of each component is determined using the Estuarine Health Index (EHI).

Chapter 5: Present Ecological Status
Describes the overall state of health (or present ecological status) of the estuary. It also summarises the overall confidence of the study and the degree to which non-flow factors have contributed to the degradation of the system.

Chapter 6: The Recommended Ecological Category

The EHI score combined with the Estuarine Importance Score (EIS) for the system determines the Recommended Ecological Category, which is provided in this chapter.

Chapter 7: Consequences of Alternative Scenarios

This chapter describes the ecological consequences of various future flow scenarios, and determines the Ecological Category for each of these using the EHI.

Chapter 8: Conclusions and Recommendations

Recommendations on the ecological water requirements for the estuary are made, including the recommended resource quality objectives (ecological specifications). Finally, monitoring requirements to improve the confidence of the EWR assessment are recommended.

Chapter 9: References

Report references are listed.

Chapter 10: Appendix A: Macrophytes of the Mhlali Estuary

A description of the dominant macrophytes and their distribution along the length of the Mhlali Estuary is provided.

Chapter 11: Appendix B: Historic records of fishes sampled in Mhlali Estuary

A list of fish species are provided based on historic records.

Chapter 12: Appendix C: Report Comments

Comments from reviewers are listed.

2 BACKGROUND INFORMATION

2.1 HYDROLOGICAL CHARACTERISTICS

The Mhlali catchment has been estimated at 256 km^2, 295 km^2 and 331 km^2 in Begg (1978). Begg (1978) estimates the river length to be between 38 km and 55 km. According to Begg (1978) annual run-off varies between 49.85 million m^3 to 59.76 million m^3.

This study estimates the Mean Annual Runoff (MAR) of 56.31 million m^3 and 51.92 million m^3, for the Reference Condition and Present State respectively.

2.2 CATCHMENT CHARACTERISTICS AND LAND-USE

2.2.1 Land-use

The land in the area surrounding the estuary is used predominantly for growing sugar cane (Begg 1978). A holiday resort has been developed on the north bank adjacent to the mouth. The south bank has been largely untouched. The central island and floodplain areas are planted with sugar cane.

To provide a broad over view of the land-use in the Mhlali Catchment (Figure 2.1) indicate that:

- About 51% of the catchment is cultivated, permanent, commercial sugarcane.
- About 28% of the catchment is thicket / bushland, with an additional 4% degraded thicket / bushland.
- About 9% of the catchment is natural grasslands, with about 3% classified as degraded grassland.
- Cultivated temporarily subsistence dryland were estimated at 2%.
- Forest Plantations: Eucalyptus spp <1%, Pine spp <1, *Aciacia* spp <1.
- Formally urban built up areas are estimated at <1%.

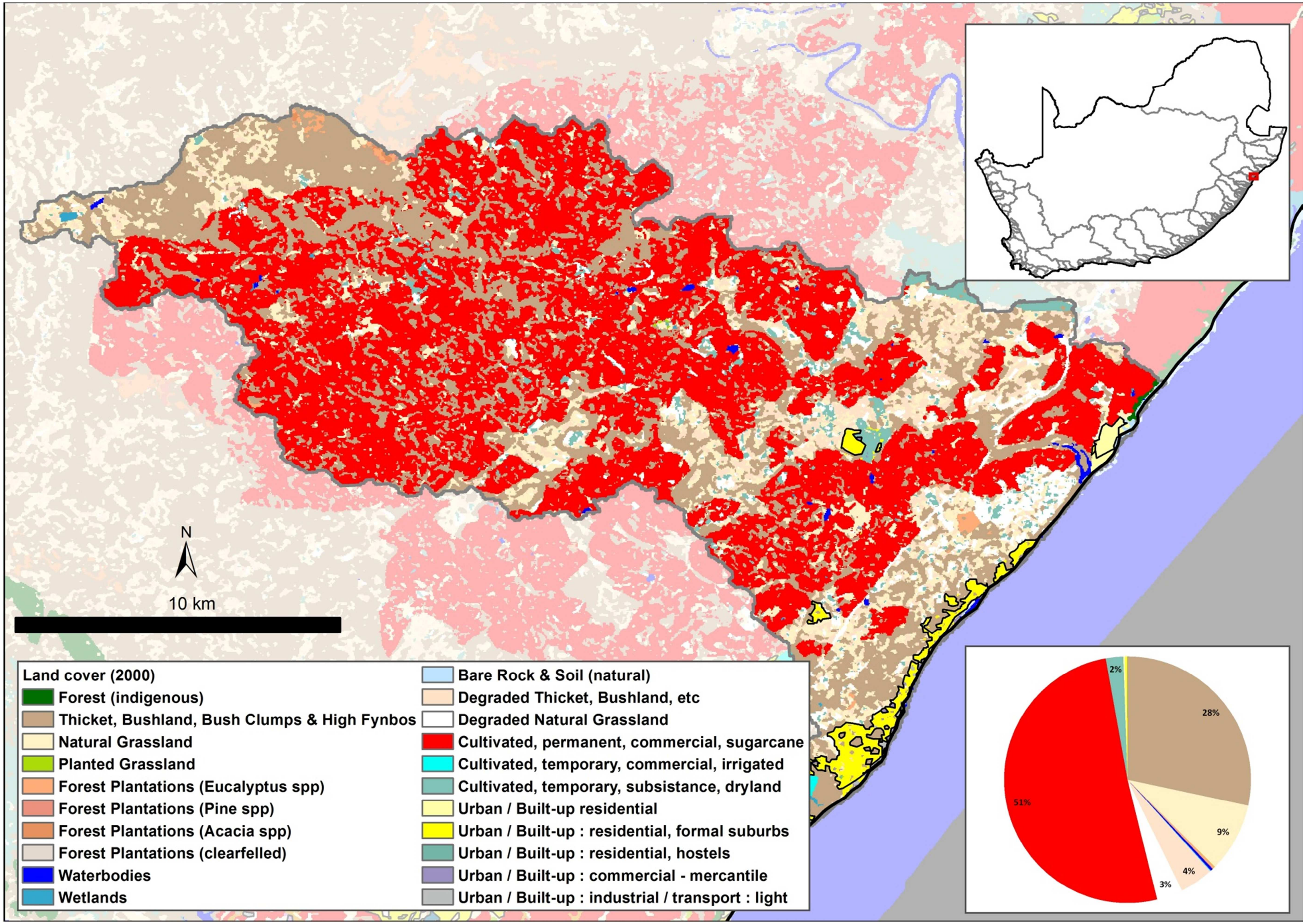


Figure 2.1 Overview of land-use in the Mhlali catchment

2.3 HUMAN ACTIVITIES AFFECTING THE ESTUARY (PRESSURES)

Table 2.1 and 2.2 provide a summary of the flow and non-flow related pressures contributing to the Present State of the Mhlali Estuary.

Table 2.1 Pressures related to flow modification

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

Table 2.2 Pressures, other than modification of river inflow presently affecting estuary

Activity	Present	Description of Impact
Agricultural and pastoral run-off containing fertilisers, pesticides and herbicides	✓	Extensive sugar cane in the floodplain areas
Shakaskraal Waste Water Treatment Works (WWTW) (approx. 3.5 km upstream of estuary) (currently 0.8 with a a license agreement to 1.28 Ml/day)	✓	Municipal wastewater, potentially high nutrients and organic matter
Tinley Manor WWTW (discharging in Zone C) (6.Ml/day from next year, with a license agreement to 18 Ml/d)	✓	Municipal wastewater, potentially high nutrients and organic matter
Bridge(s)	✓	The N2 national road crosses the river in Zone C about 3.6 km from the mouth (Figure 3.1)
Artificial breaching	✓	Yes, but breaching level unknown
Bank stabilisation and destabilisation		
Low-lying developments	✓	Sugar cane fields
Migration barrier in river	✓	Salt barrage
Recreational fishing	✓	Limited. Mostly targets the beach
Subsistence fishing (e.g. gillnet fishery)		
Illegal fishing (Poaching)		
Bait collection		
Development in the Estuary Functional Zone (EFZ)	✓	Extensive sugar cane cultivation of surrounding land
Translocated or alien fauna and flora		
Recreational disturbance of waterbirds	✓	Limited activities near the mouth

3 DELINEATION OF ESTUARY

3.1 GEOGRAPHICAL BOUNDARIES

The mouth of the Mhlali River is approximately 68 km north of Durban (Figure 3.1). The Mhlali Estuary is classified as a *"Temporarily open/closed"* type estuary as it mouth closes from time to time depending on river inflow (Whitfield 1992).

For the purposes of this EWR study, the geographical boundaries of the estuary are defined as follows (Figure 3.1):

Downstream boundary:	Estuary mouth: 29°27'41.37"S 31°16'37.04"E
Upstream boundary:	29°26'40.83"S 31°14'58.85"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

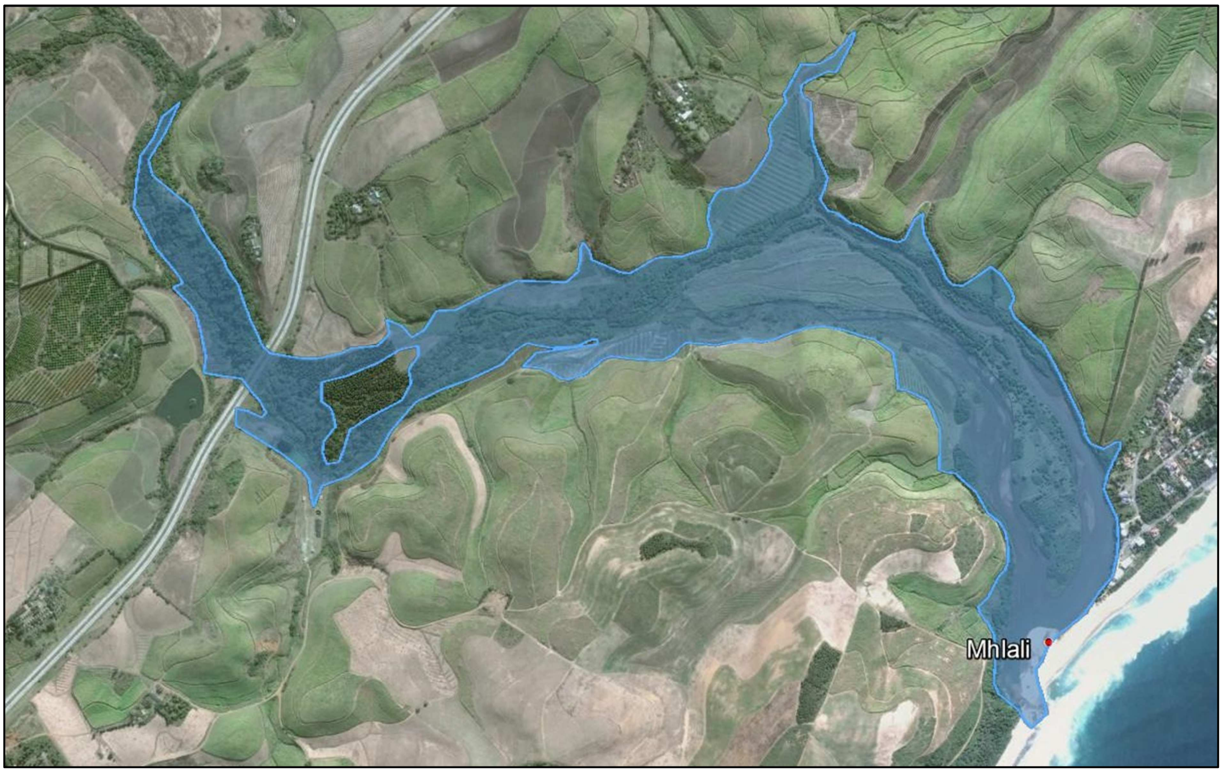


Figure 3.1 Geographical boundaries of the Mhlali Estuary based on the EFZ

3.2 ZONATION OF THE MHLALI ESTUARY

For the purposes of this study, the Mhlali Estuary is sub-divided into three distinct zones, primarily based on bathymetry (Figure 3.2):

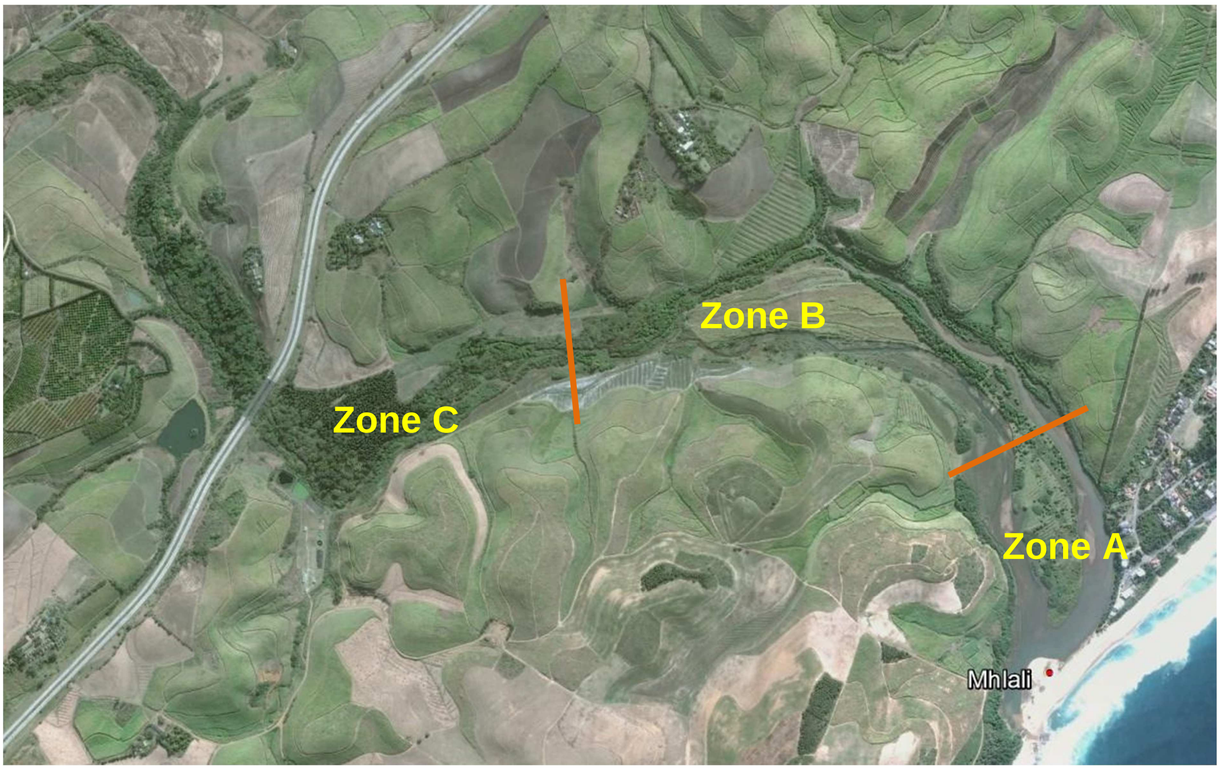


Figure 3.2 Zonation of the Mhlali Estuary

Table 3.1 below list some of the key features of the Mhlali Estuary zonation that is used to determine the weighting of scores.

Table 3.1 Key features of the Mhlali Estuary zonation

	Zone A: Lower	Zone B: Middle	Zone C: Upper
Area (ha)	5.2	2.2	2.9
Approximate % area	50%	20%	30%
Maximum depth (to MSL)	-0.5	-0.25 to 0.5	-1.0 in pools

3.3 TYPICAL ABIOTIC STATES

Based on available literature, a number of characteristic ‘states’ can be identified for the Mhlali Estuary, related to mouth condition, tidal exchange, salinity distribution and water quality. These are primarily determined by river inflow patterns, water levels and duration since last breaching. The different states are listed in Table 3.2.

Table 3.2 Summary of the abiotic states that can occur in the Mhlali Estuary

State	Flow range (m^3/s)	Description
State 1	<0.5	Closed, weeks to months
State 2	0.5 - 3	Open, limited marine
State 3	>3	Open, fresh

The transition between the different states will not be instantaneous, but will take place gradually.

To assess the occurrence and duration of the different abiotic states selected for the estuary during the different scenarios, a number of techniques were used:

- Colour coding (indicated above) are used to visually highlight the occurrence of the various abiotic states between different scenarios.
- Summary tables of the occurrence of different flows at increments of the 10%ile are listed separately to provide a quick comprehensive overview.

A summary of the typical physical and water quality characteristics of different abiotic states in the Mhlali Estuary is provided Chapter 4.

4 ECOLOGICAL BASELINE AND HEALTH ASSESSMENT

4.1 HYDROLOGY

4.1.1 Baseline description

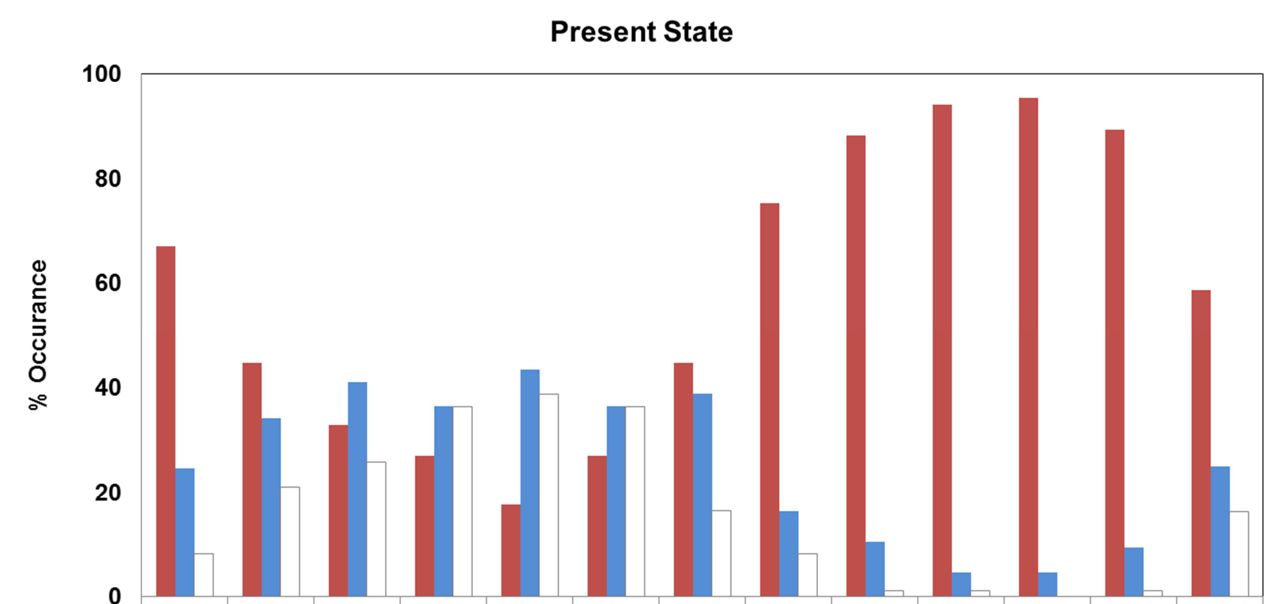
According to the hydrological data provided for this study, the present day MAR into the Mhlali Estuary is 51.55 million m^3. This is a decrease of 8% compared to the natural MAR of 56.31 million m^3. The occurrences of flow distributions (mean monthly flows in m^3/s) for the Present State and Reference Condition of the Mhlali Estuary, derived from the 85-year simulated data set, are provided in Table 4.1 and Table 4.2. A graphic representation of the occurrence of the various abiotic states is presented in Figure 4.1 and Figure 4.2. The full 85-year series of simulated monthly runoff data for the Present State and Reference Condition is provided in Tables 4.3 and 4.4.

Table 4.1 A summary of the monthly flow (in m^3/s) distribution under the Present State

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	12.93	17.09	16.39	17.47	19.98	26.63	12.02	5.81	20.45	6.22	1.01	28.78
99	12.46	13.50	14.04	15.77	17.39	23.94	11.06	5.64	5.22	1.81	0.81	7.37
90	2.00	6.32	5.60	6.60	11.12	7.92	4.60	2.15	0.54	0.38	0.38	0.50
80	1.06	3.20	3.69	4.82	7.72	5.20	2.61	0.68	0.30	0.24	0.19	0.31
70	0.52	2.20	2.40	3.45	4.12	3.76	1.65	0.43	0.20	0.08	0.11	0.24
60	0.42	1.01	1.66	2.60	2.78	2.41	0.86	0.30	0.11	0.07	0.08	0.16
50	0.32	0.63	1.07	1.74	2.11	1.53	0.60	0.22	0.08	0.07	0.07	0.09
40	0.24	0.44	0.63	0.92	1.26	0.92	0.43	0.16	0.07	0.06	0.06	0.08
30	0.15	0.35	0.46	0.56	0.65	0.55	0.32	0.12	0.07	0.06	0.05	0.06
20	0.09	0.25	0.34	0.40	0.51	0.34	0.22	0.09	0.06	0.05	0.05	0.05
10	0.07	0.11	0.15	0.26	0.25	0.18	0.09	0.08	0.05	0.05	0.05	0.05
1	0.05	0.05	0.07	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.04	0.04
0.1	0.05	0.05	0.06	0.07	0.07	0.05	0.05	0.04	0.03	0.02	0.02	0.03

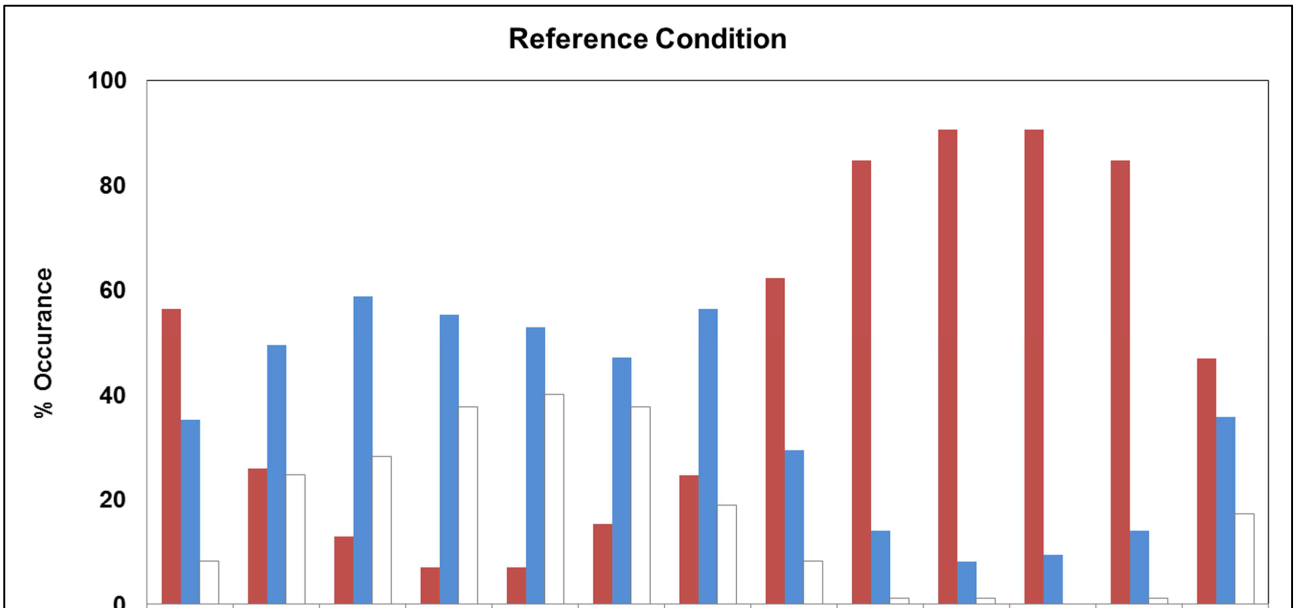
Table 4.2 A summary of the monthly flow (in m^3/s) distribution under the Reference State

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	12.96	17.13	16.44	17.53	20.01	26.65	12.04	5.83	20.54	6.46	1.05	28.87
99	12.58	13.54	14.09	15.82	17.42	23.96	11.09	5.66	5.46	1.88	0.92	7.41
90	2.06	6.35	5.71	6.64	11.15	7.93	4.74	2.40	0.63	0.48	0.49	0.66
80	1.14	3.30	3.87	5.07	7.75	5.41	2.79	0.80	0.47	0.37	0.27	0.41
70	0.68	2.28	2.66	3.55	4.23	3.90	1.92	0.59	0.33	0.23	0.25	0.36
60	0.54	1.16	1.90	2.90	3.02	2.80	1.01	0.49	0.27	0.19	0.20	0.29
50	0.46	0.79	1.38	2.03	2.36	1.75	0.81	0.41	0.23	0.16	0.17	0.24
40	0.36	0.68	0.92	1.22	1.65	1.20	0.64	0.36	0.21	0.14	0.15	0.21
30	0.31	0.58	0.74	0.84	0.95	0.84	0.53	0.31	0.17	0.13	0.12	0.18
20	0.24	0.42	0.57	0.68	0.77	0.61	0.46	0.25	0.14	0.12	0.11	0.14
10	0.19	0.31	0.43	0.54	0.59	0.44	0.31	0.19	0.12	0.09	0.09	0.11
1	0.13	0.14	0.21	0.31	0.22	0.20	0.14	0.10	0.05	0.05	0.06	0.08
0.1	0.11	0.13	0.17	0.19	0.18	0.12	0.09	0.05	0.04	0.03	0.03	0.04



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	67	45	33	27	18	27	45	75	88	94	95	89	59
State 2	25	34	41	36	44	36	39	16	11	5	5	9	25
State 3	8	21	26	36	39	36	16	8	1	1	0	1	16

Figure 4.1 Graphic presentation of the occurrence of the various abiotic states under the Present State



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	56	26	13	7	7	15	25	62	85	91	91	85	47
State 2	35	49	59	55	53	47	56	29	14	8	9	14	36
State 3	8	25	28	38	40	38	19	8	1	1	0	1	17

Figure 4.2 Graphic presentation of the occurrence of the various abiotic states under the Reference Condition

Table 4.3 Simulated monthly flows (in m^3/s) to the Mhlali Estuary for the Present State

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.71	0.68	1.82	0.94	1.64	0.80	0.39	0.15	0.06	0.04	0.04	0.05
1921	0.52	17.49	12.97	2.49	0.36	0.36	0.21	0.38	0.32	0.08	0.16	0.08
1922	5.71	6.05	1.31	4.40	3.22	0.99	0.42	0.09	0.06	0.05	0.05	0.05
1923	0.05	0.05	0.18	1.03	1.53	0.51	0.15	0.07	0.05	0.04	0.04	0.17
1924	0.22	0.64	1.70	2.74	1.72	26.93	9.35	0.30	0.07	0.06	0.06	0.24
1925	0.50	0.35	0.22	0.11	0.20	0.55	0.25	0.08	0.08	0.06	0.05	0.05
1926	0.28	0.39	0.28	0.22	2.70	16.66	5.45	0.10	0.06	0.05	0.06	0.06
1927	0.07	0.08	0.32	2.29	1.45	0.53	0.27	0.08	0.05	0.04	0.04	0.05
1928	0.07	0.25	0.41	0.64	0.63	8.07	2.89	0.14	0.49	0.88	0.44	1.47
1929	4.32	2.10	0.45	1.17	0.55	0.45	0.39	0.14	0.07	0.06	0.20	0.45
1930	0.47	0.49	0.56	3.31	1.23	0.35	0.29	0.08	0.05	0.17	0.09	0.07
1931	0.07	0.07	0.11	0.51	11.81	7.22	1.51	0.43	0.11	0.06	0.05	0.05
1932	0.19	0.34	0.52	0.44	0.23	0.17	0.14	0.07	0.06	0.05	0.05	0.05
1933	0.05	0.41	3.17	6.04	2.33	2.04	3.12	1.37	0.32	0.32	0.33	0.12
1934	0.09	0.08	0.44	3.27	4.13	2.18	0.66	5.82	22.15	6.71	0.43	0.19
1935	0.10	0.09	0.10	0.41	7.67	6.17	1.50	3.85	1.52	0.10	0.07	0.06
1936	0.17	11.35	3.67	0.26	2.29	0.84	0.56	0.16	0.15	0.07	0.10	0.08
1937	0.08	0.15	6.50	3.12	8.58	2.36	0.51	0.22	0.28	0.46	0.25	0.08
1938	0.38	1.76	1.84	0.92	8.17	6.14	1.54	0.63	0.27	0.20	0.09	0.52
1939	0.71	3.87	3.59	1.07	0.34	0.21	0.16	3.01	1.72	0.34	0.08	0.08
1940	0.15	6.03	4.04	0.91	0.15	0.31	0.84	0.32	0.07	0.06	0.05	0.09
1941	0.12	0.32	0.13	2.55	1.29	4.82	1.86	0.43	0.20	0.07	0.16	0.28
1942	0.66	7.04	11.97	3.56	3.91	5.07	7.72	2.64	0.44	0.59	1.04	0.54
1943	5.88	6.94	1.93	0.27	0.68	4.78	1.91	0.16	0.17	0.07	0.07	0.48
1944	1.15	0.88	0.29	0.21	3.30	12.13	3.91	0.28	0.08	0.07	0.05	0.05
1945	0.06	0.07	0.07	0.37	0.55	1.56	1.51	0.49	0.08	0.06	0.05	0.05
1946	0.06	0.32	0.60	1.74	11.28	3.67	1.55	0.53	0.40	0.17	0.10	0.09
1947	0.10	2.60	1.26	2.85	4.58	4.07	3.36	0.85	0.07	0.06	0.05	0.05
1948	0.38	1.80	0.91	0.52	3.64	1.29	0.76	0.33	0.09	0.07	0.05	0.06
1949	0.42	4.92	7.22	2.53	0.71	0.62	0.32	0.26	0.08	0.06	0.06	0.06
1950	0.06	0.05	0.87	0.82	0.54	3.00	1.22	0.12	0.06	0.06	0.30	0.63
1951	0.68	0.35	2.70	6.19	2.11	0.37	0.73	0.70	0.30	0.09	0.07	0.07
1952	0.07	0.19	0.90	17.66	13.84	2.40	0.22	0.08	0.05	0.05	0.05	0.15
1953	0.27	0.59	3.86	1.70	2.64	1.24	0.40	0.22	0.08	0.07	0.06	0.37
1954	12.98	6.65	0.87	6.01	2.38	4.44	2.07	0.38	0.12	0.07	0.06	0.14
1955	0.32	0.96	0.63	0.13	4.51	8.06	2.68	0.27	0.07	0.07	0.11	0.29
1956	0.28	0.47	13.55	4.78	2.84	2.01	9.88	3.11	0.08	0.07	0.06	0.30
1957	1.75	3.05	1.65	9.92	13.85	3.52	6.37	2.16	0.11	0.07	0.06	0.27
1958	0.22	1.01	1.66	0.86	0.64	0.18	0.09	0.47	0.25	0.07	0.12	0.18
1959	0.56	0.63	0.49	0.33	0.51	1.23	0.91	0.30	0.07	0.06	0.05	0.05
1960	0.15	2.26	6.79	4.26	1.18	0.59	10.86	3.60	0.55	0.24	0.09	0.24
1961	0.42	0.58	0.34	0.46	0.51	1.00	0.57	0.15	0.06	0.05	0.08	0.07
1962	0.11	6.50	2.30	6.88	2.75	4.21	1.73	0.16	0.25	0.46	0.22	0.08
1963	0.19	0.25	0.29	9.39	3.66	0.32	0.33	0.09	0.06	0.06	0.05	0.05
1964	0.32	0.44	0.50	0.49	0.34	0.10	0.06	0.08	0.41	0.37	0.40	0.41
1965	0.46	0.69	0.66	2.26	1.09	0.12	0.08	0.24	0.13	0.07	0.06	0.06
1966	0.08	0.41	0.56	5.51	4.58	6.69	2.59	0.34	0.07	0.06	0.05	0.05
1967	0.15	1.99	0.76	5.81	2.43	0.60	0.35	0.09	0.06	0.05	0.16	0.25
1968	0.31	0.37	0.41	0.30	0.53	9.35	3.50	0.81	0.39	0.08	0.07	0.08
1969	2.31	3.80	2.43	0.97	0.35	0.10	0.07	0.18	0.14	0.07	0.06	0.30
1970	1.06	0.92	3.00	2.67	5.05	7.33	2.44	5.61	2.00	0.39	0.63	0.66
1971	0.41	0.30	1.91	0.84	6.24	2.07	0.44	0.68	0.52	0.24	0.09	0.07
1972	0.07	0.22	0.37	0.90	1.00	0.74	0.49	0.13	0.06	0.05	0.18	2.15
1973	1.74	2.96	1.20	3.43	9.01	2.80	0.60	0.49	0.19	0.07	0.06	0.05
1974	0.06	0.14	1.07	8.90	7.52	1.44	0.28	0.12	0.07	0.06	0.05	0.38
1975	0.50	0.54	3.48	7.89	7.94	19.96	12.12	2.15	0.11	0.10	0.13	0.16
1976	1.24	1.03	0.63	4.35	14.50	5.00	0.61	0.10	0.07	0.07	0.06	0.30
1977	0.52	0.73	0.59	5.61	2.72	3.79	1.80	0.31	0.07	0.07	0.07	0.15
1978	2.16	8.12	2.73	0.61	0.61	0.36	0.16	0.08	0.07	0.06	0.06	0.12
1979	0.47	0.30	0.34	0.37	0.21	0.09	0.07	0.05	0.04	0.04	0.04	2.84
1980	1.23	2.19	1.09	4.98	4.38	0.97	0.14	0.48	0.27	0.07	0.48	1.57
1981	1.06	4.08	1.34	2.34	1.14	0.68	0.56	0.20	0.07	0.06	0.05	0.05
1982	0.30	0.44	0.40	0.40	0.27	0.19	0.09	0.06	0.05	0.05	0.11	0.07
1983	0.26	5.57	5.44	15.40	16.84	7.50	5.06	1.57	0.25	0.53	0.56	0.26
1984	0.43	0.45	0.21	3.45	20.26	5.72	0.10	0.06	0.05	0.05	0.05	0.05
1985	4.73	2.20	1.19	4.44	1.84	1.62	0.93	0.16	0.07	0.06	0.06	0.06
1986	0.08	0.24	1.75	4.03	1.81	4.33	1.67	0.59	0.74	0.27	0.35	31.15
1987	12.36	4.51	1.64	0.39	16.11	23.37	6.39	1.90	1.00	0.26	0.31	0.16
1988	0.33	0.63	4.36	1.64	10.88	3.22	0.43	0.19	0.07	0.07	0.06	0.06
1989	0.14	12.74	4.41	0.59	0.67	7.70	2.92	0.22	0.07	0.06	0.13	0.08
1990	0.44	0.47	3.77	2.24	8.83	9.45	2.40	0.23	0.13	0.08	0.07	0.32
1991	0.99	2.94	0.95	0.37	0.23	0.10	0.07	0.06	0.05	0.04	0.04	0.05

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1992	0.06	0.15	0.10	0.10	0.24	0.23	0.23	0.08	0.05	0.04	0.05	0.15
1993	1.76	1.04	6.82	3.25	0.54	1.53	0.60	0.09	0.05	0.05	0.09	0.07
1994	0.38	0.29	0.12	0.10	0.08	0.34	3.24	1.61	0.84	0.32	0.08	0.06
1995	0.22	1.36	16.65	13.62	9.56	2.43	0.46	0.11	0.07	0.54	0.41	0.17
1996	0.34	0.39	0.22	5.26	3.20	0.72	0.75	0.36	0.30	0.35	0.17	0.18
1997	1.44	10.20	3.57	0.41	4.08	1.38	0.32	0.11	0.07	0.05	0.05	0.06
1998	0.07	0.17	0.36	0.56	10.55	3.26	0.22	0.08	0.14	0.07	0.20	0.32
1999	7.04	2.57	3.94	12.74	11.62	2.72	0.67	5.52	1.99	0.08	0.07	0.07
2000	0.29	2.95	5.71	1.84	0.32	0.15	0.39	0.16	0.07	0.06	0.05	0.19
2001	0.66	2.96	3.86	3.95	1.69	0.34	0.43	0.13	0.07	0.40	0.76	0.47
2002	0.19	0.09	0.09	0.10	0.09	0.07	0.07	0.05	0.05	0.04	0.04	0.10
2003	0.16	0.19	0.10	0.31	0.50	0.31	0.10	0.06	0.04	0.04	0.04	0.05
2004	0.06	0.07	0.06	0.06	0.07	0.05	0.05	0.03	0.03	0.02	0.02	0.02

Table 4.4 Simulated monthly flows (in m^3/s) to Mhlali Estuary for Reference Condition

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.78	0.91	2.02	1.25	1.82	1.10	0.63	0.33	0.14	0.07	0.06	0.12
1921	0.54	17.53	13.02	2.92	0.63	0.60	0.46	0.42	0.43	0.23	0.25	0.30
1922	5.73	6.10	1.78	4.43	3.42	1.27	0.68	0.29	0.14	0.12	0.11	0.11
1923	0.11	0.13	0.31	1.21	1.74	0.88	0.38	0.19	0.12	0.08	0.07	0.20
1924	0.43	0.72	1.92	2.94	1.95	26.95	9.67	0.47	0.22	0.17	0.15	0.26
1925	0.64	0.63	0.50	0.36	0.41	0.71	0.57	0.22	0.17	0.13	0.09	0.12
1926	0.35	0.61	0.56	0.52	2.75	16.68	5.82	0.29	0.13	0.10	0.14	0.18
1927	0.22	0.28	0.49	2.45	1.69	0.84	0.52	0.23	0.11	0.07	0.07	0.12
1928	0.21	0.41	0.65	0.88	0.94	8.08	3.16	0.36	0.50	0.91	0.69	1.49
1929	4.33	2.28	0.82	1.34	0.95	0.63	0.63	0.34	0.18	0.14	0.25	0.55
1930	0.67	0.71	0.81	3.46	1.68	0.56	0.52	0.25	0.12	0.19	0.24	0.19
1931	0.20	0.20	0.31	0.69	11.84	7.32	1.78	0.52	0.31	0.14	0.11	0.13
1932	0.29	0.55	0.74	0.77	0.58	0.40	0.36	0.22	0.12	0.11	0.10	0.10
1933	0.13	0.43	3.30	6.12	2.59	2.21	3.13	1.45	0.54	0.35	0.48	0.37
1934	0.25	0.26	0.56	3.43	4.26	2.38	0.96	5.85	22.21	6.96	0.57	0.44
1935	0.32	0.32	0.30	0.57	7.70	6.25	1.82	3.87	1.75	0.28	0.18	0.18
1936	0.30	11.38	4.12	0.56	2.36	1.22	0.68	0.41	0.25	0.20	0.22	0.23
1937	0.24	0.35	6.53	3.38	8.61	2.84	0.56	0.44	0.33	0.48	0.46	0.27
1938	0.43	1.84	2.08	1.22	8.21	6.23	1.82	0.65	0.47	0.31	0.28	0.54
1939	0.90	3.90	3.77	1.46	0.64	0.49	0.38	3.02	1.74	0.58	0.25	0.24
1940	0.33	6.05	4.25	1.33	0.49	0.50	0.88	0.58	0.23	0.14	0.12	0.19
1941	0.32	0.48	0.46	2.61	1.60	4.83	2.11	0.54	0.36	0.21	0.26	0.44
1942	0.74	7.07	12.01	3.89	4.00	5.14	7.74	2.71	0.63	0.60	1.06	0.83
1943	5.90	6.97	2.27	0.62	0.81	4.82	2.16	0.38	0.27	0.22	0.18	0.49
1944	1.31	1.11	0.65	0.49	3.33	12.15	4.24	0.42	0.25	0.14	0.12	0.12
1945	0.16	0.19	0.22	0.54	0.85	1.70	1.59	0.75	0.25	0.12	0.09	0.10
1946	0.18	0.43	0.81	1.96	11.31	3.91	1.62	0.82	0.41	0.36	0.27	0.28
1947	0.30	2.63	1.56	3.03	4.68	4.19	3.38	1.15	0.22	0.13	0.12	0.12
1948	0.40	1.93	1.25	0.81	3.72	1.64	0.83	0.57	0.25	0.14	0.12	0.17
1949	0.48	4.94	7.28	2.80	1.02	0.84	0.61	0.37	0.23	0.13	0.16	0.18
1950	0.15	0.14	0.88	1.09	0.88	3.04	1.49	0.35	0.17	0.12	0.32	0.79
1951	0.84	0.67	2.75	6.25	2.50	0.61	0.80	0.80	0.49	0.24	0.21	0.19
1952	0.18	0.33	1.05	17.72	13.86	2.77	0.47	0.20	0.12	0.09	0.12	0.26
1953	0.45	0.72	3.97	1.99	2.81	1.50	0.68	0.36	0.24	0.15	0.14	0.38
1954	13.00	6.78	1.29	6.04	2.76	4.45	2.21	0.62	0.27	0.17	0.14	0.22
1955	0.48	1.05	0.96	0.53	4.54	8.08	2.88	0.49	0.23	0.15	0.19	0.41
1956	0.50	0.64	13.59	5.12	2.97	2.21	9.90	3.40	0.25	0.16	0.15	0.32
1957	1.78	3.16	1.90	9.95	13.88	3.79	6.39	2.43	0.29	0.18	0.15	0.29
1958	0.47	1.03	1.90	1.19	0.92	0.54	0.27	0.49	0.47	0.21	0.24	0.35
1959	0.63	0.86	0.78	0.65	0.73	1.40	1.08	0.52	0.21	0.12	0.11	0.13
1960	0.27	2.28	6.82	4.47	1.53	0.80	10.88	3.84	0.57	0.44	0.27	0.35
1961	0.59	0.78	0.66	0.71	0.82	1.17	0.84	0.36	0.14	0.10	0.15	0.21
1962	0.25	6.52	2.66	6.91	3.09	4.23	1.97	0.40	0.28	0.47	0.45	0.30
1963	0.35	0.47	0.54	9.43	4.02	0.62	0.51	0.29	0.17	0.14	0.12	0.14
1964	0.37	0.67	0.74	0.79	0.67	0.32	0.15	0.16	0.42	0.52	0.51	0.59
1965	0.64	0.84	0.93	2.46	1.44	0.46	0.23	0.29	0.28	0.16	0.14	0.18
1966	0.24	0.51	0.81	5.57	4.73	6.70	2.72	0.60	0.22	0.14	0.12	0.10
1967	0.22	2.02	1.16	5.83	2.75	0.84	0.63	0.28	0.14	0.10	0.18	0.41
1968	0.50	0.58	0.67	0.62	0.74	9.37	3.71	0.82	0.60	0.25	0.16	0.21
1969	2.33	3.88	2.65	1.27	0.73	0.33	0.22	0.25	0.27	0.18	0.16	0.34
1970	1.12	1.12	3.16	2.88	5.12	7.35	2.64	5.63	2.26	0.42	0.69	0.83
1971	0.66	0.54	2.01	1.22	6.27	2.42	0.64	0.69	0.63	0.41	0.27	0.21
1972	0.24	0.39	0.61	1.11	1.24	0.99	0.74	0.35	0.14	0.10	0.20	2.18
1973	1.89	3.05	1.52	3.56	9.05	3.05	0.81	0.60	0.37	0.20	0.15	0.14
1974	0.14	0.27	1.20	8.94	7.60	1.85	0.48	0.31	0.17	0.12	0.11	0.40
1975	0.78	0.74	3.58	7.92	7.97	19.98	12.15	2.35	0.32	0.22	0.27	0.34
1976	1.25	1.21	0.95	4.44	14.53	5.22	0.92	0.31	0.20	0.14	0.16	0.37

1977	0.68	0.90	0.89	5.65	2.95	3.87	1.94	0.56	0.23	0.16	0.18	0.29
1978	2.18	8.14	3.04	0.91	0.91	0.65	0.41	0.25	0.17	0.14	0.18	0.27
1979	0.55	0.60	0.57	0.67	0.54	0.29	0.20	0.13	0.08	0.06	0.06	2.87
1980	1.53	2.25	1.38	5.06	4.54	1.36	0.41	0.49	0.47	0.23	0.50	1.65
1981	1.24	4.11	1.75	2.46	1.50	0.86	0.79	0.42	0.19	0.12	0.10	0.10
1982	0.32	0.68	0.67	0.69	0.59	0.44	0.30	0.16	0.10	0.12	0.23	0.22
1983	0.34	5.60	5.57	15.46	16.87	7.59	5.07	1.73	0.43	0.55	0.74	0.51
1984	0.56	0.69	0.52	3.48	20.30	6.17	0.32	0.16	0.14	0.12	0.10	0.11
1985	4.75	2.42	1.46	4.55	2.18	1.77	1.13	0.41	0.18	0.13	0.14	0.16
1986	0.23	0.42	1.86	4.18	2.09	4.38	1.94	0.62	0.76	0.49	0.44	31.26
1987	12.50	4.56	1.94	0.74	16.14	23.39	6.75	1.91	1.13	0.44	0.44	0.41
1988	0.47	0.79	4.44	2.03	10.91	3.67	0.57	0.40	0.22	0.16	0.15	0.17
1989	0.28	12.78	4.75	0.88	0.95	7.72	3.15	0.44	0.20	0.14	0.19	0.25
1990	0.46	0.74	3.83	2.49	8.86	9.47	2.77	0.37	0.29	0.22	0.20	0.36
1991	1.05	3.04	1.39	0.62	0.57	0.31	0.22	0.13	0.10	0.08	0.07	0.09
1992	0.15	0.32	0.34	0.34	0.48	0.48	0.43	0.25	0.10	0.07	0.10	0.24
1993	1.78	1.28	6.85	3.50	0.95	1.58	0.94	0.24	0.12	0.12	0.21	0.19
1994	0.40	0.58	0.41	0.34	0.23	0.41	3.26	1.67	0.86	0.54	0.25	0.15
1995	0.29	1.42	16.70	13.67	9.59	2.68	0.73	0.32	0.16	0.55	0.68	0.40
1996	0.47	0.63	0.52	5.29	3.41	1.05	0.83	0.59	0.37	0.41	0.37	0.35
1997	1.46	10.22	3.85	0.77	4.11	1.75	0.53	0.31	0.17	0.12	0.13	0.18
1998	0.21	0.34	0.58	0.83	10.59	3.63	0.47	0.24	0.22	0.17	0.25	0.47
1999	7.06	2.92	3.98	12.79	11.64	2.96	0.87	5.54	2.25	0.24	0.17	0.20
2000	0.41	2.98	5.80	2.22	0.65	0.44	0.51	0.38	0.19	0.13	0.11	0.21
2001	0.72	3.04	4.01	4.12	1.95	0.69	0.56	0.36	0.19	0.41	0.89	0.71
2002	0.45	0.31	0.31	0.38	0.29	0.22	0.19	0.11	0.09	0.07	0.07	0.17
2003	0.35	0.41	0.36	0.51	0.78	0.61	0.34	0.11	0.06	0.05	0.07	0.10
2004	0.15	0.20	0.16	0.18	0.18	0.12	0.09	0.05	0.03	0.03	0.03	0.03

4.1.2 Low flows

Winter inflows seldom decreased (~5%) below 0.1 m^3/s under the Reference conditions (Table 4.5), while under the Present State river inflow below 0.1 m^3/s occur for 30% of the time.

Table 4.5 Summary of the change in low flow conditions to the Mhlali Estuary from the Reference Condition to the Present State

Percentile	Monthly flow (m^3/s)		% Remaining
	Natural	Present	
30%ile	0.3	0.1	39.9
20%ile	0.2	0.1	35.9
10%ile	0.1	0.1	43.2
% Similarity in low flows			**39.7**

Confidence: Medium

4.1.3 Flood regime

No large dams are present in the Mhlali catchment, any changes in the flood regime of the system would be mostly related to smaller farm dams, land-use change and associated catchment permeability. No flood analysis was done for this study, but an evaluation of the 95 %ile, 99 %ile and 99.9 %ile show that flood events occur relatively untransformed from Reference Condition to Present State, i.e. less than 5% change from Reference Condition.

Confidence: Medium

4.1.4 Hydrological health

Table 4.6 provides a summary of the hydrological health of the Mhlali Estuary.

Table 4.6 The hydrological health score

Variable	Summary of change	Score	Conf*
a.% Similarity in period of low flows	There has been a significant increase in low flow conditions under the Present State.	40	M
b.% Similarity in mean annual frequency of floods	The simulated monthly flow data indicate that under Reference Conditions floods were about 5 % higher than at present, depending on the size class.	95	M
Hydrology score		**62**	**M**

* Confidence level: L – Low; M – Medium; H - High

4.2 PHYSICAL HABITAT

4.2.1 Baseline description

The Mhlali Estuary catchment has been drastically modified and the original marginal and riparian vegetation significantly disturbed. Begg (1978, 1984) described the Mhlali Estuary as being a firm bottomed, sandy system with some areas of soft silt. He emphasised that the system is dominated by siltation arising from “agricultural malpractices” immediately around and upstream of the estuary which could have resulted in the shallowing of the system.

The shallowness of the Mhlali Estuary can be seen on historical aerial photographs (1937, 1967 and 1973) and more recent satellite imagery (2006, 2010 and 2013) of the system (see Figure 4.3 to 4.8). The shallow nature of the estuary is especially noticeable in the latter images where the mouth is open. However, considering the nature of runoff in the region, and the highly erodible soils of the area, the shallowness of the system is, to a degree, attributable to natural erosion process. What is also detectable on the above mentioned images, is the narrowing of the channels in the upper and middle reaches of the estuary due to agricultural activities and vegetation growth.

Under Reference Condition there would have been less sediments coming from the catchment and surrounding environs, e.g the 2006 satellite images shows exposed, unvegetated soils after a sugar cane harvest that poses a severe sedimentation risk for the adjacent estuary. At present, poor land-use practises are leading to more sediment, especially finer fractions, entering the system leading to changes in the sediment structure.

Figure 4.3 Historical image of the Mhlali Estuary - 1937

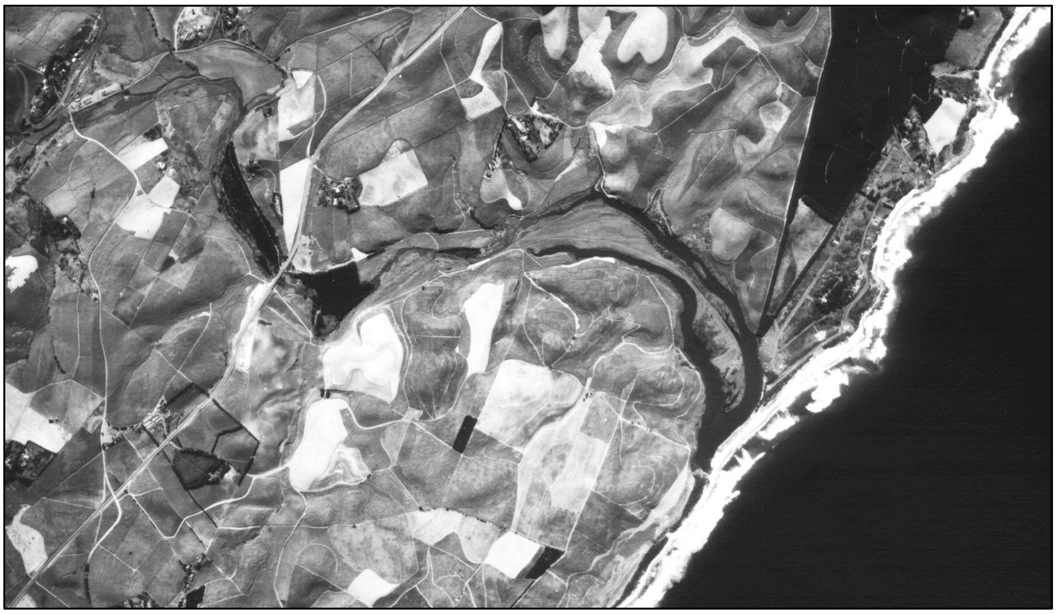


Figure 4.4 Historical image of the Mhlali Estuary - August 1967

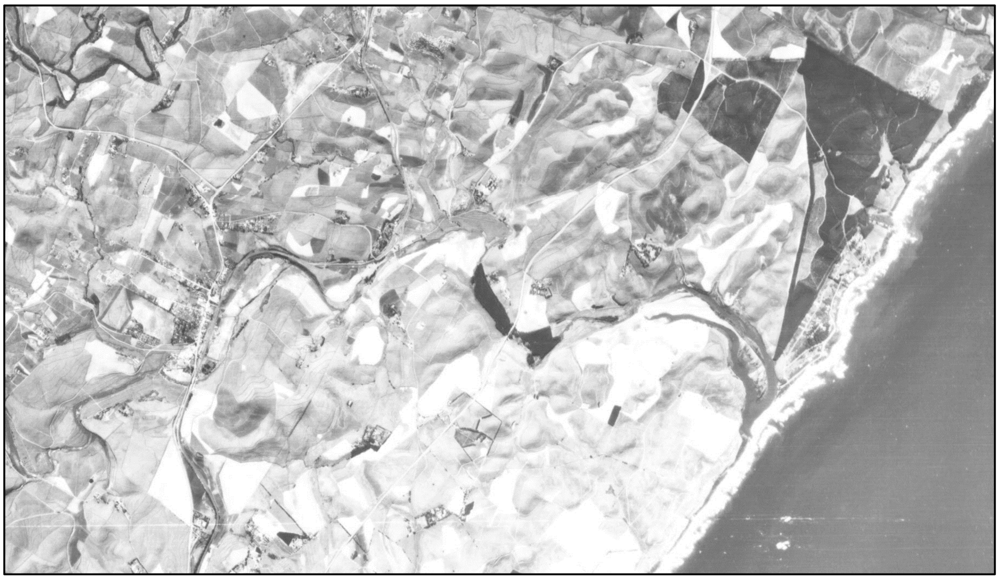


Figure 4.5 A historical image of the Mhlali Estuary - 1973

Figure 4.6 Satellite image of the Mhlali Estuary - 2 June 2006 (Source: Google Earth)

Figure 4.7 Satellite image of the Mhlali Estuary - 9 April 2010 (Source: Google Earth)

Figure 4.8 Satellite image of the Mhlali Estuary - 15 July 2014 (Source: Google Earth)

4.2.2 Physical habitat health

Table 4.7 provides a summary of the physical habitat health of the Mhlali Estuary. About 95% of the impact on the physical habitat was thought to be non-flow related.

Table 4.7 Calculation of the physical habitat score and adjusted score (net of non-flow impacts)

Variable		Score[1]	Motivation	Conf
1. Resemblance of intertidal sediment structure and distribution to Reference condition				
1a	% Similarity in intertidal area exposed	60	There has been some loss of intertidal habitat due to deposition and infilling of the intertidal area. Due to an increase in the occurrence of State 1 there is also less exposed intertidal habitat due to an increase in mouth closure and greater mouth restriction.	M
1b	% Similarity in sand fraction relative to total sand and mud	60	Information is lacking on changes in % similarity in sand fraction relative to total sand and mud, but the score of 60 is based on increase in clay and silt fractions experienced in similar systems, especially in Zone B and C.	M
2	% Similarity in subtidal components: depth, bed or channel morphology	60	There has been some infilling of sub-tidal areas as a result of the increase sediment yield from the catchment and sugarcane farming. There is also indications that the bridges are causing localise changes in bathymetry.	M
	Physical habitat score	**60**		

Variable	Score	Motivation	Conf
Anthropogenic influence:			
Percentage of overall change in intertidal and supratidal habitat caused by **anthropogenic** activity as opposed to modifications to water flow into estuary.	95	Poor agricultural practises and developments in the catchment are causing degradation and changes in sedimentation. This is offset to some extend by sand mining.	M
Percentage of overall change in subtidal habitat caused by **anthropogenic** modifications (e.g. bridges, weirs, bulkheads, training walls, jetties, marinas) rather than modifications to water flow into estuary.	95	Poor agricultural practises and developments in the catchment are causing degradation and changes in sedimentation.	M

4.3 HYDRODYNAMICS

4.3.1 Baseline description

Table 4.8 provides a summary of the hydrodynamics characteristics associated the typical abiotic states occurring in the Mhlali Estuary.

Table 4.8 Summary of the abiotic states, and associated hydrodynamic characteristics

Parameter	State 1: Closed, brackish	State 2: Open, limited marine	State 3: Open, fresh
Flow range (m^3/s)	<0.5	0.5 - 3	>3
Mouth condition	Closed	Intermitted closed	Open
Water level (m to MSL)	1 - 2 m MSL, can go to 3.0 m MSL just before breaching	Low	Low, except during floods
Inundation	Yes, intertidal areas	No	No except during floods
Tidal range (m)	-	0.25 – 0.5 m	1 m
Dominant circulation process	Wind	Tide and river	River
Retention	> 1 month	Days to weeks	< 1 day

4.3.2 Hydrodynamic health

KZN Wildlife's weekly mouth observation database shows that the Mhlali Estuary was open for about 48% of the time during the period 1993 to 2013. These record also shows that the system is closed for months at a time. Table 4.9 provides a summary of the hydrodynamic health of the Mhlali Estuary.

Table 4.9 Calculation of the hydrodynamics score

Variable	Summary of change	Score	Conf
Hydrodynamics and mouth conditions score	Mouth closure (State 1) occurs for about 59% of the time under the Present State, while the estuary was closed for about 47% under the Reference Condition. Artificial breaching at low levels are possibly disguising the actual frequency at which this is occurring.	80	H
Hydrodynamic score		**80**	**H**

4.4 WATER QUALITY

4.4.1 Baseline description

There are very limited water quality data available on the Mhlali Estuary, and that which are available vary greatly (Table 4.10).

Table 4.10 Summary of available water quality data on the Mhlali Estuary

Parameter	Dates		
	Aug 1986[1] (in estuary)	Nov 1992[2] (in estuary)	Oct 2004[3] (river just upstream)
Temperature (°C)	20	24	-
Salinity	6	6	0
pH	-	-	7
Turbidity (NTU)	-	2	-
Secchi (m)	0.14	0.17	-
Dissolved oxygen (DO) (mg/l)	7.6	7.6	-
NO_3-N (µg/l)	-	25	1 500
NH_4-N (µg/l)	-	30	<1 000

Parameter	Dates		
	Aug 1986[1] (in estuary)	**Nov 1992[2] (in estuary)**	**Oct 2004[3] (river just upstream)**
PO_4-P (µg/l)	-	8	-

1 Ramm *et al*. (1986). 2 Harrison, CSIR Durban (unpublished data).
3 Geomeasure Group (2005).

Siza Water manage two WWTW that discharges into the Mhlali, namely Shakaskraal and Tinley Manor WWTW (J Duvenhage, *Pers. Comm*., 22 Sep 2014). Details on these discharges are provided below in Table 4.11.

Table 4.11 Discharges from Shakaskraal and Tinley Manor WWTW

Parameter	Shakaskraal WWTW	Tinley Manor WWTW
Discharge location	3.5 km above head of estuary	Zone C just below N2 bridge
Current discharge volume (Ml/d)	0.8 (0.009 m^3/s)	0
Capacity (Ml/d)	1.6 (0.019 m^3/s)	6 (0.07 m^3/s) (short term) 18 (0.21 m^3/s) (long-term)
Estimated NO_3-N (µg/l)	6 000	1500
Estimated NH_4-N (µg/l)	3 000	1000
Estimated PO_4-P (µg/l)	4 000	7000

Although the Shakaskraal's license agreement requires that the effluent be treated to general limits, Siza Water currently operates the system at average concentrations as listed above (J Duvenhage, Siza Water, *Pers. Comm*.. 22 Sep 2014). The expected effluent quality for the Tinley Manor WWTW was obtained from the EIA study (Demetriades *et al*., 2006) (see Figure 4.9 below).

Figure 4.9 Tinley Manor WWTW (just downstream of N2 Bridge

In some of the Google maps (e.g. 9 April 2010) it appears as if the channel in Zone C is completely overgrown with vegetation/macrophytes. This, however, needs to be confirmed but if correct it may be related to the WWTW effluent being disposed in this Zone (downstream of the N2 Bridge).

Assuming that the estimated concentrations for the WWTWs are as indicated above, then the expected concentration in river inflow for the Present State and each of the future scenarios is provided in Table 4.12.

Table 4.12 Calculation of the nutrient concentration under the various operational flow scenarios

Present (with current Shakaskraal WWTW at 0.8 Ml/d)

Flow				NO3-N (ug/l)				NH4-N (ug/l)				DIN (ug/l)	DIP (ug/l)			
Total	Shakaskraal	Tinely Manor	River	Shakaskraal	Tinely Manor	Upstream	River	Shakaskraal	Tinely Manor	Upstream	River	River	Shakaskraal	Tinley Manor	Upstream	River
0.5	0.009	0.00	0.49	4000	1500	200	268	3000	1000	50	103	372	4000	7000	20	92
1.75	0.009	0.00	1.74	4000	1500	200	220	3000	1000	50	65	285	4000	7000	20	40
3	0.009	0.00	2.99	4000	1500	400	411	3000	1000	50	59	470	4000	7000	30	42

Scenario 1 (no WWTWs)

Flow				NO3-N (ug/l)				NH4-N (ug/l)				DIN (ug/l)	DIP (ug/l)			
Total	Shakaskraal	Tinely Manor	River	Shakaskraal	Tinely Manor	Upstream	River	Shakaskraal	Tinely Manor	Upstream	River	River	Shakaskraal	Tinley Manor	Upstream	River
0.5	0.00	0.00	0.50	4000	1500	200	200	3000	1000	50	50	250	4000	7000	20	20
1.75	0.00	0.00	1.75	4000	1500	200	200	3000	1000	50	50	250	4000	7000	20	20
3	0.00	0.00	3.00	4000	1500	400	400	3000	1000	50	50	450	4000	7000	30	30

Scenario 2 (Shakaskraal 1.6Ml/d and Tinley Manor 6 Ml/d)

Flow				NO3-N (ug/l)				NH4-N (ug/l)				DIN (ug/l)	DIP (ug/l)			
Total	Shakaskraal	Tinely Manor	River	Shakaskraal	Tinely Manor	Upstream	River	Shakaskraal	Tinely Manor	Upstream	River	River	Shakaskraal	Tinley Manor	Upstream	River
0.5	0.019	0.07	0.41	4000	1500	200	526	3000	1000	50	295	822	4000	7000	20	1148
1.75	0.019	0.07	1.66	4000	1500	200	293	3000	1000	50	120	413	4000	7000	20	342
3	0.019	0.07	2.91	4000	1500	400	448	3000	1000	50	91	539	4000	7000	30	218

Scenario 3 (more abstraction with Shakaskraal 1.6Ml/d and Tinley Manor 6 Ml/d))

Flow				NO3-N (ug/l)				NH4-N (ug/l)				DIN (ug/l)	DIP (ug/l)			
Total	Shakaskraal	Tinely Manor	River	Shakaskraal	Tinely Manor	Upstream	River	Shakaskraal	Tinely Manor	Upstream	River	River	Shakaskraal	Tinley Manor	Upstream	River
0.09	0.019	0.07	0.00	4000	1500	200	2013	3000	1000	50	1412	3425	4000	7000	20	6289
1.75	0.019	0.07	1.66	4000	1500	200	293	3000	1000	50	120	413	4000	7000	20	342
3	0.019	0.07	2.91	4000	1500	400	448	3000	1000	50	91	539	4000	7000	30	218

Scenario 4 (Shakaskraal 1.6 Ml/d and Tinley Manor 18 Ml/d)

Flow				NO3-N (ug/l)				NH4-N (ug/l)				DIN (ug/l)	DIP (ug/l)			
Total	Shakaskraal	Tinely Manor	River	Shakaskraal	Tinely Manor	Upstream	River	Shakaskraal	Tinely Manor	Upstream	River	River	Shakaskraal	Tinley Manor	Upstream	River
0.5	0.019	0.21	0.27	4000	1500	200	890	3000	1000	50	561	1452	4000	7000	20	3103
1.75	0.019	0.21	1.52	4000	1500	200	397	3000	1000	50	196	593	4000	7000	20	901
3	0.019	0.21	2.77	4000	1500	400	500	3000	1000	50	135	635	4000	7000	30	543

De Villiers and Thiart (2007) estimated natural concentrations of Dissolved Inorganic Nitrogen (DIN) and Dissolved Inorganic Phosphate (DIP) in these systems as about 50 µg/l and 10 µg/l, respectively. Estimated DIN and DIP concentrations in seawater along this part of the coast are expected to be 50 - 100 µg/l and 10 - 20 µg/l respectively. (e.g. DWAF, 1995). This suggests that even if effluent is treated to the estimated "good" effluent concentrations (see above), it can still introduce orders of magnitude higher DIN and DIP concentrations into the estuary, compared with the reference condition. While such treated effluent may be assimilated in larger systems, it becomes a major source of nutrient enrichment in smaller systems, especially during low river flows.

Based on the available data and information, a rough estimate of the water quality characteristics for the various states, in each of the three zones is presented in Table 4.13.

Table 4.13 Summary of water quality characteristics of different abiotic states in the Mhlali Estuary (differences in state between reference condition and present state and future scenarios – due to anthropogenic influences other than flow - are indicated)

Parameter	State 1: Closed	State 2: Open, limited marine	State 3: Open, fresh
Salinity	10 | 10 | 0	15 | 5 | 0	0 | 0 | 0
Temperature (^{o}C)	No data, but assumed to be largely influenced by atmospheric temperatures, i.e. higher in summer compared with winter)		
pH	Limited data, assumed to be between 7 - 8.5		
DO (mgl/l)	**Reference** 6 | 6 | 6 **Present/Scenario 1** 6 | 4 | 4 **Scenario 2** 2 | 2 | 2 **Scenario 3 and 4** 2 | 2 | 0	**Reference** 6 | 6 | 6 **Present/Scenario 1** 6 | 4 | 4 **Scenario 2, 3 and 4** 6 | 4 | 2	**Reference** 6 | 6 | 6 **Present/Future** 6 | 6 | 6
Turbidity (NTU)	**Reference** 10 | 10 | 10 **Present/Future** 10 | 10 | 20	**Reference** 10 | 10 | 10 **Present/Future** 10 | 10 | 20	**Reference** 50 | 50 | 50 **Present/Future** 200 | 200 | 200

NOTE: For the purposes of this assessment the estuary was sub-divided into three zones representing from left to right: Zone A (lower), Zone B (middle) and Zone C (upper) (see Figure 3.2).

Parameter	State 1: Closed			State 2: Open, limited marine			State 3: Open, fresh		
DIN (µg/l)	**Reference**			**Reference**			**Reference**		
	80	**80**	80	**80**	**80**	80	**100**	**100**	**100**
	Present (1 WWTW)			**Present (1 WWTW)**			**Present (1 WWTW)**		
	300	**300**	**350**	**200**	**250**	**300**	**450**	**450**	**450**
	Scenario 1 (without WWTW)			**Scenario 1 (without WWTW)**			**Scenario 1 (without WWTW)**		
	200	**200**	**250**	**100**	**200**	**250**	**450**	**450**	**450**
	Scenario 2 (2 WWTW)			**Scenario 2 (2 WWTW)**			**Scenario 2 (2 WWTW)**		
	600	**600**	**800**	**200**	**300**	**400**	**550**	**550**	**550**
	Scenario 3 (abstraction + 2 WWTW)			**Scenario 3 (abstraction + 2 WWTW)**			**Scenario 3 (abstraction + 2 WWTW)**		
	2000	**2000**	**3500**	**200**	**300**	**400**	**550**	**550**	**550**
	Scenario 4 (2 WWTW max)			**Scenario 4 (2 WWTW max)**			**Scenario 4 (2 WWTW max)**		
	1000	**1000**	**1500**	**300**	**400**	**600**	**650**	**650**	**650**
DIP (µg/l)	**Reference**			**Reference**			**Reference**		
	10	**10**	**10**	**10**	**10**	10	**20**	**20**	20
	Present			**Present**			**Present**		
	70	**70**	**90**	**20**	**0**	**40**	**40**	**40**	**40**
	Scenario 1 (without WWTW)			**Scenario 1 (without WWTW)**			**Scenario 1 (without WWTW)**		
	10	**10**	**20**	**10**	**20**	**20**	**30**	**30**	**30**
	Scenario 2 (2 WWT)			**Scenario 2 (2 WWTW)**			**Scenario 2 (2 WWTW)**		
	800	**800**	**1100**	**100**	**250**	**350**	**200**	**200**	**200**
	Scenario 3 (abstraction + 2 WWTW)			**Scenario 3 (abstraction + 2 WWTW)**			**Scenario 3 (abstraction + 2 WWTW)**		
	4000	**4000**	**6300**	**100**	**250**	**350**	**200**	**200**	**200**
	Scenario 4 (2 WWTW max)			**Scenario 4 (2 WWTW max)**			**Scenario 4 (2 WWTW max)**		
	2000	**2000**	**3000**	**600**	**800**	**900**	**550**	**550**	**550**
DRS (µg/l)	**No data**								

NOTE: For the purposes of this assessment the estuary was sub-divided into three zones representing from left to right: Zone A (lower), Zone B (middle) and Zone C (upper) (see Figure 3.2).

A summary of the water quality characteristics under the various flow scenarios are provided for each zone in Table 4.14.

Table 4.14 Summary of average changes in water quality from Reference Condition to Present State within each of the various

Parameter	Summary of change	Zone	Reference	Present
Salinity	⇧ due to increased in low flow conditions under Present state compared with reference.	A: Lower	14	14
		B: Middle	9	10
		C: Upper	1	1
DIN (µg/l)	⇧ due to increased nutrient input from anthropogenic sources (e.g. sugar cane and WWTWs) in the estuary increased under Present state (and future scenarios) compared with reference.	A: Lower	83	299
		B: Middle	83	312
		C: Upper	83	354
DIP (µg/l)	⇧ due to increased nutrient input from anthropogenic sources (e.g. sugar cane and WWTWs) in the estuary increased under Present state (and future scenarios) compared with reference.	A: Lower	12	53
		B: Middle	12	55
		C: Upper	12	70
Turbidity (NTU)	⇧ system becomes more turbid during higher flow periods (State 3) due to agriculture disturbance in catchment under Present (and future scenarios)	A: Lower	17	40
		B: Middle	17	40
		C: Upper	17	49
DO (µg/l)	⇩ dissolved oxygen level decrease in the estuary during State 1 (Closed) and State 2 (Open limited marine) as a result of organic accumulation from WWTWs under Present state (and future scenarios)	A: Lower	6	5
		B: Middle	6	5
		C: Upper	6	5
Toxic substances	⇧ urban development (e.g. Shakaskraal) may have introduced toxic substances into the estuary, assume similarity to reference as 75% for present and all future scenarios.	80% similarity between Reference and Present		

4.4.2 Water quality health

The similarity in each parameter (e.g. DO) to reference condition was scored as follows:

- Define **zones** along the length of the estuary **(Z)** (i.e. Zones A, B and C).
- **Volume fraction** of each zone **(V)** (i.e. Lower = 0.50; Middle = 0.20; Upper = 0.30).
- Different **abiotic states (S)** (i.e. States 1 to 4).
- Define the **flow scenarios** (i.e. Reference, Present, Future scenarios).
- Determine the **% occurrence** of abiotic states for each scenario.
- Define **WQ concentration range (C)** (e.g. 6 mg/l; 4 mg/l; 2 mg/l).

Similarity between Present State, or any Future Scenarios, relative to the Reference Condition was calculated as follows:

- Calculate Average concentration for each Zone for Reference and Present/Future Scenarios, respectively:
- Average Conc (Z_A) = [({∑% occurrence of states in C_1}*C_1)+ ({∑% occurrence of states in C_2}*C_2)+({∑% occurrence of states in C_n}*C_n)] divided by 100
- Calculate similarity between Average Conc's Reference and Present/Future Scenario for each Zone using the Czekanowski's similarity index: ∑(min(ref,pres)/(∑ref + ∑pres)/2
- For the final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions.

For the final scores, a weighted average of the similarity scores of different zones was computed using the volume fractions (Table 4.15).

Table 4.15 Summary of changes and calculation of the water quality health score

Variable		Summary of change	Score[1]	Conf
1	**Salinity**			
	Similarity in salinity	⇧ due to increase in low flow conditions	97	L
2	**General water quality in estuary**			
a	DIN and DIP concentrations	⇧ due to nutrient enrichment from agriculture and WWTWs	39	L
b	Turbidity (transparency)	⇧ due to increased turbidity from agricultural disturbance especially during higher flows (State 3)	58	L
c	Dissolved oxygen (mg/l)	⇩ due to organic accumulation from WWTWs especially during State 1 (Close) and State 2 (Open, limited marine)	93	L
d	Toxic substances	⇧ urban inputs	80	L
Water quality health score				
% of impact non-flow related			**100**	**H**
Adjusted score				

[1] $\text{Score} = (0.6 * 1, +0.4 * (\min(2\,\text{a. to } 2\text{d}))$

4.5 MICROALGAE

4.5.1 Overview

i) Main grouping and baseline description

The microalgae component comprises the autotrophic microorganisms, i.e. those that contain chlorophyll and, as a result, are able to convert sunlight into living material. In this capacity they are at the base of the food chain and responsible for most of the food consumed by the primary consumers.

Microalgae are strongly influenced by the open water surface area and water depth which together provides the volume of habitat. The area of intertidal habitat is where microphytobenthic communities provide a considerable foraging area for the primary consumers when under water. The flow regime either provides a stable set of habitats or an unstable set in that low flows generally produce the ideal estuarine condition with seawater underlying fresh water. If the mouth is open for very long periods, low oxygen concentrations can alter the proportions of the microalgal groups

ii) Description of factors influencing microalgae

The factors influencing the different microalgal groups are summarised in Table 4.16. Based on these considerations, the expected influence of the different abiotic states on microalgae is described in Table 4.17 and 4.18.

Table 4.16 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings

Variable	Phytoplankton	Microphytobenthos (MPB)
Mouth conditions	Prolonged closure will result in a maximum of benthic microalgae. Very short periods of closure with complete resetting is optimal for phytoplankton	Prolonged closure will likely result in dominance of cyanophytes as opposed to diatoms. Estuary resets once or twice per annum is optimal
Retention times of water masses	Prolonged closure would likely decrease the species richness.	Prolonged closure would likely decrease the species richness and the ration of MPB groups.
Flow velocities (e.g. tidal velocities or river inflow velocities)	A flow that provides a relatively stable position of the River Estuary Interface (REI) is optimal (salinity at the REI ~ 10 – 15 psu[1].	A flow that provides a relatively stable position of the REI is optimal (salinity at the REI ~ 10-15psu.
Total volume and/or estimated volume of different salinity ranges	Total volume is very important but salinity, even > 40 PSU for short periods (weeks) is not harmful.	Total volume is very important but salinity, even > 40 PSU for short periods (weeks) is not harmful.
Floods	At least one good scouring each year is optimal because it resets the system and the species will quickly reappear.	At least one good scouring each year is optimal because it resets the system and the species will quickly reappear.
Salinity	Salinity in the range of 5 - 45 PSU is fine for phytoplankton	Salinity in the range of 5 - 45 PSU is fine for MPB.
Turbidity	Turbidity from a flood is not important but long term turbidity may reduce productivity	Long term turbidity (weeks) will affect productivity.
Mouth conditions	An increase in mouth closure in combination with sedimentation would decrease the volume for growing plankton.	Prolonged mouth closure together with high organic matter inputs might alter the MPB group structure with cyanophytes becoming dominant rather than the diatoms.
Retention times of estuary water	An increase in retention of the magnitude described would be very small with regard to productivity.	An increase in retention of the magnitude described would be very small with regard to productivity.
Open water area	Proportional reduction with loss of open water area (37 - 16).	Proportional reduction with loss of open water area (43% remaining).
Salinity	Very little effect when > 5 PSU. When < 5 PSU there can be a few freshwater species present. Very seldom that freshwater diatoms appear in an estuary sample.	Very little salinity effect with estuary MPB. This was established during at prolonged survey at St. Lucia where salinity rose from normal to ~150 PSU.
Mouth condition	Mouth open - Biomass maximum at ~15 PSU. Vertical salinity gradient.	Mouth never closed - MPB elevated at low flows.
Water flow rate	Under water high flow rates most of the microalgae are suspended in the water column.	Many diatoms that are commonly benthic (epipelic) are found in the water column. This is especially the case where the fine sediment fraction is suspended due to turbulence.
Water retention time	Phytoplankton biomass elevated at long retention time with diatoms on the sediment.	MPB biomass elevated at long retention time.
Floods	Only temporary reduction in phytoplankton biomass as a result of flooding. Consumer population also reduced - therefore little effect.	Only temporary reduction in MPB biomass as a result of flooding. Consumer population also reduced - therefore little effect.
Turbidity	Because high turbidity occurs at the time of flooding there is very little effect on phytoplankton.	Possible small reduction in MPB productivity.

Variable	Phytoplankton	Microphytobenthos (MPB)
Water quality	Low nutrient content - maximum species diversity. Diversity decreases at high nutrient levels.	No evidence of a species change at high nutrient levels.
Toxins	Literature indicates that there is an unspecified adverse effect with certain toxins.	No information.
Macrophyte community structure	Diatom phytoplankton exchange onto and off submerged aquatic surfaces.	MPB high with high density of rooted aquatic macrophytes. Food availability to juvenile fauna increases - also security.
Oxygen levels	No effect on phytoplankton.	No effect on MPB.

1 Practical Salinity Units

Table 4.17 Summary of Microalgae responses to different abiotic states

State	Response
State 1	During closed conditions much of the microalgal biomass would sink to the sediment surface. The total biomass would remain largely unchanged.
State 2	With the mouth open on occasions there would be some flow and the high productivity REI area would develop.
State 3	As the main state at present the productivity would remain healthy with high productivity boosted by high nutrient levels.

iii) Reference condition

Relative change from Reference to Present State are summarised in Table 4.18.

Table 4.18 Summary of relative changes from Reference Condition to Present State

Key drivers	Change
Loss of open water area	10%
Increase in nutrient levels	20%
TOTAL CHANGE	**10%**

4.5.2 Microalgae health

In the reference state there would have been high flows much of the time. The microalgal groups would probably have differed in that the flagellate community would have been lower than at present. The absence of sugar cane would have left the open water area larger and the biomass would have been lower. Hence the main effect of loss of water area would have been compensated for by the persistent higher growth because of the higher N and P levels. Health scores are summarise d in Table 4.19. About 95% of the impact on microalgae was thought to be non-flow related.

Table 4.19 Microalgae component health score

Variable	Summary of change	Score	Conf
1. Species richness	Small decrease in community richness and increase in cyanophytes	95	L
2. Abundance	Increase in total biomass as a result of increased nutrients	90	M
3. Community composition	Very small change due to frequent resetting of the estuary	95	M
Biotic component health score			
% of impact non-flow related		**95**	**M**
Adjusted score		**99**	

4.6 MACROPHYTES

4.6.1 Overview

i) Main grouping and baseline description

Figure 4.10 shows the distribution of macrophyte habitats in 2013 mapped in ArcGis 10.1 using 2013 ESRI™ basemaps. This map has a low confidence as this was a desktop study with no ground truthing and vegetation mapping in the field. For example the area mapped as swamp forest probably contains a large number o f alien invasive trees (Table 4.20).

Observations from the north bank in 2013 showed that swamp forest with lagoon hibiscus (*Hibiscus tiliaceus*) occurred near the mouth of the estuary where the gradient was unsuitable for sugarcane cultivation. Wild date palm (*Phoenix reclinata*) and Natal wild banana (*Strelitzia nicolai*) were also present. Swamp forest likely extends to the middle and upper reaches of the estuary, however this may be coastal forest and a field visit would be needed to confirm this. Common reed (*Phragmites australis*) and the sedge *Schoenoplectus scirpoides* fringed the water channel in the lower reaches. The island closest to the mouth consisted of a matrix of grasses, *P. australis* and *Hibiscus tiliaceus.* A sandbar and rocks were present at the mouth when visited in July 2013.

The Environmental Impact Assessment report (Geomeasure group, 2005) for the Tinley Manor WWTW on the south bank below the N2 described the following invasive aquatic macrophytes in the river; water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*) and parrots feather (*Myriophyllum aquaticum*). The site of the WWTW is approximately 3.5 km from the mouth of the estuary. Algal blooms were also reported in the estuary and were expected to increase as a result of WWTW discharges. For the streambed and adjacent floodplain of the proposed development area extensive infestation by alien plants was reported. Dominant species were *Chromolaena odorata*, *Lantana camara*, *Eucalyptus* species, *Pinus* species, Brazilian Pepper (*Schinus terebinthifolius)* and Syringa (*Melia azedarach)*. Indigenous species along the banks were Wild Date Palm (*Phoenix reclinata*), Pigeon wood (*Trema orientalis*), Powder Puff Tree (*Barrington racemosa*), Hewitt's Dwarf Morning Glory (*Hewittia malabarica*), Umdoni trees (*Syzygium cordatum*), Quinine tree *(Rauvolfia caffra*), Natal Mahogany (*Trichillia dregeana*), Perdepis *Clausena anisata* and Splendid Acacia (*Acacia robusta*).

The floodplain has been extensively transformed by sugarcane cultivation. This is also the dominant activity in the catchment which would lead to soil erosion and downstream sedimentation, shallowing and macrophyte encroachment into the main river channel. According to the Tinley Manor Environmental Impact Assessment (EIA) report (Geomeasure group, 2005) "Large areas of the riparian zone and its buffers have been artificially drained and cultivated for sugarcane whilst remaining areas are infested with alien plants." The general impression is of an extensively degraded system.

Table 4.20 Macrophyte habitats and functional groups recorded in the estuary with examples of dominant species in italics

Habitat type	Distribution	Area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	25
Intertidal sand and mudflats	Intertidal zone consisting of sand/mud banks that provides area for microphytobenthos to inhabit. This was not mapped but is a dynamic habitat that would change over time in response to floods and dry periods.	
Swamp forest	Lagoon hibiscus (*H. tiliaceus*) and other trees occur behind the reeds and sedges in the lower reaches of the estuary	25
Reeds and sedges	Common reed (*P. australis*) and *S. scirpoides* fringed the water channel.	11

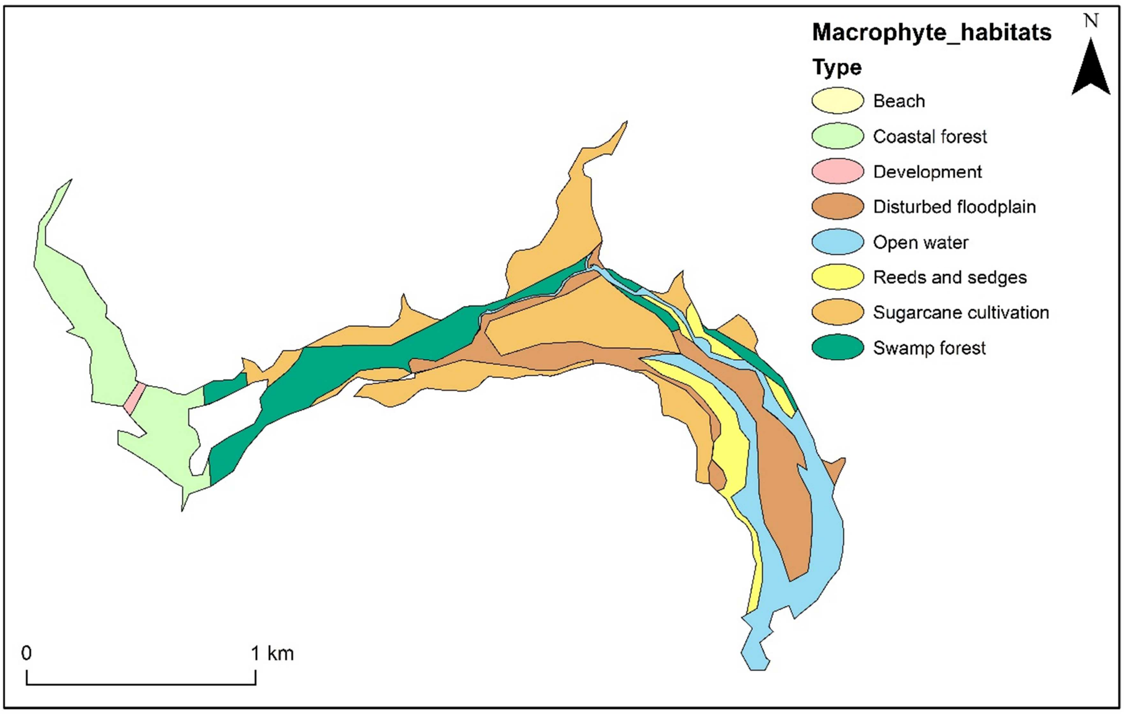


Figure 4.10 Distribution of macrophyte habitats at Mhlali Estuary in 2013

ii) Description of factors influencing macrophytes

The effect of abiotic characteristics and processes, as well as other biotic components on macrophyte habitats is described in Table 4.21.

Table 4.21 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on macrophyte habitats

Variable	Grouping	
	Reeds and sedges	Swamp forest
Mouth conditions	An increase in mouth closure in combination with sedimentation and nutrient inputs would cause expansion of macrophytes into the main water channel.	*H. tilicaeus* is able to withstand basal inundation caused by mouth closure for long periods.
Retention times of	An increase in retention time and high nutrient levels would encourage growth of	

Variable	Grouping	
	Reeds and sedges	Swamp forest
water masses	reeds, hygrophilous grasses, algal blooms and invasive floating macrophytes.	
Flow velocities (e.g. tidal velocities or river inflow velocities)	There has been a small decrease in base flow but floods have remained largely natural. Floods are important in resetting the estuary and clearing the channel of macrophyte growth.	
Total volume and/or estimated volume of different salinity ranges	The estuary is mostly fresh with reeds, sedges and swamp forest dominant.	
Floods	Floods remain similar to natural conditions. Large floods would scour the estuary removing vegetation and creating more open water surface area.	
Salinity	Salinity ranges are within favourable conditions for reed and swamp forest growth. Some salinity intrusion during the open mouth phase would be important in restricting the expansion of aquatic invasive macrophytes such as water hyacinth and parrot's feather.	
Turbidity	The estuary has become more turbid during high flow conditions (State 3) due to agriculture disturbance and run-off from the catchment. This together with high flow would prevent the establishment of submerged macrophytes.	
Dissolved oxygen	Organic accumulation from WWTWs under present conditions has resulted in a lower DO compared to natural conditions. This would not impact the macrophytes.	
Nutrients	WWTW inputs and sugarcane cultivation has greatly increased nutrient concentrations in the estuary. High nutrients levels encourage the proliferation of *Phragmites* spp. and other macrophytes.	
Sediment characteristics (including sedimentation)	Extensive agriculture in the catchment and on the surrounding estuary banks has resulted in erosion, run-off and sedimentation in the estuary. Sedimentation would encourage macrophyte growth particularly into the main estuary channel.	
Other biotic components	Large areas of estuarine habitat have been removed for sugarcane cultivation. Invasive plants have proliferated in the floodplains of this estuary displacing indigenous species. Little natural habitat remains although there is always the potential for rehabilitation.	

The impacts of different abiotic states on the macrophytes groups is summarised in Table 4.22.

Table 4.22 Summary of Macrophyte responses to different abiotic states

State	Response
State 1	During closed conditions salinity becomes homogenous in the lower and middle reaches and the estuary is not turbid. Dieback of reeds and sedges may occur in response to an increase in water level and flooding.
State 2	Mouth intermittently open, longitudinal salinity gradient develops. Salinity is within the tolerance range of reeds and swamp forest.
State 3	Estuary is fresh and turbid, together with nutrient input the growth of reeds would be encouraged.

iii) Reference condition

It is likely that under natural conditions reeds (*P. australis*) and swamp forest (*H. tiliaceus*) were dominant. However there has been a proliferation of reeds due to sedimentation and nutrient input and the swamp forest habitat has been invaded by exotic species such as Brazilian pepper. Begg (1978) described swamp forest with a few scattered clumps of freshwater mangrove (*Barringtonia racemosa*) on the southern bank of Mhlali Estuary. Beds of *Phragmites* spp. occurred on the island between the two arms of the system. *Echinocloa* sp. grass was growing above the weir. A mild bloom of the alga *Chaetomorpha* sp. was reported during open mouth conditions in 1981. *Barringtonia racemosa* was not evident during our site visit, but may still be present in the estuary as mentioned in the 2005 EIA report (Geomeasure group, 2005).

There have been major losses of macrophyte habitat due to the removal for the cultivation of sugarcane Table 4.23 and 4.24. Over 70 % of reed habitat has been lost to sugarcane cultivation. Changes associated with mouth state and nutrient concentrations may have also affected macrophyte abundance and distribution. A reduction in MAR and increase in low flow conditions has encouraged macrophytes to spread thus decreasing open water habitat. Invasive species in the riparian zone have likely displaced some indigenous species.

Table 4.23 Comparison of area (ha) for the different macrophyte habitats at Mhlali Estuary under natural, earliest aerial imagery (1937) and present (2013) conditions

Macrophyte habitat	Natural	1937	2013
Open Water	40	40	25
Sand/mud flats	10	10	0
Reeds and sedges	45	30	11
Swamp forest	28	16	25
Floodplain	42	42	24
Disturbed floodplain	0	0	30
Sugarcane cultivation	0	27	49
Development	0	0	1
TOTAL	**165**	**165**	**165**

Table 4.24 Summary of relative changes from the Reference Condition to Present state

Key drivers	Change
Sugarcane cultivation in the floodplain	⇩ macrophyte habitat.
⇧ nutrients from catchment activities	⇧ growth of all macrophytes, in particular reed, sedge and grass expansion as well as invasive aquatics.
⇧ mouth closure	Estuary experiences an increase in mouth closure and thus remains fresh and turbid. Calm sheltered conditions encourage growth of aquatic invasives.
⇧ sedimentation	⇧ habitat for reeds and sedges, infilling in upper reaches lead to vegetation encroachment in the middle-upper reaches.
TOTAL CHANGE	**⇧ aquatic invasives, some localised increases in reeds and sedges, loss of open water area in the middle-upper reaches.**

4.6.2 Macrophyte health

Health scores are summarised in Table 4.33. About 80% of the impact on macrophytes was thought to be non-flow related.

Table 4.25 Macrophyte component health score

Variable	Summary of change	Score	Conf
1. Species richness	Sugarcane cultivation in the floodplain and invasive species have displaced some indigenous species.	80	L
2. Abundance	Sugarcane cultivation has reduced the area of macrophytes. Reed and sedge habitat have declined by over 70 % since natural conditions. There have been some localised increases in reeds and sedges due to infilling and shallowing as well as high nutrient input.	51	L

3. Community composition	Under natural conditions reeds, sedges would have been dominant on the floodplain. At present, however, a large area is covered by disturbed habitat and sugarcane. The increase in low flow and input of nutrients from the WWTW has caused macrophytes to cover large areas of the water channel and open sand and mud banks resulting in loss of this habitat. Aquatic invasive plants are present.	52	L
Biotic component health score		**51**	
% of impact non-flow related		**80**	**L**
Adjusted score		**61**	

4.7 INVERTEBRATES

4.7.1 Overview

i) Main grouping and baseline description

The macrobenthic invertebrates or benthos refers to those organisms, attached to, living on (epifauna) or in (infauna) the substratum. The species composition, abundance and spatial distribution of these benthic macrofaunal communities may fluctuate widely both spatially and temporally. These variations may be ascribed to normal fluctuations of reproduction, recruitment and mortality as well as aperiodic changes due to random environmental fluctuations in physical or chemical conditions. The biomass of benthic invertebrates in unpolluted and healthy estuaries and coastal embayments is often high. It declines if communities are affected by prolonged periods of poor water quality especially when anoxia and hypoxia are common.

The most visible feature of the benthos in this system is the wide distribution of the burrowing prawn or "cracker" *Callianassa kraussi,* whose burrows were abundant in the mouth area and up both the north and south channels. Previous MER surveys carried out in 2008 produced 23 taxa dominated by polychaete worms and amphipod crustaceans.

ii) Description of factors influencing invertebrate fauna

The mouth dynamics critically influence any estuarine environment in terms of *i.a.* the presence or absence of inter-tidal areas, salinity gradients, sediment suspension, causing increased turbidity, sediment sorting and dispersal by tidal currents and animal migration between the estuarine and marine environments. While permanently open and temporarily open/closed systems have distinct and regionally significant estuarine functions it would be of importance to establish whether the breaching pattern of the Mhlali has changed because of river flow modification. It has, for instance, been established in the case of the oHlanga that water added to the system by treatment works in the catchment has increased the breaching frequency and resulted in major, mainly adverse, changes in the functioning of this system.

The salinity conditions prevailing in the estuary during the course of the survey were generally tolerable as far as estuarine organisms are concerned but extended periods of salinities below the measured general lower levels of *ca.* 5 would be expected to reduce the faunal diversity.

Dissolved oxygen levels in water are highly susceptible to biological influences either through the reducing effects of organic decomposition or the destabilising effects of nutrient enhanced daytime photosynthesis followed by nocturnal respiration. The oxygen levels recorded in the uMhlali estuary, particularly in the deeper waters of the upper reaches following extended periods of mouth closure are already cause for concern. Added nutrients and organic materials, over and above the already excessive loads, could well result ultimately in deoxygenated conditions and fish kills which have become virtually commonplace in eThekwini estuaries.

The abundance of *C. kraussi* indicates regular penetration of seawater into the system as this species is incapable of breeding in very low salinities. Collection of *C. kraussi* for bait was noted at the start of the survey when the mouth was open and the water shallow during low tide periods. Comparison of the benthic community data with those from the 16 eThekwini estuaries (MER, unpublished) indicate that in comparison with the very few relatively pristine temporarily open/closed systems, there was some reduction in the abundance and variety of molluscs and isopod crustaceans suggesting some degree of degradation. The increase in total individual abundance from July to October coincided with an extended period of predominant mouth closure which has been shown in other similar systems to enhance the development of the benthic fauna.

It is an arguable point that the total area and volume of the estuary have been reduced over the last century through infilling and mouth breaching practices. Equally there appears to have been a change in the pattern of mouth breaching but reliable historical data are lacking. The benthic community shows some indication of degradation The most disturbing aspects of the uMhlali estuary in the present context are the high nutrient and bacterial levels and the abundance of the invasive alien snail *Tarebia granifera.* Added nutrients and organic material, the latter often derived from enhanced plant growth resulting in turn from added nutrients, have been shown in other systems such as the uMdloti and oHlanga to result in deoxygenation and depletion of faunal populations. It is also disturbing that the bacterial levels recorded strongly indicate a danger to human health. This situation is in contrast to that described by Harrison *et al*., (2000) who classified the water quality, on the basis of its suitability for aquatic life in terms of dissolved oxygen, unionized ammonia and oxygen absorbed, human contact in terms of faecal coliform levels and trophic status in terms of nitrate nitrogen and ortho-phosphate as “good”. The significance of the invasive snail has not been investigated but it is spreading rapidly in coastal freshwater and estuarine environments in the province and it would be naïve to assume that there is no long term significance.

Table 4.26 and 4.27 provide a summary of the invertebrate groupings responses to various abiotic and biotic processes.

Table 4.26 Summary of Invertebrate responses to different abiotic states

State	Response
State 1	During closed conditions salinity gradient disrupted and system freshens excluding estuarine species and reducing overall diversity. DO reductions possible.
State 2	Mouth intermittently open, longitudinal salinity gradient develops. Salinity is within the tolerance range of a range of estuarine and marine species resulting in increased diversity and better water quality due to dilution and flushing. Improved water quality can result in increased abundance.
State 3	Estuary freshens and steady outflow from the system –invertebrate species tolerant of fresh, turbid condition found under this state – often dominate by Insecta.

iii) Reference condition

Table 4.27 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
Sugarcane cultivation in the floodplain	⇩ habitat diversity and spatial availability results in decrease in invertebrate diversity and predominantly abundance.
⇧ nutrients from catchment activities	⇧ invasive species such as *T. granifera* ? but predominantly changes in water quality and dissolved oxygen in particular eliminating the less tolerant species from the system and preventing succession within this community.
⇧ mouth closure	Greater stability but clearer water and fresher conditions. Eliminates more typical estuarine species from occurring in the system
TOTAL CHANGE	**⇧ loss of open water area and benthic substrate habitats, ⇧ freshening resulting in exclusion of species and anoxic conditions**

4.7.2 Invertebrate health

Health scores for the invertebrate component are provided in Table 4.28. About 80% of the impact on invertebrates was thought to be non-flow related.

Table 4.28 Invertebrate component health score

Variable	Summary of change	Score	Conf
1. Species richness	Approximately 70% of the original species remain. Species losses are primarily associated with anthropogenic effects such as habitat loss, water quality effects and artificial breaching. It is estimated that more estuarine species occurred in the past when more estuarine benthic habitat was available with a higher diversity of habitat.	70	L
2. Abundance	Loss of water column and benthic habitat by infilling and loss of the prolonged closed phase has reduced the carrying capacity of the system moving away from the reference condition.	40	L
3. Community composition	Absence of typical estuarine species with the loss of the development of a climax invertebrate community changes the relative proportions of the estuarine r and k strategists. Appearance of the alien snail *T. granifera* in the system has moved the system further from reference condition.	50	L
Biotic component health score		**40**	**L**
% of impact non-flow related		**80**	**L**
Adjusted score		**88**	

4.8 FISH

4.8.1 Overview

i) Main grouping and baseline description

Fishes with a variety of life histories use South African estuaries and several estuarine association guilds have been applied to categorise the estuarine ichthyofauna (Table 4.29). Most widely used has been that of Whitfield (1994) (see below), although more recent refinements have applied (e.g. Harrison and Whitfield, 2008) based on functional use categories more globally applicable (e.g. Elliot *et al*., 2007).

Table 4.29 Classification of South African fish fauna according to their dependence on estuaries (Whitfield, 1994)

Category	Description
I	Truly estuarine species, which breed in southern African estuaries; subdivided as follows:
Ia	Resident species which have not been recorded breeding in the freshwater or marine environment.
Ib	Resident species which have marine or freshwater breeding populations.
II	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries; subdivided as follows:
IIa	Juveniles dependent of estuaries as nursery areas.
IIb	Juveniles occur mainly in estuaries, but are also found at sea.
IIc	Juveniles occur in estuaries but are more abundant at sea.
III	Marine species which occur in estuaries in small numbers but are not dependent 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.
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments. Includes the following subcategories:
Va	Obligate catadromous species.
Vb	Facultative catadromous species.

For the purposes of this assessment Whitfield's categorisation (above) was used as a basis to classify fishes as:

- Estuarine resident: Species that complete their life cycles in South African estuaries (Whitfield's categories Ia and Ib).
- Estuarine dependent marine: Species which breed at sea with the juveniles dependent on South African estuaries (Whitfield's categories IIa, IIb and Vb).
- Marine: Species which use South African estuaries opportunistically, but are not dependent upon these systems to complete their life cycles (Whitfield's categories IIc and III).
- Freshwater: Species which can (and mostly do) complete their life cycles in fresh water (Whitfield's category IV).
- Catadromous: Anguillid eels, which use estuaries only as transit routes between the marine and freshwater environments (Whitfield's category Vb).

There are of course other ways of categorising, or grouping, components of estuarine fish assemblages. Feeding guilds are another common approach and in this respect most South African species can be assigned to categories as being:

- Detritivores: Species that feed predominantly on detritus, deriving nutrition from bacteria on decaying vegetation and microphytobenthos.
- Zooplanktivores: Species that feed on zooplankton, mostly small crustaceans.
- Zoobenthivores: Species that feed on benthic invertebrates living on, or in the sediments.
- Piscivores: Species that prey upon other fishes.

Fishes in the Mhlali estuary have been sampled on four (documented) occasions in the last 20 years and a wide range of species (51) has been recorded (Appendix B). These include representatives from all functional estuarine use groups and the main trophic categories. Estuarine dependant fishes dominate the assemblage accounting for 21 of the 51 tax reported. They also dominate by abundance and on average have accounted for 64% of fishes sampled in the estuary. This is a slight under estimate. Begg's surveys relied upon beam trawling only as a means of sampling (Begg, 1984a). This gear is biased towards smaller, slower moving species, often estuarine resident species at the expense of larger, faster swimming fishes, often estuarine dependent species. Indeed, Begg (1984a) noted that mullet occurred in far greater abundance in the estuary than indicated by beam trawl results.

The full species array is one typical of KwaZulu-Natal temporary open/closed estuaries, with some noted exceptions. *Antennarius striatus* and *Pterois miles* are species not normally associated with estuaries but which rather occur in marine waters and *Himantura uarnak* occurs in open estuaries, but seldom in temporary open/closed systems in KwaZulu-Natal. These fishes, all reported by Begg (1984a) occurred in low abundance during open mouth phases and the former two were encountered only when salinity maximums were at, or very close to that of seawater. Their occurrence should be regarded as chance.

ii) Description of factors influencing fish

A wide variety of factors influence fish in temporarily open/closed estuaries. The main flow related factors influencing fish in the Mhlali estuary are listed below (Table 4.30). A summary of fish responses to different estuarine states is given in Table 4.31.

Table 4.30 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings

<table>
<tr><th colspan="4">Grouping</th></tr>
<tr><th>Estuarine resident</th><th>Estuarine dependent marine</th><th>Marine</th><th>Freshwater</th></tr>
<tr><td colspan="4">Mouth closure</td></tr>
<tr><td colspan="4">Mouth condition has significant direct effects on estuarine biota as the proximal determinant of marine estuarine connectivity. It also has secondary effects via its impacts on physico-chemical conditions in the estuary. Under natural conditions salinity is the most relevant parameter in this regard, but under conditions on elevated nutrient inputs and organic loads oxygen concentration becomes increasingly pertinent with prolonged mouth closure.</td></tr>
<tr><td>Most resident species proliferate under closed mouth conditions. Salinity regimes support the full array of estuarine breeding species. Water quality becomes limiting under present day conditions due to low oxygen levels (associated with nutrient loads to the system).</td><td>Recruitment of marine spawning fishes is reduced by prolonged mouth closure but short periods of closure may benefit estuarine dependent species that are already in the system. Numbers of species and abundance declines with prolonged mouth closure. Under present day nutrient loads, water quality becomes limiting during prolonged mouth closed conditions (low dissolved oxygen levels). This results in a reduced estuarine dependent marine fishes.</td><td>Recruitment of marine spawning fishes is reduced by prolonged mouth closure. Salinity regimes are also not supportive of the great majority of marine species. Numbers of species and abundance declines markedly with prolonged mouth closure.</td><td>Increase in abundance of selected salinity tolerant species, most notably Oreochromis mossambicus. Under present day nutrient loads, water quality becomes limiting during prolonged mouth closed conditions (low dissolved oxygen levels) but tolerant species are likely to persist and proliferate.</td></tr>
<tr><td colspan="4">Floods</td></tr>
<tr><td colspan="4">Floods open and scour the system of sediments and marginal vegetation and are important in maintaining habitat suitable for estuarine and estuarine dependent species. Prolonged periods without floods allow bank vegetation to encroach into shallow areas and the estuary is canalised by stands of reeds. This reduces habitat complexity of open waters (subtidal and intertidal sand flats). This negatively affects the estuarine fish assemblage, but benefits freshwater species.</td></tr>
<tr><td>The larvae of resident species are washed into the sea at the onset of floods. Juveniles and adults of small bodied species may also be affected.</td><td colspan="2">Juvenile and adults leave the estuary, but can return on receding floodwaters, aided by tidal intrusion. Juvenile marine spawning species and catadramous species use floodwaters in the sea as a cue for locating and migrating into estuaries.</td><td>Floods may flush some individuals downstream and even out to sea, where mortalities can occur because of osmoregulatory shock.</td></tr>
</table>

Grouping			
Estuarine resident	**Estuarine dependent marine**	**Marine**	**Freshwater**
Prey abundance			
Food resources are an obvious driver of fish composition and abundance in the estuary. Prey abundance is impacted by various variables related to flow, including those listed above. Prey abundance is included as a main factor affecting fishes here because there is little doubt that it has affected fishes markedly in the Mhlali.			
Estuarine resident species that occur most abundantly are zooplankton feeders. Zooplankton abundance increases under closed mouth conditions.	Juveniles and adults of most species are benthic feeders, although larval and early stage juveniles of many species prey on zooplankton. Larger fishes prey on larger crustaceans in the estuary, particularly sandprawn and penaeid prawns. These prey items (particularly the latter) are sensitive to estuarine changes and have undergone marked declines in recent history. Mullet are detritivores and food resources are less impacted.		The dominant freshwater species in the estuary is detritivores and shown high plasticity in diet. It is resilient to trophic changes in the system.

Table 4.31 Summary of fish responses to different abiotic states

State	Response
State 1: Closed, weeks to months	High water levels and increased estuary volume result in greater water column productivity and benefit most species that are in the estuary. Estuarine resident species especially benefit from reduced predation and increased zooplankton abundance. Detritivorous estuarine dependent dishes (mullet) also benefit, but prolonged closure restricts recruitment potential of these and other estuarine dependent marine fishes. Intertidal habitat is lost. Some freshwater species will be affected by higher salinities and precluded from the lower and middle reaches of the estuary. Inundation of vegetation provides improved habitat for these species however. Under current nutrient inputs, prolonged mouth closure will result in poor water quality conditions. Low oxygen concentrations will be detrimental and limit fish abundance and diversity. The main freshwater species, however, is tolerant of salinities and expected oxygen concentrations throughout the system and will proliferate.
State 2: Open, limited marine	A good salinity gradient creates conditions that support the highest diversity of estuarine associated fishes in the estuary. Habitat diversity (subtidal and intertidal) plays an added role in this. Recruitment of marine spawning species is not limited by mouth state. All fish guilds occur in the estuary, although freshwater species are mostly limited to the middle and upper reaches. *Oreochromis mossambicus* may occur in the lower reaches, but only sporadically. Importantly, salinity conditions in the lower reaches support an abundance of estuarine prawns that are an important component of the diets of several important estuarine dependent fish species.
State 3: Open, fresh	Estuarine residents will occur throughout the estuary, but preferred habitat and prey abundance for these species is reduced. Recruitment of marine spawning species is not limited by mouth state, but low salinities preclude use of the estuary by marine fishes and it is likely that even most estuarine dependent marine fishes will be limited to using the lower reaches of the system. Select estuarine dependent species (*Myxus capensis*, *Mugil cephalus*, *Valamugil cunnesius* most abundantly) will occur throughout. Prey abundance and availability for benthic feeding estuarine dependent species is reduced and this is reflected in reduced fish abundance. Freshwater fishes will be represented by *O. mossambicus* occurring in all reaches of the estuary.

iii) Reference condition

Under reference conditions, the Mhlali estuary occurred in a predominantly open marine phase during the wet season months of November through to April. This provided optimum conditions for estuarine dependent fishes to recruit into the estuary and access abundant prey resources. Over the dry months of May to October, the system was predominantly (but not permanently) closed. A good mix of water column (plankton) and benthic productivity supported the full array of species from all life history and trophic guilds. Sediment and nutrient loads to the estuary were natural and the system was likely deeper with less vegetation encroachment than present, most notably in the upper reaches. Overall, the estuary had a greater area of open water habitat and sand and mud flats. These conditions supported an abundance of estuarine crustaceans and fishes.

The Mhlali estuary appears to have been a temporarily open/closed estuary that historically supported a particularly diverse fauna. Of sixty systems surveyed south of the uThukela in the early 1980s the Mhlali supported the fourth most species (fishes and crustaceans) (Begg, 1984b). Indeed, number of species in the system was higher than that reported for several permanently open estuaries.

Significant changes have occurred. The estuary occurs in a closed mouth state (State 1) much more frequently than under reference condition, and in an open, limited marine condition (State 2) much less frequently. This has implications for recruitment of marine spawning species. Prevailing salinity gradients are also impacted although, in terms of water quality variables, this has less of an impact on the fish fauna than low oxygen concentrations caused by high nutrient loads to the estuary (which is exacerbated by increased and prolonged mouth closure). Habitat quality has also degraded significantly from the reference condition. Sedimentation has occurred which has resulted in loss of system volume, but probably more significant is the encroachment of vegetation into the estuary, especially in the upper reaches. This has decreased water habitat.

Changes in the systems mouth dynamics, water quality and habitats have also had negative impacts on fishes favoured prey species. Prey abundances for benthic feeding fishes in particular appear to have suffered marked declines. An outstanding feature of the invertebrate fauna of the Mhlali estuary in the early 1980s was the abundance of penaeid prawns (Begg, 1984a). The system supported higher abundances of *Fenneropenaeus indicus* than any other system surveyed by Begg (1984a). This undoubtedly provided a rich food source for the diversity of estuarine dependent fishes sampled in the system, including several line fish species.

A summary of present day changes compared to reference conditions is given in Table 4.32 below.

Table 4.32 Summary of relative changes from Reference Condition to Present state.

Key drivers	Change
Mouth closure	Under reference state a higher frequency of open, limited marine conditions (State 2) occurred. Present state sees increased frequency and duration of mouth closure (State 1). This limits recruitment of marine spawning species. Abundance of these fishes is consequently decreased.
Water quality	Although most species in the system tolerate the different salinity regimes under all defined states the salinity gradient under open, limited marine conditions (State 2) is most beneficial to estuarine dependent (and a limited number of marine) species. Reduction in the frequency of this state and its associated salinity gradient further limit the number and abundance of marine spawning species. More significant however, is degraded water quality from excessive nutrient loads delivered to the system. This results in depressed oxygen concentrations which limit the diversity and abundance of all fishes, with the exception on the freshwater *O. mossambicus*.
Habitat	Losses in intertidal and subtidal habitat have occurred. This is governed by sedimentation, reduced flood frequency, increased nutrients and encroachment of vegetation. This reduces the abundance of all estuarine fishes in the estuary. Some freshwater species may have benefited from increased marginal vegetation.

Key drivers	Change
Prey availability	A marked reduction in the abundance of penaeid prawns has occurred, limiting prey availability for select estuarine dependent species, and therefore their abundance in the estuary.

4.8.2 Fish health

The Present Ecological State (PES) of the Mhlali fish assemblage is described and scored in Table 4.33 below. About 80% of the impact on fish was thought to be non-flow related.

Table 4.33 Fish component health score

Variable	Summary of change	Score	Conf
1. Species richness	Species richness is reduced compared to the reference condition. There is increased mouth closure, but the estuary does open over the main recruitment periods for estuarine dependent marine fishes. Loss of recruitment potential is therefore limited. Salinity regimes during the closed phase also support all the main species. Water quality (depressed oxygen concentrations) impacts species richness. Added to the loss of estuary area which has occurred with subtidal and intertidal habitat losses. This results in the system supporting fewer species.	70	L
2. Abundance	Reduced recruitment noted above is likely to have some impact on the abundance of estuarine dependent fishes. Specialist overwash recruiters (e.g. *Rhabdosargus holubi* and *M. capensis*) will be less impacted and are likely to dominate the estuarine dependent component of the fish community. Loss of aquatic habitats (intertidal banks, subtidal area) and reed encroachment also reduces fish abundance. Overfishing has also impacted stocks of some key species (including mullet for bait, which are susceptible to cast netting in this shallow system). Loss of subtidal and intertidal area, as well as backfill habitat causes a reduction in estuarine nursery function and fish abundance. Water quality (high nutrient loads and reduced oxygen concentrations) probably plays the most significant role in limiting abundance of key fish species.	60	L
3. Community composition	Reed encroachment has impacted large areas, replacing open water sandbanks. This markedly changes species composition to one that is dominated by freshwater species (*O. mossambicus*) from one previously dominated by mullet (and other estuarine dependent) species.	60	L
Biotic component health score		**60**	
% of impact non-flow related		**80**	**L**
Adjusted score		**92**	

4.9 BIRDS

4.9.1 Overview

i) Main grouping and baseline description

The aquatic avifauna of the Mhlali Estuary is very poorly known. The site is not included in the nation-wide Co-ordinated Waterbird Counts Project of the Animal Demography Unit, University of Cape Town. The estuary is relatively inaccessible, at least partially explaining this dearth of knowledge. It is not regularly visited by bird-watchers. For the purposes of this study, the birds found on the estuary have been grouped into six groups (Table 4.34).

Table 4.34 Waterbird feeding guilds and their defining features and typical/dominant species

Main foraging guilds	Defining features and typical/dominant species
Swimming piscivores	This group, which favours expanses of open, deep water, essentially comprises the cormorants, although the African Darter will also enter estuaries when and where these are dominated by freshwater conditions, as well as the pelicans (both Great White and Pink-backed pelicans). The two most common cormorants are the White-breasted and Reed cormorants, although small numbers of Cape Cormorants will also seasonally enter some systems during the winter-spring period. The very shallow nature of Mhlali Estuary offers little suitable habitat for this guild.
Aerial piscivores	The primary aerial piscivores (species hunting from the wing, or elevated perches, over open water) in estuaries are terns (primarily Caspian, Swift, Lesser Crested, Sandwich, Common and Little terns), aquatic raptors (African Fish Eagle and Osprey) and kingfishers (mainly Pied, Giant and Malachite kingfishers). The fact that many terns often use open sandbanks in estuaries for roosting rather than foraging is particularly relevant in the case of Mhlali Estuary, which once hosted a major tern roost in such circumstances.
Large wading piscivores	The primary large wading piscivores are the herons and egrets (especially Goliath, Grey, Purple and Black-crowned Night herons and Little Egret). These species are characteristic of wetland shorelines and their ability to extend their hunting range into inundated areas depends primarily on their size/leg-length. Storks (essentially the Woolly-necked Stork in this region) and African Spoonbill are additional large wading piscivores. Salinity militates against the abundance of amphibians (frogs) and hence the large wading predatory waterbirds that tend to specialise on these animals, e.g. Hamerkop and Yellow-billed Egret.
Small wading invertebrate feeders	The main groups here are the shorebirds (e.g. sandpipers, plovers, stints, thick-knees, etc.), i.e. the migratory Palaearctic waders and their resident counterparts. These species feed on benthic macroinvertebrates. Like the large wading piscivores, many of these species are characteristic of wetland shorelines but many also exploit inter-tidal sand- and mud-flats. Indeed these inter-tidal areas are often the most important habitat for many of the Palaearctic waders and some a wholly reliant on these habitats on their non-breeding grounds. A large diversity of species characterises this group, e.g. sandpipers, plovers, lapwings, stilts, oystercatchers and thick-knees. Ibises, essentially African Sacred and Hadeda ibises, are likely also best placed in this group despite their size, although both species likely obtain the bulk of their food outside estuaries, indeed wetlands generally, as in the case of the Egyptian Goose (see below).
Swimming herbivorous waterfowl	Salinity also militates against the growth of higher vegetation in most estuaries (although this does not apply to much of the broader Mhlali Estuary area), limiting the food supply for herbivorous waterfowl (ducks and geese) in many instances. It also severely curtails the abundance of the otherwise ubiquitous Red-knobbed Coot, and some other rallids, in these habitats. Waterfowl, however, do occur when and where estuaries are dominated by freshwater conditions, e.g. African Black Ducks – river specialists, typically occur in the upper reaches of estuaries where rivers enter these systems. Some waterfowl, however, feed on a mixture of plant material and invertebrate food such as small crustaceans. These birds, like terns, are also attracted to roost at estuaries. The Egyptian Goose is a particularly abundant, and increasing, estuarine waterfowl but it likely obtains most of its food in surrounding dryland habitats, e.g. lawns, pastures and cropfields. The same applies to the Spur-winged Goose. Mhlali Estuary is characterised by extensive encroachment by aquatic vegetation.
Carnivorous and scavenging gulls	Gulls, primarily the Kelp and Grey-headed gulls along the KZN coastline, have an unparalleled dietary breadth as carnivores, feeding on both vertebrate and invertebrate matter both live and dead (scavenged). Their breadth of foraging strategies is equally broad. Gulls, like terns, often also use estuaries as roosting sites, coming in from the nearby coastline for this purpose.

ii) Description of factors influencing birds

Table 4.35 and Table 4.36 lists the expected effects of various abiotic and biotic factors on the different waterbird feeding guilds present at Mhlali Estuary.

Table 4.35 Effect of abiotic characteristics and processes, as well as other biotic components (variables) on various groupings (generalist gulls excluded from consideration due to their overall resilience, unpredictability and adaptability)

Grouping			
Swimming and large wading piscivores	**Aerial piscivores**	**Swimming herbivorous waterfowl**	**Small wading invertebrate feeders**
Mouth condition			
Indirectly, through influence on water level and fish.		Indirectly, through influence on macrophytes.	Mouth closures have negative effect on preferred inter-tidal sandbanks in lower estuary. Also affects roosting terns and waterfowl.
Salinity			
Indirectly, through influence on fish.		Prefer lower salinities.	Some Palaearctic waders reliant on seawater conditions.
Turbidity			
Negatively affects visibility for foraging.		Negatively affects submerged aquatic plants.	Only if impacts benthic macroinvertebrates.
Intertidal area			
Indirectly, through influence on fish.	Indirectly, through influence on fish. Shallow water at high tide likely valuable as foraging area.	Only important for this group if exposes submerged food plants, e.g. *Zostera*, at low tide. Roosting habitat also exposed at low tide.	Critically important habitat for waders which rely mostly on intertidal areas for feeding.
Sediment characteristics (including sedimentation)			
Indirectly, through influence on fish.		Can enhance macrophyte growth, e.g. reeds.	Most waders prefer medium to fine sand; a few prefer coarse sand and mud. Sedimentation can smother benthic macroinvertebrates.
Primary productivity			
Indirectly though influence on food supply.			
Submerged macrophytes abundance			
Indirectly, through influence on fish (food and cover).		Has positive influence on herbivorous waterfowl numbers.	Indirectly, if affects benthic macroinvertebrates.
Abundance of reeds and sedges			
Indirectly, through influence on fish (food and cover). Encroaches on roosting habitat of terns.		Has positive influence on some herbivorous waterfowl species.	Encroachment of macrophytes largely at expense of open habitats required by waders.
Abundance of zooplankton			
Indirectly, through influence on fish.		Assumed positive for some omnivorous species.	
Benthic invertebrate abundance			
Indirectly, through influence on fish.			Primary food source for invertebrate-feeding waders.
Fish biomass			
Piscivores will increase with increasing numbers of small to medium-sized fish.			Indirectly, if fish compete for benthic macroinvertebrates.

Table 4.36 Summary of bird responses to different abiotic states

State	Response
State 1: Closed	The deep water conditions of a closed-mouth state increase habitat for swimming piscivores and, possibly, aerial piscivores. Where this results in back-flooding into the floodplain, it can also increase habitat for wading piscivores and herbivorous waterfowl, indeed for waterbirds generally. The lack of tidal conditions though results in reduced habitat for many key small invertebrate-feeding waders, and likely also reduces potentially suitable exposed sandbanks for roosting terns and gulls.
State 2: Tidal, intermittently closed	A condition intermittent between that described directly above and below.
State 3: Tidal	Where this is associated with extensive inter-tidal sand flats and mudflats, it can provide key habitat for key small invertebrate-feeding waders. Exposed sandflats and mudflats are also suitable for roosting terns and gulls.
State 4: Freshwater dominated	Probably the least productive scenario from a waterbird perspective under normal circumstances.

iii) Reference condition

Key threats operating to shift the estuary away from its reference condition include: extensive sugar-cane planting in the catchment and floodplain, siltation, water abstraction and other flow-related factors, water pollution including eutrophication and inflows from waste-water treatment plants, the spread of both alien and indigenous (reedbeds) aquatic vegetation and human disturbance (Table 4.37).

Table 4.37 Summary of relative changes from Reference Condition to Present state

Key drivers	Change
Sugar-cane planting in floodplain and catchment.	Direct loss of estuarine habitat. Increased siltation and turbidity of estuary. Directly effects visual predatory piscivores.
Water abstraction.	Reduced flow with profound impact on estuarine ecology, especially for deeper-water species such as swimming piscivores.
Water pollution, including eutrophication and inflow from WWTW.	Eutrophication promotes encroachment of macrophytes in the estuary.
Macrophyte encroachment at cost of exposed sandflats in main river channel.	Loss of habitat to waterbirds requiring open wetland conditions.
Human disturbance at the mouth.	Negatively impacts roosting terns and gulls.
TOTAL CHANGE	**60%**

4.9.2 Bird health

The Present Ecological State of the Mhlali bird assemblage is described and scored in Table 4.38 below. About 80% of the impact on fish was thought to be non-flow related.

Table 4.38 Bird component health score

Variable	Summary of change	Score	Conf
1. Species richness	Some key species likely no longer present at the estuary or now only rare visitors.	70	L
2. Abundance	Likely an overall decrease in waterbird numbers.	50	L
3. Community composition	Likely loss of some rarer species and increase in hardy generalists, e.g. Blacksmith Lapwing and Egyptian and Spur-winged geese.	40	L
Biotic component health score		**40**	**L**
% of impact non-flow related		**80**	**L**
Adjusted score		**88**	

5 PRESENT ECOLOGICAL STATE

5.1 OVERALL ESTUARINE HEALTH INDEX SCORE

The Estuarine Health Index (EHI) scores allocated to the various abiotic and biotic health parameters for the Mhlali Estuary and the overall PES for the system under the present state are calculated from the overall EHI score (Table 5.1). The EHI score for the Mhlali Estuary in its present state was estimated to be 57 (i.e. 57% similar to natural condition), which translates into a PES of D (summarised in Table 5.1).

The Mhlali Estuary is in a D Category, which is mostly attributed to the following factors:

- Significant loss of habitat in the EFZ as a result of sugar cane farming.
- Increase nutrient input as a result of WWTW and poor catchments practises, causing excessive growth of reed and aquatic invasive plants in intertidal and subtidal habitats; and
- Artificial breaching of the estuary mouth.

The Mhlali Estuary is on a steep trajectory downwards as significant further deterioration in estuary health is anticipated once the Shakaskraal WWTW runs at full capacity and the Tinley Manor WWTW (planned for 2015) discharges into the estuary. See Chapter 7 for more detail.

Table 5.1 Estuarine Health Score (EHI) for the Mhlali Estuary

Variable	Estuarine health score		
	Overall	**Excluding flow related pressures**	**Conf**
Hydrology	62	62	L
Hydrodynamics and mouth condition	80	80	L
Water quality	62.2	62.2	L
Physical habitat alteration	60	98	L
Habitat health score	**66**	**76**	
Microalgae	50	100	L
Macrophytes	51	90	L
Invertebrates	40	88	L
Fish	60	92	L
Birds	40	92	L
Biotic health score	**48**	**92**	
ESTUARY HEALTH SCORE	**57**	**84**	
PRESENT ECOLOGICAL STATUS (PES)	**D**	**B**	
OVERALL CONFIDENCE	**L**	**L**	

5.2 RELATIVE CONTRIBUTION OF FLOW AND NON-FLOW RELATED IMPACTS ON HEALTH

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 84, which would raise the PES to a B Category. This suggests that non-flow related impacts have played a significant role in the degradation of the estuary to a D, but that flow-related impacts are also one of the main causes of its degradation.

The highest priority is to address the quality of influent water. Of the non-flow-related impacts, water quality problem as a result of the high nutrient load associated with the WWTWs and poor catchments practises was found to be the most important factor that influenced the health of the system. The excess nutrients in the inflowing water increased plant growth and loss of open intertidal and riparian habitat (e.g. sand and mudbanks that use to be important bird habitats). A low oxygen event that is associated with high nutrient and organic inputs reduce invertebrate abundance to 40% of Reference Conditions and prevents the system from functioning as an effective fish nursery. This in turn reducing food availability to birds.

Another key non-flow related pressure was the **loss of riparian area due to sugarcane farming** in the EFZ, causing a loss the habitat and loss of a buffer area against human disturbance.

Confidence levels were low for most of the abiotic components and biotic components. The overall confidence of the study was LOW (Table 3.36).

In terms of the abiotic components, it was not possible to define and characterise the three abiotic states for this system with high/medium confidence, mainly because long-term continues mouth state/water level data and river inflow records were not available. Water quality data on river inflow also was not available for river inflow near the head of the estuary Very limited information was available on the biotic components of the study.

6 THE RECOMMENDED ECOLOGICAL CATEGORY

6.1 CONSERVATION IMPORTANCE

The Estuary Importance Score (EIS) takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account. 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 present state. The scores have been determined for all South African estuaries, apart from functional importance, which is scored by the specialists in the workshop. The Estuary Importance scores for five components and the importance rating is presented in Tables 6.1 and 6.2, respectively.

Table 6.1 Estimation of the functional importance score of the Mhlali Estuary

Functionality	Score
a. Estuary: Input of detritus and nutrients generated in estuary	20
b. Nursery function for marine-living fish	70
c. Movement corridor for river invertebrates and fish breeding in sea	20
d. Migratory stopover for coastal birds	40
e. Catchment detritus, nutrients and sediments to sea	20
f. Coastal connectivity (way point) for fish	40
Functional importance score - Max (a to f)	**70**

Historically the Mhlali supported a very good diversity of fish species. This is reduced under present day conditions. Although the Mhlali is a relatively small system located on a section of coast with a relative abundance of estuaries, the nature of the system (bathymetry, mouth dynamics and resulting salinity regimes over different states) renders its nursery potential good. From a functional importance perspective, it can be considered of medium nursery value for estuarine associated fish species in the region.

Table 6.2 EIS for the Mhlali Estuary

Criterion	Weight	Score
Estuary Size	15	60
Zonal Rarity Type	10	10
Habitat Diversity	25	90
Biodiversity Importance	25	80
Functional Importance	25	70
Weighted Estuary Importance Score		**63**

The EIS for the Mhlali Estuary, is therefore estimated to be 63 (Table 6.2), i.e., the estuary is rated as “Important” (Table 6.3).

Table 6.3 EIS and significance

Importance score	Description
81 – 100	Highly important
61 – 80	**Important**
0 – 60	Of low to average importance

6.2 RECOMMENDED ECOLOGICAL CATEGORY

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' Ecological Category based on its PES. The relationship between EHI Score, PES and minimum REC is set out in Table 6.4.

Table 6.4 Relationship between the EHI, PES and minimum REC

EHI Score	PES	Description	Minimum Ecological Category
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of importance and level of protection or desired protection of a particular estuary (Table 6.5).

Table 6.5 Estuary protection status and importance, and the basis for assigning a Recommended Ecological Category

Protection status and importance	REC	Policy basis
Protected area	**A or BAS[1]**	**Protected and desired protected areas should be restored to and maintained in the best possible state of health.**
Desired Protected Area		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category.
Important	**PES + 1, min C**	**Important estuaries should be in an A, B or C category.**
Of low to average importance	PES, min D	Estuaries to remain in a D category.

1 BAS = Best Attainable State

The PES for the Mhlali Estuary is a D, with a steep downwards trajectory. The Mhlali Estuary is rated as “Important” from a biodiversity perspective and should therefore be in a C Category.

In addition, the system also forms part of the core set of priority estuaries in need of protection to achieve biodiversity targets in the National Estuaries Biodiversity Plan for the National Biodiversity Assessment – NBA (Turpie *et al*., 2012). The NBA 2011 (Van Niekerk and Turpie, 2012) recommends that the minimum Category for the Mhlali be a B, that the system be a granted partial no-take protection, and that 50% of the estuary margin be undeveloped (Table 6.6).

Table 6.6 National Estuary Biodiversity Plan requirements

Estuary Requirements	Mhlali
Current health category	C
National and/or Regional Priority set	South Africa
Recommended extent of protection	Partial
Recommended extent of undeveloped margin	50%
Provisional estimate of REC	B

Based on the above and the reversibility of impacts, the REC for the Mhlali Estuary is a B Category.

7 CONSEQUENCES OF ALTERNATIVE SCENARIOS

7.1 DESCRIPTION OF SCENARIOS

The proposed scenarios for the Mhlali system are summarised in Table 7.1.

Table 7.1 Summary of flow scenarios

Scenarios	Description	MAR (10^6 m^3)	% Remaining
Reference	Natural Flow	56.31	100
Present	Present day (including WWTW: Shakaskraal (0.8 Ml/d))	51.55	92
Scenario 1	Present, with all waste water removed	51.26	91
Scenario 2	Present day (WWTW: Shakaskraal (1.6 Ml/d) and Tinley Manor (6 Ml/d))	54.03	96
Scenario 3	Abstraction and WWTW (WWTW: Shakaskraal (1.6 Ml/d) and Tinley Manor (6 Ml/d))	46.94	83
Scenario 4	WWTW at full capacity (1.6 Ml/d and 18Ml/d)	58.41	104
Scenario 5	Present minus WWTW, including remedial actions: rehab of flood plain, removal of old weir, no artificial breaching, no sugar cane farming in the EFZ	51.26	91

7.2 VARIABILITY IN RIVER INFLOW

The occurrences of the flow distributions (mean monthly flows in m^3/s) under the future Scenarios of the Mhlali Estuary, derived from a 85-year simulated data set, are provided in Table 7.2 to 7.5 and Figure 7.1 to 7.4. The full sets 85-year series of simulated monthly runoff data for the future Scenarios are listed in Table 7.6 to 7.10.

Table 7.2 Summary of the monthly flow (in m^3/s) distribution under Scenario 1 and 5

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	12.92	17.08	16.38	17.46	19.97	26.62	12.01	5.80	20.45	6.22	1.01	28.77
99	12.45	13.49	14.03	15.76	17.38	23.93	11.05	5.64	5.21	1.81	0.80	7.37
90	1.99	6.31	5.59	6.59	11.11	7.91	4.59	2.15	0.53	0.37	0.38	0.50
80	1.05	3.19	3.69	4.81	7.72	5.19	2.60	0.68	0.29	0.23	0.18	0.30
70	0.52	2.19	2.40	3.44	4.12	3.75	1.64	0.42	0.19	0.07	0.10	0.23
60	0.42	1.01	1.65	2.59	2.78	2.41	0.86	0.30	0.11	0.06	0.08	0.15
50	0.32	0.63	1.06	1.73	2.10	1.53	0.59	0.21	0.07	0.06	0.06	0.08
40	0.24	0.44	0.62	0.91	1.25	0.91	0.42	0.15	0.06	0.06	0.05	0.07
30	0.15	0.34	0.45	0.56	0.64	0.55	0.31	0.11	0.06	0.05	0.04	0.05
20	0.08	0.24	0.33	0.39	0.50	0.33	0.21	0.08	0.05	0.04	0.04	0.05
10	0.06	0.10	0.14	0.26	0.24	0.17	0.08	0.07	0.04	0.04	0.04	0.04
1	0.04	0.05	0.06	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03
0.1	0.04	0.04	0.05	0.06	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02

Table 7.3 Summary of the monthly flow (in m³/s) distribution under Scenario 2

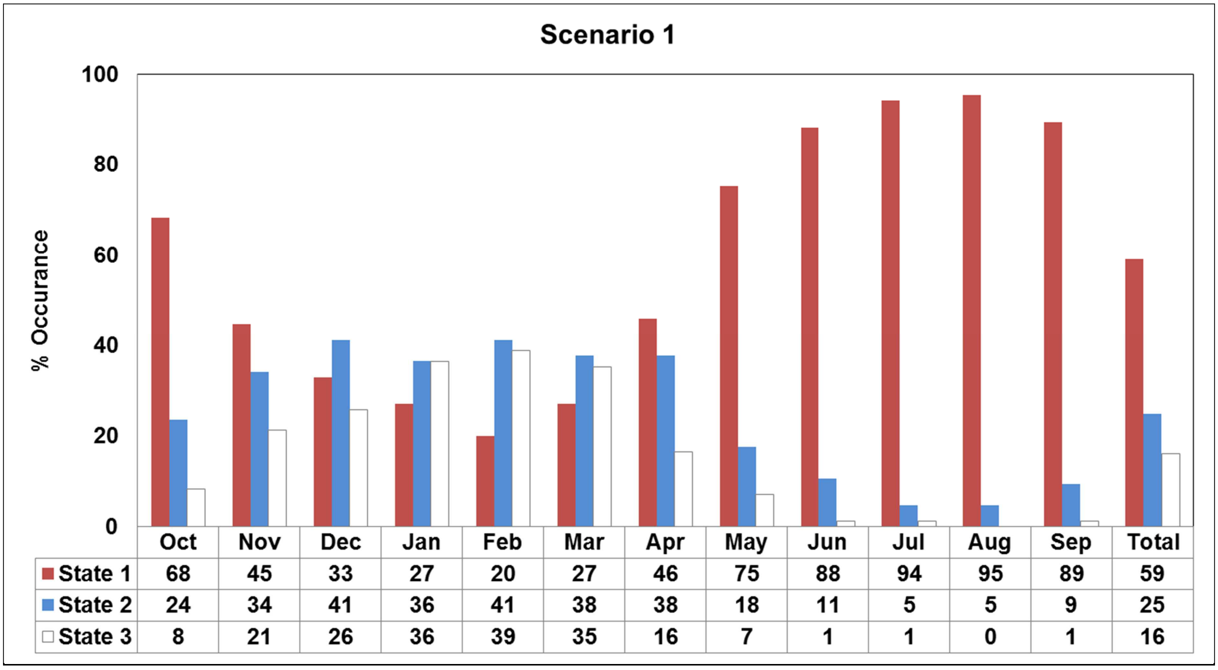
%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	13.01	17.17	16.47	17.55	20.06	26.71	12.10	5.88	20.53	6.30	1.09	28.86
99	12.54	13.58	14.12	15.84	17.47	24.02	11.14	5.72	5.30	1.89	0.88	7.45
90	2.08	6.40	5.68	6.68	11.20	7.99	4.68	2.23	0.62	0.46	0.46	0.58
80	1.14	3.28	3.77	4.90	7.81	5.28	2.69	0.76	0.38	0.32	0.26	0.39
70	0.60	2.28	2.48	3.53	4.21	3.84	1.73	0.51	0.28	0.16	0.19	0.32
60	0.50	1.10	1.74	2.68	2.87	2.49	0.95	0.38	0.19	0.15	0.16	0.24
50	0.40	0.71	1.15	1.81	2.19	1.61	0.68	0.30	0.16	0.15	0.15	0.17
40	0.32	0.52	0.71	1.00	1.35	1.00	0.51	0.24	0.15	0.14	0.14	0.16
30	0.23	0.43	0.54	0.64	0.73	0.63	0.40	0.19	0.15	0.14	0.13	0.14
20	0.16	0.33	0.41	0.47	0.60	0.42	0.30	0.16	0.14	0.13	0.13	0.14
10	0.15	0.19	0.23	0.34	0.34	0.25	0.17	0.15	0.13	0.12	0.13	0.13
1	0.13	0.13	0.15	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.12	0.12
0.1	0.13	0.13	0.14	0.14	0.15	0.13	0.13	0.11	0.11	0.10	0.10	0.11

Table 7.4 Summary of the monthly flow (in m³/s) distribution under Scenario 3

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	12.69	16.85	16.15	17.24	19.72	26.40	11.77	5.57	20.21	5.99	0.78	28.53
99	12.22	13.26	13.81	15.53	17.13	23.71	10.82	5.41	4.98	1.58	0.57	7.13
90	1.76	6.08	5.37	6.37	10.86	7.68	4.36	1.92	0.30	0.15	0.15	0.26
80	0.82	2.96	3.46	4.59	7.47	4.97	2.36	0.45	0.09	0.09	0.09	0.09
70	0.29	1.96	2.17	3.21	3.87	3.53	1.40	0.20	0.09	0.09	0.09	0.09
60	0.19	0.77	1.42	2.36	2.53	2.18	0.62	0.09	0.09	0.09	0.09	0.09
50	0.09	0.39	0.83	1.50	1.85	1.30	0.36	0.09	0.09	0.09	0.09	0.09
40	0.09	0.20	0.40	0.68	1.00	0.69	0.19	0.09	0.09	0.09	0.09	0.09
30	0.09	0.10	0.22	0.33	0.39	0.32	0.09	0.09	0.09	0.09	0.09	0.09
20	0.09	0.09	0.10	0.16	0.25	0.10	0.09	0.09	0.09	0.09	0.09	0.09
10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.09	0.09	0.07
1	0.03	0.01	0.05	0.03	0.06	0.08	0.02	0.02	0.01	0.01	0.06	0.00
0.1	0.02	0.01	0.04	0.03	0.02	0.07	0.01	0.01	0.01	0.00	0.02	0.00

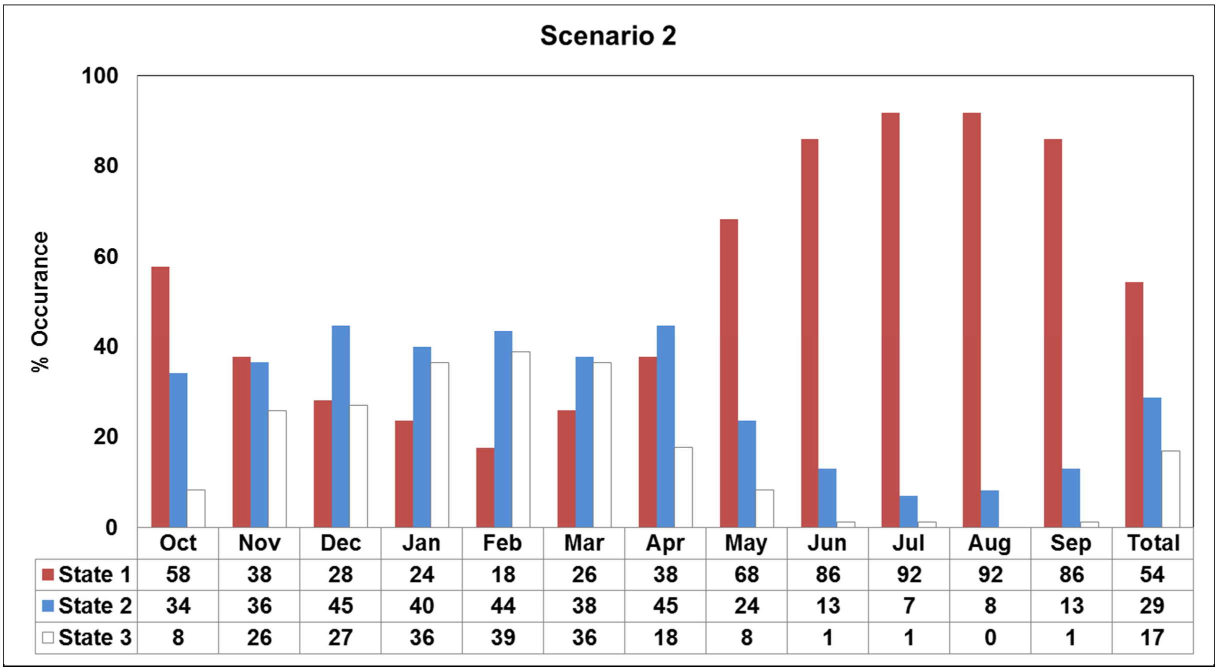
Table 7.5 Summary of the monthly flow (in m³/s) distribution under Scenario 4

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	13.15	17.31	16.60	17.69	20.21	26.85	12.24	6.02	20.68	6.44	1.23	29.00
99	12.67	13.73	14.26	15.98	17.62	24.16	11.29	5.86	5.45	2.03	1.02	7.60
90	2.21	6.54	5.82	6.82	11.36	8.13	4.82	2.37	0.76	0.60	0.60	0.73
80	1.27	3.42	3.91	5.04	7.96	5.42	2.83	0.90	0.52	0.45	0.40	0.53
70	0.74	2.42	2.62	3.66	4.36	3.98	1.87	0.65	0.42	0.30	0.33	0.47
60	0.64	1.24	1.87	2.82	3.02	2.63	1.09	0.52	0.34	0.29	0.30	0.39
50	0.54	0.86	1.28	1.95	2.34	1.75	0.82	0.44	0.30	0.28	0.28	0.32
40	0.46	0.67	0.85	1.13	1.50	1.14	0.65	0.37	0.30	0.28	0.28	0.30
30	0.37	0.57	0.68	0.78	0.88	0.77	0.55	0.33	0.29	0.28	0.27	0.29
20	0.30	0.47	0.55	0.61	0.75	0.56	0.44	0.30	0.29	0.27	0.27	0.28
10	0.29	0.34	0.37	0.48	0.49	0.39	0.32	0.29	0.28	0.26	0.27	0.27
1	0.27	0.28	0.29	0.31	0.31	0.28	0.28	0.27	0.26	0.25	0.25	0.27
0.1	0.27	0.27	0.28	0.28	0.30	0.27	0.27	0.25	0.25	0.24	0.24	0.25



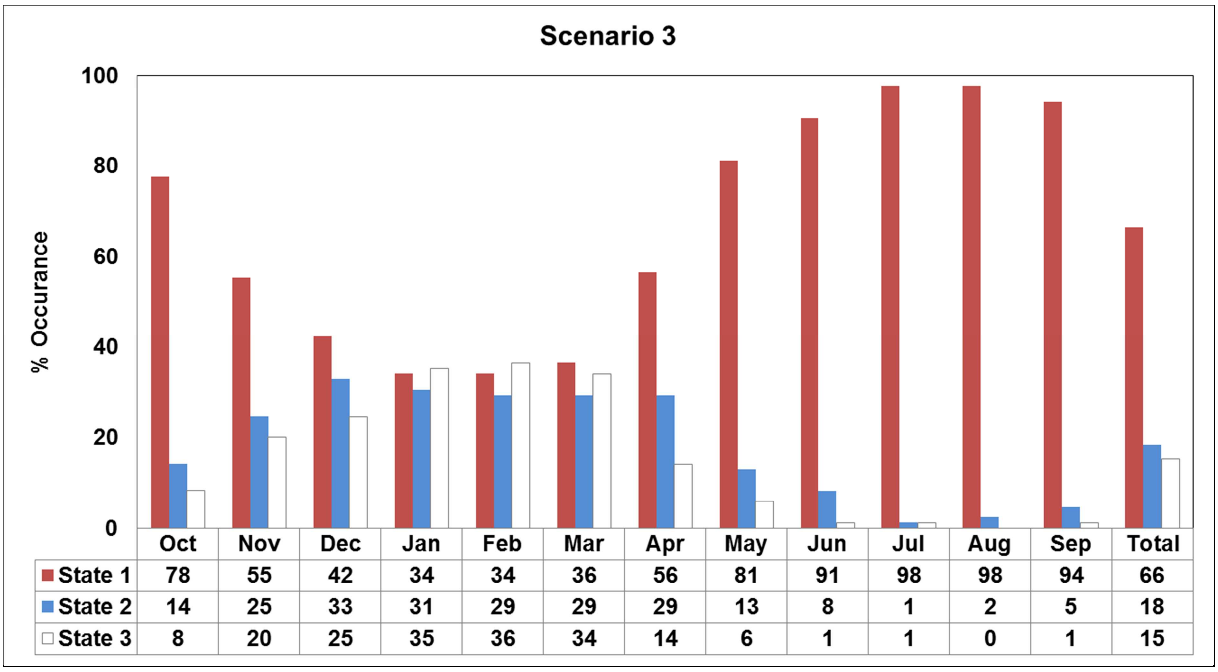
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	68	45	33	27	20	27	46	75	88	94	95	89	59
State 2	24	34	41	36	41	38	38	18	11	5	5	9	25
State 3	8	21	26	36	39	35	16	7	1	1	0	1	16

Figure 7.1 Graphic presentation of the occurrence of the various abiotic states under the Scenario 1 and 5



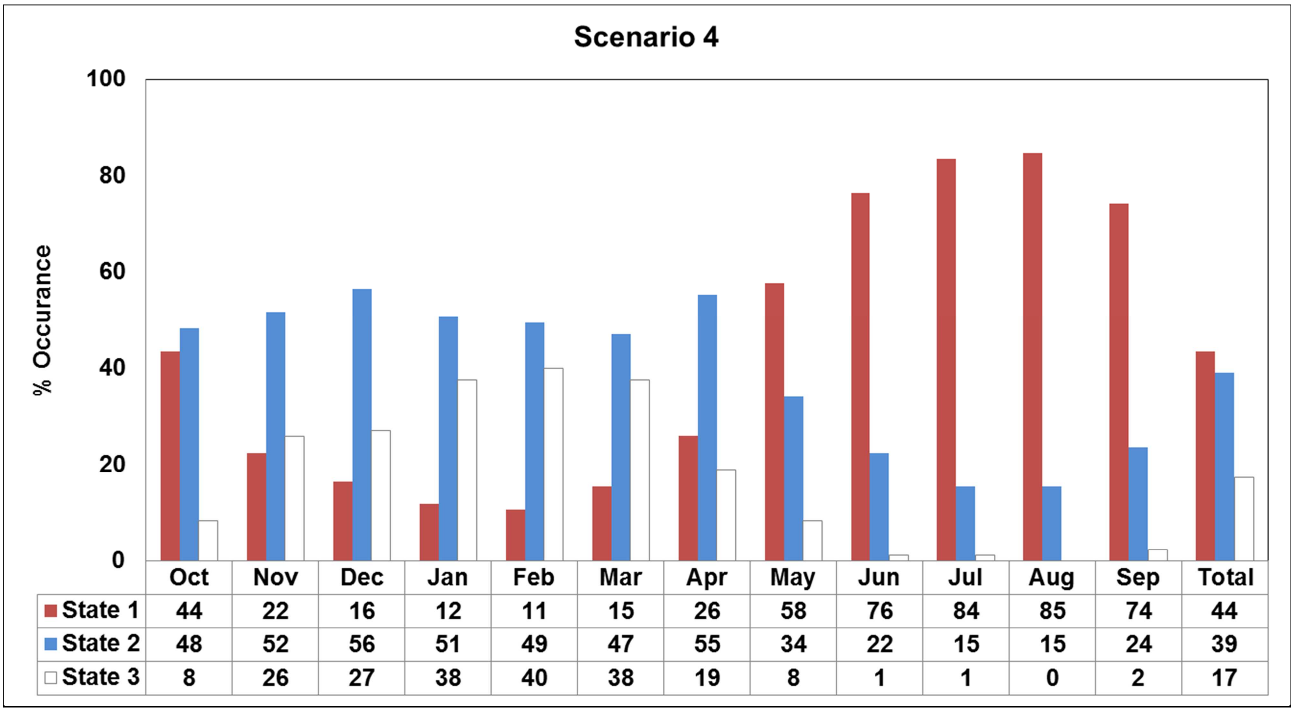
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	58	38	28	24	18	26	38	68	86	92	92	86	54
State 2	34	36	45	40	44	38	45	24	13	7	8	13	29
State 3	8	26	27	36	39	36	18	8	1	1	0	1	17

Figure 7.2 Graphic presentation of the occurrence of the various abiotic states under Scenario 2



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	78	55	42	34	34	36	56	81	91	98	98	94	66
State 2	14	25	33	31	29	29	29	13	8	1	2	5	18
State 3	8	20	25	35	36	34	14	6	1	1	0	1	15

Figure 7.3 **Graphic presentation of the occurrence of the various abiotic states under Scenario 3**



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
State 1	44	22	16	12	11	15	26	58	76	84	85	74	44
State 2	48	52	56	51	49	47	55	34	22	15	15	24	39
State 3	8	26	27	38	40	38	19	8	1	1	0	2	17

Figure 7.4 **Graphic presentation of the occurrence of the various abiotic states under Scenario 4**

Table 7.6 Simulated monthly flows (in m^3/s) to the Mhlali Estuary for Scenario 1 (and 5)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.70	0.67	1.81	0.93	1.63	0.79	0.38	0.14	0.05	0.03	0.03	0.04
1921	0.52	17.48	12.96	2.48	0.35	0.35	0.20	0.38	0.31	0.07	0.15	0.08
1922	5.70	6.04	1.31	4.39	3.22	0.98	0.41	0.08	0.05	0.04	0.04	0.04
1923	0.04	0.04	0.17	1.02	1.52	0.50	0.15	0.07	0.05	0.04	0.03	0.17
1924	0.22	0.63	1.69	2.74	1.72	26.92	9.34	0.29	0.07	0.06	0.06	0.24
1925	0.49	0.34	0.22	0.10	0.19	0.54	0.25	0.07	0.08	0.05	0.04	0.04
1926	0.27	0.38	0.27	0.21	2.70	16.66	5.44	0.09	0.05	0.04	0.05	0.05
1927	0.06	0.08	0.31	2.28	1.44	0.52	0.26	0.07	0.04	0.03	0.03	0.04
1928	0.06	0.24	0.41	0.63	0.62	8.06	2.88	0.13	0.48	0.87	0.44	1.46
1929	4.31	2.09	0.44	1.16	0.54	0.44	0.39	0.13	0.06	0.06	0.19	0.44
1930	0.46	0.48	0.55	3.30	1.22	0.34	0.28	0.07	0.05	0.16	0.08	0.06
1931	0.06	0.06	0.10	0.50	11.80	7.21	1.50	0.42	0.10	0.06	0.04	0.04
1932	0.18	0.34	0.51	0.44	0.23	0.16	0.13	0.07	0.05	0.04	0.04	0.04
1933	0.04	0.41	3.17	6.03	2.32	2.03	3.11	1.36	0.31	0.31	0.32	0.11
1934	0.08	0.07	0.43	3.26	4.13	2.18	0.65	5.82	22.14	6.71	0.42	0.18
1935	0.09	0.08	0.09	0.40	7.66	6.16	1.49	3.85	1.52	0.09	0.07	0.05
1936	0.16	11.35	3.67	0.25	2.29	0.84	0.56	0.16	0.14	0.06	0.09	0.07
1937	0.07	0.14	6.49	3.11	8.57	2.35	0.50	0.21	0.27	0.46	0.24	0.08
1938	0.37	1.75	1.83	0.91	8.17	6.13	1.54	0.63	0.26	0.19	0.08	0.51
1939	0.70	3.87	3.58	1.06	0.34	0.20	0.15	3.00	1.71	0.33	0.07	0.07
1940	0.15	6.02	4.03	0.91	0.14	0.31	0.83	0.31	0.07	0.06	0.04	0.08
1941	0.12	0.31	0.13	2.55	1.28	4.81	1.85	0.43	0.19	0.07	0.15	0.27
1942	0.65	7.03	11.97	3.55	3.90	5.06	7.71	2.63	0.44	0.58	1.03	0.53
1943	5.87	6.93	1.92	0.26	0.67	4.77	1.90	0.15	0.17	0.07	0.07	0.47
1944	1.15	0.88	0.29	0.21	3.29	12.12	3.90	0.27	0.07	0.06	0.04	0.04
1945	0.05	0.06	0.06	0.37	0.54	1.55	1.50	0.48	0.07	0.05	0.04	0.04
1946	0.06	0.31	0.59	1.73	11.27	3.66	1.55	0.52	0.39	0.16	0.09	0.08
1947	0.09	2.59	1.25	2.84	4.57	4.07	3.35	0.84	0.07	0.05	0.04	0.04
1948	0.37	1.79	0.91	0.52	3.63	1.28	0.75	0.32	0.08	0.06	0.04	0.05
1949	0.41	4.91	7.22	2.52	0.70	0.61	0.31	0.25	0.07	0.05	0.06	0.05
1950	0.05	0.05	0.86	0.81	0.53	2.99	1.21	0.11	0.05	0.05	0.29	0.62
1951	0.67	0.34	2.70	6.18	2.10	0.36	0.72	0.69	0.29	0.08	0.07	0.06
1952	0.06	0.18	0.89	17.65	13.83	2.40	0.21	0.07	0.04	0.04	0.04	0.15
1953	0.26	0.59	3.86	1.70	2.63	1.24	0.39	0.21	0.07	0.06	0.05	0.36
1954	12.97	6.64	0.87	6.00	2.38	4.43	2.06	0.37	0.11	0.06	0.05	0.13
1955	0.32	0.95	0.62	0.13	4.50	8.05	2.67	0.27	0.07	0.06	0.10	0.28
1956	0.28	0.47	13.54	4.78	2.83	2.00	9.88	3.11	0.07	0.06	0.05	0.30
1957	1.75	3.04	1.65	9.91	13.84	3.51	6.36	2.15	0.10	0.07	0.06	0.26
1958	0.21	1.00	1.65	0.85	0.63	0.18	0.08	0.47	0.25	0.07	0.11	0.17
1959	0.56	0.62	0.48	0.32	0.50	1.22	0.90	0.29	0.06	0.05	0.04	0.04
1960	0.14	2.25	6.78	4.26	1.17	0.58	10.85	3.59	0.54	0.23	0.08	0.23
1961	0.41	0.57	0.33	0.46	0.50	1.00	0.57	0.14	0.05	0.04	0.07	0.06
1962	0.10	6.49	2.29	6.87	2.74	4.20	1.72	0.15	0.24	0.45	0.21	0.08
1963	0.19	0.24	0.28	9.38	3.65	0.31	0.32	0.08	0.05	0.06	0.04	0.05
1964	0.32	0.43	0.49	0.48	0.33	0.09	0.05	0.07	0.40	0.36	0.40	0.40
1965	0.45	0.68	0.65	2.26	1.09	0.12	0.07	0.24	0.12	0.06	0.05	0.05
1966	0.07	0.40	0.55	5.51	4.57	6.68	2.58	0.34	0.07	0.06	0.04	0.04
1967	0.14	1.99	0.75	5.80	2.42	0.60	0.35	0.08	0.05	0.04	0.15	0.24
1968	0.31	0.36	0.41	0.29	0.52	9.34	3.49	0.80	0.38	0.07	0.06	0.08
1969	2.30	3.79	2.42	0.97	0.34	0.10	0.06	0.17	0.13	0.06	0.06	0.29
1970	1.05	0.91	2.99	2.66	5.04	7.33	2.43	5.60	1.99	0.38	0.63	0.65
1971	0.41	0.29	1.90	0.83	6.23	2.06	0.43	0.67	0.51	0.24	0.08	0.07
1972	0.07	0.21	0.36	0.89	1.00	0.73	0.48	0.12	0.05	0.04	0.18	2.15
1973	1.74	2.95	1.19	3.42	9.01	2.79	0.59	0.48	0.18	0.06	0.06	0.05
1974	0.05	0.14	1.06	8.89	7.51	1.44	0.27	0.11	0.06	0.05	0.04	0.37
1975	0.50	0.54	3.47	7.88	7.94	19.95	12.11	2.14	0.10	0.09	0.12	0.15
1976	1.23	1.02	0.62	4.34	14.50	5.00	0.61	0.09	0.06	0.06	0.05	0.30
1977	0.52	0.72	0.59	5.60	2.71	3.78	1.79	0.30	0.07	0.06	0.06	0.14
1978	2.15	8.11	2.72	0.60	0.60	0.35	0.15	0.07	0.06	0.05	0.06	0.11
1979	0.46	0.30	0.33	0.36	0.20	0.09	0.06	0.04	0.03	0.03	0.03	2.84
1980	1.22	2.18	1.08	4.97	4.37	0.96	0.14	0.47	0.26	0.07	0.47	1.57
1981	1.05	4.07	1.33	2.34	1.13	0.67	0.55	0.19	0.06	0.05	0.04	0.04
1982	0.29	0.43	0.39	0.39	0.26	0.18	0.08	0.06	0.04	0.04	0.10	0.07
1983	0.25	5.57	5.43	15.40	16.83	7.49	5.05	1.56	0.25	0.53	0.56	0.25
1984	0.42	0.44	0.20	3.45	20.26	5.71	0.09	0.06	0.05	0.04	0.04	0.04
1985	4.72	2.20	1.19	4.43	1.83	1.61	0.92	0.15	0.06	0.05	0.05	0.05
1986	0.07	0.23	1.74	4.02	1.81	4.32	1.66	0.58	0.74	0.27	0.35	31.15
1987	12.35	4.51	1.64	0.38	16.11	23.36	6.38	1.89	1.00	0.25	0.31	0.15
1988	0.32	0.63	4.36	1.63	10.87	3.21	0.42	0.18	0.07	0.06	0.05	0.05
1989	0.13	12.74	4.40	0.58	0.66	7.69	2.91	0.21	0.06	0.05	0.12	0.08
1990	0.43	0.46	3.76	2.23	8.82	9.44	2.39	0.22	0.12	0.07	0.07	0.31
1991	0.98	2.93	0.94	0.36	0.22	0.09	0.07	0.05	0.04	0.04	0.03	0.04

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1992	0.05	0.14	0.09	0.09	0.23	0.22	0.22	0.07	0.04	0.03	0.04	0.14
1993	1.75	1.03	6.82	3.24	0.53	1.53	0.59	0.08	0.05	0.04	0.08	0.06
1994	0.37	0.29	0.11	0.09	0.07	0.33	3.23	1.61	0.84	0.31	0.07	0.05
1995	0.21	1.35	16.64	13.62	9.55	2.42	0.45	0.10	0.06	0.53	0.41	0.16
1996	0.34	0.39	0.21	5.26	3.19	0.71	0.74	0.35	0.29	0.34	0.16	0.17
1997	1.44	10.19	3.57	0.41	4.07	1.37	0.31	0.10	0.06	0.04	0.04	0.05
1998	0.06	0.16	0.35	0.55	10.55	3.25	0.21	0.07	0.13	0.06	0.19	0.31
1999	7.03	2.57	3.93	12.73	11.61	2.71	0.66	5.51	1.98	0.07	0.06	0.07
2000	0.28	2.94	5.70	1.84	0.32	0.15	0.39	0.16	0.06	0.05	0.04	0.19
2001	0.66	2.95	3.85	3.94	1.68	0.33	0.42	0.12	0.06	0.39	0.75	0.46
2002	0.18	0.08	0.09	0.10	0.08	0.06	0.06	0.04	0.04	0.03	0.03	0.09
2003	0.15	0.19	0.09	0.31	0.50	0.30	0.09	0.05	0.03	0.03	0.03	0.04
2004	0.05	0.06	0.05	0.06	0.06	0.04	0.04	0.03	0.02	0.01	0.01	0.02

Table 7.7 Simulated monthly flows (in m^3/s) to the Mhlali Estuary for Scenario 2

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.78	0.76	1.90	1.02	1.73	0.88	0.47	0.22	0.14	0.12	0.12	0.13
1921	0.60	17.57	13.05	2.57	0.45	0.44	0.29	0.46	0.40	0.16	0.24	0.17
1922	5.79	6.13	1.39	4.48	3.31	1.07	0.50	0.17	0.14	0.13	0.13	0.13
1923	0.13	0.13	0.25	1.11	1.61	0.59	0.24	0.15	0.14	0.12	0.12	0.25
1924	0.30	0.72	1.78	2.82	1.81	27.01	9.43	0.38	0.15	0.14	0.14	0.32
1925	0.57	0.43	0.30	0.19	0.29	0.62	0.34	0.16	0.17	0.14	0.13	0.13
1926	0.35	0.47	0.35	0.30	2.79	16.74	5.53	0.18	0.14	0.13	0.14	0.14
1927	0.15	0.17	0.40	2.37	1.53	0.61	0.35	0.16	0.13	0.12	0.12	0.13
1928	0.15	0.33	0.49	0.72	0.72	8.15	2.97	0.22	0.57	0.96	0.52	1.55
1929	4.39	2.18	0.53	1.25	0.64	0.53	0.47	0.22	0.15	0.14	0.28	0.53
1930	0.55	0.57	0.64	3.39	1.31	0.43	0.37	0.16	0.14	0.25	0.16	0.15
1931	0.15	0.15	0.19	0.59	11.90	7.30	1.59	0.50	0.19	0.14	0.13	0.13
1932	0.27	0.42	0.60	0.52	0.32	0.25	0.22	0.15	0.14	0.13	0.13	0.13
1933	0.13	0.49	3.25	6.12	2.41	2.12	3.20	1.44	0.40	0.40	0.41	0.20
1934	0.16	0.16	0.52	3.35	4.22	2.26	0.74	5.90	22.23	6.79	0.50	0.27
1935	0.18	0.17	0.18	0.49	7.76	6.25	1.58	3.93	1.60	0.18	0.15	0.14
1936	0.25	11.44	3.75	0.34	2.38	0.92	0.64	0.24	0.23	0.15	0.18	0.16
1937	0.16	0.23	6.58	3.20	8.67	2.44	0.59	0.30	0.36	0.54	0.33	0.17
1938	0.46	1.84	1.92	1.00	8.26	6.22	1.62	0.71	0.35	0.28	0.16	0.60
1939	0.79	3.95	3.67	1.15	0.43	0.28	0.24	3.08	1.80	0.42	0.16	0.16
1940	0.23	6.11	4.12	0.99	0.23	0.39	0.92	0.40	0.15	0.14	0.13	0.17
1941	0.20	0.40	0.21	2.63	1.37	4.89	1.94	0.51	0.28	0.15	0.24	0.36
1942	0.74	7.12	12.05	3.64	4.00	5.15	7.80	2.71	0.52	0.67	1.12	0.62
1943	5.96	7.02	2.00	0.34	0.76	4.86	1.99	0.24	0.25	0.15	0.15	0.56
1944	1.23	0.96	0.37	0.29	3.39	12.21	3.99	0.35	0.16	0.15	0.13	0.13
1945	0.14	0.15	0.15	0.45	0.64	1.64	1.59	0.57	0.16	0.14	0.13	0.13
1946	0.14	0.40	0.68	1.81	11.37	3.74	1.64	0.61	0.48	0.25	0.18	0.17
1947	0.18	2.68	1.34	2.93	4.66	4.15	3.44	0.93	0.15	0.14	0.13	0.13
1948	0.46	1.88	0.99	0.60	3.73	1.37	0.84	0.41	0.17	0.15	0.13	0.14
1949	0.50	5.00	7.30	2.61	0.79	0.70	0.40	0.34	0.16	0.14	0.14	0.14
1950	0.14	0.14	0.94	0.90	0.62	3.08	1.30	0.19	0.14	0.14	0.38	0.71
1951	0.75	0.43	2.78	6.26	2.19	0.45	0.81	0.78	0.38	0.17	0.15	0.15
1952	0.15	0.27	0.97	17.74	13.92	2.48	0.30	0.16	0.13	0.13	0.13	0.24
1953	0.35	0.68	3.94	1.78	2.73	1.32	0.48	0.30	0.16	0.15	0.14	0.45
1954	13.06	6.73	0.95	6.09	2.47	4.51	2.15	0.46	0.20	0.15	0.13	0.22
1955	0.40	1.04	0.71	0.21	4.60	8.14	2.76	0.35	0.15	0.15	0.19	0.37
1956	0.36	0.56	13.62	4.86	2.92	2.09	9.97	3.19	0.16	0.15	0.14	0.39
1957	1.83	3.13	1.73	9.99	13.94	3.60	6.45	2.24	0.19	0.15	0.14	0.35
1958	0.29	1.09	1.74	0.94	0.73	0.26	0.17	0.55	0.34	0.15	0.19	0.26
1959	0.64	0.71	0.57	0.41	0.59	1.31	0.99	0.38	0.15	0.14	0.13	0.13
1960	0.22	2.34	6.87	4.34	1.27	0.67	10.94	3.68	0.63	0.31	0.16	0.32
1961	0.50	0.66	0.42	0.54	0.60	1.08	0.66	0.23	0.14	0.13	0.16	0.15
1962	0.19	6.58	2.38	6.96	2.84	4.29	1.81	0.24	0.33	0.54	0.30	0.17
1963	0.27	0.33	0.37	9.47	3.75	0.40	0.41	0.16	0.14	0.14	0.13	0.14
1964	0.40	0.52	0.57	0.56	0.43	0.18	0.14	0.16	0.49	0.44	0.48	0.49
1965	0.54	0.77	0.74	2.34	1.18	0.20	0.16	0.32	0.21	0.15	0.14	0.14
1966	0.16	0.49	0.63	5.59	4.67	6.77	2.67	0.42	0.15	0.14	0.13	0.13
1967	0.22	2.08	0.84	5.88	2.51	0.68	0.44	0.16	0.14	0.13	0.24	0.33
1968	0.39	0.45	0.49	0.38	0.62	9.42	3.58	0.88	0.47	0.16	0.15	0.17
1969	2.39	3.88	2.51	1.05	0.43	0.18	0.15	0.26	0.22	0.15	0.14	0.38
1970	1.14	1.00	3.08	2.74	5.14	7.41	2.52	5.69	2.08	0.47	0.71	0.74
1971	0.49	0.38	1.99	0.92	6.33	2.15	0.52	0.76	0.60	0.32	0.16	0.15
1972	0.15	0.30	0.45	0.98	1.09	0.81	0.57	0.21	0.14	0.13	0.26	2.23
1973	1.82	3.04	1.28	3.51	9.10	2.87	0.68	0.56	0.27	0.15	0.14	0.14
1974	0.13	0.22	1.15	8.98	7.61	1.52	0.36	0.19	0.15	0.13	0.13	0.46
1975	0.58	0.63	3.56	7.96	8.03	20.03	12.20	2.23	0.19	0.18	0.21	0.24
1976	1.31	1.11	0.71	4.42	14.59	5.08	0.69	0.18	0.15	0.15	0.14	0.39

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1977	0.60	0.81	0.67	5.69	2.80	3.86	1.88	0.39	0.15	0.15	0.15	0.23
1978	2.24	8.20	2.80	0.69	0.70	0.44	0.24	0.16	0.15	0.13	0.14	0.20
1979	0.55	0.39	0.42	0.45	0.29	0.17	0.15	0.13	0.12	0.12	0.12	2.92
1980	1.31	2.27	1.16	5.06	4.47	1.05	0.22	0.56	0.35	0.15	0.56	1.66
1981	1.14	4.16	1.42	2.42	1.23	0.75	0.64	0.28	0.15	0.13	0.13	0.13
1982	0.38	0.52	0.48	0.47	0.36	0.27	0.17	0.14	0.13	0.13	0.19	0.15
1983	0.34	5.66	5.51	15.48	16.92	7.58	5.14	1.65	0.34	0.61	0.64	0.34
1984	0.51	0.53	0.29	3.53	20.35	5.80	0.18	0.14	0.14	0.13	0.13	0.13
1985	4.81	2.28	1.27	4.52	1.93	1.70	1.01	0.24	0.15	0.14	0.13	0.14
1986	0.16	0.32	1.83	4.11	1.90	4.41	1.75	0.67	0.83	0.35	0.43	31.23
1987	12.44	4.59	1.72	0.47	16.20	23.45	6.47	1.98	1.08	0.34	0.39	0.24
1988	0.41	0.71	4.44	1.72	10.96	3.30	0.51	0.27	0.15	0.15	0.14	0.14
1989	0.22	12.82	4.48	0.67	0.76	7.78	3.00	0.29	0.15	0.14	0.21	0.17
1990	0.52	0.55	3.85	2.31	8.92	9.52	2.48	0.31	0.21	0.16	0.15	0.40
1991	1.07	3.02	1.03	0.44	0.32	0.18	0.15	0.13	0.13	0.12	0.12	0.13
1992	0.14	0.23	0.18	0.18	0.32	0.31	0.31	0.16	0.13	0.12	0.13	0.23
1993	1.84	1.12	6.90	3.33	0.62	1.61	0.68	0.16	0.14	0.13	0.17	0.15
1994	0.46	0.37	0.19	0.18	0.16	0.42	3.32	1.69	0.93	0.40	0.16	0.14
1995	0.29	1.44	16.73	13.70	9.64	2.51	0.54	0.19	0.15	0.62	0.49	0.25
1996	0.42	0.47	0.29	5.34	3.28	0.80	0.83	0.44	0.38	0.43	0.25	0.26
1997	1.52	10.28	3.65	0.49	4.17	1.46	0.40	0.19	0.15	0.13	0.13	0.14
1998	0.15	0.25	0.44	0.63	10.64	3.33	0.30	0.16	0.22	0.15	0.28	0.40
1999	7.12	2.65	4.02	12.82	11.70	2.80	0.75	5.60	2.07	0.16	0.15	0.15
2000	0.37	3.03	5.79	1.92	0.41	0.23	0.47	0.24	0.15	0.14	0.13	0.27
2001	0.74	3.04	3.94	4.03	1.78	0.41	0.51	0.21	0.15	0.48	0.84	0.55
2002	0.27	0.17	0.17	0.18	0.18	0.15	0.15	0.13	0.13	0.12	0.12	0.18
2003	0.24	0.27	0.18	0.39	0.59	0.38	0.18	0.13	0.12	0.12	0.12	0.13
2004	0.14	0.15	0.14	0.14	0.15	0.13	0.13	0.11	0.11	0.10	0.10	0.10

Table 7.8 Simulated monthly flows (in m^3/s) to the Mhlali Estuary for Scenario 3

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.39	0.35	1.50	0.62	1.29	0.48	0.06	0.09	0.09	0.09	0.09	0.09
1921	0.21	17.16	12.65	2.17	0.01	0.04	0.09	0.07	0.09	0.09	0.09	0.09
1922	5.39	5.72	1.00	4.08	2.88	0.67	0.09	0.09	0.09	0.09	0.09	0.09
1923	0.09	0.09	0.09	0.71	1.18	0.19	0.09	0.09	0.09	0.09	0.09	0.09
1924	0.09	0.31	1.38	2.43	1.38	26.61	9.02	0.09	0.09	0.09	0.09	0.09
1925	0.18	0.02	0.09	0.09	0.09	0.23	0.09	0.09	0.09	0.09	0.09	0.09
1926	0.09	0.06	0.09	0.09	2.36	16.35	5.12	0.09	0.09	0.09	0.09	0.09
1927	0.09	0.09	0.09	1.97	1.10	0.21	0.09	0.09	0.09	0.09	0.09	0.09
1928	0.09	0.09	0.10	0.32	0.28	7.75	2.56	0.09	0.16	0.56	0.13	1.14
1929	4.00	1.77	0.13	0.85	0.20	0.13	0.07	0.09	0.09	0.09	0.09	0.12
1930	0.15	0.16	0.24	2.99	0.88	0.03	0.09	0.09	0.09	0.09	0.09	0.09
1931	0.09	0.09	0.09	0.19	11.46	6.90	1.18	0.11	0.09	0.09	0.09	0.09
1932	0.09	0.02	0.20	0.13	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1933	0.09	0.08	2.86	5.72	1.98	1.72	2.79	1.05	0.09	0.09	0.01	0.09
1934	0.09	0.09	0.12	2.95	3.79	1.87	0.33	5.51	21.82	6.40	0.11	0.09
1935	0.09	0.09	0.09	0.09	7.32	5.85	1.17	3.54	1.20	0.09	0.09	0.09
1936	0.09	11.03	3.36	0.09	1.95	0.53	0.24	0.09	0.09	0.09	0.09	0.09
1937	0.09	0.09	6.18	2.80	8.23	2.04	0.18	0.09	0.09	0.15	0.09	0.09
1938	0.06	1.43	1.52	0.60	7.83	5.82	1.22	0.32	0.09	0.09	0.09	0.19
1939	0.39	3.55	3.27	0.75	0.09	0.09	0.09	2.69	1.39	0.02	0.09	0.09
1940	0.09	5.70	3.72	0.60	0.09	0.09	0.51	0.09	0.09	0.09	0.09	0.09
1941	0.09	0.09	0.09	2.24	0.94	4.50	1.53	0.12	0.09	0.09	0.09	0.09
1942	0.34	6.71	11.66	3.24	3.56	4.75	7.39	2.32	0.12	0.27	0.72	0.21
1943	5.56	6.61	1.61	0.09	0.33	4.46	1.58	0.09	0.09	0.09	0.09	0.15
1944	0.84	0.56	0.09	0.09	2.95	11.81	3.58	0.09	0.09	0.09	0.09	0.09
1945	0.09	0.09	0.09	0.06	0.20	1.24	1.18	0.17	0.09	0.09	0.09	0.09
1946	0.09	0.09	0.28	1.42	10.93	3.35	1.23	0.21	0.07	0.09	0.09	0.09
1947	0.09	2.27	0.94	2.54	4.23	3.76	3.03	0.53	0.09	0.09	0.09	0.09
1948	0.06	1.47	0.60	0.21	3.29	0.97	0.43	0.01	0.09	0.09	0.09	0.09
1949	0.10	4.59	6.91	2.21	0.36	0.30	0.09	0.09	0.09	0.09	0.09	0.09
1950	0.09	0.09	0.55	0.50	0.19	2.68	0.89	0.09	0.09	0.09	0.09	0.30
1951	0.36	0.02	2.39	5.87	1.76	0.05	0.40	0.38	0.09	0.09	0.09	0.09
1952	0.09	0.09	0.58	17.34	13.49	2.09	0.09	0.09	0.09	0.09	0.09	0.09
1953	0.09	0.27	3.55	1.39	2.29	0.93	0.07	0.09	0.09	0.09	0.09	0.04
1954	12.66	6.32	0.56	5.69	2.04	4.12	1.74	0.06	0.09	0.09	0.09	0.09
1955	0.01	0.63	0.31	0.09	4.16	7.74	2.35	0.09	0.09	0.09	0.09	0.09
1956	0.09	0.15	13.23	4.47	2.49	1.70	9.56	2.80	0.09	0.09	0.09	0.09
1957	1.44	2.72	1.34	9.60	13.50	3.20	6.04	1.84	0.09	0.09	0.09	0.09
1958	0.09	0.68	1.34	0.54	0.29	0.09	0.09	0.16	0.09	0.09	0.09	0.09
1959	0.25	0.30	0.17	0.01	0.16	0.91	0.58	0.09	0.09	0.09	0.09	0.09
1960	0.09	1.93	6.47	3.95	0.83	0.27	10.53	3.28	0.22	0.09	0.09	0.09
1961	0.10	0.25	0.02	0.15	0.16	0.69	0.25	0.09	0.09	0.09	0.09	0.09

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1962	0.09	6.17	1.98	6.56	2.40	3.89	1.40	0.09	0.09	0.14	0.09	0.09
1963	0.09	0.09	0.09	9.07	3.31	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1964	0.01	0.11	0.18	0.17	0.09	0.09	0.09	0.09	0.08	0.05	0.09	0.08
1965	0.14	0.36	0.34	1.95	0.75	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1966	0.09	0.08	0.24	5.20	4.23	6.37	2.26	0.03	0.09	0.09	0.09	0.09
1967	0.09	1.67	0.44	5.49	2.08	0.29	0.03	0.09	0.09	0.09	0.09	0.09
1968	0.09	0.04	0.10	0.09	0.18	9.03	3.17	0.49	0.06	0.09	0.09	0.09
1969	1.99	3.47	2.11	0.66	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1970	0.74	0.59	2.68	2.35	4.70	7.02	2.11	5.29	1.67	0.07	0.32	0.33
1971	0.10	0.09	1.59	0.52	5.89	1.75	0.11	0.36	0.19	0.09	0.09	0.09
1972	0.09	0.09	0.05	0.58	0.66	0.42	0.16	0.09	0.09	0.09	0.09	1.82
1973	1.43	2.63	0.88	3.11	8.67	2.48	0.27	0.17	0.09	0.09	0.09	0.09
1974	0.09	0.09	0.75	8.58	7.17	1.13	0.09	0.09	0.09	0.09	0.09	0.05
1975	0.19	0.22	3.16	7.57	7.60	19.64	11.79	1.83	0.09	0.09	0.09	0.09
1976	0.92	0.70	0.31	4.03	14.16	4.69	0.29	0.09	0.09	0.09	0.09	0.09
1977	0.21	0.40	0.28	5.29	2.37	3.47	1.47	0.09	0.09	0.09	0.09	0.09
1978	1.84	7.79	2.41	0.29	0.26	0.04	0.09	0.09	0.09	0.09	0.09	0.09
1979	0.15	0.09	0.02	0.05	0.09	0.09	0.09	0.09	0.09	0.09	0.09	2.52
1980	0.91	1.86	0.77	4.66	4.03	0.65	0.09	0.16	0.09	0.09	0.16	1.25
1981	0.74	3.75	1.02	2.03	0.79	0.36	0.23	0.09	0.09	0.09	0.09	0.09
1982	0.09	0.11	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1983	0.09	5.25	5.12	15.09	16.49	7.18	4.73	1.25	0.09	0.22	0.25	0.09
1984	0.11	0.12	0.09	3.14	19.92	5.40	0.09	0.09	0.09	0.09	0.09	0.09
1985	4.41	1.88	0.88	4.12	1.49	1.30	0.60	0.09	0.09	0.09	0.09	0.09
1986	0.09	0.09	1.43	3.71	1.47	4.01	1.34	0.27	0.42	0.09	0.04	30.83
1987	12.04	4.19	1.33	0.07	15.77	23.05	6.06	1.58	0.68	0.09	0.09	0.09
1988	0.01	0.30	4.05	1.32	10.53	2.90	0.10	0.09	0.09	0.09	0.09	0.09
1989	0.09	12.42	4.09	0.27	0.32	7.39	2.59	0.09	0.09	0.09	0.09	0.09
1990	0.12	0.14	3.45	1.92	8.48	9.13	2.07	0.09	0.09	0.09	0.09	0.09
1991	0.67	2.61	0.63	0.05	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1992	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1993	1.44	0.71	6.51	2.93	0.19	1.22	0.27	0.09	0.09	0.09	0.09	0.09
1994	0.06	0.09	0.09	0.09	0.09	0.02	2.91	1.30	0.52	0.00	0.09	0.09
1995	0.09	1.03	16.33	13.31	9.21	2.11	0.13	0.09	0.09	0.22	0.10	0.09
1996	0.03	0.07	0.09	4.95	2.85	0.40	0.42	0.04	0.09	0.03	0.09	0.09
1997	1.13	9.87	3.26	0.10	3.73	1.06	0.09	0.09	0.09	0.09	0.09	0.09
1998	0.09	0.09	0.04	0.24	10.21	2.94	0.09	0.09	0.09	0.09	0.09	0.09
1999	6.72	2.25	3.62	12.42	11.27	2.40	0.34	5.20	1.66	0.09	0.09	0.09
2000	0.09	2.62	5.40	1.53	0.09	0.09	0.07	0.09	0.09	0.09	0.09	0.09
2001	0.35	2.63	3.54	3.63	1.34	0.02	0.10	0.09	0.09	0.08	0.44	0.14
2002	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2003	0.09	0.09	0.09	0.09	0.16	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2004	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

Table 7.9 Simulated monthly flows (in m^3/s) to the Mhlali Estuary for Scenario 4

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1920	0.92	0.90	2.04	1.15	1.88	1.02	0.61	0.36	0.29	0.26	0.26	0.27
1921	0.74	17.71	13.19	2.71	0.60	0.57	0.44	0.60	0.54	0.29	0.37	0.31
1922	5.93	6.27	1.53	4.61	3.46	1.21	0.64	0.31	0.28	0.27	0.27	0.27
1923	0.27	0.27	0.39	1.24	1.77	0.72	0.38	0.29	0.28	0.26	0.26	0.40
1924	0.44	0.86	1.92	2.96	1.96	27.15	9.58	0.52	0.30	0.28	0.28	0.47
1925	0.71	0.57	0.44	0.33	0.44	0.76	0.48	0.29	0.31	0.28	0.27	0.27
1926	0.49	0.61	0.49	0.44	2.94	16.88	5.68	0.32	0.29	0.27	0.28	0.29
1927	0.29	0.31	0.53	2.51	1.68	0.75	0.49	0.29	0.27	0.26	0.26	0.27
1928	0.29	0.47	0.63	0.85	0.87	8.28	3.11	0.36	0.71	1.10	0.66	1.69
1929	4.53	2.32	0.67	1.39	0.79	0.67	0.62	0.36	0.29	0.28	0.41	0.67
1930	0.68	0.71	0.78	3.52	1.46	0.57	0.51	0.30	0.28	0.39	0.30	0.29
1931	0.29	0.29	0.32	0.73	12.05	7.44	1.73	0.64	0.33	0.28	0.27	0.27
1932	0.41	0.57	0.74	0.66	0.47	0.39	0.36	0.29	0.28	0.27	0.27	0.27
1933	0.27	0.64	3.39	6.26	2.56	2.26	3.34	1.58	0.54	0.53	0.55	0.34
1934	0.30	0.30	0.66	3.49	4.37	2.40	0.88	6.04	22.37	6.93	0.64	0.41
1935	0.31	0.32	0.31	0.62	7.91	6.38	1.72	4.07	1.75	0.31	0.29	0.29
1936	0.38	11.58	3.89	0.48	2.53	1.06	0.79	0.38	0.37	0.29	0.32	0.30
1937	0.29	0.37	6.72	3.33	8.82	2.58	0.73	0.44	0.50	0.68	0.47	0.31
1938	0.59	1.98	2.06	1.14	8.41	6.36	1.77	0.85	0.49	0.41	0.30	0.74
1939	0.93	4.10	3.81	1.28	0.58	0.42	0.39	3.22	1.94	0.56	0.30	0.30
1940	0.37	6.25	4.26	1.13	0.39	0.53	1.06	0.53	0.30	0.28	0.27	0.32
1941	0.34	0.54	0.35	2.77	1.52	5.03	2.08	0.65	0.42	0.29	0.38	0.51
1942	0.88	7.26	12.19	3.78	4.15	5.29	7.94	2.85	0.67	0.81	1.25	0.76
1943	6.10	7.16	2.14	0.48	0.91	5.00	2.13	0.38	0.40	0.29	0.29	0.70
1944	1.37	1.11	0.51	0.43	3.54	12.35	4.13	0.49	0.30	0.28	0.27	0.27
1945	0.28	0.29	0.29	0.59	0.79	1.77	1.73	0.71	0.30	0.28	0.27	0.27
1946	0.28	0.54	0.81	1.95	11.52	3.88	1.78	0.75	0.62	0.38	0.31	0.32
1947	0.32	2.82	1.48	3.07	4.81	4.29	3.58	1.06	0.30	0.28	0.27	0.27
1948	0.60	2.02	1.13	0.74	3.88	1.51	0.98	0.55	0.31	0.29	0.27	0.29
1949	0.64	5.14	7.44	2.75	0.95	0.84	0.54	0.47	0.30	0.28	0.28	0.29
1950	0.28	0.28	1.08	1.03	0.77	3.22	1.44	0.33	0.29	0.28	0.52	0.85
1951	0.89	0.57	2.92	6.40	2.34	0.59	0.95	0.92	0.52	0.31	0.29	0.29
1952	0.28	0.41	1.11	17.88	14.07	2.62	0.44	0.29	0.27	0.27	0.27	0.38
1953	0.49	0.82	4.08	1.92	2.88	1.46	0.63	0.44	0.30	0.28	0.28	0.59
1954	13.20	6.87	1.09	6.23	2.62	4.65	2.30	0.59	0.34	0.29	0.27	0.36
1955	0.54	1.18	0.85	0.35	4.75	8.27	2.91	0.49	0.30	0.28	0.32	0.51
1956	0.50	0.70	13.76	5.00	3.07	2.23	10.11	3.33	0.30	0.28	0.28	0.53
1957	1.97	3.28	1.87	10.13	14.09	3.74	6.59	2.37	0.34	0.29	0.28	0.49
1958	0.43	1.23	1.88	1.08	0.88	0.40	0.31	0.69	0.48	0.29	0.33	0.41
1959	0.78	0.85	0.71	0.55	0.75	1.44	1.13	0.52	0.29	0.28	0.27	0.27
1960	0.36	2.48	7.00	4.48	1.42	0.81	11.08	3.82	0.78	0.45	0.30	0.46
1961	0.64	0.81	0.56	0.68	0.75	1.22	0.80	0.37	0.29	0.27	0.30	0.29
1962	0.32	6.72	2.52	7.09	2.99	4.42	1.96	0.37	0.47	0.68	0.44	0.31
1963	0.41	0.47	0.50	9.61	3.90	0.53	0.55	0.30	0.29	0.28	0.27	0.28
1964	0.54	0.66	0.71	0.70	0.58	0.32	0.28	0.30	0.63	0.58	0.62	0.63
1965	0.68	0.91	0.87	2.48	1.33	0.34	0.30	0.46	0.35	0.28	0.28	0.29
1966	0.29	0.63	0.77	5.73	4.82	6.90	2.81	0.56	0.30	0.28	0.27	0.27
1967	0.36	2.22	0.97	6.02	2.66	0.82	0.58	0.30	0.28	0.27	0.37	0.47
1968	0.53	0.59	0.63	0.52	0.77	9.56	3.72	1.02	0.61	0.29	0.29	0.31
1969	2.53	4.02	2.65	1.19	0.59	0.32	0.29	0.40	0.36	0.29	0.28	0.52
1970	1.28	1.15	3.21	2.88	5.29	7.55	2.66	5.82	2.22	0.61	0.85	0.88
1971	0.63	0.52	2.13	1.06	6.48	2.28	0.66	0.90	0.74	0.46	0.30	0.30
1972	0.29	0.44	0.59	1.12	1.24	0.95	0.71	0.35	0.29	0.27	0.40	2.38
1973	1.96	3.18	1.42	3.64	9.25	3.01	0.82	0.70	0.41	0.29	0.28	0.28
1974	0.27	0.37	1.28	9.12	7.76	1.66	0.50	0.33	0.29	0.27	0.27	0.61
1975	0.72	0.77	3.70	8.10	8.18	20.17	12.35	2.36	0.34	0.31	0.35	0.39
1976	1.45	1.25	0.85	4.56	14.74	5.22	0.84	0.31	0.29	0.28	0.28	0.53
1977	0.74	0.95	0.81	5.83	2.95	4.00	2.02	0.53	0.30	0.28	0.28	0.37
1978	2.37	8.34	2.94	0.83	0.85	0.57	0.39	0.29	0.29	0.27	0.28	0.34
1979	0.69	0.53	0.56	0.59	0.45	0.31	0.29	0.27	0.27	0.26	0.26	3.07
1980	1.45	2.42	1.30	5.19	4.62	1.19	0.37	0.69	0.49	0.29	0.70	1.80
1981	1.27	4.30	1.55	2.56	1.38	0.89	0.78	0.42	0.29	0.27	0.27	0.27
1982	0.52	0.66	0.62	0.61	0.51	0.40	0.31	0.28	0.27	0.27	0.33	0.30
1983	0.47	5.80	5.65	15.62	17.08	7.72	5.28	1.78	0.48	0.75	0.78	0.48
1984	0.65	0.67	0.43	3.67	20.50	5.94	0.32	0.28	0.28	0.27	0.27	0.27
1985	4.95	2.43	1.41	4.66	2.08	1.84	1.15	0.37	0.29	0.28	0.27	0.28
1986	0.30	0.46	1.96	4.25	2.05	4.54	1.89	0.81	0.97	0.49	0.57	31.38
1987	12.57	4.74	1.86	0.61	16.35	23.59	6.61	2.11	1.23	0.48	0.53	0.39
1988	0.55	0.86	4.58	1.86	11.12	3.44	0.66	0.40	0.30	0.28	0.28	0.28
1989	0.36	12.97	4.62	0.81	0.91	7.92	3.14	0.43	0.29	0.28	0.35	0.31
1990	0.65	0.69	3.99	2.45	9.07	9.66	2.62	0.45	0.35	0.30	0.29	0.54
1991	1.21	3.16	1.17	0.58	0.47	0.32	0.30	0.27	0.27	0.26	0.26	0.27
1992	0.28	0.37	0.32	0.31	0.48	0.44	0.45	0.30	0.27	0.26	0.27	0.37
1993	1.98	1.27	7.04	3.46	0.77	1.75	0.83	0.30	0.28	0.27	0.31	0.29
1994	0.60	0.52	0.33	0.32	0.32	0.56	3.46	1.83	1.07	0.54	0.30	0.29
1995	0.43	1.58	16.86	13.84	9.80	2.65	0.68	0.32	0.29	0.75	0.63	0.39
1996	0.56	0.62	0.43	5.48	3.43	0.93	0.97	0.58	0.52	0.56	0.38	0.41
1997	1.66	10.42	3.79	0.63	4.32	1.60	0.54	0.33	0.29	0.27	0.27	0.29
1998	0.29	0.39	0.57	0.77	10.79	3.47	0.44	0.29	0.36	0.29	0.42	0.54
1999	7.26	2.80	4.16	12.96	11.85	2.93	0.89	5.73	2.21	0.30	0.28	0.30
2000	0.50	3.18	5.93	2.06	0.56	0.37	0.62	0.38	0.29	0.28	0.27	0.42
2001	0.88	3.18	4.07	4.17	1.93	0.55	0.65	0.35	0.29	0.62	0.98	0.69
2002	0.40	0.32	0.31	0.32	0.33	0.29	0.29	0.27	0.27	0.26	0.26	0.32
2003	0.37	0.42	0.32	0.53	0.74	0.52	0.32	0.27	0.26	0.25	0.26	0.27
2004	0.28	0.29	0.28	0.28	0.30	0.27	0.27	0.25	0.25	0.24	0.24	0.25

7.3 ABIOTIC COMPONENTS

7.3.1 Hydrology

7.3.1.1 Low flows

Table 7.10 provides a summary of the changes in low flow that have occurred under the different scenarios.

Table 7.10 Summary of the change in low flow conditions to the Mhlali Estuary under a range of flow scenarios

Percentile	Monthly flow (m^3/s)					
	Natural	Present	1 (and 5)	2	3	4
30%ile	0.3	0.1	0.2	0.3	0.1	0.4
20%ile	0.2	0.1	0.1	0.2	0.1	0.3
10%ile	0.1	0.1	0.1	0.1	0.1	0.3
% Similarity in low flows		**39.7**	**56.8**	**100**	**45**	**58.1**

Confidence: High

7.3.1.2 Flood regime

There are no large dams at present in the Mhlali catchment. Similarly any changes in the flood regime under the future scenarios would be mostly related to smaller farm dams, land-use change and associated catchment permeability. An evaluation of the 95 %ile, 99 %ile and 99.9 %ile show that floods occur relatively untransformed from Reference Condition to Present State and Future Scenario 1 to 4, i.e. less than 5% change from Reference.

Confidence: Medium

A summary of the hydrology scores are provided in Table 7.11.

Table 7.11 EHI scores for hydrology under the different scenarios

Variable	Scenario					
	Present	1 (and 5)	2	3	4	Conf
a. Similarity in low flows	40	57	100	45	58	L
b. Similarity floods	95	95	95	95	95	M
Hydrology score	**72**	**97**	**65**	**73**	**72**	**L/M**

7.3.2 Hydrodynamics and mouth condition

This section provides a description of the changes in the occurrences of mouth conditions for each of the scenarios.

Present	Mouth closure (State 1) occurs for about 59 % of the time under the Present State, while the estuary was closed for about 47% of the time under the Reference Condition.
Scenario 1 to 5	Mouth closure would occur for 59%, 54%, 67%, 44% and 59% respectively under Scenarios 1 to 5.

Table 7.12 provides a summary of the hydrodynamics and mouth condition scores for the Mhlali Estuary.

Table 7.12 EHI scores for hydrodynamics and mouth condition under different scenarios

Variable	Scenario						
	Present	1	2	3	4	5	Conf
Hydrodynamics and mouth conditions score	80	80	87	70	93	80	**L**

7.3.3 Water quality

Table 7.13 provides Summary of the occurrence of the abiotic states under the Reference Condition, Present State and Scenarios 1 to 5.

Table 7.13 Summary of the occurrence of the abiotic states under the Reference Condition, Present State and Scenarios 1 to 5

Abiotic State	Natural	Present	Scenario				
			1	2	3	4	5
State 1: Closed, weeks to months	47	59	59	54	67	44	59
State 2: Open, limited marine	36	25	25	29	18	39	25
State 3: Open, fresh	17	16	16	17	15	17	16

Scoring of Future scenarios in respect of Salinity/DIN/DIP, SS/Turbidity/ Transparency, DO and Toxic substances, followed a similar approach as described earlier for the Present State. Based on the above the estimated changes in water quality (salinity, DIN, DIP, suspended solids and dissolved oxygen) in different zones under the different scenarios are presented in Table 7.14 Details on the change in the axial salinity gradient, DIN/DIP, suspended solids, dissolved oxygen, and toxic substances are provided in Table 7.14.

Table 7.14 Estimated changes in water quality in different zones under different scenarios

Zones in Estuary	Volume weighting for Zone	Estimated SALINITY concentration based on distribution of abiotic states under a range of Scenario Groups						
		Reference	Present	1	2	3	4	5
A: Lower	0.65	14	14	14	14	14	15	14
B: Middle	0.25	9	10	10	10	11	9	10
C: Upper	0.10	1	1	1	1	1	1	1

Zones in Estuary	Volume weighting for Zone	Estimated DIN concentration (µg/l) based on distribution of abiotic states under a range of Scenario Groups						
		Reference	Present	1	2	3	4	5
A: Lower	0.65	83	299	215	476	1462	665	215
B: Middle	0.25	83	312	240	505	1480	707	240
C: Upper	0.10	83	354	282	642	2507	1005	282

Zones in Estuary	Volume weighting for Zone	Estimated DIP concentration (µg/l) based on distribution of abiotic states under a range of Scenario Groups						
		Reference	Present	1	2	3	4	5
A: Lower	0.65	12	53	13	495	3745	1208	13
B: Middle	0.25	12	55	13	539	4772	1286	13
C: Upper	0.10	12	70	22	730	4337	1765	22

Zones in Estuary	Volume weighting for Zone	Estimated TURBIDITY (NTU) based on distribution of abiotic states under a range of Scenario Groups						
		Reference	Present	1	2	3	4	5
A: Lower	0.65	17	40	40	42	38	42	40
B: Middle	0.25	17	40	40	42	38	42	40
C: Upper	0.10	17	49	49	51	46	51	49

Zones in Estuary	Volume weighting for Zone	Estimated DISSOLVED OXYGEN concentration (mg/l) based on distribution of abiotic states under a range of Scenario Groups						
		Reference	Present	1	2	3	4	5
A: Lower	0.65	6	5	5	4	3	4	5
B: Middle	0.25	6	5	5	3	3	3	5
C: Upper	0.10	6	5	5	3	1	2	5

Table 7.15 Summary of water quality changes under different scenarios

Parameter	Summary of changes
Changes in longitudinal salinity gradient and vertical stratification	Slight ⇧ due to increase in low flow conditions.
Inorganic nutrients in estuary	⇧ due to nutrient enrichment from agriculture and WWTWs.
Turbidity in estuary	⇧ due to increased turbidity from agricultural disturbance especially during higher flows (State 3).
Dissolved oxygen in estuary	⇩ due to organic accumulation from WWTWs especially during State 1 (Close) and State 2 (Open, limited marine).
Toxic substances in estuary	⇧ urban inputs.

A summary of the water quality scores are provided in Table 7.16.

Table 7.16 EHI scores for water quality under different scenarios

	Variable	Scenario Group						
		Present	1	2	3	4	5	Conf
1	**Salinity**							
	Similarity in salinity	97	97	98	96	99	97	L
2	**General water quality in the estuary**							
a	N and P concentrations	39	73	17	6	12	73	L
b	Turbidity	58	58	56	61	56	58	L
c	Dissolved oxygen	93	93	75	66	77	93	L
d	Toxic substances	80	80	80	80	80	80	L
	Water quality score*	**62**	**74**	**49**	**42**	**47**	**74**	**L**

* $Score = (0.4 * 1. + 0.6 * (\min(2a.\ to\ 2d.))$

7.3.4 Physical habitats

Table 7.17 provides a summary of the changes in physical habitat under the different scenarios for the Mhlali Estuary. Physical habitat scores are summarised in Table 7.18.

Table 7.17 Summary of physical habitat changes under different scenarios

Parameter		Scenario Group
1a	% Similarity in intertidal area exposed	Under Scenarios 1 to 5 the sediment processes are similar to the Present State. There are some loss of intertidal habitat due deposition and infilling of the intertidal habitat. In addition, Under Scenario 2 and 3 there is also less exposed intertidal habitat due to increases mouth closure and greater mouth restriction. While under Scenario 4 there is more exposed intertidal habitat due to decrease mouth closure.
1b	% Similarity in sand fraction relative to total sand and mud	Under Scenarios 1 to 5 the sand: mud ratio is similar to the Present State. The score of 60 is based on increase in clay and silt fractions experienced in similar systems, especially in Zone B and C.
2	% Similarity in intertidal area: depth, bed or channel morphology	Under Scenarios 1 to 4 the subtidal area are similar to the Present State. There has been some infilling of sub-tidal areas as a result of the increase sediment yield from the catchment and sugarcane farming in the surrounding environs. There is also indications that the bridges are causing localise changes in bathymetry of the system. Under Scenario 5 water levels increase to more natural levels. The subtidal score was adjusted to reflect this change in average water level under this scenario.

Table 7.18 EHI scores for physical habitat under different scenarios

Variable	Scenario Group						
	Present	1	2	3	4	5	Conf
1a. Intertidal areas and sediments	60	60	65	55	70	60	L
1b.Similarity in sand fraction	60	60	60	60	60	60	L
2. Subtidal area and sediments	60	60	60	60	60	80	L
Physical habitat score	**60**	**60**	**61**	**59**	**63**	**73**	**L**

7.4 BIOTIC COMPONENT

7.4.1 Microalgae

Changes and scores are summarised in Table 7.19 and Table 7.20.

Table 7.19 Summary of change in microalgae component under different scenarios

Scenario	Summary of Changes
Natural	Natural.
Present	Main change is loss of open water area and some elevated nutrients.
1	Reduced microalgal biomass – closer to reference.
2	Considerable increase in microalgal biomass *cf* present.
3	Much higher microalgal biomass than present with changes in species composition.
4	Much higher microalgal biomass than present with changes in species composition.
5	Decrease in nutrients to acceptable levels.

Table 7.20 EHI scores for microalgae component under different scenarios

Variable	Scenario						
	Present	1	2	3	4	5	Conf
1. Species richness	50	55	50	50	50	70	L
2. Abundance	50	55	20	20	20	80	L
3. Community composition	60	60	60	60	60	70	L
Biotic component score	50	55	20	20	20	70	**L**

7.4.2 Macrophytes

The increase in low flow and input of nutrients from the WWTW has caused macrophytes to cover large areas of the water channel and open sand and mud banks resulting in loss of this habitat. There has also been an increase in aquatic invasives indicative of eutrophic conditions. The future scenarios mostly deal with these responses (Table 7.21). In Scenario 1 the effect of the WWTW is removed, thus resulting in an improvement of macrophytes. The decrease in nutrients would reduce the extent of aquatic invasives and prevent some reed growth in the main water channel. For Scenario 2 there is an increase in waste water inflow, low flow conditions are improved and the mouth is open more frequently, however the increased nutrients result in a eutrophic, degraded estuary. There will be an increase in invasive aquatics and reeds and sedges. For Scenario 3 there is abstraction and a decrease in MAR but the WWTWs are operational. As a result of this there is an excessive increase in nutrients as the mouth is closed more frequently. Invasive aquatics will proliferate and there will be an increase in reeds, sedges and grasses with little remaining open water surface area. Scenario 4 represents the WWTWs at full capacity and MAR will be > 104% of natural. The mouth will be open more frequently which will dilute some of the nutrient effect.

Overall the macrophytes respond to the large increases in nutrients as a result of wastewater input. This would result in algal blooms (both phytoplankton and macroalgae), infestation by aquatic invasives such as the rooted aquatics e.g. parrots feather or the floating aquatics e.g. water hyacinth. All macrophytes particularly reeds, sedges and grasses would grow rapidly in response to the increase in nutrients. Die-back would increase the organic load in the estuary resulting in anoxic conditions.

Table 7.21 Summary of change in macrophytes component under different scenarios

Scenario	Summary of Changes
Scenario 1	⇩ nutrients which would reduce the extent of aquatic invasives and prevent some reed and other macrophyte growth into the main water channel. The mouth is closed for 59% of the time which is similar to present.
Scenario 2	⇧ wastewater flow ⇩ State 1 (i.e. closed mouth conditions, mouth closed for 54% of the time), ⇧ nutrients causes ⇧ eutrophication resulting in ⇧ reeds, sedges, grasses and invasive aquatic species.
Scenario 3	Worst case scenario ⇩ in MAR (81 %) and ⇧ nutrient concentrations from WWTW that are retained in the estuary due to ⇧ State 1 (i.e. closed mouth conditions, mouth closed for 66% of the time). ⇧ reeds, algal blooms and invasive floating macrophytes due to nutrients. Invasive aquatics will become a problem.
Scenario 4	⇧ MAR (104 %) due to full capacity WWTW. State 1 resembles natural conditions closed for 44% of time compared to 47%. ⇧ nutrient concentrations from WWTW but because mouth opens not as severe as Scenario 3. ⇧ reeds, algal blooms and invasive floating macrophytes.
Scenario 5	Much improved scenario where the input of nutrients is reduced and sugarcane is removed from the EFZ. There will be less reed encroachment and development of algal blooms and

Scenario	Summary of Changes
	floating invasive macrophytes. An increase in species richness is expected.

Macrophyte scores are summarised in Table 7.22.

Table 7.22 EHI scores for macrophyte component under different scenarios

Variable	Scenario						
	Present	1	2	3	4	5	Conf
1. Species richness	80	80	75	70	75	85	L
2. Abundance	52	54	50	47	50	70	L
3. Community composition	52	55	50	48	48	70	L
Biotic component score	**52**	**54**	**50**	**47**	**48**	**70**	**L**

7.4.3 Invertebrates

This section describes the changes in invertebrates for the different run-off scenarios. Changes and scores are summarised in Table 7.23 and Table 7.24.

Table 7.23 Summary of change in invertebrates component under different scenarios

Scenario	Summary of Changes
1	Slight improvement in flows and water quality will produce a very small change in the invertebrate community relative to the present day.
2	Addition of WWTW discharge and mouth state. The invertebrate community would respond to the increase in mouth opening (state 1) but water quality impacts, which already limit invertebrate species richness and abundance, become even limiting. Reduced dissolved oxygen concentrations will prevent the development of a typical estuarine invertebrate community affecting the benthos more than the zooplankton but with prolonged exposure the water column will also be impacted.
3	High nutrients and reduced flushing increases the likelihood of severe impact to the invertebrate communities as described for 2. Marked reductions in species richness and abundance predicted.
4	Higher volumes of nutrient rich WWTW outflows influences the mouth state with increased open periods similar to reference. However nutrient concentrations at levels to promote nuisance plant growth and algal blooms will further exacerbate the dissolved oxygen issues.
5	Reduced nutrient inputs and more typical estuarine salinities will promote the development of a diverse community with amphipods, tanaeids and others being present in the community. Abundance levels are anticipated to increase in response to the improved water quality and more stable conditions. Increased carrying capacity available during closed periods with the removal of artificial breaching impacts and the potential for more of the EFZ to be utilised by the aquatic fauna present in the system.

Table 7.24 EHI scores for invertebrates component under different scenarios

Variable	Scenario						
	Present	1	2	3	4	5	Conf
1. Species richness	70	80	65	50	65	85	L
2. Abundance	40	45	30	20	30	80	L
3. Community composition	50	60	40	30	30	80	L
Biotic component score	**40**	**45**	**30**	**20**	**30**	**80**	L

7.4.4 Fish

Responses of fishes in the Mhlali estuary to different water resource development scenarios are informed by anticipated changes in hydrology, water quality and aquatic microalgae, macrophytes and invertebrates as reported upon in other specialist reports conducted as part of the wider EWR study. These are presented in summary format in Table 7.25 below. The health scores of the fish assemblages under these different scenarios are provided in Table 7.26.

Table 7.25 Summary of change in fish component under different scenarios

Scenario	Summary of Changes
1	Changes in flows and water quality are marginal for the fish assemblage. No notable difference from fish health under present day conditions is expected under this scenario. EHI scores are therefore expected to remain the same as present.
2	Flows remain broadly similar to present day, with addition of WWTW outflows. This results in a slight decrease in mouth closure (State 1) and an increase in mouth open (State 2) frequency. This would benefit the fish composition of the estuary. However, water quality impacts, which already limit species richness and fish abundance, become even more critical because of elevated nutrient loads. DO over the whole estuary during the closed phase is not supportive of fishes and marked impacts to the fish community are expected.
3	This scenario sees similar loads of nutrients delivered to the system as in Scenario 3, but with lower river flows. Impacts noted above are therefore exacerbated. Water quality becomes critical under both Sates 1 and 2. Marked reductions in species richness and abundance are expected.
4	Full capacity WWTW outflows results in higher than reference condition flows. Water quality impacts on the fish fauna, however, are significant.
5	Present flows without WWTW inputs, and remedial measures will result in significant improvement in the fish community. Although mouth closure will occur more frequently than under the reference condition, increases (compared to present day) in species richness and abundance of fishes could be expected, as well as shift in species composition that includes an increase in estuarine associated species relative to freshwater fishes.

Table 7.26 EHI scores for fish component under different scenarios

Variable	Scenario						
	Present	1	2	3	4	5	Conf
1. Species richness	70	70	60	30	40	75	L
2. Abundance	60	60	40	30	30	70	L
3. Community composition	60	65	50	35	40	70	L
Biotic component score	**60**	**60**	**40**	**30**	**30**	**70**	L

7.4.5 Birds

This section describes the changes in bird for the different run-off scenarios. Changes and scores are summarised in Table 7.27 and Table 7.28.

Table 7.27 Summary of change in bird component under different scenarios

Scenario	Summary of Changes
1	Improvement in waterbird habitat related to enhanced water quality.
2 - 4	Deterioration in conditions related to waterbirds associated with decreased water quality and expected habitat loss through burgeoning macrophtyte growth, both resulting in decrease in food availability. Also increased human disturbance in Estuary Functional Zone.
5	Even greater improvement than under Scenario 1, due to the various management interventions enhancing estuary functioning and drawing estuary back towards reference condition.

Table 7.28 EHI scores for bird component under different scenarios

Variable	Scenario						
	Present	1	2	3	4	5	Conf
1. Species richness	70	75	50	30	35	80	L
2. Abundance	50	55	30	20	25	65	L
3. Community composition	40	45	30	20	25	60	L
Biotic component score	**40**	**45**	**30**	**20**	**25**	**60**	**L**

7.5 ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

The individual EHI scores, as well as the corresponding ecological category under different scenarios are provided in Table 7.29. The estuary is currently in a D Category. An evaluation of the four scenarios provided the following insights:

- Under Scenario 1 the Mhlali Estuary will improve slightly in health to a C Category, as a result of improved water quality. This scenario represents the recent past before the varouis current and planned WWTW came on line.
- While, under Scenario 2 the estuary will deteriorate further in health by about 3% as a result of deteriorating water quality conditions.
- Under Scenario 3 the estuary will deteriorate significantly, by about 15 % as a result of severely deteriorating water quality conditions and reduce in river flow. Under this scenario treated effluent become the dominant source of freshwater to the system under low to average inflow conditions.
- Under Scenario 4 the estuary will also deteriorate significantly, by about 14%, as a result of severely deteriorating water quality conditions and an increase in freshwater inflow associated with the maximum discharges to the system.

None of the scenarios (1 to 4) achieved the REC for the Mhlali Estuary. Therefore a sensitivity test, Scenario 5, was conducted. Scenario 5 is based on the freshwater inflow simulated for Scenario 1 in conjunction with the following management interventions:

- Reduce the nutrient input from the WWTW and catchment to control growth of reeds and aquatic invasive plants.
- Remove the sugarcane from the EFZ (below 5 m contour) to allow for a buffer against human disturbance and the development of a transitional vegetation ecotone between estuarine and terrestrial ecosystems.
- Removal of vegetation from main river channel in upper reaches, including invasive aliens plants and strands of eucalypts (using CoastCare programme).
- Ensure that the estuary is not artificial breached; and
- Remove the old saltwater weir from middle reaches of system.

Scenario 5 achieved the REC of a B.

Table 7.29 EHI score and corresponding Ecological Categories under the different runoff scenarios

Variable	Weight	Scenario Group						
		Present	1	2	3	4	5	Conf
Hydrology	25	62	72	97	65	73	72	L
Hydrodynamics and mouth condition	25	80	80	87	70	93	80	L
Water quality	25	62.2	74	49	42	47	74	L
Physical habitat alteration	25	60	60	61	59	63	73	L
Habitat health score		**66**	**71**	**74**	**59**	**55**	**75**	
Microalgae	20	50	55	20	20	20	70	L
Macrophytes	20	51	53	49	40	48	70	L
Invertebrates	20	40	45	30	20	30	80	L
Fish	20	60	60	40	30	30	70	L
Birds	20	40	45	30	20	25	60	L
Biotic health score		**48**	**52**	**34**	**26**	**31**	**70**	
ESTUARY HEALTH SCORE		**57**	**62**	**54**	**42**	**43**	**72**	**L**
ECOLOGICAL STATUS		**D**	**C**	**D**	**D**	**D**	**B**	

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 STUDY CONFIDENCE

Note that, while the study may be of low confidence regarding key aspects driving component scores (e.g. the precise river flow rate at which the Mhlali Estuary mouth closes, the absolute number of fish species occurring in the system), the study team were of **HIGH confidence that the current nutrient levels (estimated from general effluent standard concentrations and recorded waste water inflow) in the inflowing water, far exceed the assimilative capacity of this small estuary.**

It can also be stated with **HIGH confidence that the system is on a DOWNWARDS TRAJECTORY OF CHANGE**. Similarly, while the study team have of LOW confidence in the absolute PES score, they are of **HIGH confidence that the proposed future WWTW discharge scenarios will further degrade the system significantly into a lower Category D**. It is even possible that the system may even degrade to an E Category.

8.2 ECOLOGICAL WATER REQUIREMENTS

The **'recommended Ecological Water Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this.

Based on this assessment, we have ascertained that the REC for the Mhlali Estuary is a Category B.

The flow requirements for the estuary are the same as those described for Scenario 5 (removal of waste water) and are summarised in Table 8.1.

Table 8.1 The ecological flow requirements (in m^3/s) of the Mhlali Estuary

%ile	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
99.9	12.92	17.08	16.38	17.46	19.97	26.62	12.01	5.80	20.45	6.22	1.01	28.77
99	12.45	13.49	14.03	15.76	17.38	23.93	11.05	5.64	5.21	1.81	0.80	7.37
90	1.99	6.31	5.59	6.59	11.11	7.91	4.59	2.15	0.53	0.37	0.38	0.50
80	1.05	3.19	3.69	4.81	7.72	5.19	2.60	0.68	0.29	0.23	0.18	0.30
70	0.52	2.19	2.40	3.44	4.12	3.75	1.64	0.42	0.19	0.07	0.10	0.23
60	0.42	1.01	1.65	2.59	2.78	2.41	0.86	0.30	0.11	0.06	0.08	0.15
50	0.32	0.63	1.06	1.73	2.10	1.53	0.59	0.21	0.07	0.06	0.06	0.08
40	0.24	0.44	0.62	0.91	1.25	0.91	0.42	0.15	0.06	0.06	0.05	0.07
30	0.15	0.34	0.45	0.56	0.64	0.55	0.31	0.11	0.06	0.05	0.04	0.05
20	0.08	0.24	0.33	0.39	0.50	0.33	0.21	0.08	0.05	0.04	0.04	0.05
10	0.06	0.10	0.14	0.26	0.24	0.17	0.08	0.07	0.04	0.04	0.04	0.04
1	0.04	0.05	0.06	0.08	0.07	0.06	0.05	0.04	0.03	0.03	0.03	0.03
0.1	0.04	0.04	0.05	0.06	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02

8.3 ECOSPECS

Note that since the estuary has to be restored from a D to a B Category, the thresholds of potential concern (TPCs) should be seen as targets to be met within 5 years. Thereafter the estuary should be maintained such that these thresholds are not breached. The TPCs for the Mhlali Estuary are listed in Table 8.1 and Table 8.2.

Table 8.2 Mhlali Ecological specifications and thresholds of potential concern for abiotic components

Abiotic Component	Ecological Specification	Threshold of Potential Concern	Causes
Water Quality (PES/REC)	Salinity distribution not to cause exceedance of TPCs for fish, invertebrates, macrophytes and microalgae (see above)	▪ Salinity values > 20 PSU in middle reaches during the low flow season ▪ No 10 – 15 PSU zone detected in the estuary for two consecutive sampling events in a row during surveys ▪ Freshwater dominated (i.e. 0 PSU) for > 20% of the time	Flow regime changes
	System variables (pH, dissolved oxygen and turbidity) not to cause exceedance of TPCs for biota (see above)	River inflow: ▪ 7.0 < pH > 8.5 over 2 months ▪ DO < 6 mg/l ▪ Turbidity > 15 NTU (low flow) ▪ Turbidity high flows naturally turbid Estuary: ▪ Average turbidity > 10 NTU (low flow) ▪ Turbidity high flow, naturally turbid ▪ Average 7.0 < pH > 8.5 ▪ Average DO < 6 mg/l	▪ Agricultural return flow ▪ Municipal wastewater (organic loading)
	Inorganic nutrient concentrations (NO_3-N, NH_3-N and PO_4-P) not to cause in exceedance of TPCs for macrophytes and microalgae (see above)	River inflow: ▪ NO_x-N >200 µg/l over 2 months ▪ NH_3-N> 20 µg/l over 2 months ▪ PO_4-P > 10 µg/l over 2 months Estuary: ▪ Average NO_x-N > 200 µg/l ▪ Average NH_3-N > 20 µg/l ▪ Average PO_4-P > 10 µg/l	▪ Agricultural return flow (nutrients) ▪ Municipal wastewater (nutrients)
	Presence of toxic substances not to cause exceedence of TPCs for biota (see above)	River inflow: ▪ Trace metals (to be determined) ▪ Pesticides/herbicides (to be determined) Estuary: ▪ Total metal concentrations in estuary waters exceed target values as per SA Water Quality Guidelines for coastal marine waters (DWAF, 1995) ▪ Total metal concentration in sediment exceeds target values as per WIO Region guidelines (UNEP/Nairobi Convention Secretariat and CSIR, 2009)	▪ Agricultural return flow (pesticides/herbicides) ▪ Municipal wastewater including industrial trade effluent (e.g. metals)
Hydrology	Maintain a flow regime to create the required habitat for birds, fish, macrophytes, microalgae and water quality	▪ River inflow distribution patterns differ by more than 5% from that of Scenario 1 (i.e. approved flow scenario for the Mhlali Estuary).	Flow reduction

Abiotic Component	Ecological Specification	Threshold of Potential Concern	Causes
Hydrodynamics	Maintain a mouth conditions to create the required habitat for birds, fish, macrophytes, microalgae and water quality	▪ Mouth closure regime shifts by ± 5% from present baseline of 52% of the time for more than 1 year in a row ▪ Breaching levels are < 3.0 m MSL	▪ Flow reduction or increase ▪ Artificial breaching or too frequent breaching due to increase flow
Sediment dynamics	Flood regime to maintain the sediment distribution patterns and aquatic habitat (instream physical habitat) so as not to exceed TPCs for biota (see above)	▪ River inflow distribution patterns (flood components) differ by more than 20% (in terms of magnitude, timing and variability) from that of the Present State (2013) ▪ Suspended sediment concentration from river inflow deviates by more than 20% of the sediment load-discharge relationship to be determined as part of baseline studies (Present State 2013) ▪ Findings from the bathymetric surveys undertaken as part of a monitoring programme indicate changes in the sedimentation and erosion patterns in the estuary have occurred (± 0.5 m). ▪ Intertidal and subtidal habitat in Zone C and D are not available for estuarine species (increase by > 20% from present).	▪ Reduced floods ▪ Poor landuse
	Changes in sediment grain size distribution patterns not to cause exceedance of TPCs in benthic invertebrates (see above).	▪ The median bed sediment diameter deviates by more than a factor of two from levels to be determined as part of baseline studies (Present State 2013). ▪ Sand/mud distribution in middle and upper reaches change by more than 20% from Present State (2013). ▪ Changes in tidal amplitude at the tidal gauge of more than 20% from Present State (2013)	▪ Reduced floods ▪ Poor landuse

Table 8.3 Ecological specifications and thresholds of potential concern for biotic components

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
Microalgae	Maintain current microalgae assemblages, specifically > 5 diatom species at a frequency >3% of the total population in saline reaches (i.e. Zone A in low flow)	▪ Medium phytoplankton: > 2µg/l for more than 50% of the stations ▪ MPB: > 10mg m^2 for more than 50% of the stations in the saline portion of the estuary ▪ Observable bloom in the estuary	Excessive nutrient levels in the water
Macrophytes	▪ Maintain the distribution of macrophyte habitats	▪ No increase in area covered by estuarine macrophytes; reclamation from sugarcane and disturbance	▪ Reduced flow, sedimentation, infilling and spread of vegetation.
	▪ No invasive aquatic species present in the estuary e.g. water hyacinth	▪ Invasive plants (e.g. syringa berry, Spanish reed, Brazilian pepper tree) cover > 5% of total macrophyte area. Eucalyptus stand below the N2 present ▪ Floating invasive aquatics observed in the estuary	▪ Disturbance
	▪ No sugarcane in the EFZ (estuarine functional zone).	▪ Sugarcane is present in the estuarine functional zone.	▪ Increase in nutrients and possible eutrophication.
Invertebrates	▪ Maintain a high species diversity (including seasonal variation) ▪ An invertebrate community assemblage in the estuary based on species diversity and abundance that includes a variety of indigenous benthic macroinvertebrates ▪ Molluscan groups including *Brachidontes* bivalves present in the fresher zones of the estuary or more widespread throughout the estuary during fresh conditions ▪ However, abundance of all taxon groups should be higher during winter / low flow and closed mouth periods ▪ The thallasinid *C. kraussi* should be present in the northern arm of the system.	▪ Species diversity should remain between 30 - 50 species ▪ Polychaetes, amphipods and tanaeids should numerically dominate during all seasons ▪ The abundance of benthic macroinvertebrates should not vary by more than 10% excluding seasonal variation	▪ Nutrient enrichment ▪ Dissolved oxygen ▪ Loss of baseflows ▪ Mouth closure ▪ Artificial breaching
Fish	▪ High nursery value function in the estuary is the result of water quality supportive of aquatic life, including sensitive species, and functional habitats over all estuarine zones, including areas that back fill during the mouth closed state ▪ Permanent populations of estuarine resident species occur in the estuary	▪ *O. mossambicus* dominate the fish assemblage (by abundance) ▪ Absence from the system of two or more of the following estuarine dependent species: o *Solea bleekeri, Pomadasys commersonnii, Acanthopagrus vagus, Rhabdosargus holubi, Terapon jarbua,*	▪ Poor water quality ▪ Habitat infill ▪ Mouth breaching

Component	Ecological Specification	Threshold of Potential Concern	Possible causes
	▪ No exotic fish species occur	*Gerres methueni* and *Monodactylus* spp. ▪ Less than four mullet species occur. ▪ Any one of the following estuarine residents taxa does not occur: o *Glossogobius callidus Ambassis* spp. and *Gilchristella aestuaria*. ▪ No piscivorous species occur (both *Caranx* spp and *Argyrosomus japonicus* absent). ▪ Presence of predatory exotic fish species	
Birds	The estuary should contain a relatively rich avifaunal waterbird community that includes representatives of all the major groups, i.e. aerial (e.g. kingfishers), swimming (e.g. cormorants) and large wading piscivores (e.g. herons), small invertebrate-feeding waders, including migratory Palaearctic sandpipers, herbivorous waterfowl (e.g. ducks and geese) and roosting terns and gull	▪ Disappearance or lack of successful breeding by resident pair of African Fish Eagles ▪ Numbers of bird species drops below 20 for 3 consecutive counts ▪ Number of roosting terns recorded in mid-summer fewer than 500	▪ Encroachment of aquatic vegetation into the estuary/riverbed, i.e. reedbeds, aquatic grasses and alien trees ▪ Eutrophication of water supply, e.g. nutrients ▪ Unavailability of food supply, e.g. due to excessive turbidity, alien floating macrophytes, etc. ▪ Human disturbance ▪ Reduction in food supply

8.4 MONITORING REQUIREMENTS

Sustainable management of the Mhlali Estuary can only be achieved through a sound understanding of its biophysical process based on appropriate and reliable quantitative data. However, the collection, processing and interpretation of such data are often time consuming and costly, and often require considerable scientific expertise.

Recommendation for the monitoring of Mhlali Estuary's biophysical processes based on the following documentation: 1) current data collection methods, 2) the baseline data requirements for the Resource Directed Measures methods for estuaries addressing the Ecological Reserve (Version 2 and 3) (DWAF, 2008) and 3) the guidelines and procedures to design resource monitoring programmes for estuaries as part of the Ecological Reserve Determination process for estuaries (Taljaard *et al.,* 2003).

Resource monitoring programmes can be sub-divided into (Taljaard *et al.,* 2003):

- ***Baseline surveys (or studies)***, the purpose of which is to collect data and information to characterize and understand the ecosystem functioning of a specific system. The baseline studies that are carried out for an Ecological Reserve determination study at Comprehensive level may be considered as the baseline data against which the long-term monitoring is carried out on estuaries. If less than the recommended baseline studies for a comprehensive assessment was carried out, due to the Ecological Reserve study being carried out at a rapid or intermediate level as was the case for the Great Brak Estuary, additional 'baseline' work will definitely be required to produce sufficient baseline data against which future long-term monitoring can take place.
- ***Long-term (or compliance) monitoring programmes*** to assess (or audit) whether the management objectives are being achieved. The purpose of long-term monitoring programmes, in this context, is to assess (or audit) whether the Ecological Specifications (defined as part of the Ecological Reserve determination process) are being complied with after implementation of the Reserve. In addition, these programmes can also be used to improve and refine the Ecological Reserve measures (including the Resource Quality Objectives), in the longer-term through an iterative process (Taljaard *et al*., 2003). Although baseline studies and long-term monitoring programmes have different purposes, it is extremely important that long-term monitoring programmes follow on from similarly structured baseline studies. In essence, the monitoring activities selected for the long-term monitoring programme should be derived from the monitoring activities conducted as part of the baseline studies, but implemented on less intensive spatial and/or temporal scales (Taljaard *et al*., 2003).

It is important to note the difference between survey and monitoring: Surveys normally refers to short-term or once-off, intensive investigations on a wide range of parameters to obtain a better understanding of estuarine processes. Monitoring refers to ongoing data collection of a selection of indicator parameters in order to determine long-term change and trends. Long-term monitoring can be done for several reasons, one of which is for compliance monitoring.

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

- River inflow (i.e. flow gauging).

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

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

Criteria that should be considered in the selection and prioritisation of biotic indicators for long-term monitoring programmes include:

- The biotic indicators should be particularly sensitive to potential impacts associated with changes in river inflow and water quality, such as state of the mouth, tidal variation, sedimentation/erosion, salinity distribution patterns and deterioration in water quality.
- Biotic components considered to be on a 'trajectory of change' or that are particularly sensitive to abiotic components that are on a 'trajectory of change' (e.g. long term sedimentation), should also be considered for inclusion as indicators in long-term monitoring programmes.
- Biotic components that are of regional or national biodiversity importance are also suitable indicators, particularly when also sensitive to changes in river inflow and water quality.
- Biotic indicators should also be representative of the important food chains present in a particular system.
- The selection of biotic indicators should also present a balance between indicators that provides 'early warning' signals and those that reflect longer-term, more cumulative effects. For example, fish are often considered to be useful 'early warning' indicators, while macrophyte distribution patterns are often better indicators of cumulative, longer-term changes in estuaries.
- Biotic indicators should include economic important indicators where relevant.

Recommended base line monitoring requirements to improve EWR study confidence (Table 8.3) and the minimum monitoring requirements to ascertain impacts of changes in freshwater flow to the estuary and any improvement or reductions therein are listed in Table 8.3 below.

Table 8.4 Recommended baseline monitoring requirements

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Hydrodynamics	Record water levels.	Continuous.	At bridge.
	Measure freshwater inflow into the estuary.	Continuous.	Above the estuary.
	Aerial photographs of estuary (spring low tide).	Every 3 years.	Entire estuary.
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100 m). The vertical accuracy should be about 5 cm.	Every 3 years.	Entire estuary.
	Set sediment grab samples (at cross section profiles) for analysis of Particle Size Distribution (PSD) and origin (i.e. using microscopic observations).	Every 3 years (with invertebrate sampling).	Entire estuary (6 stations).
Water quality	Longitudinal salinity and temperature profiles system variables (e.g. pH, DO, turbidity, and inorganic nutrients) taken along the length of the estuary collected at: ▪ End of low flow season (i.e. period of maximum seawater intrusion/closed mouth). ▪ Peak of high flow season (i.e. period of maximum flushing by river water).	Once-off.	Entire estuary (10 stations).
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary, where considered an issue (must also include sediment grain size analysis of samples).	Once-off.	Focus on sheltered, depositional areas.
Microalgae	▪ Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae. ▪ Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. High Performance Liquid Chromatography (HPLC). ▪ Intertidal and subtidal benthic chlorophyll-a measurements.	Monthly sampling for 2 years (seasonal trends).	Entire estuary (5 stations).

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Macrophytes	▪ Field survey to map and verify the present low confidence vegetation map, particularly the area currently mapped as swamp forest. ▪ Map the areas of invasive species, identify rare and endangered macrophytes and identify areas for floodplain rehabilitation. ▪ Compile a comprehensive macrophyte species list.	Summer survey every 3 years.	Entire estuary.
Invertebrates	▪ Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. ▪ Record benthic invertebrate species and abundance, based on subtidal and intertidal benthic grab and core samples at a series of stations up the estuary, and counts of hole densities. ▪ Measures of sediment characteristics at each station.	Summer and winter survey for 3 years.	Entire estuary (7 stations).
Fish	Fish species, sizes (standard length) and abundance (Catch Per Unit Effort) as sampled by gill net and seine net. Physico-chemical characteristics of the full water column measured; concurrently with fish sampling.	Summer and two winter survey for 3 years.	Entire estuary (7 stations).
Birds	Undertake counts of all water-associated birds, identified to species level (water status, including mouth condition to be noted and data kept separate for separate standard estuary sections)	▪ A series of monthly counts of all waterbirds for one year. ▪ Also a series of monthly counts of roosting terns (and gulls) made at dusk for one year.	Entire estuary (data kept separate for separate standard estuary sections). On the sandbank at the mouth or on sandbanks in the riverbed itself.
	Locate and monitor African Fish Eagle nest(s).	African Fish Eagle nest to be located annually in winter when incubating and subsequently checked when with small young and when young close to fledging (three visits in total during ca June – September).	Entire estuary.

Table 8.5 Recommended long-term monitoring requirements

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Hydrodynamics	Record water levels.	Continuous.	At bridge.
	Measure freshwater inflow into the estuary.	Continuous.	Above the estuary.
	Aerial photographs of estuary (spring low tide).	Every 3 years.	Entire estuary.
Sediment dynamics	Bathymetric surveys: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but in more detailed in the mouth (every 100 m). The vertical accuracy should be about 5 cm.	Every 3 years.	Entire estuary.
	Set sediment grab samples (at cross section profiles) for analysis of PSD and origin (i.e. using microscopic observations).	Every 3 years (with invert sampling).	Entire estuary (6 stations).
Water quality	Monitoring effluent volume and concentration from Shakaskraal and Tinley Manor WWTWs.	Weekly.	End of pipe.
	Water quality (e.g. system variables, nutrients and toxic substances) measurements on river water entering at the head of the estuary.	Monthly continuous.	Station in River downstream of Shakaskraal WWTW.
	Longitudinal salinity and temperature profiles (and any other in situ measurements possible e.g. pH, DO, turbidity) collected during high and low tide at: ▪ End of low flow season (i.e. period of maximum seawater intrusion/closed mouth). ▪ Peak of high flow season (i.e. period of maximum flushing by river water).	Seasonally every year.	Entire estuary (10 stations).
	Water quality parameters (i.e. system variables, and inorganic nutrients) taken along the length of the estuary (at least surface and bottom samples).	Coinciding with biotic surveys or when significant change in quality expected.	Entire estuary (10 stations).
	Measurements of organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along length of the estuary, where considered an issue (must also include sediment grain size analysis of samples).	Every 3 - 6 years.	Focus on sheltered, depositional areas.

Ecological Component	Monitoring Action	Temporal Scale (Frequency And When)	Spatial Scale (No. Stations)
Microalgae	▪ Record relative abundance of dominant phytoplankton groups, i.e. flagellates, dinoflagellates, diatoms and blue-green algae. ▪ Chlorophyll-a measurements taken at the surface, 0.5 m and 1 m depths, under typically high and low flow conditions using a recognised technique, e.g. HPLC, fluoroprobe. ▪ Intertidal and subtidal benthic chlorophyll-a measurements.	Summer and winter survey every 3 years.	Entire estuary (5 stations).
Macrophytes	▪ Map the area covered by the different macrophyte habitats. ▪ Compile a species list and check for expansion of invasive plants, reed, sedge and grass areas.	Summer survey every 3 years.	Entire estuary.
Invertebrates	▪ Record species and abundance of zooplankton, based on samples collected across the estuary at each of a series of stations along the estuary. ▪ Record benthic invertebrate species and abundance, based on subtidal and intertidal core samples at a series of stations up the estuary, and counts of hole densities. ▪ Measures of sediment characteristics at each station.	Winter/low flow survey every 3 years.	Entire estuary (7 stations).
Fish	▪ Fish species, sizes (standard length) and abundance (Catch Per Unit Effort) as sampled by gill net and seine net. ▪ Physico-chemical characteristics of the full water column measured; concurrently with fish sampling.	Winter/low flow survey every 3 years.	Entire estuary (7 stations).
Birds	Undertake counts of all water-associated birds, identified to species level (water status, including mouth condition to be noted and data kept separate for separate standard estuary sections).	Winter and summer counts of all waterbirds, including counts of roosting terns (and gulls) made at dusk.	Entire estuary (data kept separate for separate standard estuary sections). Roost counts to cover the sandbank at the mouth or on sandbanks in the riverbed itself.
	Locate and monitor African Fish Eagle nest.	African Fish Eagle nest to be located annually in winter when incubating and subsequently checked when with small young and when young close to fledging (three visits in total during June – September).	Entire estuary.

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10 APPENDIX A: MACROPHYTES OF THE MHLALI ESTUARY

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10.1 INTRODUCTION

Mhlali Estuary (29º 27' 43.0524" S 31º 16' 39.1332" E) is a temporarily open/closed estuary situated on the subtropical north coast of KwaZulu-Natal, South Africa. The NBA of 2011 reported the overall health of Mkomazi Estuary as an Ecological Category of a ‘C’ (moderately modified) with all components scoring ‘fair’ and hydrodynamics scoring a ‘good’, on a scale of excellent to poor (van Niekerk and Turpie, 2012). Mhlali Estuary has experienced a medium reduction in flow and habitat loss and medium threats from pollution. Mining, artificial breaching, fishing and bait collection has been reported (van Niekerk and Turpie, 2012). Mkomazi Estuary is important (67.5) for its habitat (90) and the biodiversity (80) it supports and should therefore be partially protected (Turpie *et al*., 2007; van Niekerk and Turpie, 2012).

Begg (1978) described Mhlali Estuary ‘botanically unimportant’ due to habitat removal for sugarcane cultivation. The estuary was severely silted and degraded. Heydorn (1985) stated that Mhlali Estuary was in a fair condition and had potential for conservation. Weir construction had negative impacts on the estuary and the forest was severely depleted. According to Ramm *et al.* (1986) sugarcane had been planted on the centre island and cattle grazing was encouraged once the cane was harvested. Cooper *et al*. (1993) described the estuary to be in near pristine condition and Harrison (2000) stated that the aesthetic value was good. Demetriades (2007) in an inventory of sandmining operations in KwaZulu-Natal described four past or present sandmining activities at Mhlali Estuary. Riparian vegetation had been removed for sandmining activities and loose unconsolidated sediments further exacerbate siltation in the estuary.

In terms of macrophyte distribution Begg (1978) described beds of *Phragmites* sp. occurring on the island between the two arms of the estuary. Swamp forest with a few scattered clumps of freshwater mangrove (*Barringtonia racemosa*) was present on the southern bank of Mhlali Estuary.

The EIA report (2005) for the Tinley Manor WWTW on the south bank below the N2 described the following invasive aquatic macrophytes in the river; water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*) and parrots feather (*Myriophyllum aquaticum*). The site of the WWTW is approximately 3.5 km from the mouth of the estuary. Algal blooms were also reported in the estuary and were expected to increase as a result of WWTW discharges. For the streambed and adjacent floodplain of the proposed development area extensive infestation by alien plants was reported. Dominant species were *Chromolaena odorata*, *Lantana camara*, *Eucalyptus* species, *Pinus* species, Brazilian Pepper and Syringa. Indigenous species along the banks were Wild Date Palm (*Phoenix reclinata*), Pigeon wood (*Trema orientalis*), Powder Puff Tree (*Barrington racemosa*), Hewitt’s Dwarf Morning Glory (*Hewittia malabarica*), Umdoni trees (*Syzygium cordatum*), Quinine tree *(Rauvolfia caffra*), Natal Mahogany (*Trichillia dregeana*), Perdepis *Clausena anisata* and Splendid Acacia (*Acacia robusta*).

The floodplain has been extensively transformed by sugarcane cultivation. This is also the dominant activity in the catchment which would lead to soil erosion and downstream sedimentation, shallowing and macrophyte encroachment into the main river channel. According to the Tinley Manor EIA report (2005) “Large areas of the riparian zone and its buffers have been artificially drained and cultivated for sugarcane whilst remaining areas are infested with alien plants." The general impression is of an extensively degraded system.

Mhlali Estuary was visited in July 2013 so as to determine the present distribution of macrophyte habitats as part of the ecological water requirements study. A vegetation map for present conditions was produced. The distribution and area covered by different macrophyte habitats was compared with the earliest aerial photograph available from 1937. These changes would then provide input to the present ecological status of the estuary.

10.2 MATERIALS AND METHODS

Mhlali Estuary was briefly visited in July 2013 so as to identify the dominant macrophytes and note their distribution along the length of the estuary. Historical distribution of macrophyte habitats were determined using available literature. The present and past distribution of habitats within the estuary was mapped using ESRI™ ArcMap 10.1 (2012). The 5 m contour line was used to delineate the boundaries of the estuary. The ESRI™ World Imagery basemap of 2013 was used to map present macrophyte distribution. Past area of habitats was mapped using the oldest available aerial images (1937) that had been rectified. The macrophyte habitats mapped are shown in Table 10.1. The area covered by each macrophyte habitat presently was compared with its past cover to provide an indication of the percentage change in the estuary over time.

10.3 RESULTS AND DISCUSSION

10.3.1 Species composition and macrophyte habitats

Although not mapped swamp forest supporting lagoon hibiscus (*Hibiscus tiliaceus*) occurred on the banks near the mouth of the estuary where the gradient was unsuitable for sugarcane cultivation (Figure 10.1). Wild date palm (*Phoenix reclinata*) and Natal wild banana (*Strelitzia nicolai*) was conspicuous amongst the swamp forest (Figure 10.2). Swamp forest likely extends to the middle and upper reaches of the estuary, however this may be coastal forest vegetation and more intensive fieldwork would be required for confirmation. This area would contain invasive trees and shrubs. Common reed (*Phragmites australis*) and *Schoenoplectus scirpoides* fringed the water channel in the lower reaches. The side of the centre island closest to the mouth consisted of a matrix of grasses, *P. australis* and *H. tiliaceus (*Figure 10.1). A sandbar and rocks were present at the mouth when visited in July 2013.

Table 10.1 Macrophyte habitats and functional groups recorded in the estuary (spp. examples in italics).

Habitat type	Distribution	Area (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	25
Intertidal sand and mudflats	Intertidal zone consisting of sand/mud banks that provides a possible area for microphytobenthos to inhabit. Could not be mapped, but is dynamic and would change over time.	/
Swamp forest	Lagoon hibiscus (*H. tiliaceus*) and other swamp forest trees present behind the reeds and sedges in the lower reaches of the estuary	25
Reeds and sedges	Common reed (*P. australis*) and *S. scirpoides* fringed the water channel.	11

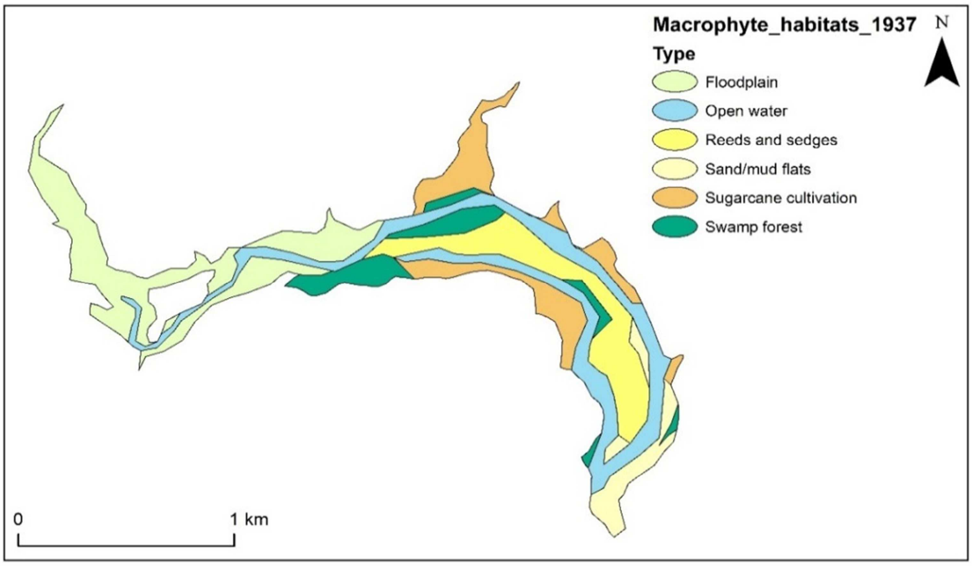

Figure 10.1 Distribution of macrophyte habitats at Mhlali Estuary in 1937

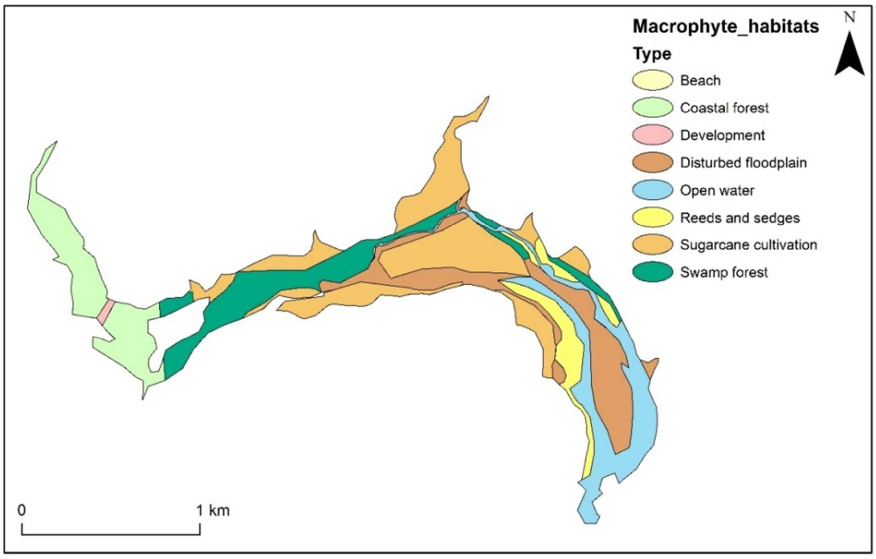

Figure 10.2 Distribution of macrophyte habitats at Mhlali Estuary in 2013

Figure 10.3 Lower reaches of Mhlali Estuary with a matrix of swamp forest, reeds and grasses present on the centre island and swamp forest on the steep south bank. Note the sugarcane cultivation on the south bank (Photo from Meredith Cowie, July 2013)

Figure 10.4 Phoenix reclinata and Strelitzia nicolai amongst grasses on the north bank of Mhlali Estuary (Photo from Meredith Cowie, July 2013)

10.3.2 Changes over time in the macrophyte habitats

The present dominance of reeds (*P. australis*) and swamp forest *(H. tiliaceus*) are highly likely the historical macrophyte community situation. Major changes in macrophyte habitat were due to removal for the cultivation of sugarcane. Over 70 % of reed habitat has been lost to sugarcane cultivation. Changes associated with mouth state and nutrient concentrations may have also affected macrophyte abundance and distribution. A reduction in MAR has decreased open water habitat. Although not visible from the short site visit, invasive species have likely also displaced some indigenous species.

Table 10.2 Comparison of area (ha) for the different macrophyte habitats at Mhlali Estuary under natural, earliest aerial imagery (1937) and present (2013) conditions

Macrophyte habitat	Natural	1937	2013
Open Water	40	40	25
Sand/mud flats	10	10	0
Reeds and sedges	45	30	11
Swamp forest	28	16	25
Floodplain	42	42	24
Disturbed floodplain	0	0	30
Sugarcane cultivation	0	27	49
Development	0	0	1
TOTAL	**165**	**165**	**165**

10.4 REFERENCES

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11 APPENDIX B: HISTORIC RECORDS OF FISHES SAMPLED IN MHLALI ESTUARY

Table 11.1 Historic records of fishes sampled in Mhlali Estuary (% abundance), frequency (%) of occurrence and average abundance (%) indicated

Reference	Begg (1984a)[1]	Ramm *et al*. (1986)[2]	Harrison *et al*. (2000)[3]	Forbes and Demetriades (2009)[4]	Frequency of Occurrence	Average abundance
Sampling date	**1980-1981 (6 surveys over wet and dry seasons)**	**1986 (Aug)**	**1998 (Oct)**	**2008 (Jul, Oct)**		
Oreochromis mossambicus	60	13	80	2	100	9.7
Valamugil cunnesius	58	3	50	30	100	7.9
Valamugil buchanani	55	17	2		75	8.6
Rhabdosargus holubi	110		147	10	75	7.9
Solea bleekeri	258		3	1	75	4.1
Myxus capensis		6	37	1	75	4.1
Liza macrolepis	13	6	7		75	3.2
Mugil cephalus	11	4	28		75	2.9
Pomadasys commersonnii	93	1	24		75	2.7
Ambassis natalensis	16		5	15	75	2.4
Liza alata		2	9	5	75	1.9
Gerres methueni	8		10	1	75	0.6
Mullet fry			111	95	50	16.3
Ambassis productus	191		59		50	4.8
Terapon jarbua	175		58		50	4.6
Oligolepis acutipennis	260		2		50	4.0
Liza dumerilii			27	14	50	2.8
Monodactylus argenteus	9		55		50	2.0
Rhabdosargus sarba	38			8	50	1.6
Glossogobius giuris	88		2		50	1.4
Gilchristella aestuaria	70		3		50	1.2
Glossogobius callidus			11	1	50	0.5
Caranx sexfasciatus	7		2		50	0.2
Acanthopagrus vagus	2		3		50	0.1
Lutjanus fulviflamma	4		2		50	0.1
Argyrosomus japonicus	3		1		50	0.1
Arothron immaculatus	2		1		50	0.1
Psammogobius knysnaensis	47				25	0.7
Scomberoides tol		1			25	0.5
Hilsa kelee		1			25	0.5
Caranx hippos (?)		1			25	0.5
Valamugil robustus				3	25	0.4
Liza richardsonii				2	25	0.3
Pomadasys multimaculatum	17				25	0.3
Leiognathus equula	16				25	0.2
Pomadasys kakaan	16				25	0.2
Valamugil seheli			5		25	0.2
Oligolepis keiensis			4		25	0.1
Caffrogobius natalensis			3		25	0.1

Reference	Begg (1984a)[1]	Ramm *et al*. (1986)[2]	Harrison *et al*. (2000)[3]	Forbes and Demetriades (2009)[4]	Frequency of Occurrence	Average abundance
Sampling date	**1980-1981 (6 surveys over wet and dry seasons)**	**1986 (Aug)**	**1998 (Oct)**	**2008 (Jul, Oct)**		
Caranx ignobilis			3		25	0.1
Bothus pantherinus	6				25	0.1
Glossogobius biocellatus	5				25	0.1
Valamugil spp.			2		25	0.1
Liza tricuspidens			1		25	<0.05
Gerres filamentosus	2				25	<0.05
Epinephelus andersoni (?)	2				25	<0.05
Eleotris fusca	1				25	<0.05
Croilia mossambica	1				25	<0.05
Favonigobius reichei	1				25	<0.05
Platycephalus indicus	1				25	<0.05
Antennarius straitus	1				25	<0.05
Himantura uarnak	1				25	<0.05
Pterois miles	1				25	<0.05
Estuarine resident	35.9		11.5	8.5	75	14.0
Estuarine dependent marine	48.7	41.8	76.4	89.4	100	64.1
Marine straggler	6.4	34.5	1.3	1.1	100	10.8
Freshwater	9.0	23.6	10.8	1.1	100	11.1
Catadromous						
Detritivore	11.9	92.7	47.4	80.9	100	58.2
Zooplanktivore	17.3	1.8	16.1	8.0	100	10.8
Zoobenthivore	69.8	1.8	35.7	11.2	100	29.6
Piscivore	0.9	3.6	0.8		75	1.3

1 Begg, G.W. 1984a. The Estuaries of Natal. Part 2. Supplement to NTRP Report Vol.41. Natal Town and Regional Planning Main Series Report Vol 55:1-631
2 Ramm, A.E.L., Cerf, E.C., Harrison, T.D. 1986. The Mhlali Estuary. Natal Estuary Status Report. No 61. CSIR. 11 pp.
3 Harrison, T.D., Cooper, J.A.G. and Ramm, A.E.L 2000. Geomorphology, ichthyofauna, water quality and aesthetics of South African estuaries. Division of Water, Environment and Forestry Technology, Environmentek, CSIR, South Africa, prepared for the Department of Environmental Affairs and Tourism. Report ENV-DC 2000-01.
4 Forbes, A.T. and Demetriades N.T. 2009. Ecological assessment of the uMhlali Estuary: July – October. Specialist estuarine report for Siza Water. MER Report 1/09.

12 APPENDIX C: REPORT COMMENTS

Comments from Mmaphefo Twala: 30 January 2015.

Comments	Status
The report title could perhaps include EWR and Recommended RQOs?	Changed as agreed with DWS
The page after the Document Index page: replace Water Affairs with Water and Sanitation	Done
Page i: remove 'comments received from DWS' below the Acknowledgements	Done
Page ii, missing word: "increase in nutrient input…"	Done
Table on page ii: write confidence in full in the last column and also indicate what the L, L/M stand for, or write in full.	Done
Page iii, missing word in the first sentence at the top of the page: "…causing a loss in the habitat…"	Done
Page iv, second paragraph: edit 50% by removing the space in between the number and the sign	Done
Page iv, first bullet at the bottom: spelling error for the word 'various'	Done
Page xiii: add TOCE and TPC to the list	Done
Page numbers are not visible on the printed report for the rest of the document: format error.	Done
1 Introduction, 1st paragraph, last sentence: "in this Mvoti to Umzimkulu WMA Classification study"	Done
Page 3, remove: "An estuary cannot be allocated an REC…"	Done
Page 3, step 4, remove: "Quantify of the…"	Done
2 Background information page: numbering error should be 2.2.1, 2nd paragraph on this section: "….in the Mhlali Catchment (Figure 2.1) indicates…."	Done
Page 16: error in numbering paragraphs: 4.1.1, 4.1.2 and 4.2.3?	Done
Table 4.7, 1a: "…due to increases in mouth closure…"	Done
Table under 4.7: Anthropogenic influence: separate table? 1st row, 4th paragraph, confirm the sand mining statement there. 2nd row: remove space between the two words 'subtidal habitat'	Done, change to left justified
Page 23, 2nd paragraph: remove the highlighted part "…assuming that this will be the estimated…"	Done
Table 4.14: previously zones were labelled A, B and C but now column 4 refers to Lower, Middle and Upper; maintain one to avoid confusion.	Done
Fix or remove all the reference errors: i.e section 4.9, 7.3.3"Error! Reference source not found"	Done
Table 8.5 Water Quality: which variables should be monitored and what levels should these be at?	Is listed in Ecospecs, and monitoring
5.3 "The overall confidence of the study was LOW": perhaps elaborate further what this implies in terms of the usefulness of the outcomes of the study.	Done
Scenarios are labelled 'Sc MK2 'etc for rivers and grouped A-F for estuaries. It gets confusing	Scenarios developed before larger study naming convention was developed. Scenario results grouped and renamed in Integration reports